Role of Blockchain Technology in Supply Chain Management

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***Abstract*— Blockchain technology has drew interest for its capability in supply chain management to has prompt efficiency in terms of improved transparency. Blockchain has received a lot of attention with its promises of improving supply chain through accountability. This paper aims to evaluate the benefits and risks of incorporating blockchain in supply chain management networks with especial focus on peer-reviewed articles, conference papers, and literatures documented between 2015 to 2021. From the paper, it is apparent that blockchain brings critical advantages, such as real-time tracking of product movement, less fake products, and fewer errors, which is stored in the shared platform for every stakeholder's view. Also, the use of smart contracts promotes automated execution of a contract so that the responsibility and performance of agreements are enhanced as well as operationalism. Combine examples of Walmart and IBM's operation solution Food Trust and the shipping logistics platform Trade Lens to demonstrate the use of blockchain for the optimistic outcome in different fields. However, the broad implementation of blockchain has some barriers; these are; reluctance by the supply chain executor to adopt new structures and systems among partners, high initial costs, and diversity with blockchain solutions that does not support operational norms across platforms. These challenges therefore call for more concentrated efforts in enhancing the understanding of education on blockchain technology and supply chain actors, setting of standard practices for the ecosystem and associating the pertinent players to allow for the considerably more effective operation of the technology. This research is useful for those academics as well as practitioners who are planning to pursue the strategy of blockchain implementation in supply chain management. The direction for further research should be to address the mentioned challenges and identify the state-of-the-art approaches, formats and standards, and the ways of implementing them in practice.**

***Keywords*—** *Blockchain, Supply Chain Management, Transparency, Traceability, Accountability*

1. Introduction

Modern companies and humanitarian environments depend much on supply chain management (SCM), which guarantees the smooth flow of commodities, services, and data across several networks [1]. Effective SCM has become especially important in humanitarian operations since crises and natural disasters have become ever more frequent and severe. Such situations often reveal major difficulties including limited resources, poor coordination, and differences in power and responsibility among parties. Recent research has shown, these problems can impede the timely and effective delivery of basic relief [2]. Dealing with these issues calls for creative ideas combining strong plans with cutting-edge technology instruments. For many of the inefficiencies afflicting conventional supply chains, blockchain technology has become a transforming answer. Blockchain improves supply chain actor traceability, responsibility, and cooperation by using a distributed and transparent ledger. Initiatives like Extended Producer Responsibility (EPR), which demand exact tracking of goods during their lifetime to guarantee sustainable practices, especially call for this [3]. Blockchain integration help to greatly lower inefficiencies and raise compliance in such systems. Examining its advantages, drawbacks, and uses across several industries, this paper investigates how blockchain can transform supply chain management [4]. It offers a critical viewpoint on how the technology might support sustainability and efficiency in supply chain processes.

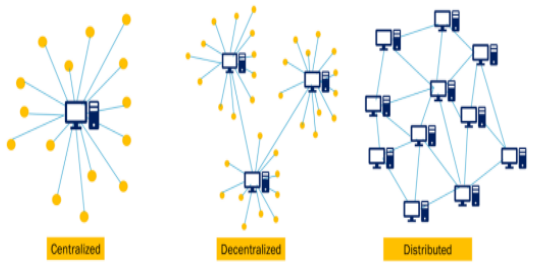


Figure 1 Blockchain and distributed ledger (Önder and Treiblmaier, 2018)

Blockchain technology has attracted interest in better supply chain management during the last few years [5]. Raw resource procurement and final product delivery constitute components of supply chain management. From raw ingredients to finished goods, blockchain technology can help expose responsibility for the entire chain. This paper examines blockchain technology in supply chain management, together with its advantages and drawbacks.

1.2 Benefits of Using Blockchain

Blockchain technology improves operational performance and addresses important inefficiencies, hence changing supply chain management [6]. Its dispersed and scattered ledger which safely and transparently logs transactions—defines its main strength. By means of an immutable record of all transactions, this system enables supply chain players to easily monitor and validate activities. The capacity of blockchain to increase supply chain traceability and openness becomes one of its most important benefits. Blockchain reduces the need for middlemen by letting all parties access the same data, therefore lowering the possibility of mistakes or dishonesty [7]. Every product in the supply chain can be found back to its source, therefore guaranteeing authenticity and helping to identify fake items. This improved visibility helps participants to build confidence and promotes ethical and responsible procurement methods. The unbreakable ledger of a blockchain offers still another important advantage more responsibility. Every transaction is noted permanently, making all participants answerable for their deeds. As it becomes simpler to track responsibility, this lowers the possibility of unethical behavior including child labor or environmental infractions [8]. Using smart contracts; blockchain technology also increases efficiency by automaton. These agreements automatically carry pre-defined criteria, therefore eliminating the need for human involvement and lowering delays [9]. Procedures include inventory control, payment validation, and compliance monitoring to speed up and become more accurate. By digitizing documents and offering real-time transaction validation, blockchain also greatly reduces administrative expenses and paperwork. This simplification increases general operational efficiency and helps supply chain partners to cooperate better. Notwithstanding these advantages, obstacles including high implementation costs, complexity, and lack of interoperability still prevent general acceptance. Realizing block chain's ability to revolutionize supply chain management calls upon addressing these challenges.

2. Literature Review

Research already in publication on blockchain technology in supply chain management carried out between 2015 and 2021, highlights how well it could solve important inefficiencies and obstacles. Particularly in humanitarian and commercial settings, blockchain has been found as a transforming tool that improves transparency, traceability, responsibility, and automation inside supply chains. By allowing all users to view a shared, unchangeable record and hence build confidence among stakeholders, blockchain technology provides openness. This openness helps to spot fraud, guarantee ethical standards are followed, and lower mistakes. Real-time tracking of products across the supply chain made possible by the traceability of the technology guarantees the authenticity of goods and helps to reduce the risk related to counterfeit items Tamper-proof records help to build accountability by assigning all actors responsibility for their activities [10]. Utilizing smart contracts, automation simplifies tasks including inventory control, order validation, and payment settlements, so saving time and money [11]. Still, major obstacles limit blockchain's general acceptance. The lack of consistent protocols across different blockchain systems causes interoperability problems, which makes smooth supply chain participant cooperation challenging. Especially for small and medium-sized businesses, the high expenses connected with integrating blockchain technology including infrastructure investment and training remain intolerable.

Furthermore, stakeholders who are cautious about adjusting to new technologies and distributing private information in a distributed setting continue to object to change [12]. In essence, even if blockchain offers great opportunities to transform supply chain management, attaining its full potential depends on addressing its difficulties. To support efficient implementation across several supply chains, the main priorities of ongoing research should be developing standardized frameworks, reducing costs, and encouraging cooperation.

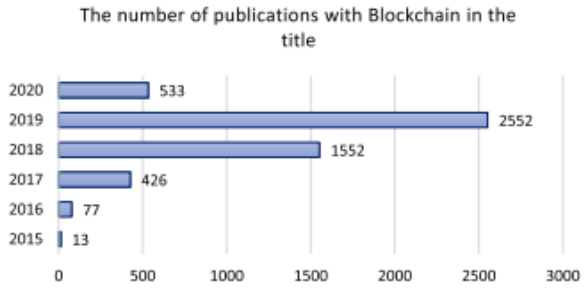


Figure 2: Number of Publications with Blockchain

Finding and fixing relief chain issues is one of the key worries in humanitarian supply chain management. Natural disaster frequency and intensity worldwide call for humanitarian supply chains to react fast. Aid organizations have to recognize, nonetheless, additional difficulties Most studies on humanitarian supply chains have naturally concentrated on these problems; some have looked at the difficulties of delivering humanitarian aid all across the supply chain. 2009 saw Kovacs and Spens looking at humanitarian organizations, catastrophe relief efforts, and emergency and disaster scenarios.

2.1Competitive Nature of Blockchain

Blockchain technology solves inefficiencies and promotes more cooperation, openness, and operational efficiency, hence improving competitive advantages in supply chain management [13]. Blockchain uses a distributed architecture, unlike conventional supply chain systems that sometimes

depend on centralized and third-party middlemen, therefore allowing direct interactions among stakeholders [14]. This strategy eliminates delays, lessens reliance on middlemen, and helps to lower expenses. Decentralization which guarantees data is kept and distributed throughout a peer-to-peer network is one of block chain's main competitive traits. This lowers the single point of failure risk and builds confidence among players in the supply chain. By providing real-time, immutable records available to all parties, therefore guaranteeing the integrity and veracity of the data, blockchain transparency further increases competitiveness Smart contracts, which automate agreements between parties and hence improve processes, also offer another benefit. These agreements reduce transaction times and increase efficiency by running pre-defined terms free from human interference. Smart contracts, for example, can automatically set payments after delivery criteria are satisfied, therefore guaranteeing flawless processes and improved responsibility. Blockchain provides unique advantages over conventional supply chain systems like tokenization, openness, and verification. By lowering errors, increasing traceability, and so boosting general performance, these qualities enable improved integration and cooperation among supply chain components, so building a competitive edge. Blockchain presents itself as a transforming agent in the competitive scene of supply chain management by overcoming obstacles including resource constraints, legal constraints, and coordination problems [15].

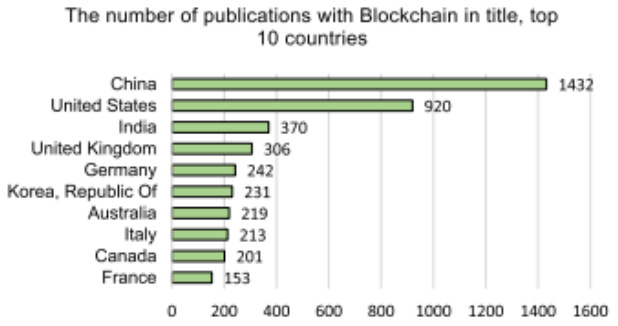


Figure 3 Top countries with the most publications of Blockchain titles (Stafford and Treiblmaier, 2020).

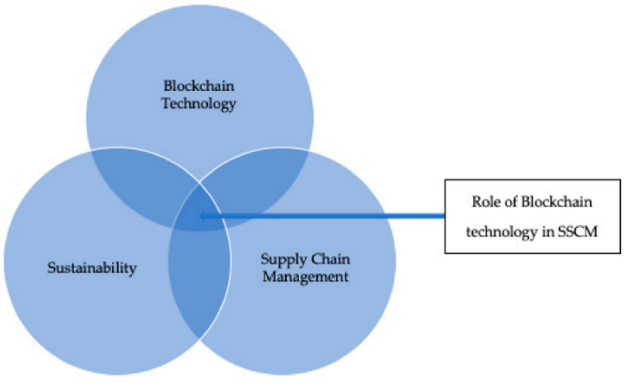


Figure 4 Blockchain Technology and Sustainability

2.3 Sustainability

By allowing traceability and responsibility throughout supply chains, blockchain technology helps to greatly support sustainability. Its capacity to produce unchangeable, transparent records lets companies monitor the source of products, therefore guaranteeing ethical procurement and lowering environmental effects. This end-to-end visibility helps reduce inefficiencies including the bullwhip effect, in which inadequate communication magnifies imbalances in supply and demand, hence causing resource waste. Blockchain combined with sensor technology and the Internet of Things (IoT) may track quantifiable criteria such as equipment availability or cold chain product temperature, therefore guaranteeing effective use of resources [16]. While keeping great data quality, this improves proactive risk management and cooperative planning. Practical uses show the sustainability possibilities of blockchain. In the fashion business, for instance, luxury companies like Stella McCartney track components using blockchain to guarantee moral labor standards and sourcing. Likewise, blockchain systems like Ever ledger monitor the provenance of natural resources like diamonds, therefore encouraging openness and lessening dishonest behavior. Blockchain supports the inclusion of sustainable practices into supply chains by certifying carbon credits and facilitating peer-to-peer energy trade in the renewable energy sector [17]. By verifying documentation like shipping manifests and customs forms, blockchain also lowers administrative costs and waste. Hence, reducing paperwork in international trade. Blockchain supports worldwide sustainability objectives by allowing effective communication and resource allocation, therefore reducing waste, promoting responsible purchases, and improving environmental stewardship. These features make blockchain a transforming instrument for supply chain management's sustainable development driving power.

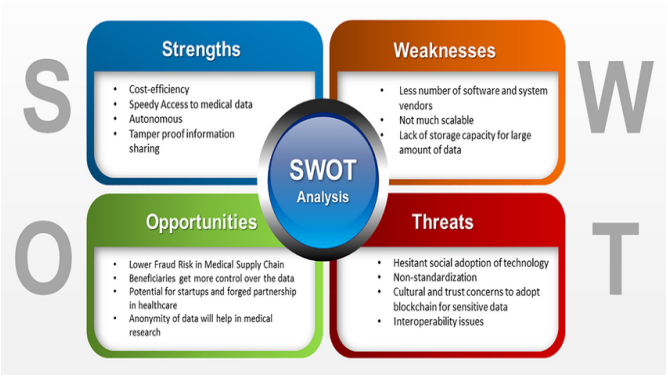


Figure 5 SWOT Analysis

2.4 Blockchain Implementation Following a Pandemic

The COVID-19 epidemic exposed weaknesses in world supply systems, therefore causing major disruptions in many different sectors. Labor shortages, manufacturing pauses, and limited delivery capacity presented difficulties for companies that resulted in supply-demand mismatches and unstable finances. By improving supply chain visibility, resilience, and cooperation, blockchain technology has become

increasingly important in helping to offset these disturbances. Blockchain-enabled supply chains (BESCs) use distributed ledgers to offer real-time transactional data like inventory levels and shipping statuses, thereby helping companies to quickly identify possible interruptions [18]. Smart contracts, for example, automate condition-based approvals and payment settlements, therefore guaranteeing operational continuity even during crises. Blockchain lowers opportunistic behaviors such as panic buying and hoarding by encouraging openness and trust, thereby allowing supply chain players to work efficiently [19]. Blockchain uses during the epidemic include monitoring medical supplies and immunizations. Blockchain systems helped to confirm cold-chain compliance for vaccinations, therefore guaranteeing appropriate handling and storage all through the distribution process. Companies with complicated supply chains such as international stores also used blockchain to find substitute suppliers and reroute shipments, therefore reducing the effect of supplier shortages. Finally, blockchain's capacity to guarantee transparency, offer real-time data, and automate important procedures helps it to be a necessary tool for managing supply chain interruptions and strengthening resilience in post-pandemic activities [20].

2.5 Blockchain Algorithms in the Supply Chain

Blockchain algorithms form the foundation of secure, transparent, and efficient supply chains. Distributed ledger technology ensures that all participants in the network have access to the same immutable records, eliminating discrepancies and enhancing trust. Cryptographic systems provide robust data security, preventing unauthorized modifications and safeguarding sensitive supply chain information. The role of algorithms extends to enabling traceability and efficiency. For example, consensus mechanisms, such as Proof of Work (PoW) and Proof of Stake (PoS), validate transactions and maintain ledger integrity without relying on centralized authorities [21]. Smart contracts, built on blockchain algorithms, automate tasks such as order processing and payment verification, streamlining supply chain workflows and reducing human errors 6666. By incorporating blockchain algorithms, businesses can enhance the transparency, accuracy, and speed of their supply chain operations, ensuring resilience and adaptability in dynamic environments.

2.6 Theoretical Framework of Blockchain Technology in Supply Chain Management

A robust theoretical framework is essential for understanding the integration of blockchain technology into supply chain management, offering insights into its mechanisms and potential benefits. Several established theories provide a foundation for analyzing the role of blockchain in enhancing supply chain efficiency, transparency, and collaboration.

Three primary theories help contextualize block chain’s role in supply chains:

2.6.1Value Chain Theory

Introduced by Michael Porter, this theory emphasizes identifying activities within the supply chain that create value [15]. Blockchain enables greater efficiency and transparency, supporting value creation through enhanced traceability and automation.

2.6.2 Transaction Cost Economics

This theory explores the costs and risks associated with transactions in supply chains [14]. Blockchain minimizes these costs by providing immutable records, reducing fraud, and streamlining operations through smart contracts.

2.6.3Resource-Based Approach

This perspective focuses on leveraging resources and capabilities strategically. Blockchain is viewed as a critical resource that enhances supply chain competitiveness and operational excellence.

2.7Distributed Ledger Technology

Distributed ledger technology (DLT) underpins blockchain and ensures decentralized, transparent transaction recording. By utilizing cryptographic techniques such as public-private key encryption and hashing, DLT ensures data integrity and security [22].Its decentralized structure eliminates reliance on intermediaries, fostering real-time visibility and trust among supply chain participants. This approach enables organizations to efficiently coordinate activities across the supply chain, mitigating errors and delays.

2.8Trust and Transparency

Trust is critical in supply chain networks, and blockchain fosters it through tamper-proof and transparent records. Social exchange theory highlights the mutual trust benefits of blockchain, while the theory of reasoned action explains participants' willingness to adopt blockchain due to perceived benefits such as enhanced transparency and reduced risk of fraud [23]. This trust-centric design transforms supply chain collaboration, ensuring accountability and reliability among stakeholders.

3.Methodology

This paper investigates supply chain management's application of blockchain technology using a methodology of systematic literature review. Compiling pertinent papers, spotting patterns, and filling in gaps in the body of current research depend much on systematic reviews. Targeting keywords helped one search important databases including IEEE, Science Direct, and Google Scholar. Inclusion requirements guaranteed that only high-quality industry reports pertinent to the issue and peer-reviewed publications would be taken under consideration. Using thematic classification, data analysis sought out recurrent trends and themes in the literature. These ideas were arranged into insightful analyses of blockchain possibilities, drawbacks, and supply chain applications. The examined material was assessed using criteria for quality including methodological rigor, data analysis quality, and relevance of research topics.

The 220 papers included in the study provide a thorough knowledge of the topic since most of them investigate blockchain's uses using conceptual approaches and qualitative empirical techniques.

3.1 Aims and Objectives

- Investigate the potential benefits of blockchain technology for enhancing supply chain security, traceability, and transparency.
- Analyze challenges and limitations, such as financial constraints, cost, and legal concerns, affecting blockchain adoption.
- Examine blockchain applications in product monitoring, inventory management, and payment processing.
- Evaluate the impact of blockchain-based systems on customer satisfaction and operational efficiency.

3.2 Research Questions

1. What are the potential benefits of implementing blockchain technology in supply chain management, and how can these be measured and quantified?
2. What are the main challenges and limitations of blockchain adoption in supply chain management, and how can they be overcome?
3. How can blockchain enhance supply chain sustainability, reduce costs, and improve efficiency?

4. Results & Discussion

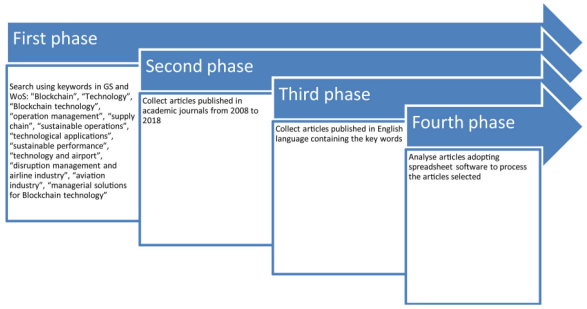
This study highlights the transformative potential of blockchain technology in supply chain management, emphasizing its ability to enhance transparency, accountability, and efficiency[24]. Findings from the literature review indicate that blockchain's decentralized ledger system enables real-time tracking of goods, reduces fraud, and minimizes errors. Automation through smart contracts further streamlines processes, reducing administrative overheads and operational delays.

Table 1 Similarity Analysis of Data

Word	Similarity	Word	Similarity
Bitcoin	0.906903	Analysis	0.693042
Ledger	0.897149	Challenges	0.683677
Security	0.821995	Privacy	0.674539
Distributed	0.795304	Trust	0.643097
Block	0.795384	Implementation	0.640840
Application	0.7541384	lot	0.637737
Peer	0.754152	Smart	0.630747
Public	0.7486ffi	Access	0.690417
Private	0.724236	Technology	0.617000
Design	0.715209	Adoption	0.613373

Practical applications demonstrate blockchain's impact across industries. For example, Walmart and IBM's **Food Trust** platform improves food traceability, enhancing safety and consumer trust by reducing recall times. The **Trade Lens** platform, developed by [25], streamlines shipping logistics by enabling secure and transparent data sharing among stakeholders, reducing paperwork, and increasing operational efficiency.

Table 2: Data extraction Pathway



Challenges, such as high implementation costs, interoperability issues, and resistance to change, persist. However, solutions like scalable blockchain frameworks, standardization efforts, and education on blockchain benefits can address these barriers. The integration of blockchain with technologies like IoT offers additional resilience by enabling real-time data sharing and predictive analytics, ensuring optimized supply chain operations even during disruptions.

4.4Case Study Analysis

4.4.1Walmart and IBM – Food Traceability

The IBM Food Trust platform, utilized by Walmart, has revolutionized food safety by allowing end-to-end traceability of products such as mangoes and pork [2]. This blockchain-enabled system reduces the time needed to trace contaminated products from days to seconds, significantly improving recall efficiency and consumer trust.

4.4.2 TradeLens – Shipping Logistics

Francisco & Swanson, 2018 resulted in the blockchain-based TradeLens platform. By digitizing shipping processes and sharing data among stakeholders, TradeLens has reduced paperwork, improved cargo visibility, and enhanced collaboration in global trade.

4.4.3 Stella McCartney – Ethical Fashion Sourcing

Luxury fashion brand Stella McCartney collaborates with Provenance to track the origin and sustainability of materials like cotton and silk. Blockchain ensures transparency in sourcing practices, enabling customers to make informed, ethical purchasing decisions. These case studies illustrate how blockchain addresses real-world supply chain challenges, offering enhanced transparency, operational efficiency, and sustainability.

4.5 Thematic Analysis

The literature reveals several key themes in blockchain's application to supply chain management:

- **Transparency and Accountability**: Blockchain's decentralized ledger ensures tamper-proof records, enhancing trust and reducing fraudulent practices.
- **Automation and Efficiency**: Smart contracts automate repetitive tasks like payments and compliance checks, reducing errors and improving speed.
- **Barriers to Adoption**: High costs, complexity, and resistance to change are significant hurdles, requiring standardization and stakeholder education.

These themes underline blockchain's potential to transform supply chains while highlighting the need to address implementation challenges.

4.6Application of Blockchain Technology in Logistics

By bettering real-time tracking and inventory control, blockchain improves logistics. One source of truth made possible by distributed ledgers helps stakeholders precisely monitor product locations, conditions, and delivery times. This visibility reduces overstocking or shortages maximizes inventory levels, and lessens delays [26]. Blockchain simplifies procurement and manufacturing by giving quick access to data including pricing and supply levels. Smart contracts reduce manual interventions by automating purchase orders and activating manufacturing per specified criteria. Blockchain tracks shipments in real-time in distribution, therefore raising customer happiness and lowering delivery mistakes. Blockchain can, for example, guarantee temperature compliance in cold chains, therefore ensuring product integrity on route. By automating tasks and cutting middlemen, these programs increase supply chain efficiency, build consumer confidence, and lower prices.

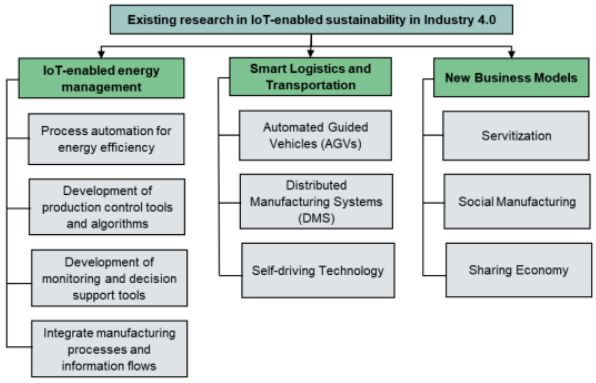


Figure 6: Existing research in IoT enabled Sustainability in Industry 4.0

4.7 IoT Integration

IoT combined with blockchain produces a strong ecosystem for supply chains. While blockchain guarantees safe storage and openness, IoT devices track real-time data on asset conditions including temperature and location [27]. For instance, whereas blockchain stores these values in a tamper-proof ledger, IoT-enabled sensors in logistics track shipment conditions including humidity and temperature. For sectors like medicines and perishables, where storage conditions must be followed exactly, this skill is absolutely vital. Predictive analytics made possible by IoT-blockchain integration helps companies anticipate demand, maximize inventory, and avoid disruptions. Walmart's joint venture with IBM shows how IoT and blockchain together improve food traceability, therefore guaranteeing quality and safety.

4.8 Application of Blockchain Technology in Aviation

The aircraft supply chain gains much from blockchain technologies. Blockchain is used by airports and airlines to monitor luggage movement, hence lowering cases of lost or delayed bags. This raises operational effectiveness and passenger delight. Blockchain also guarantees correct inventory control for food and duty-free products used in airports [28]. Equipment such as luggage handling systems has securely kept maintenance and repair records, therefore improving dependability and lowering downtime. Still, another essential use is cargo tracking. Blockchain guarantees timely delivery by letting stakeholders track shipments from warehouses to aircraft and ultimate locations, therefore lowering cargo loss or damage. These programs simplify and increase the security and openness of aviation supply chains.

4.9 Challenges

The adoption of blockchain technology in supply chains presents difficulties like data privacy issues, scalability, and interoperability. Blockchain systems could suffer from slower processing speeds and more fees as transaction volumes rise [29]. Aiming for scalability, solutions include off-chain processing and sharing. Another challenge is interoperability amongst blockchain systems since different protocols and data formats impede cooperation among players of the supply chains. Perfect integration depends on consistent framework building. In supply chains including sensitive data like trade secrets and price, data privacy is absolutely vital [30]. Although blockchain openness is a virtue, it begs questions about illegal access. Zero-knowledge proofs and other privacy-enhancing technologies help with these problems. Obstacles include also high implementation costs and opposition to change. By teaching interested parties about blockchain's advantages and investigating cost-sharing schemes, these difficulties can be lessened. Energy-efficient consensus systems help to also solve environmental issues regarding the energy consumption of blockchain technologies.

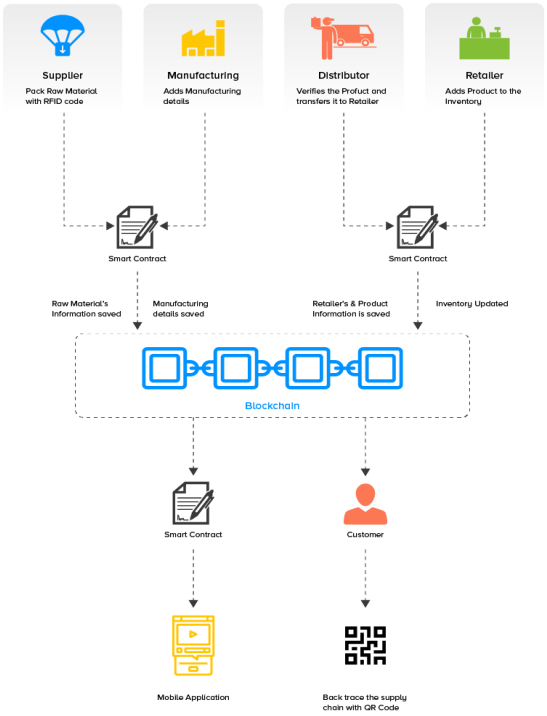


Figure 7: Implementation of Block Chain

4.10Future Aspects of Blockchain Technology

Blockchain's future in supply chains rests in including smart contracts, IoT, and artificial intelligence. Real-time tracking and predictive analytics made possible by blockchain-i-t synergy guarantee proactive risk control. The joint effort of Walmart and IBM shows this integration in food traceability [31]. By automating payment settlements and lowering expenses, smart contracts simplify supply chain finance. Blockchain's promise to improve efficiency and support ethical sourcing methods is demonstrated by sites like TradeLens and Ever ledger. Blockchain also provides immutable product authenticity records as a means of counterfeit protection. Big data analytics and artificial intelligence working together can provide ideas for supply chain optimization and demand forecasts. Standardizing, governance structures, and privacy-preserving technology will be especially important as blockchain acceptance rises. As these fields develop, blockchain will allow effective, open, and sustainable supply chain ecosystems [32].

5. Conclusion

Blockchain technology remains as a powerful solution to supply chain management through increasing, transparency, traceability, security, and, efficiency, sustainability. This structural characteristic makes it very suitable for ethical standards, the running of operations, and safe exchange of information. The analysis and VP scenarios of its application in the sphere of food, shipping, luxury goods and drugs show that blockchain represents a great value for the elaborate supply chains across the world. Through the reduction of expenses and overheads as well as the development of effective methods of sourcing in a non-defective manner, blockchain creates positive concord among the participants in the chain.

Specifically, the application of blockchain in a company setting can enhance the ability to create competitive advantages as well as meet the constantly changing market needs, using real-time transparency, smart contract, and the record of the deal in the block. Yet, in order to unlock the full potential achievable with blockchain technology, questions concerning compatibility, performance, security of the data and legislation remain to be answered. In future, more research is needed on the advancement in standardization techniques, implementing block chain with new technologies such as IoT's artificial intelligence & big data analytical tools and the sustainable effects on the supply chain performance of food products. The testing and sharing of the results by enterprises and their initiatives with other similar concerns is important in proving the utility of blockchain and encouraging its adoption. The following paper explains how the proactive use of blockchain technology will enable the organizations to create more robust, responsive, and effective supply chain structures. It is one's belief that by breaking through the existing barriers or challenges the adoption of blockchain technology, education, and collaboration, block chain will revolutionize the supply chain management industry by enhancing its efficiency and sustainability.

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