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Blockchain for enterprise supply chain management: Enhancing visibility, traceability and security

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Abstract

The emergence of centralized and disintermediated systems is driving a sea change in supply chain management and thus requires a core adaptation in the tracking and verification of goods and services. Contemporary supply chains are shifting their focus towards customers, focusing on the satisfaction of consumers by offering quality products and services on time. Advanced technologies' integration is becoming indispensable for companies willing to be competitive and responsive to market demand. Decentralizing the supply chain allows organizations to avoid dependence on traditional intermediaries, and it enables various participants to be treated as peers in a network using distributed ledger technology. This transformation enhances transparency and trust, bolsters security and efficiency, and reduces fraud and economic losses. Implementation will, however, require proper understanding in both blockchain technology and its application in operating supply chains, to which 20th-century practices are seriously insufficient to meet today's needs of the global digital world.

Keywords: Supply chain management; Decentralization; Customer satisfaction; Advanced technologies

1. Introduction

1.1. Introduction to Supply Chain Management

In these increasingly fragmented and complex supply chain networks, companies are vying for dominance over their competition (Hald & Kinra, 2019). This situation becomes even more complex as more steps are introduced into an organization's supply chain to allow for more and more risk-averse mission-critical goods and services (Lin et al., 2019). Forward-thinking companies are revisiting their end-to-end supply chain processes and redesigning them. The challenge has been creating a single, real-time source of truth (Cole et al., 2019). A recent innovation concerned the miraculous way of the blocks put together to create an endless chain; simply put, we call this blockchain (Banerjee, 2018). Just as the internet broke down data silos and democratized information management, blockchain has the potential to do the same for the world's transaction engines (Rejeb & Rejeb, 2020).

Most supply chains are built on the notion of a single enterprise. It follows the basic steps of providing a product—request, design, plan, procure, make, delivery, and return (Feng et al., 2020). The physical product follows the flow of these functional steps. The paperwork lags and tries to keep up with the product. The paperwork ends up with many systemic issues (Esmaeilian et al., 2020). The information flow going from enterprise to enterprise involves a lot of emails, telephones, meeting minutes, and order and shipment details are exchanged slowly, just so both sides have a record (Kumar et al., 2020). This slow movement of information creates significant silos for planners and risk managers on either side of the transaction. It's unlikely that these companies have the same software system, and even if they do,

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there are firewalls between the systems (Sunny et al., 2020). As a result, especially for managing risk, there is no single, integrated 'source of truth' for complex global supply chains (Azzi et al., 2019).

1.2. Definition and Importance

Supply chain management (SCM) has evolved over time with various tools and technologies to make it more efficient and effective (Cole et al., 2019). One of the latest additions to this is blockchain technology. But as of today, there is still a gap in understanding the potential of blockchain in supply chain management (Rejeb, 2018). This paper addresses blockchain in enterprise supply chain management by categorizing current research and practice into visibility, traceability, and security, and provides a review of blockchain-driven initiatives in SCM (Lin et al., 2019). Due to a growing competitive market, various organizations have recognized the significance of these three components in supply chain management (Hald & Kinra, 2019). Out of a number of elements that hold the underlying force of supply chain management, traces of assets and products within the chain have received particular attention, integrating visibility with security (Feng et al., 2020). Different companies want to know about the products that they are dealing with. However, it is a huge challenge for companies to share the necessary information between partners and vendors (Esmaeilian et al., 2020). In doing so, blockchain, the new entrant, is expected to play a considerable role in these three components of supply chain management (Sunny et al., 2020).

1.3. Key Components and Processes

The blockchain, which is the key building block of the system, is a distributed or decentralized public ledger that ensures secure, transparent, and tamper-proof tracking of events and data across the supply chain network of participating stakeholders (Banerjee, 2018). The basic process of the blockchain is to record transactions of all valid activities in the form of blocks, thereby creating a chain (Dalal et al., 2017). This avoids double bookkeeping of each stakeholder. Transparency and visibility of information are enabled through a shared ledger that is available to all stakeholders (Rejeb & Rejeb, 2020). Authorization, verification, and confirmation of these activities and the data are performed in a multiparty consensus by a large number of nodes in the network and separately controlled by a permissioned blockchain network (Lin et al., 2019). With the multiple distributed nodes in the network, the decentralized cryptocurrency ensures operational reliability and security in a blockchain-powered solution (Feng et al., 2020).

2. Challenges in Traditional Supply Chain Management

Many challenges in supply chain management (SCM), both internal operational challenges and external strategic challenges, exist in traditional SCM that have yet to be fully addressed, especially with regard to end-to-end visibility and traceability (Lin et al., 2019). Internal operational challenges, including operational silos and legacy systems, hinder a connected, data-driven, and real-time ecosystem in an enterprise or across the whole supply chain (Rejeb & Rejeb, 2020). External strategic challenges include counterfeiting, product fraud, data errors, food recalls, and globally outsourced and fragmented logistics that increase the costs and effort required for end-to-end visibility and traceability (Esmaeilian et al., 2020). A lack of end-to-end visibility and traceability limits transparency in supply chains, undermining consumer trust and the brand equity of businesses (Hald & Kinra, 2019).

Vulnerable data privacy, data conflicts of interest, single-point failures, data fraud, security breaches, regulatory compliance, auditability, and governance are all supply chain data security issues that expand with a series of interconnected data and processes (Feng et al., 2020). Supply chain data problems should be combated by end-to-end trust through transparency and collaboration rather than trust through authority (Cole et al., 2019). Technologies such as paper documentation, barcodes, RFID, and GPS have been used to improve SCM visibility and traceability (Rogerson & Parry, 2020). However, such technologies are subject to data conflicts, limited tamper resistance, permanent data erasure, permanent data reuse, data repudiation, and forgery and tamper security weaknesses (Kumar et al., 2020). These limitations cause the challenges associated with data sharing, data tampering, and data resurrection and reacquisition capabilities in traditional SCMs (Sunny et al., 2020).

2.1. Lack of Transparency and Visibility

For manufacturers, visibility and traceability are key capabilities that enable them to maintain flexibility, support customers when working against time, and stay ahead of the competition in a digitally connected world (Banerjee, 2018). It is not uncommon for customers to lack complete visibility of the production and supply status of any given manufactured product (Lin et al., 2019). They may be highly dependent on the visibility and control tools offered by manufacturing firms to manage their own tactics by processing all necessary data into massive datasets from different sources and thus find ways for better forecast accuracy that can add value (Feng et al., 2020). This is often because these tools aggregate production and logistics data across different silos, both within the manufacturers and between those parties who are involved in the value chain, which may include carriers, lenders, or regulators (Rejeb, 2018).

There is a lack of visibility that data-sharing between partners would actually eliminate. However, organizations are unwilling to share such sensitive data due to the visibility of their vulnerability (Esmaeilian et al., 2020). This inflexibility has a negative impact on the number of supply chain situations (Rogerson & Parry, 2020). For example, the inordinate connection of multiple companies and other parties involved in global food supply chains contributed to a particularly difficult process of tracing and combating the sources of outbreaks of salmonella (Dalal et al., 2017). Companies combine information retrieval from ERP, WMS, and trade portals to track the production characteristics. These platforms are often not reliable or not interoperable, nor do they have high monitoring capabilities, particularly if operation-related data stored in ERP or WMS applications are unavailable (Hald & Kinra, 2019). A significant lack of traceability, reliability, and insight into disruptions, as well as a high fraud risk in global pharmaceutical or other goods supply chains, exists (Queiroz et al., 2020).

2.2. Data Silos and Inefficiencies

Poor accessibility and sharing of supply chain information among stakeholders result in fragmented communication (Kumar et al., 2020). This is partly because firms have their private databases of business-critical information. There are huge economic benefits if both suppliers and customers share better information, for example, by replacing forecasted demand with actual changes in inventory replenishment requests (Lin et al., 2019). Studying the collaborative practices in the supply chains of leading manufacturers has identified a set of critical issues that limit supply chain collaboration, among which is the ability of firms to manage the trade-off between sharing critical and proprietary information (Rejeb & Rejeb, 2020).

Both the cost and accuracy of supply chain forecasts are directly influenced by how well demand information is shared (Feng et al., 2020). Information latency includes interpretation, internal reporting, and action latency. Improving demand signal accuracy and demand latency is quantified to determine the cost of information sharing and the value of information accuracy (Esmaeilian et al., 2020). If information improves and better reflects real demand, the pipeline of the downstream entities can be shortened through lower review latency and faster decision-making (Sunny et al., 2020). The supply chain bullwhip effect can be eliminated. When there are larger price fluctuations, the forward buying strategy can be beneficial. However, when buyers have access to better information due to improved forecasts, the value of forward buying will be reduced (Hald & Kinra, 2019). On the other hand, the effect of demand information inaccuracy has the same impact as the bullwhip effect, but opposite in direction (Banerjee, 2018).

3. Introduction to Blockchain Technology

You may view the state of the global blockchain market as one poised for growth and significant innovation, particularly within the enterprise space (Banerjee, 2018). Once perceived as the sole domain and purview of virtual currencies, blockchain technology and its use cases are now breaking out of the cryptocurrency shadow and influencing technology investment decisions and new product direction (Cole et al., 2019). The slow evolution of blockchain is giving way to rapid acceleration as commercialization pushes the technology out of leading-edge R&D labs and into production within multiple verticals such as financial services, retail, and professional services (Rejeb & Rejeb, 2020). Blockchain has made the leap from prototype to production and is revolutionizing the manner in which businesses do business (Esmaeilian et al., 2020). While led by financial services and assessed for trade, post-trade, and settlement applications, blockchain is also enabling the prospective rearchitecture of insurance, asset management, and capital markets, among other vertical industries (Lin et al., 2019). Healthcare has rapidly come into focus, bolstered by the advances in information sharing, auditing, and workflows that blockchain offers, even as media and entertainment, professional services, telecom, and oil and gas actively explore the technology (Feng et al., 2020). Blockchain as a service deployed on enterprise infrastructure or the cloud has become popular, where the blockchain can operate in tandem with conventional enterprise applications or as a plug-in supporting a new breed of software applications (Sunny et al., 2020).

3.1. Definition and Key Features

As an emerging technology, blockchain creates value by enhancing trust and transparency in complex multi-stakeholder systems (Hald & Kinra, 2019). This can be established by reducing the reliance on centralized or semi-centralized records as the single source of truth; enabling trusted traceability from one state to another through transparent and immutable cryptographic proofs; and facilitating trusted integrity checks to identify unauthorized modifications of the data while the data is being transmitted through inter-organizational boundaries (Dalal et al., 2017). Due to the lack of a universal definition of blockchain, this research adopts the following specific definition in the context of blockchain for supply chain management in enterprises: "Blockchain is an immutable, decentralized, and transparent peer-to-peer network infrastructure that enables distributed consensus with verifiable transactions, collectively maintained by the participating exchanging entities with a set of predefined rules" (Queiroz et al., 2020).

The key features of blockchain, as its name suggests, are block and chain. Each block in the blockchain is a ledger structured to contain data, the hash of the block's previous block, and a timestamp (Chang & Chen, 2020). When a new block is created, it is linked to the previous block and the composite growth is called creating a chain, hence the term blockchain (Azzi et al., 2019). Digital signatures certify that the data in each block has not been altered and the authenticity of the source (Cole et al., 2019). Digital signatures are computed based on a one-pass public key algorithm that transmits a private key held by the signer to generate the digital signature (Rejeb & Rejeb, 2020).

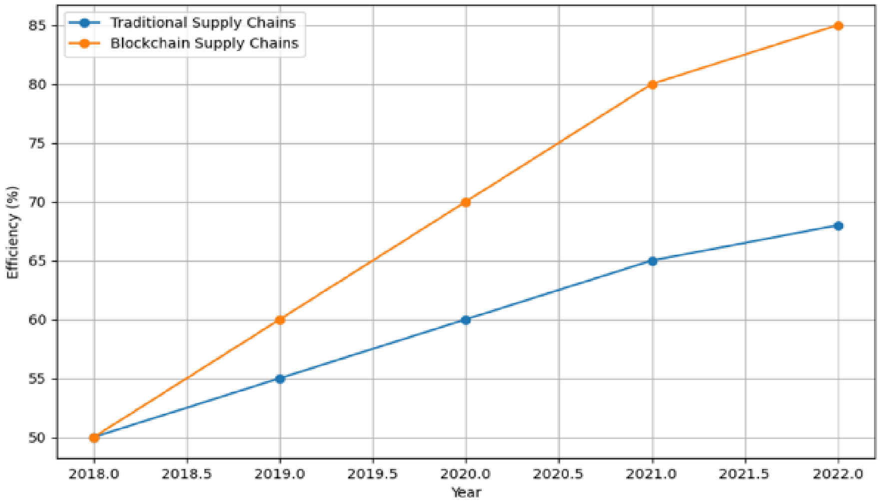

Figure 1 Blockchain vs. Traditional Supply Chains

3.2. Decentralization and Consensus Mechanisms

Decentralization of systems is considered to be one of the core distinguishing factors of blockchain technology (Banerjee, 2018). A blockchain is a decentralized ledger maintained using consensus mechanisms, and all participating nodes maintain a copy of the ledger, making the system decentralized (Kumar et al., 2020). In the context of a blockchain-based supply chain, decentralization directly improves the visibility, traceability, and verifiability of the products (Lin et al., 2019). In a supply chain, participating entities may not trust a central authority to govern the ledger, as the entity managing the centralized database could potentially manipulate the data to support a particular party's interests (Feng et al., 2020). A decentralized ledger ensures increased visibility and traceability, and verifiability against past data, as the ledger is maintained by multiple independent parties participating in the process (Esmaeilian et al., 2020).

The consensus mechanism is a fundamental concept in blockchain technology, whereby participating nodes agree, corroborate, and finalize the entries in the ledger (Hald & Kinra, 2019). The consensus mechanism ensures that the ledger remains consistent and accurate and eliminates double spending in the context of cryptocurrencies (Rejeb, 2018). However, distributed systems built for enterprise supply chain management usually have traditionally strayed away from using consensus mechanisms due to the trust and security issues that the mechanism brings (Sunny et al., 2020). Consensus mechanisms are designed to ensure the stability of the network by keeping all the participating nodes in sync and pursuing the same goal (Rogerson & Parry, 2020). The consensus ensures the blocks in the blockchain are tamper-proof and the ledger of transactions is incorruptible (Queiroz et al., 2020). All of this ensures that the data in the blockchain can be trusted (Chang & Chen, 2020).

Table 1 Comparison of Traditional and Blockchain-Based Supply Chains

Feature	Traditional Supply Chain	Blockchain-Based Supply Chain
Transparency	Limited	High
Traceability	Manual	Automated

Security	Moderate	Enhanced
Cost Efficiency	Low	High

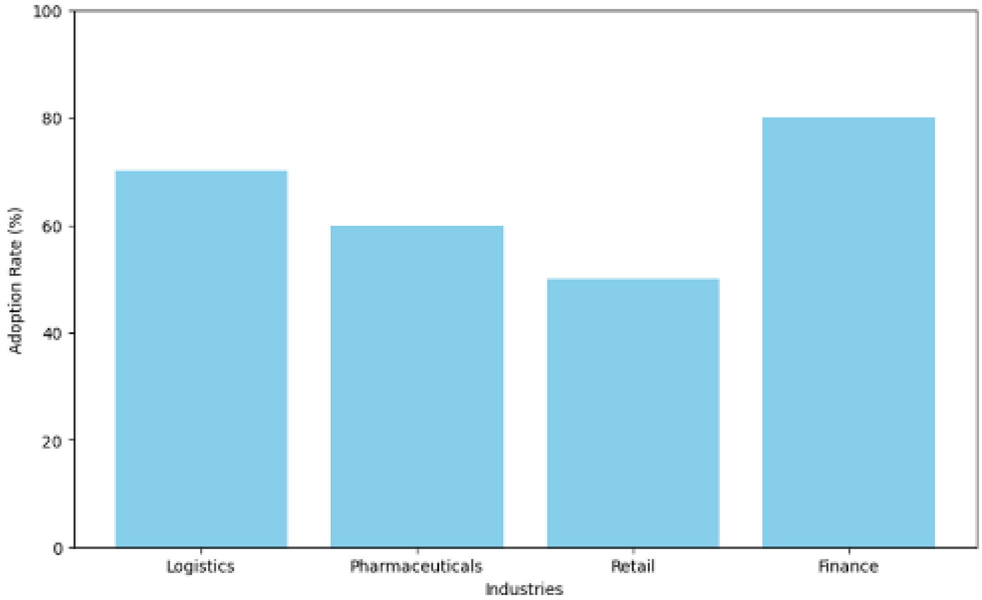

Figure 2 Adoption of Blockchain Across Industries

4. Applications of Blockchain in Supply Chain Management

Blockchain is expected to enhance the management and performance of supply chain management systems through its support for encrypted, tamper-proof, and auditable databases (Lin et al., 2019). Having gained roots in cryptocurrency applications, blockchain is now recognized for its potential in business sectors, especially in enterprise supply chain management applications (Feng et al., 2020). In this scenario, the paper illustrates one of the most commonly deployed permissioned blockchains for the application of traceability, transparency, and security in the supply chain (Hald & Kinra, 2019). We also discuss and demonstrate blockchain-inclusive enterprise supply chain management with an open-source logistics model. The deployment is evaluated through some simulation experiments based on empirical enterprise logistics and blockchain techniques (Rejeb & Rejeb, 2020).

While organizations increasingly seek to embrace a blockchain-based collaborative supply chain, they may lack extensive rules specific to deployment scenarios or insights to assess or optimize critical parameters of the blockchain deployment (Kumar et al., 2020). This paper targets these problems by introducing an alternative to the enterprise SCM framework. Transparent, auditable, and tamper-proof databases that blockchain naturally provides can grant an institutionally shared supply-demand history (Cole et al., 2019). Through traceability and accountability, blockchain can increase auditability and compliance (Banerjee, 2018). Compared with the traditional applied enterprise supply chain, the alternative solution uses blockchain technologies, contracts, and DevOps practices to promote data integrity, end-to-end visibility, and active tracking in the management and validation phases of each contractually bound transaction within a blockchain-enabled enterprise supply chain (Azzi et al., 2019). These efforts will enhance specific visibility, traceability, accountability, and security in the SCM systems that will lead to superior performance in an era of IoT and big data (Sunny et al., 2020).

4.1. Enhancing Transparency and Traceability

Industry 4.0, characterized by the expansive practice of the 'Internet of Things (IoT)', necessitates that companies generate massive e-transaction data that may become a business asset (Lin et al., 2019). Multiple e-transactions occurring at various facilities and locations can be an unwieldy tool to manage, and corporate needs for supply chain transaction transparency and integrity continue to grow (Rejeb & Rejeb, 2020). Thus, for companies practicing supply chain management, our study suggests the use of blockchain technology to overcome these recent difficulties (Esmaeilian et al., 2020). Enterprise supply chain visibility, traceability, and security in this manner can be enhanced

(Feng et al., 2020). The initial supply chain processing steps necessary to prepare business-essential e-transactions as blockchain entries are introduced. By managing e-transactions as immutable blockchain entries from the beginning, end-to-end supply chain visibility is obtainable, further distributing the secure management of enterprise IoT devices across supply chain network nodes (Cole et al., 2019).

For the fastest new product, fastest delivery time, and lowest cost, companies are engaged in the competitive activity that is supply chain management (Banerjee, 2018). Meeting these three customer expectations, however, is no longer solely a corporate internal process. To meet these customer demands, most companies must partner with their suppliers and other supply chain participants in collaborative supply chain relationships (Rogerson & Parry, 2020). The business-essential online e-transactions between supply chain collaboration partners is a distinctive supply chain management paradigm that extends the internal 'inside-out' direction of rules, tasks, and e-transaction data to suppliers with 'outside-in' and suppliers' suppliers with 'far-out' tasks (Sunny et al., 2020). Companies are being asked to respond directly to customers, not only for cost, delivery, and quality assurance, but more recently with transparency and traceability of how, when, and where e-transactions were completed (Hald & Kinra, 2019). By making use of blockchain technology, corporate transparency and traceability can lead to significant supply chain network adjustments that substantially enhance management throughout the enterprise (Queiroz et al., 2020). For companies practicing supply chain management, blockchain technology may be the ultimate tool currently available to overcome these major visibility, traceability, transparency, and security difficulties (Lin et al., 2019).

4.2. Improving Supply Chain Efficiency

The opportunity to bring publicity into the supply chain was recognized (Rejeb & Rejeb, 2020). Visibility should help organizations anticipate problems before they occur, which has a wide range of advantages, such as enhancing overall supply chain efficiency (Feng et al., 2020). Not only does blockchain possess the potential to enhance visibility and the traceability of goods as they move through the supply chain, but it can also offer real and substantial advantages in terms of the security of data being exchanged (Sunny et al., 2020). The supply chain should also benefit from better customer service and cost reduction through improvements in speed and accuracy (Cole et al., 2019). Originating from the need to increase supply chain visibility, it is believed that the key factor for realizing the potential advantages of blockchain is data sharing, enabled through a blockchain: “only if all actors within the supply chain can be persuaded to share data with additional members, can blockchain be used to reach its full potential, because by doing so, less than favorable behavior can be immediately identified” (Banerjee, 2018).

5. Benefits and Advantages of Using Blockchain in Supply Chain Management

The effects of implementing a blockchain into enterprise supply chain management are extensive. These effects can be classified into two categories: direct and indirect. Direct effects are those that result from the blockchain's implementation, such as having access to real-time data (Hald & Kinra, 2019). They also provide user rights for visibility into important information. Indirect effects are those that are either the results of the direct effects or the benefits that occur over time from using a blockchain-based supply chain management solution (Esmaeilian et al., 2020). Such effects include reducing the need to make time-consuming decisions and providing tools and information for better choices (Rejeb & Rejeb, 2020). Few of the most important benefits of using a blockchain in enterprise supply chain management are detailed next. Such benefits generated by blockchain adoption are related to infrastructure improvements, simplification, cost reduction, scalability, and improved customer service (Feng et al., 2020).

- New Economic Infrastructure

User participation is inherently supported, and different kinds of users from all types of organizations, including suppliers, transporters, wholesalers, and retailers, can join. This results in various benefits associated with the programmable economy, such as reintermediation and decentralized trust (Banerjee, 2018).

- Value Chain Simplification

Disintermediation has the potential to simplify the value chain in terms of fewer linkages in the production stages through to sales, and can allow direct sales between the manufacturer and customer. With data exchanged directly on the blockchain, there is also minimized manual data entry through the transaction process, hence there are fewer opportunities for errors (Sunny et al., 2020).

- Lower Transaction and Administrative Costs

The elimination of intermediaries such as banks and brokers aims to reduce costs related to transactions and clearing and settlement overheads (Lin et al., 2019). Overall, it is estimated that blockchain could generate global cost savings of up to 73 billion dollars annually across all sectors (Cole et al., 2019).

- Supply Chain Scalability

As organizations grow, they can quickly add additional internal users, external suppliers, or service providers to the blockchain supply chain platform, and rapidly connect and engage without the need for expensive layers of new or existing software-based links and relationships. The growth of new suppliers, products, administrations, and distribution agents is unhindered, thus opening more global markets to supply chain organizations for purchase, sale, trade, and investment (Rogerson & Parry, 2020).

- Customer Service and Product Development Improvements

Demand for immediate updates and visibility, and for more accuracy in forecasting customer service deliveries, is increasing. Such information exists on customer and partner blockchain applications that are unavailable in traditional sources, and blockchain-generated transparent demand signals will now be visible in real time (Rejeb & Rejeb, 2020). In flow, the business gains knowledge to assist with demand management, detect errors with products, and understand how well they serve the customers, and very quickly and efficiently respond with product adjustments (Feng et al., 2020). Data from properly identified misbehaving parts can also guide improvements to the production process (Kumar et al., 2020).

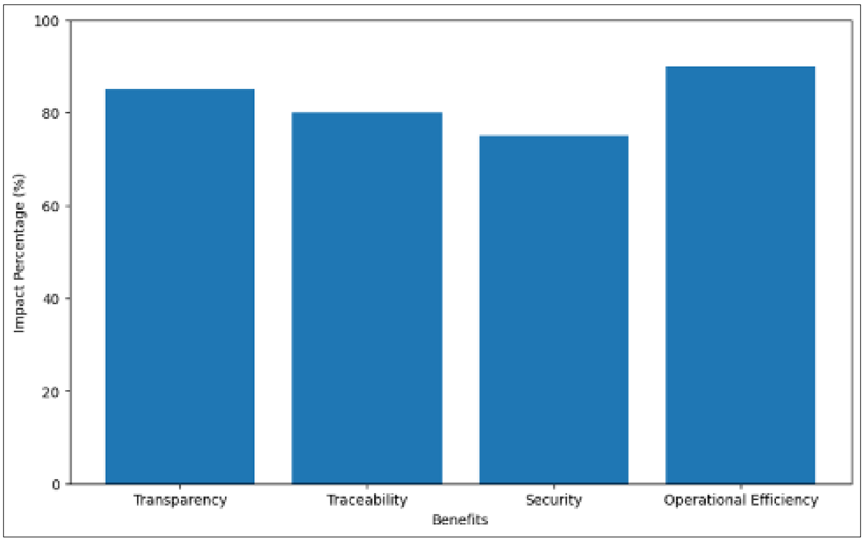

Figure 3 Blockchain Benefits in Supply Chain Management

5.1. Enhanced Security and Data Integrity

Data security and integrity pose the biggest threat to enterprise supply chain management operations because they need to share data with many different stakeholders (Azzi et al., 2019). Blockchain enhances security by allowing only authorized parties to view transactions recorded on the blockchain and protects data with cryptographic techniques (Hald & Kinra, 2019). Blockchain technology was designed with the intent to create transactions that cannot be changed, cannot be reverse engineered, and where not even the original creator of the transaction can delete the records (Lin et al., 2019). Transactions recorded in the blockchain cannot be altered because they are linked to the previously recorded transaction by the cryptographic tool of hashing (Rejeb, 2018). As such, once a transaction is recorded to the next block in the blockchain, the transaction is effectively immutable and as secure as a transaction can become (Feng et al., 2020). In the blockchain, tampering with transactions is nearly impossible. Blockchain enhances security and data integrity (Cole et al., 2019). Blockchain can ensure that there is only one source of the data and that data is shared with many different stakeholders across the supply chain network (Banerjee, 2018). Participating in the blockchain network requires that a participating company share data with other participating companies that are in the same blockchain network. Data can be shared with multiple companies that are in the same network, but data cannot be accessed by external parties (Sunny et al., 2020). Any unauthorized access to a blockchain network can be detected (Dalal et al., 2017).

Table 2 Blockchain-Enabled Features and Their Benefits

Blockchain Feature	Description	Benefit
Immutability	Tamper-proof transaction records	Improved trust
Transparency	Shared ledger accessible to all participants	Increased accountability
Smart Contracts	Automated contract execution	Operational efficiency

5.2. Cost Reduction and Operational Efficiency

To reduce operating costs and improve operational efficiency, the ledger feature of blockchain platforms can calculate and share verified information, including contracts, transaction records, shipping addresses, quantities, prices, and tracking numbers (Lin et al., 2019). Importantly, this allows operators' data to be recorded in real time and made accessible to supply chain participants operating under different roles, developing opportunities for changes in the traditional supply chain operating model from separation and intermediation to collaboration and centralization (Esmaeilian et al., 2020). The traditional operating model requires local importers and exporters to conduct data analysis, customs declaration, certificate of origin, and other formal documents through a variety of intermediaries, including shipping companies, customs, banks, accounting firms, and professional certification agencies (Rogerson & Parry, 2020). This is time-consuming, cumbersome, and costly. If information and business resources can be shared, the procedures can be integrated (Feng et al., 2020). A more efficient and consistent management hosted by smart contracts can enhance the efficiency of core operations, reduce costs, and improve the quality of customs declaration, billing, inspection, and auditing (Hald & Kinra, 2019).

The distribution and implementation of blockchain contracts can provide powerful support for supply chain visualization, asset tokenization, message encryption, digital signing, or coding for data transactions, making it possible to create more accurate verified signature records (Rejeb & Rejeb, 2020). Furthermore, access control and sharing protocols can ensure that only the appropriate parties can access the data, and their access history and trajectory data are accurate and reliable (Cole et al., 2019). Small and medium-sized enterprises, which are the mainstay of modern supply chains, will receive high-quality and efficient coordination and collaboration support, regardless of whether there is strong professional knowledge or advanced IT capabilities (Azzi et al., 2019).

6. Case Studies and Examples of Blockchain Implementation in Supply Chains

This section provides a better understanding of blockchain in the supply chain by operationalizing our framework through a set of case studies and company examples across different industries in order to showcase attributes, as well as to compare and contrast their adoption and implementation challenges (Hald & Kinra, 2019).

6.1. Retailing and Consumer Goods

A variety of well-known retail and consumer goods companies have promoted discussions and developed projects and use cases (Feng et al., 2020). The food industry represents not only the largest but also the most mature sector in respect to early blockchain implementations within the supply chain (Rejeb & Rejeb, 2020). Recently, a "game changer" project was launched—i.e., identifying and controlling foodborne infections, disease outbreaks, governmental fines, or goodwill losses caused by tainted food or the delayed dissemination of information about food defects that lead to consumer illness (Lin et al., 2019). Innovative projects have also been initiated.

6.1.1. Food Industry

Some of the different actors in the agri-food industry could provide diverse temperature data from trucks, railways, or intermodal containers in case of the multi-modality of transport of products (Rogerson & Parry, 2020). Allowing both carriers and shippers to have access to the same information would prevent disputes, making it possible to agree on penalty negotiations, or helping to forecast the quality or the remaining shelf life of the fresh products (Banerjee, 2018). Therefore, whereas the temperature of a cargo is the main deteriorating factor, monitoring it might only be the tip of the iceberg in the food industry (Esmaeilian et al., 2020). More detailed systems can be designed, including an IoT installed in transportation units to transmit data in real-time to an intermediary such as a carrier's server (Sunny et al., 2020). From there, it is the warehouse or factory manager who, through the API, is able to incidentally become finally traceable up to the delivery of the products (Azzi et al., 2019).

In the warehouses, another phase of food logistics, the maintenance of good product conditions is performed using an automatic, preventive, refrigerated, or controlled cooling system (Rejeb, 2018). Security features and product items for a multitude of applications in many areas, such as the food industry, life sciences, personalized food supplements, and others, can be utilized (Lin et al., 2019). For example, a small edible spectroscopic compound encoding a morphologic code of the product can be inserted in the edible labels of the food and traced with a spectrometer or the use of a smartphone (Cole et al., 2019). For a blockchain provider, information including details of shipments, massive amounts of sensor data, and location details is provided for tracking food products (Feng et al., 2020).

Table 3 Use Cases Across Industries

Industry	Use Case Example	Benefit
Food	Tracking foodborne illness	Enhanced safety
Pharmaceuticals	Monitoring drug authenticity	Regulatory compliance
Retail	Tracking product provenance	Customer trust
Logistics	Real-time tracking of shipments	Operational efficiency

6.2. Pharmaceutical Industry

The purpose of this subsection is to present the current concerns of pharmaceutical companies and how distributed ledger technology could help address the challenges faced in the pharmaceutical industry (Hald & Kinra, 2019). The objective is not to prove that the use of this technology can bring value to pharmaceutical companies; rather, it is to discuss and provide insights on how this technology can be used (Rejeb & Rejeb, 2020). The pharmaceutical industry is a key sector across the world, producing a wide range of medicinal products to save or improve people's lives (Rogerson & Parry, 2020). Not only are these products important, but also their predecessors, the active pharmaceutical ingredients, which are either natural sources or chemical compounds used in the production of different medicinal products (Kumar et al., 2020). These industries are highly regulated and are connected to compliance promotion rather than prevention. For instance, to ensure safety, random testing in order to check the quality of the ingredients used by medicinal product manufacturers is suggested (Lin et al., 2019).

This technology can verify the authenticity of products and trace the records. The structure of the platform, as well as the concepts presented, can be used for any validation process from other manufacturing industries (Cole et al., 2019). Distributed ledger technology, especially public chains, can bring greater security to verify the authenticity of world pharmaceutical raw material providers and their certificates (Azzi et al., 2019). Clinical trial phases and follow-up related to medical patients after treatment could be monitored by a genuine platform (Banerjee, 2018). In the perspective of semi-large enterprises, only certain organizations would be capable of dealing with creating all these typical frameworks; besides, it could cope with the resources and demands fulfillment (Rejeb & Rejeb, 2020). If pharmaceutical multi-enterprise clusters apply for a more advanced solution related to financial or incentive models with distributed ledger technology techniques, the founders could pay miners directly through wallets to stimulate dependability (Feng et al., 2020).

7. Regulatory and Compliance Considerations for Blockchain in Supply Chains

In the previous sections, we have covered various design choices and tools offered in blockchain and, in relation to the enterprise use cases, thematic practical application of blockchain (Hald & Kinra, 2019). However, as illustrated, blockchain requires suitable governance to ensure correct information is added to the ledger and that data on the ledger is correctly interpreted. In other words, "the blockchain isn’t going to monitor itself" (Feng et al., 2020). Appropriate regulatory systems can complement the governance of blockchain and contribute to enhancing trust and a coherent use of the technology (Rejeb & Rejeb, 2020). With the attributes blockchain is promoting, there are certainly roles for government regulators to consider regarding its enabling, adopting, operational, and monitoring phases (Cole et al., 2019). Below, we discuss regulatory considerations that are particularly relevant to areas such as supply chain, which can benefit from blockchain technology (Lin et al., 2019).

7.1. Principles for Imposing Regulation

Before launching into the regulation and compliance challenges and approaches for using blockchain technology in supply chain management systems, let us offer some principles of regulatory governance that we believe can be usefully applied (Azzi et al., 2019). These are adapted from the literature on regulation in other sectors and can credibly be seen to have more wide-ranging implications beyond supply chain use cases (Rejeb, 2018). The specific countries or jurisdictions in which blockchain is used will decide the scope of the regulation, the way it is implemented, and its objectives (Sunny et al., 2020). The principles are aimed at helping countries and other jurisdictions to consider the nature of the regulatory response that they want to implement or instigate (Hald & Kinra, 2019). We do not expect to see all or any of these suggested methods spelled out specifically in regulation documentation where blockchain is used. But reflecting on the consequences and outcomes of blockchain innovations through these principles can provide a useful light to help identify what managing governance systems can be imposed (Kumar et al., 2020).

7.1.1. Data Privacy and Protection Regulations

Data privacy and protection regulations obligate organizations to oversee their customers' data (Feng et al., 2020). This includes the collection, use, and disclosure of data, necessitating greater restrictions and privacy protections (Lin et al., 2019). These rules require companies to guarantee that they obtain legally needed consent, store the data securely and confidentially, and provide individuals the ability to demand deletion of their data (Rogerson & Parry, 2020). By using blockchain, enterprise supply chain management systems are capable of defending against illegitimate access and guaranteeing data integrity by keeping sensitive data off the blockchain and using cryptographic methods (Cole et al., 2019).

Keeping fragmented, encrypted personal data in off-chain storage, masking the hashes and allowing access only via decryption keys stored at a permissioned network can be suggested as a solution to the problem (Rejeb & Rejeb, 2020). Thus, centralized solutions involving an intermediary can be avoided and data privacy can be sustained (Azzi et al., 2019). However, the development of such complicated technological infrastructures can be demanding, as handling encryption, decryption, and cryptographic protection can be complex (Banerjee, 2018). Consequently, enhancing collaboration with cybersecurity firms and incorporating their tools into the existing platform can aid companies in consulting and helping with the use of their technologies (Esmaeilian et al., 2020).

7.2. Industry-Specific Compliance Standards

The system can also help cross-industry companies and those in the buy-services category to build comprehensive supply chain compliance indicators (Lin et al., 2019). The food production industry is very strict in the production process and product indicators. The food component supply enterprise collection-distributed component provider will be strictly checked for food safety indicators (Rejeb & Rejeb, 2020). The transportation industry has high requirements for environmental standards, energy consumption indicators, and social responsibility when transporting goods, and the courier industry has even higher requirements (Sunny et al., 2020). The manufacturing industry has strict process indicators and social responsibility requirements (Cole et al., 2019). If the auditing companies or platforms can also be based on blockchain supply chain data to verify whether the supplier's products meet the standards, the audit time and cost can be greatly reduced (Feng et al., 2020).

It proposed a blockchain solution for tracing colored gemstones. The system is point-to-point for distributed gemstone resources and can be modified by this work (Hald & Kinra, 2019). Not all industries need such industrial compliance rules to be effective, but within certain industries, due to the protection of rights and interests, safety, and reputation of the industry, such a set of rules is valuable (Lin et al., 2019). These industries include but are not limited to agricultural food, pharmaceuticals, clothing, electronic products, chemical products, and more (Azzi et al., 2019). There are no blockchain platforms that target the supply chain data of established industrial compliance rules to verify the effectiveness of compliance with specific industry rules (Rejeb & Rejeb, 2020). It believes that under certain industry-based scenarios, a blockchain platform can provide an immediate channel for the customer to audit the supplier and product or, in the case of an incident risk, may help to trace the source of the incident and minimize the risk (Feng et al., 2020).

8. Future Trends and Innovations in Blockchain for Supply Chain Management

Blockchain technology has introduced a paradigm for decentralized and trusted transactions in many application domains, including supply chain management (Banerjee, 2018). The distributed ledger system offers many unique features for such applications, of which the foremost cited one is the immutable audit trail and the trust in the data origin (Hald & Kinra, 2019). Blockchain has the potential to solve a variety of problems that are experienced in supply chain management, such as traceability, transparency, and trust in various data sources (Esmaeilian et al., 2020). However, blockchain technology comes with its own challenges, such as scalability, security, and standardization (Rejeb & Rejeb, 2020). Nevertheless, in its current state, blockchain technology is already being explored, implemented, and tested in many use cases, be it from the aspects of integration to traceability or quality control (Feng et al., 2020). With firms already investing in blockchain technology through consortiums, we expect that the collaboration and communication aspects of blockchain technology are bound to be well addressed; but further innovation will be needed in order to address important technical features such as smart contracts, the genesis, and the data structure itself (Cole et al., 2019). In addressing data quality and data handling issues, it is argued that for blockchain technology to reach its full potential for supply chains, a major overhaul will be needed (Lin et al., 2019). This chapter begins by providing a comprehensive overview of blockchain technology and why it is suitable for supply chain management. We then analyze the literature through the dimensions of what, when, and why blockchain is used. Subsequently, we examine the gaps in the literature as well as analyze the future outlook.

8.1. Integration with IoT and AI

The utilization of AI with blockchain to solve supply chain problems will result in a reliable, transparent, and trustworthy system for a more effective supply chain network (Sunny et al., 2020). At the same time, the collection of data from IoT sources is massive and continuous, and the provenance information of the data is of crucial importance (Lin et al., 2019). The integration of blockchain technology into the supply chain system will address the determinants of continuous and mutable data security breach problems within IoT devices (Azzi et al., 2019). Blockchain technology can bring transparency, traceability, status, and security of the material data in every supply chain found with IoT devices (Rejeb & Rejeb, 2020). Blockchain technology can also help agents legitimize, validate, coordinate, and transact with trust in a decentralized system, where no middleman is needed (Feng et al., 2020).

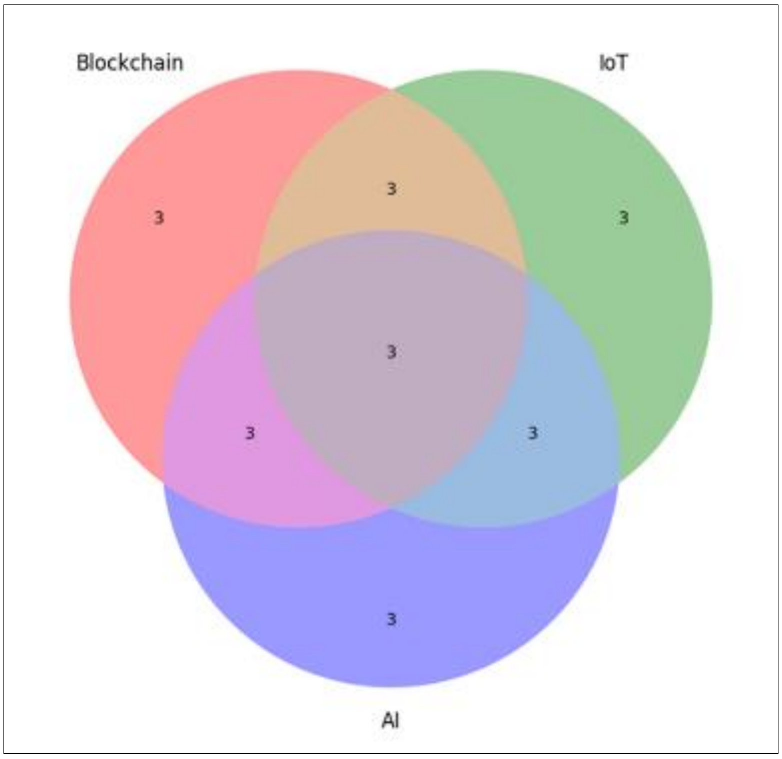

Figure 4 Blockchain Integration with IoT and AI

A solution was developed to strengthen the visibility of smart supply chains (Hald & Kinra, 2019). It resorts to storing the data that derive from the different process stages, contributed by the integration of IoT technologies or by personnel, to blockchain platforms (Rogerson & Parry, 2020). It leverages the timestamps on blockchain-derived data to offer visibility services that are exclusively focused on transparency, traceability, lifecycle, and status of information (Esmaeilian et al., 2020).

In the industrial automation domain, a collaboration was formed with a blockchain-as-a-service company and an intelligent edge solution provider to meet the challenges that materialize with blockchain (Banerjee, 2018). This solution allows enterprises to run IoT devices on blockchain networks at the location where the devices are controlled (Lin et al., 2019). The business logic of the chaincode can be implemented, where time savings can also be achieved from the computation of the results at the intelligent edge (Sunny et al., 2020). The aim of the proof of concept is to showcase that blockchain networks can lay a practical foundation to protect the development and traceability of processes in industrial settings (Rejeb & Rejeb, 2020).

8.2. Interoperability and Standards

The lack of agreed standards has been a significant barrier to the wide-scale adoption of blockchain technologies, particularly in regard to multi-organizational enterprise networks (Cole et al., 2019). This can result in blockchain networks becoming more interoperable and hinder the establishment of global distributed consensus on transactions (Feng et al., 2020). The degree of interoperability achieved depends significantly on the design architectures of blockchain systems (Rejeb, 2018). A consortia-based approach, which is a prerequisite of most enterprise blockchain platforms, can push narrow standards from a technical perspective (Azzi et al., 2019). One of the main problems that enterprise blockchains are grappling with is that they are only accessible to partners who rely on the same blockchain or those stakeholders who have joined the same consortium (Hald & Kinra, 2019). However, real-life supply chain ecosystems are crowd networks where parties use different blockchain bases and different ecosystems (Sunny et al., 2020).

Commercial supply chains are built on a mixture of large, small, and medium-sized firms, from very large multinational firms to sole traders and not-for-profit stakeholder communities (Lin et al., 2019). Not all stakeholders will then be able, or even willing, to join a given blockchain's ecosystem (Rejeb & Rejeb, 2020). This plurality of ecosystems will then lead, by default, critical masses to shift from a role. The benefits derived from a more plural paradigm may indeed be an example that the lived or lifeworld is remodeling the operative or system environment of technology (Banerjee, 2018). Theoretically, the democratic paradigm sees the most inclusive database layer ecosystems on which the entire institutional fabric of society should be based and dependent (Cole et al., 2019).

Governments, regulators, and standard setters at an international level can help with this debate, facilitating global harmonization, transparency, and accountability (Feng et al., 2020). The case for interoperability has then to be taken more seriously. In our globalized society, this is essential for technology to fulfill its full potential, which is not only the efficiency transcendent goal measured by the present value for the key organizational stakeholders (Lin et al., 2019).

9. Challenges and Limitations of Blockchain in Supply Chain Management

In this chapter, we reviewed the applications of blockchain technology in a supply chain management context under several themes, including traceability, visibility, security, and quality management (Hald & Kinra, 2019). We presented the results as a series of blockchain models with associated data, the identified requirements, technologies, and existing implementations (Feng et al., 2020). Furthermore, we identified the future directions of this topic. The challenges of blockchain for enterprise supply chain management are also emphasized (Esmaeilian et al., 2020).

Although blockchain technology can bring multiple benefits and even reform the present supply chain frameworks, its deployment should face multiple challenges and limitations (Rejeb & Rejeb, 2020). In this part, we will identify these significant issues that include the concern of integration, the limitation of scalability, the requirement of approval, the trust issue of participating nodes, the friction of gains distribution, the need for amending regulations and standards, the limitation of recruitment, and the concern of lack of potential benefits assessment (Sunny et al., 2020).

9.1. Scalability and Performance Issues

Another set of problems in large-scale blockchain projects concerns blockchain scalability and performance issues (Lin et al., 2019). Simply put, blockchain scalability refers to the ability of the technology to handle the transaction load (Cole et al., 2019). In general, the capability to handle an increasing number of transactions needs to be improved. Efficient data processing and high performance become necessary elements of a successful blockchain solution (Rejeb & Rejeb, 2020). Mining and consensus algorithms such as proof of work need to change to maintain consistency and guarantee the benefits of immutability and traceability (Banerjee, 2018).

At present, insufficient understanding of the scalability of the state-of-the-art approaches might lead to the formulation of ineffective solutions (Feng et al., 2020). Small transaction capacities could influence the entire blockchain system and severely restrict the practical effectiveness of blockchain (Hald & Kinra, 2019). Several aspects have also been widely researched and used to enhance blockchain performance. Researchers have studied consensus algorithms, especially resulting from the increasing centralization in Bitcoin (Sunny et al., 2020). Focused mainly on public cryptocurrency blockchains, consensus algorithms, and on-chain scaling, critics of proof of work have suggested transitioning to cheaper, greener, or faster alternatives (Azzi et al., 2019).

While encryption technologies are a fundamental tool capable of achieving watermarking and fingerprinting, they are rarely incorporated into the design of security-sensitive systems in a meaningful way (Rogerson & Parry, 2020). Utilization of state-of-the-art encryption techniques may be essential to support secure transactions, scalability by trusted off-chain mechanisms, voting systems, and the provision of meaningful cryptographic analysis in the blockchain (Lin et al., 2019). Furthermore, current approaches to enhance blockchain economic throughput through technologies such as state channels and sidechains could suffer from free-rider and prisoner's dilemma problems as they lack incentives for participants ensuring blockchain-level consensus (Rejeb & Rejeb, 2020). Active work is being done to address these economic disincentives by employing third-party guarantees or designing viable chain-specific compensation mechanisms (Banerjee, 2018).

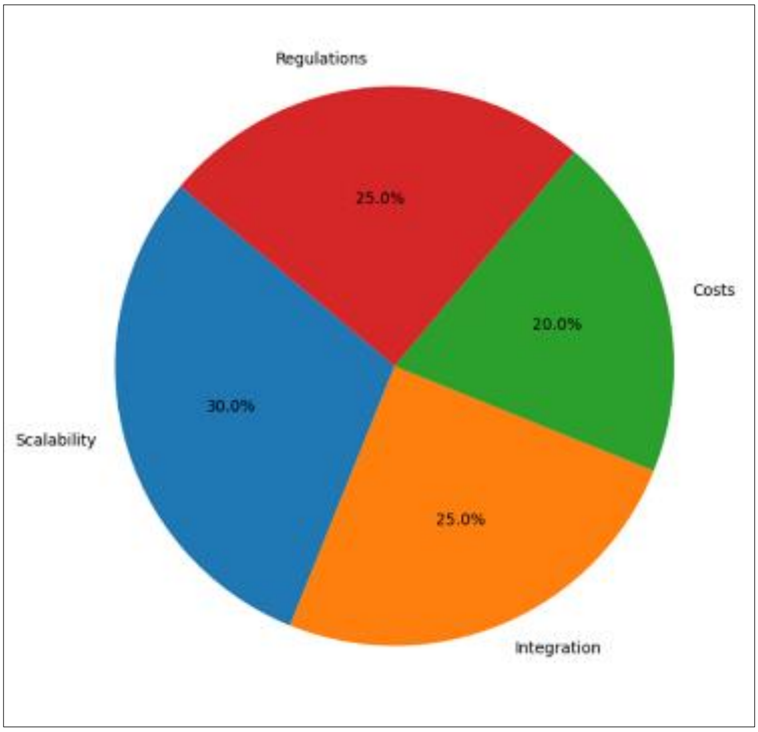

Figure 5 Challenges in Blockchain Deployment

9.2. Integration with Legacy Systems

Although the integration of blockchain technology with the current supply chain management systems may sound a bit challenging, it turns out that it is actually not as hard as expected (Feng et al., 2020). There are many vendors that specialize in creating user-friendly APIs and SDKs that can be easily integrated with current legacy or proprietary systems and can be deployed on top of any major cloud infrastructure (Hald & Kinra, 2019). Existing supply chain management platforms can easily connect with these networks and utilize blockchain networks to improve efficiency, transparency, security, and cost-effectiveness of the supply chain (Lin et al., 2019).

These vendors provide either a private or consortium blockchain-based service through a secured API or standardized protocol-based services that are much faster and cheaper than creating a private or public blockchain from scratch (Azzi et al., 2019). Some providers also enable the connection to different existing SCM software packages and support bi-directional flow of data with data mapping, harmonization, transformation, data cleanup, and data consistency (Sunny et al., 2020). The transactions can be filtered and transferred from different supply chain partners to various stakeholders with customized dashboards according to the different needs of these stakeholders (Rejeb & Rejeb, 2020). Automatic reconciliation and easy configuration also help current SCM customers reduce the effort of integrating their existing systems with these vendors (Banerjee, 2018).

10. Best Practices and Strategies for Successful Implementation of Blockchain in Supply Chains

We identify several best practices to capture business value through effective implementation of blockchain in supply chains (Hald & Kinra, 2019). These practices also help to minimize potential complexity-related risks and costs (Banerjee, 2018). Although these insights are drawn from both firm and supply chain perspectives, we recognize that these best practices should reflect the inter-organizational nature of a supply chain, as most blockchain deployments need multiple stakeholders working together to fully capture the business value embedded in the supply chain (Rejeb & Rejeb, 2020). These best practices address organizational maturity and readiness, application configuration, technology architecture, governance, risk and compliance, and adoption (Esmaeilian et al., 2020). By comprehending the best practices before their blockchain deployment, supply chain organizations may manage the challenges related to scalability and interoperability and foster broader adoption for the consortium (Feng et al., 2020).

In this sense, the concept of readiness can also be linked to the competency framework of the firms contemplating such a solution (Sunny et al., 2020). Moreover, deployment readiness in blockchain is different from other technologies. Here, businesses looking to launch a blockchain network must develop, operate, and trust it with competitors and other stakeholders included in the same supply chain ecosystem (Cole et al., 2019). That is why its maturity must be balanced between the potential value and organizational readiness to share with cross-boundary stakeholders (Lin et al., 2019). Organizational readiness provides a comprehensive understanding of the organization and partners' capabilities and plans (Azzi et al., 2019). Business leaders need to re-examine the consortium members' technological and operational capabilities, as well as the ecosystem, to assist the business in developing a strategy to evaluate the organizational readiness of partners in conjunction with their maturity model (Rejeb, 2018). With this overview, their efforts may help form the decision-making process and guide the way to execute the deployment of the blockchain solution (Hald & Kinra, 2019).

10.1. Collaboration and Partnerships

Blockchain technology is still in its early and complex stage of development (Banerjee, 2018). A large number of standardization and governance initiatives are attracting participants, including industry organizations, academia, various types of service providers, and major technology providers (Lin et al., 2019). Collaboration initiatives resulted in the creation of numerous consortiums in different industries, such as logistics, pharmaceuticals, finance, and intellectual property rights, among others (Rejeb & Rejeb, 2020). These consortia potentially pool risk, reduce the implementation complexity for companies in a specific industry, and align standards with specific industry requirements (Feng et al., 2020). The prime benefit of such a partnership and/or consortium is that the required ecosystem of participants is more easily enticed to join (Hald & Kinra, 2019).

In addition to blockchain use in industry-specific use cases, there are promising potential use cases that are cross-industry and deliver mutual ROI (Esmaeilian et al., 2020). Collaboration efforts for this type of blockchain initiative are required to pool larger groups to jointly fund and cooperatively engage in such R&D, resulting in bigger potential mutual gains from a wider pool of industries leveraging their existing digital investments (Sunny et al., 2020). These benefits are also the guiding force for participation in the collaborative effort (Cole et al., 2019). Customers also welcome market leaders to agree on standards, which can accelerate market implementation (Lin et al., 2019). Small market leaders may not support a higher risk similar to the first driver mentioned (Azzi et al., 2019). Initially, the participation of market leaders will increase collaboration's value (Rejeb & Rejeb, 2020). It is expected that top companies in different industries will meet and search for consensus to establish the first practical standard (Feng et al., 2020).

10.2. Pilot Projects and Proof of Concepts

Commercial blockchain solutions for supply chains are still rare (Hald & Kinra, 2019). Moreover, despite their estimated transformative potential and relevance, blockchain adoption is still undertaken without a strong link to research and innovation (Lin et al., 2019). However, there is an increasing number of pilot projects and proof-of-concepts in supply chain management that have demonstrated the practical business potential of some aspects of a blockchain approach (Rejeb & Rejeb, 2020). These initiatives are predominantly the result of collaboration between blockchain technology providers and supply chain actors (Esmaeilian et al., 2020). There is a particular focus on food and pharmaceutical supply chains (Sunny et al., 2020). The majority of these projects seek to provide consumers with reliable information regarding the products they consume (Banerjee, 2018). They do so by ensuring that products are authentic, by facilitating product provenance, and by providing detailed information on environmentally friendly supply chains (Feng et al., 2020).

Because the focus in initiator organizations is not on value generation and on using the technology for identity and access management, these blockchain initiatives voluntarily create a tension between organizations that exercise existing control over supply chains through a regulated and democratized system for collectively monitoring and governing their supply chains (Rejeb, 2018). We aim to mitigate these problems by proposing a number of design principles for blockchain-based supply chain control that build on existing oversight, values, trust, and inquiry research (Cole et al., 2019). By providing these principles, we induct three characteristics – democratization, equity, and identity diversity – that can be absent or different in blockchain-enabled supply chain management (Sunny et al., 2020).

11. Conclusion and Key Takeaways

This paper lays out the potential benefits for enterprises of using blockchain in managing their supply chains (Banerjee, 2018). Basing our analysis on thirteen case studies from different sectors of industry, we identify three use cases that blockchain technology addresses:

- Enhancing transparency for more efficient business processes by providing real-time visibility over transactions occurring at multiple locations, and thereby enabling better decision-making around demand, operations, and supply.
- Traceability of information throughout the chain of custody, thus facilitating more rapid containment of quality issues or the location of unsafely sourced inputs and
- Security of records that can be used for auditing and regulation enforcement by public authorities, as well as enforcement of relevant contractual settlements within the supply chain.

The paper points out that the advantages of using blockchain—decreasing the risk of supply chain breakdowns and subsequently minimizing their costs—increase mostly as they broaden across a supply chain in terms of the number and heterogeneity of participants that take part in the information-sharing process. It, therefore, provides a business case analysis for the utility of adopting this technology to manage corporate supply chains.

There are several technology enablers playing a crucial role in the success of blockchain-based solutions for the enterprise, apart from blockchain technology itself. To meet large-scale enterprise requirements, as we learn from the case studies, a blockchain solution must be designed focusing on four critical aspects: information and asset transfer, security and privacy, performance and scalability, and multi-access control. These four areas influence application design, consortium management, security and privacy controls, asset structure, and much more in determining the blockchain solution's architecture.

Many enterprise supply chain environments face the design need for integrating blockchain technologies into existing, traditional information technologies. Moreover, time, cost-effectiveness, and privacy protection become important factors in the business setting when building a blockchain solution. This paper identifies potentials and limitations and recognizes both from enterprises embracing this new technology.

However, blockchain’s greatest value aligns with certain types of problems like simultaneous transaction transparency, multiparty process automation, and collateral data management . Blockchain technology ushers in an era that ultimately reinvents the IT infrastructure used to work better within and beyond the enterprise. This paper provides ontological insights into defining the bases of analysis for collaboration governance mechanisms in cross-organizational entities underpinned by blockchain technology, valuable for use in practice.

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