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Deploying Blockchain Technology in the Supply Chain

Jian Zhang

Abstract

In the rapidly evolving environment of the international supply chain, the traditional network of manufacturers and suppliers has grown into a vast ecosystem made of various products that move through multiple parties and require cooperation among stakeholders. Additionally, the demand for improved product visibility and source-to-store traceability has never been higher. However, traditional data sharing procedures in today's supply chain are inefficient, costly, and unadaptable as compared to new and innovative technology. Blockchain technology has shown promising results for improving supply chain networks in recent applications and has already impacted our society and lifestyle by reshaping many business and industry processes. In an effort to understand the integration of blockchain technology in the supply chain, this paper systematically summarizes its current status, key characteristics, potential challenges, and pilot applications.

Keywords: supply chain, blockchain, smart contract, traceability, security, digitalization

1. Introduction

The supply chain plays a crucial role in modern businesses by allowing them to achieve efficiency, responsiveness, and success. Over the past several decades, the scale of businesses has expanded, the number of geographic locales involved in the production process has grown, and product portfolios have diversified. As a result, the supply chain has grown from a traditional network of manufacturers and suppliers, to a vast ecosystem made of various products that move through multiple parties and require cooperation among stakeholders [1]. Additionally, due to the rapid evolution of e-commerce, the demand for improved product visibility and source-to-store traceability has never been higher. However, the inefficiency of data sharing in current supply chain networks has dramatically impacted the operations of retailers and manufacturers. For example, information gaps between data collected by factories and by retailers make it challenging to trace product history and offer customized products.

To overcome these challenges and improve supply chain performance, industries have explored innovative technologies that support efficient collaboration and coordination within and among different organizations [2, 3]. Among these technologies, blockchain provides a promising future and allows the supply chain to provide better visibility, transparency, and acuity of transactions throughout the entire process [4]. The blockchain technology that powers cryptocurrency has caught the attention of businesses, especially those in supply chain management. A 2017 study indicated that nearly 62% of supply chain executives claimed to have engaged with blockchain

technology [5]. Although blockchain-based applications in the supply chain are still in their early stages, we believe this technology will significantly remodel the supply chain system [6–8]. Analysts forecast that blockchain technology can help supply chain management gain one-third improvement in most of its common processes [9]. A blockchain network is as a distributed ledger—transactions are contained in blocks that are linked together in chronological order to form a tamper-proof chain, which is usually stored in all network nodes [10, 11]. As such, blockchain technology provides a means to create tamper-proof logs of business activities and transactions [12]. Transaction data are immutable because they cannot be tampered with once they are distributed, accepted, and validated by network consensus and stored in the blocks [13]. By eliminating intermediaries to achieve trust among all stakeholders, efficiency improves and cost is reduced for the entire supply chain.

Despite the general acceptance that blockchain technology facilitates faster, more easily auditable interactions and allows for the exchange of immutable data among supply chain partners [14], it will take time for this technology to be adopted and to revolutionize the supply chain. Currently, most applications of blockchain are conceptual expositions, and empirical evidence on the implementation of it is limited [15]. Furthermore, few studies have been conducted on the challenges of deploying blockchain in the supply chain, such as organizational readiness, technical expertise, scalability, and compatibility with existing systems. Therefore, this study will provide a systematic analysis of how blockchain technology fits in the supply chain network and discuss potential challenges with its implementation.

2. Supply chain

2.1 Overview

Supply chain encompasses the end-to-end flow, including the physical and correlated data flow of raw material, products, information, and money. It plays a unique and critical role in businesses and determines the performance of organizations. Supply chain manages or is involved in sourcing, procurement, manufacturing, distribution, and logistics, and, thus, affects speed-to-market, the cost of a product, service perception, and capital requirements in businesses [16]. Supply chain integrates a set of fragmented and often geographically discrete processes into a cohesive system to deliver value to the customer. The core functions and operations of a typical supply chain network are illustrated in **Figure 1**.

2.2 Problems with today’s supply chain

Evolving customer requirements, challenges from competition, geographically separated operations, and the adoption of new business models (such as

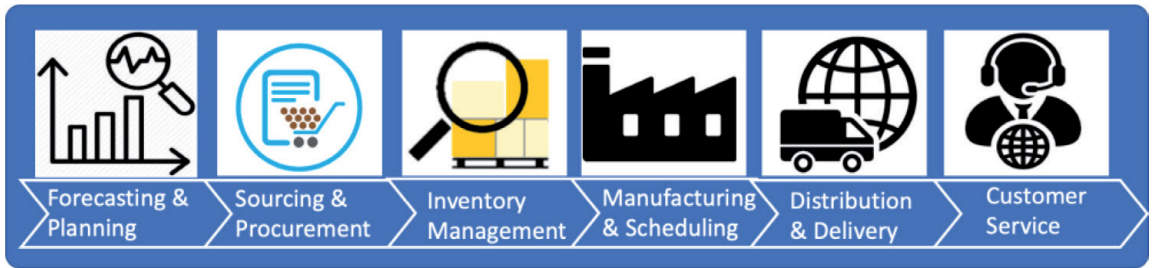


Figure 1.
Supply chain and operations.

e-commerce) make the current supply chain a highly complex system. Over the past decade, e-commerce and hand-held digital devices have substantially changed the daily lives of people, especially in the ways they shop. There is an ever-increasing demand for customized products, a simplified and efficient shopping experience, and transparency about the value and provenance of goods. These needs bring new opportunities to businesses but impose significant challenges to current supply chains. These outdated supply chains struggle to improve demand management, to provide data visibility for the entire flow, or to track goods from raw material to end consumer—all of which are tremendously complex. Furthermore, the old technology of today's supply chain fails to provide adequate risk management, to reduce costs, or to meet rapidly changing market requirements. We summarize the main challenges in current supply chains here:

Lack of traceability: In the last few years, traceability has become crucial for supply chains to address, especially in regard to customer service and planning and forecasting in business operations. However, it is difficult to deploy a centralized system in an interconnected network, especially where trust among participants is limited. Instead, there are several discrete systems among involved parties that consist of various databases that impede product tracking throughout the entire supply chain network [17].

Stakeholder distrust: Trust is an essential factor in supply chain management, and an effective supply chain network must be built on a solid foundation of it [18]. However, distrust among participants is the single greatest obstacle to improving supply chain networks [19]. Consequently, most stakeholders in the network primarily rely on third-party intermediaries to serve as agents of trust and to verify transactions, which dramatically increase operational cost and reduce process efficiency.

Limited transparency: The term “transparency” in the supply chain refers to the extent to which all stakeholders own a shared understanding of and access to accurate and adequate information about products [20, 21]. A transparent supply chain network improves trust among stakeholders and guarantees the integrity of products and associated data. However, the discrete databases in current supply chain networks offer minimal transparency, and most of the useful information in them is lost when products and data are transferred from one stakeholder to another. Furthermore, there are issues with inconsistent data sharing, relying on paper documentation, and inadequate interoperability. These critical challenges remain despite years of significant research investment. The crisis of Chipotle Mexican Grill outlets [7] is an important and sad example of how the current supply chain system is inefficient at, and possibly incapable of, offering transparency throughout the entire lifecycle of products.

Outdated means of data sharing: In current supply chain networks, data are shared between many organizations using paper-based documentation. Oftentimes, important documents, such as bills of lading, letters of credit, invoices, insurance policies, and various certificates, must travel with their associated goods around the world [22]. For example, about 200 communications were needed for Maersk, a global transport and logistics company, to complete a single shipment of frozen goods from Mombasa to Europe in 2014 [23]. These communications created a stack of documents about 25 centimeters in height [24]. Constrained by this outdated and inefficient data sharing method, ships and airplanes are often delayed in ports when the paperwork does not match the carried goods [22].

Compliance challenges: Currently, businesses have to meet increasingly strict regulatory standards to provide safe products and services to customers. Recently, the U.S. Food and Drug Administration and Federal Trade Commission adopted several standards to increase food safety and offer full visibility of food flows in the

supply chain. However, under current supply chain processes, it is difficult to obtain this information from a variety of stakeholders and to develop a database that complies with new standards.

3. Blockchain technology

Blockchain is an innovational technology that enhances customer service, drives end-to-end value, and increases the efficiency of operations [25]. Additionally, it allows distrusting or unfamiliar stakeholders to create shared and secure data records [26]. In sum, when an exchange of valuable data and goods is necessary, blockchain technology expedites transactions, streamlines the process, enhances transparency, reduces waste, and, ultimately, reduces cost [27]. Consequently, new types of internet and associated business models have been built off of this robust technology [22]. Blockchain promises to be the primary driver of secure and efficient economic and social systems in the future.

3.1 What is blockchain technology?

3.1.1 Chained architecture

The basic concepts of blockchain were introduced by Satoshi Nakamoto in Bitcoin [28], a digital cryptocurrency that can work without the need of a trusted intermediary. It offers a distributed ledger that tracks and sustains a tamper-proof record of transactions in a decentralized network. In essence, it is a unique database system that is created, replicated, synchronized, and maintained by all participants in the decentralized network. Blockchain operates in a decentralized peer-to-peer network [29] to validate and store all transactions in a consensus that is agreed upon by all nodes in the network, without any central authority to validate the transaction (as with an intermediary). All completed and validated transactions are logged in the distributed ledger in a verifiable, secure, transparent, and permanent manner along with a timestamp and other details [30]. In this way, the exchange of tangible and intangible data and assets among participants can be recorded digitally. Each stakeholder maintains a copy of the synchronized ledger, which prevents a single point of system failure or data loss [22]. When changes are made, such as adding a new block, all copies in the network are simultaneously updated, and records are permanently registered in all ledgers [31]. These changes are stored into blocks that create a chain [32], where a block is linked to the preceding one by storing its hash (a unique data that is mapped from the given block) [33]. **Figure 2** shows the fundamental chained architecture of a blockchain network.

In **Figure 2**, notice that except for the first block (called the genesis block), each block has its hash as a unique ID that includes the hash of the previous block. In this way, a chronological chain is formed. Additionally, the hash mechanism provides enhanced data security. Usually, a block stores a set of time-stamped transactions that are validated by stakeholders in the network. Once it gains consensus, the block is accepted and stored by all parties in the blockchain and can no longer be modified. Therefore, trust in and transparency of transactions between organizations are significantly improved.

3.1.2 Permissionless vs. permissioned blockchain

Since the introduction and success of Bitcoin, many blockchain-based platforms can be categorized as either a permissionless or permissioned blockchain. Virtually,

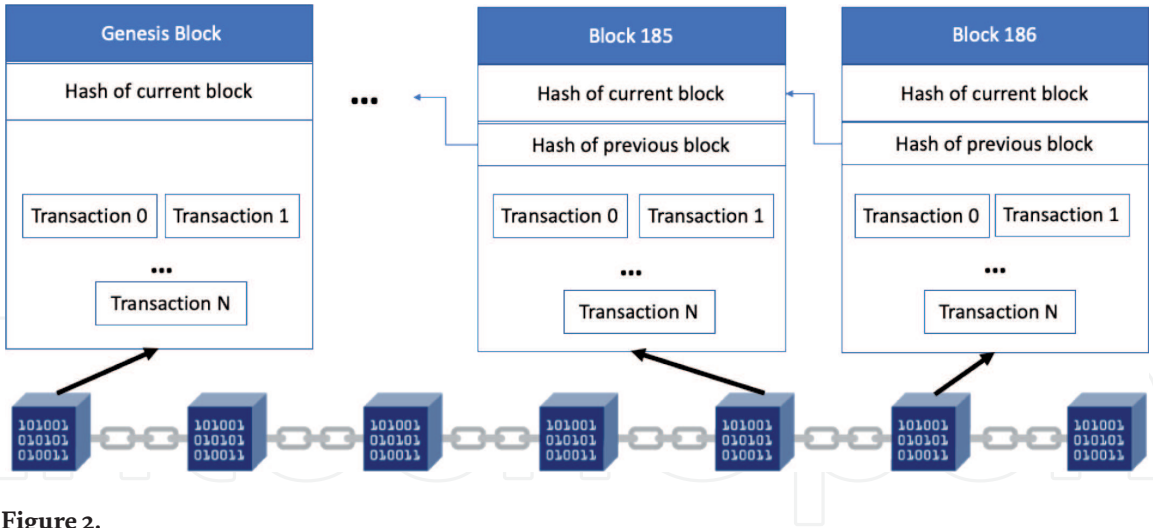


Figure 2.
The architecture of a data chain in a blockchain network.

anyone can join and participate anonymously in a permissionless blockchain network. Accordingly, it is also called a public blockchain, and these two notions will be used interchangeably in the remaining sections. Within this type of network, trust among users is limited or nonexistent. To overcome this lack, miners (detailed later) are introduced to validate transactions.

In contrast, permissioned blockchain is a network for a group of identified users operating under a governance model, called a consensus, to improve transactional trust. To join this type of network, new users need permission from the majority of the group or a delegated user; hence, it is also called a private blockchain, and we use both notions interchangeably in this paper. These networks facilitate trust among users and do not require costly miners. More efficient consensus protocols (such as the Byzantine fault tolerant protocol) validate data, improve network throughput, and reduce the latency of transactions.

3.1.3 Key characteristics

Blockchain technology has many unique features that allow for the creation of a verifiable, secure, transparent, and immutable distributed ledger, the core characteristics of which are summarized as follows:

1. **Versatile value exchange:** Blockchain provides a secure and efficient platform for recording the transactions of intellectual property rights, the provenance of services and goods, asset ownership, cryptocurrency exchange, and more.
2. **Distributed governance:** A blockchain network is not controlled by any designated authority, organization, or person, and the need for trusted intermediaries to verify transactions is eliminated. It is a distributed database that provides secure and validated data for all participants in the network simultaneously. Thus, there is full transparency along the entire stream of transactions, and assets and data can be transferred between several organizations in a quick and efficient way.
3. **Decentralized architecture:** The ledger is decentralized and stored in all nodes (i.e., individual stakeholder databases) of the network, and failure of it at a central infrastructural point is not possible. Therefore, it fosters a robust network that improves the quality, reliability, and availability of services and information.

4. **Logically centralized:** With only one transaction record shared with and agreed upon by all participants, a blockchain network behaves like a logically centralized system.
5. **Data transparency:** Blockchain technology allows for a highly transparent network that is visible to each stakeholder at all times. This dramatically reduces the chances of illegal transactions.
6. **Immutable data:** Once a block with a set of transactions is verified by the consensus and stored in the chain, the encapsulated data can no longer be modified.
7. **Enhanced data security:** Blockchain technology utilizes asymmetric cryptography and digital signature algorithms to ensure data security and individual identity.

3.1.4 Main components and data flow

To cater to the vastly different needs of unique businesses and users, many blockchain networks are created, and each contains a slightly different set of features; however, a basic foundation remains the same for all. As an example, we use Bitcoin, the first and the most successful permissionless blockchain system, to illustrate the key components of typical data flow in a blockchain network:

Block: A data structure that is used to collect a set of transactions and is protected by adding a hash value to ensure the integrity of stored data. It is an essential component and is deployed in all blockchain networks.

Digital wallet: A secure repository for a user to store the private and public key pair. It interacts with the Bitcoin network so a user can receive and send digital currency (Bitcoins) and monitor their balance.

Node: A client who participates in transactional activities on the blockchain network. First and most importantly, a node owns a complete and permanent copy of the ledger that consists of all historical transactions. It works as a cornerstone to store a full copy of the tamper-proof ledger in each node in a blockchain network. Second, a node contributes to the network by broadcasting transactions and enabling miners to validate and create blocks.

Miner: A miner, a special user in the Bitcoin network, collects and validates all broadcasted transactions and creates new blocks. It competes with other miners in the network to solve a mathematical puzzle, widely known as a proof-of-work problem. The first to win the puzzle adds a new block to the chain and gains a specific amount of reward, such as a small number of Bitcoins. When a block is added, all nodes synchronize their local copy, ensuring their ledger is up-to-date. A miner or mining procedure is used for validation in many permissionless blockchains, whereas validation is executed by nodes under the control of a consensus in most permissioned blockchains.

Consensus: An agreement between nodes in a blockchain network that submits transactional information, and is one of the most critical components of blockchain technology. A blockchain network is updated via the deployed consensus protocol to ensure that transactions and blocks are ordered correctly, to guarantee the integrity and consistency of the distributed ledger, and, ultimately, to enhance trust between stakeholders (nodes). Additionally, a consensus algorithm can help a distributed or decentralized network unanimously make a decision [11, 29]. Prevalent consensus algorithms include proof-of-work, proof-of-stake, Byzantine fault tolerance, delegated proof-of-stake, proof-of-elapsed time, and proof-of-authority matched [34, 35].

In a typical open and permissionless blockchain network such as Bitcoin, when a user starts a transaction, the digital wallet verifies and signatures the transaction before broadcasting it to all nodes in the network. The verified transaction is added to a block that collects a set of new transactions. Miners validate the block, and once validated, the block is added to the existing blockchain by all nodes. This completes the transaction. The following is an illustration of typical data flow within the Bitcoin network:

A typical permissioned blockchain follows a similar data flow to that illustrated in **Figure 3**, where a signature is added to the transaction, which is then submitted or broadcasted to the network and added to a block. After the block is validated, the transaction is permanently stored in the chain. Permissioned blockchain differs from permissionless blockchain by how blocks and transactions are validated. To gain better performance and lower latency, most permissioned blockchain networks deploy efficient consensus protocols (e.g., the Byzantine fault tolerance consensus used by Hyperledger Fabric) that nodes use for validation.

3.2 What is a “smart contract”?

The term “smart contract” was first proposed by Nick Szabo, and defined as “a set of promises, specified in the digital form, including protocols within which the parties perform on these promises” [36]. The smart contract concept was integrated into Ethereum’s blockchain network to facilitate, verify, and enforce contract negotiations and to improve the contract performance. Before transactions are conducted in a blockchain network, a smart contract that defines the conditions,

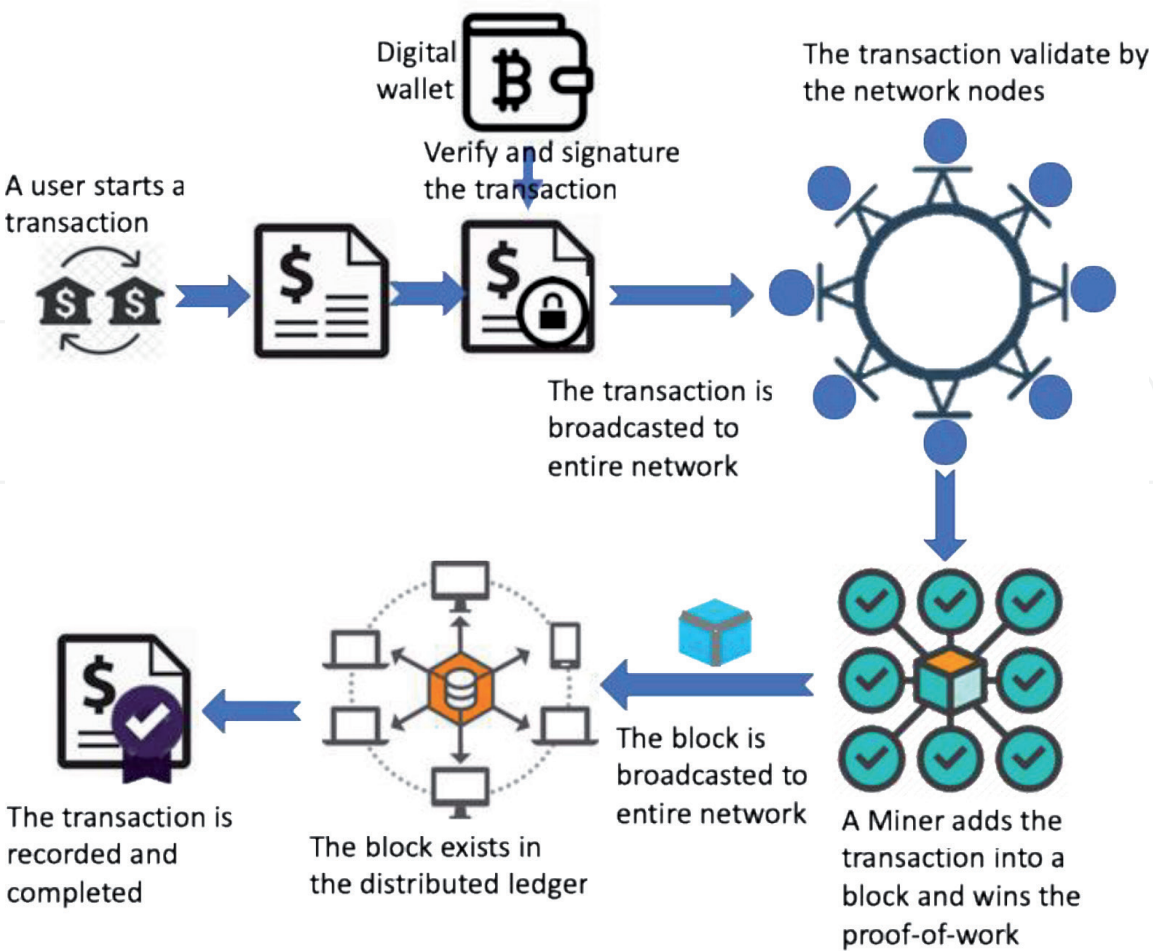


Figure 3.
Data flow of an open blockchain network [27].

obligations, rights, and concepts between stakeholders is created. This information is recorded as executable computer code to reduce ambiguity. Smart contracts are stored and shared in a distributed ledger that all participants have access to. These contracts automatically self-execute when all of the pre-set conditions are satisfied within a blockchain network. Thus, stakeholders who agreed upon a smart contract have more trust for each other and have a reduced risk of error and fraud [37]. The following details additional advantages of smart contracts:

- **Cost-saving:** by eliminating intermediaries and reducing process time;
- **Accurate:** all agreements, conditions, etc. are recorded in terms of computer codes that provide a more accurate and efficient means of information storage;
- **Speedy:** Whenever the pre-defined conditions are met, the smart contract is executed autonomously and in real-time;
- **Transparent:** Smart contracts are available and fully visible to all participants involved in the network; and
- **Secure:** Smart contracts are stored using encryption and are distributed on all nodes of the blockchain network simultaneously.

3.3 Existing blockchain platforms and applications

There are many blockchain platforms with different consensus algorithms, development tools, and programming languages [38]. We introduce a few important blockchain platforms and applications herein.

Bitcoin: The initial and most famous blockchain network to offer cryptocurrency transactions. It was launched in 2009 and has rapidly grown to be a significant currency system both online and offline. Since the mid-2010s, increasingly more businesses have begun accepting Bitcoin as payment. At the time of this writing (March 2019), the market capitalization of Bitcoin was about \$68 billion [39]—it takes around 10 minutes to create a new block [40].

Ethereum: An open-source blockchain platform that was introduced by Buterin [41] and first launched in 2015. It is the first, and possibly the most advanced, blockchain network to introduce smart contracts for decentralized applications (Dapps). The primary Ethereum network serves as a public blockchain network; however, it is also possible to create a private blockchain network based on Ethereum. Quorum [42] is one such example and deploys the Ethereum network to create an enterprise-ready distributed ledger and smart contract platform, both of which contribute to faster processing. In Ethereum's main network where a majority of transactions take place, it takes about 10–15 seconds to create a new block [43]. However, the number of transactions processed per minute is still as limited as Bitcoin.

Hyperledger fabric: An open-source, private blockchain network that is designed for enterprise applications. Hyperledger Fabric was established under the Linux Foundation and is maintained by a variety of organizations [44]. It employs a configurable architecture that provides various features, such as distributed ledger frameworks, smart contract engines, pluggable consensus protocols, user interfaces, and more. These versatile characteristics allow for a broad range of business applications, including finance, insurance, supply chain, healthcare, and human resources.

Skuchain: A blockchain network that is designed for enterprise supply chains in global trade [45]. It creates a zero-knowledge collaborative platform for global

supply chains and provides precise control in inventory procurement across all partners, reducing friction and the costs of supply chain processes.

Sweetbridge: A blockchain-based application that enables real-time financial systems to assure transactional data are trustworthy between different parties. It integrates trusted identity, smart legal contracts, smart accounting, and payment rails into a transaction for all parties to see in real-time [46].

Zervnetwork: A decentralized trading platform based on blockchain technology. It aims to provide frictionless transactions among all participants within the defense industry [47].

IOTA: An open-source distributed ledger that is being built to power the future of the Internet of Things (IoT) with feeless microtransactions and data integrity for machines [48].

4. Chain integration

In recent years, Blockchain technology has been recognized as a critical technology with inherent capabilities to dramatically improve supply chain efficiency [49–51]. A study from Eye for transport stated that more than 16% of the 300 companies surveyed agree that data interchange, tracking, and visibility are the foremost reasons to deploy blockchain technology in the supply chain [52]. However, we discuss the benefits, challenges, and risks of integrating blockchain technology in the supply chain and introduce several pilot initiatives below.

4.1 Benefits to supply chain

The adaptation of blockchain technology can significantly alleviate or even eliminate the aforementioned problems in today's supply chain. Blockchain technology empowers the supply chain with improved efficacy, efficiency, and transparency and reduced transactional time and cost. There are many ways blockchain technology benefits the supply chain:

Advanced traceability: With the adoption of blockchain technology, traceability within the supply chain is greatly improved; it produces a fully auditable trail of all items flowing through the network. Combined with IoT-based devices, such as RFID technology, a blockchain-enabled supply chain can automatically collect the item-level data of massive quantities of products in real-time. Additionally, this information is associated with timestamps and collection locations to form an audit trail that is complete, accurate, and easy-to-access, from the product's origin to the customer. Furthermore, thanks to the immutability of blockchain data and the digital signatures required to confirm information ownership, data stored in this chain offers a secure and full history of any item in the entire supply chain. In the event of a compromised product, improved traceability enables the source of the issue to be identified more quickly, which reduces the cost of recalling products and improves disruption resolution between stakeholders. Advanced traceability gives stakeholders and customers more confidence in a product's authenticity and quality.

Improved transparency: Blockchain technology provides reliable identity management in the supply chain [53] by enabling all parties to know who is performing what actions, at what time, and where. This information is stored and shared in distributed ledgers that can be conveniently accessed by involved and authenticated stakeholders. Through the integration of physical and digital flows across the supply chain, the connectivity of multiple trading partners will improve [54, 55]. Therefore, a blockchain-enabled supply chain with its transparent and complete inventory of product flow helps businesses make better forecasts and

decisions. Additionally, improved transparency serves as a powerful tool for fighting fraud and counterfeiting.

Boosted efficiency: One of the primary motivations for implementing blockchain technology is to replace the outdated, paper-heavy processes in place today. As one of the benefits of digitalization, the logically centralized data ledger provides up-to-date local copies to all stakeholders within the network. All transactions are committed and immediately validated by all involved parties, and data are automatically synchronized to each party's local copy. Blockchain technology makes it safer and faster to maintain the quality of transactions and associated data [56] by reducing human error and eliminating the need for third-party intermediaries and for local ledger reconciliation. Finally, the autonomous and self-executing blockchain-based smart contract replaces tedious processes and improves flexibility in supply chain management.

Greater security: It is nearly impossible to impact blockchain technology through hacking attacks like those that threaten centralized databases of intermediaries (e.g., banks). It is structured so that when there is an attempted hack into a specific block, all preceding blocks in the entire history must also be tampered with. Thus, blockchain provides a more secure way to maintain a log of business activities and transactions [12].

Enhanced trust: The transactions of a blockchain-based supply chain are created and recorded based on peer-to-peer interaction that can be trusted by the associated digital signatures. Additionally, a reliable identity management mechanism [53] allows for the collection of time, location, and other data at every action on a product in the supply chain. All data are synchronized to all stakeholders in real-time, which enhances trust among stakeholders within the supply chain network.

Easy compliance: A blockchain-enabled supply chain network records all transactions with precise details, such as timestamps, environmental conditions, and location. These accurate, tamper-proof records can serve as the source of a business's data integrity and be easily accessed for regulations and compliance.

4.2 Challenges with blockchain technology

Although blockchain technology is widely recognized as a promising solution for issues with today's supply chain, the application of it requires significant changes in both technological and cultural contexts. Additionally, more comprehensive evaluations of it are needed to unveil and address its challenges before the full potential of this new technology can be realized [22, 57].

Throughput and performance: Due to its decentralized architecture, each transaction is approved by all or a majority of nodes in a blockchain network. This approval process limits the throughput of a blockchain network; for example, Bitcoin, a public blockchain, can only process from 3 to 30 transactions per second. However, a private blockchain-based supply chain network must process far more transactions, possibly thousands per second, for the entire system. Thus, it is imperative to improve the transaction capacity of blockchain technology for full scalability. Fortunately, a private blockchain network's ability to improve the throughput of transactions may mitigate this processing challenge.

Standardization: Standardization is a critical concern for the adoption of blockchain technology in the supply chain. In essence, this technology offers a ubiquitous and general-purpose platform for digital data sharing and permanent storage. Interestingly, a major question still remains: what content and format should be adopted for transactional data that facilitates interpretation by all participants? A data standard must be established and agreed upon by the entire supply chain community. However, there is no existing standard that can be adapted for this purpose.

In recent years, much effort, such as EPCIS [58] that proposed GS1, has been made to overcome this gap, however, it is still not widely accepted and implemented in supply chains.

Data privacy: The immutability and transparency of blockchain technology raise a concern with data privacy when deployed for supply chains. Once data are stored in blockchains it cannot be changed, and, thus, it is imperative that a reliable mechanism that protects users' privacy is designed. The task of balancing an individual's right to privacy in an open blockchain network is very challenging. Currently, most blockchain networks, such as Bitcoin, provide limited control to users over the data and where they can transfer it to [22]. Most networks offer only pseudonymity to its users for privacy, so, although transactions are public for all nodes, the real identity of their owners is never revealed. This is unacceptable for supply chains, as nobody is willing to leak information to competitors about Confidential detail or the amount of merchandise moving in a network. Furthermore, with the limited number of stakeholders in the supply chain, it would be easy to figure out the owner of the transactional data and anonymity would disappear. To address this, private blockchain technology (such as Hyperledger Fabric) can support the creation of a channel for limited and trusted parties who are involved in specific transactions [44]. In this way, an unauthenticated user is forbidden to join the channel or access its data. It should be noted that a blockchain network can be designed to only serve as metadata of the workflow and the contents and details of all transactions within it are stored in external data repositories. Therefore, this technology provides a log of transactions on which no private data are stored [13].

4.3 Pilot initiatives

Since late 2016, retail giants Walmart and IBM worked together for a pilot project to develop a blockchain-based system for tracking produce in the U.S. and pork in China. The project traced each product and collected its associated data, including origin farm/factory, storage temperature, and serial number. With this technology, tracking reports for each product were produced within minutes and the speed and accuracy of identifying and recalling contaminated food products were significantly improved [59]. On May 31, 2017, Walmart released the results of this pilot project and reported that blockchain technology helped them trace the origin of Chinese pork and U.S. mangoes in 2.2 seconds, which would normally take as long as several weeks in a traditional supply chain platform [60].

Intel conducted a public demo to explore the implementation of blockchain technology for tracking seafood in the supply chain. They aimed to create a network that assists multiple parties with food storage condition (i.e., temperature) control and with tracking food from sea to table. Several public records of this project are available on the Traceability Blockchain website [61]. These records detail how to use blockchain technology to collect seafood product data (i.e., locations, time-stamps, owners, temperatures, etc.) from fishermen, transports, and restaurants within the entire supply chain network. This seafood blockchain can foster more trust between customers and sellers, improve and expedite the food safety network, and enhance consumer experiences.

In 2018, el Maouchi introduced TRADE, a fully transparent and decentralized traceability system for the supply chain that leverages blockchain technology [17]. It is a single system in which multiple participants can transfer and track products flowing through the supply chain. Additionally, it enables customers and other parties in the system to view and verify product data. Experiments show that each actor on the TRADE system can create about 351 and validate 437 transactions per second.

Since August 2018, IBM and Maersk (the world's largest shipping company) have teamed up to create TradeLens, a blockchain-based system for the global supply chain. TradeLens aims to create a platform for multiple trading parties to securely share databases containing massive amounts of transactional information, and to build a more collaborative environment for global trading. This system is a powerful tool for establishing a single and consistent shared status of each transaction in near real-time while maintaining stakeholder confidentiality. Reports show that TradeLens significantly reduced delays caused by documentation errors and reduced the transit time associated with shipping packaging materials to manufacturers in the U.S. up to 40% [62].

5. Conclusion

Introduced in 2009 as the foundation for Bitcoin, blockchain technology shows the significant capacity to benefit today's supply chain. It provides a decentralized platform that shares any type of transaction and that records information with an immutable and permanent historical trail. We believe it has a significant future in the supply chain, as it promises to deliver an efficient, transparent, and collaborative network for organizations to quickly and securely share data across the variety of supply chain sectors and processes. This technology allows businesses to build a more flexible and responsible supply chain, and to robustly address new external and internal challenges.

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