

A Review on Blockchain-Based Frameworks for Enhancing Security and Traceability in Drug Supply Chains

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Abstract:

The global pharmaceutical supply chain is essential in ensuring the safe production, distribution, and delivery of drugs to patients. However, this complex network faces significant challenges, including counterfeit drugs, security breaches, and inefficiencies in tracking. These issues threaten patient safety and cost the pharmaceutical industry billions of dollars each year. Counterfeit drugs alone have been linked to over a million deaths globally, with an increasing need for solutions that ensure drug authenticity and protect consumers. Blockchain technology, originally developed for cryptocurrency, has emerged as a promising solution to these challenges. Its decentralized, immutable ledger allows for enhanced security, transparency, and traceability, making it an ideal tool for addressing vulnerabilities within the drug supply chain. Blockchain enables the tracking of pharmaceutical products from manufacturers to end consumers in real-time, ensuring authenticity and compliance with regulatory standards. It also enhances security by preventing data tampering and enabling all stakeholders, including manufacturers, distributors, and regulators, to access a shared, trusted view of the supply chain.

This review paper examines how blockchain technology can enhance the security and tracking of the pharmaceutical supply chain. We explore its core principles, including decentralized data management, cryptographic security, and smart contracts. We also discuss real-world implementations in the pharmaceutical industry and how blockchain is helping to meet regulatory requirements such as the Drug Supply Chain Security Act (DSCSA). Additionally, we highlight the benefits of blockchain for drug traceability, reducing counterfeit risks, and improving overall supply chain efficiency. Finally, this paper addresses the challenges and limitations of blockchain adoption, including scalability issues, integration with existing systems, and privacy concerns. Despite these challenges, blockchain holds great potential for transforming the pharmaceutical industry, providing a secure and transparent solution to combat counterfeit drugs and improve the global drug supply chain. Through this review, we aim to demonstrate that blockchain technology is not only viable but a necessary tool for enhancing drug supply chain security and protecting patients worldwide.

1. INTRODUCTION

The pharmaceutical supply chain is a highly intricate and regulated global system responsible for ensuring the safe delivery of medications from manufacturers to patients. However, this vital system faces numerous challenges, including the proliferation of counterfeit drugs, lack of transparency, inefficient tracking, and compliance with stringent regulatory frameworks [1], [2].

Counterfeit drugs are a particularly serious issue, causing significant economic losses and posing threats to public health. It is estimated that counterfeit drugs contribute to over a million deaths annually, especially in low- and middle-income countries, where the regulation and monitoring of pharmaceutical products are less stringent [3]. The complexity of the drug supply chain exacerbates these problems, as drugs pass through multiple intermediaries, making it difficult

to maintain real-time visibility and traceability of products.

Blockchain technology has emerged as a potential solution to many of these challenges by offering a decentralized, transparent, and immutable ledger for recording transactions [4]. Blockchain was initially developed to support digital currencies like Bitcoin, but its application has since expanded to various industries, including supply chain management. In the pharmaceutical sector, blockchain can enhance security by providing a tamper-proof record of transactions, reducing the risk of counterfeit drugs entering the supply chain, and ensuring that all stakeholders—manufacturers, distributors, regulators, and patients—have access to reliable, real-time information [5], [6].

One of the key benefits of blockchain is its ability to provide end-to-end traceability in the supply chain. By leveraging blockchain, every transaction or movement of a drug can be recorded in a decentralized ledger that is visible to all participants in the supply chain [7]. This increases transparency and helps ensure the authenticity of the drugs being distributed. In addition to enhancing traceability, blockchain can also improve regulatory compliance by automating and recording the necessary documentation through the use of smart contracts—self-executing contracts with terms directly written into lines of code [8], [9]. These smart contracts can be used to automatically enforce regulatory requirements, ensuring that pharmaceutical products meet the necessary standards before they move to the next stage of the supply chain.

In recent years, the pharmaceutical industry has witnessed several successful implementations of blockchain technology to combat counterfeiting and improve supply chain transparency. For instance, the United States Drug Supply Chain Security Act (DSCSA) mandates that pharmaceutical companies implement systems that allow for the tracing of drugs through the supply chain, and blockchain is emerging as a leading technology in helping companies meet these requirements [10], [11]. These efforts not only enhance security but also streamline operations and

reduce the administrative burdens associated with regulatory compliance.

While the benefits of blockchain technology are clear, there are still challenges to its widespread adoption in the pharmaceutical supply chain. Scalability remains a key concern, as the volume of transactions in global supply chains can overwhelm existing blockchain systems [12]. Additionally, privacy concerns arise as blockchain's transparency can conflict with the need to protect sensitive patient or business information. Moreover, the integration of blockchain with legacy systems and the willingness of industry stakeholders to collaborate are other factors that could hinder adoption [13].

Despite these challenges, blockchain technology holds great promise for transforming the pharmaceutical supply chain. By enhancing security, ensuring the authenticity of drugs, and improving traceability, blockchain has the potential to address some of the most pressing issues faced by the pharmaceutical industry today. This paper will explore how blockchain technology can be leveraged to enhance security and traceability in the drug supply chain, review real-world applications, and discuss the challenges and limitations associated with its implementation.

2. LITERATURE REVIEW

The global pharmaceutical supply chain has long faced challenges related to counterfeit drugs, lack of transparency, inefficient tracking, and security vulnerabilities. In recent years, blockchain technology has emerged as a promising solution to enhance the traceability, integrity, and security of drug supply chains. This section provides an overview of the existing literature that explores blockchain-based frameworks and their application in pharmaceutical logistics.

Ref. No.	Authors	Focus Area	Key Contributions	Relevance to Drug Supply Chain
[1]	Dasaklis et al. (2019)	Blockchain in supply chain management	State-of-the-art review and future outlook	Provides foundational understanding of blockchain in SCM
[2]	Casino et al. (2019)	Blockchain applications review	Classifies blockchain use cases, highlights gaps	Establishes a framework to classify drug-related blockchain applications
[3]	Reyna et al. (2018)	Blockchain and IoT integration	Discusses challenges and synergies of IoT with blockchain	Relevant for real-time drug tracking using IoT sensors
[4]	Xu et al. (2021)	Identity management via blockchain	Proposes a secure model using blockchain in IoT/Supply Chain	Highlights access control and identity security in pharma chains
[5]	Liu et al. (2019)	Blockchain for drug traceability	Proposes and implements a traceability system	Direct application to secure pharmaceutical logistics
[6]	Salah et al. (2019)	Pharma supply chain traceability	End-to-end blockchain model for drug traceability	Strong emphasis on anti-counterfeit and data immutability
[7]	Bocek et al. (2017)	Blockchain use-case in pharma	Real-world implementation for pharma logistics	Demonstrates practical feasibility in drug tracking
[8]	Kamilaris et al. (2019)	Blockchain in agriculture/food	Reviews blockchain in food chains	Offers transferable insights on traceability for pharma supply
[9]	Agrawal et al. (2018)	Blockchain for pharma traceability/security	Outlines security benefits and implementation concerns	Focuses on secure drug movement and validation
[10]	Chen et al. (2020)	Quality management via blockchain	Framework for quality tracking in supply chains	Relevant for maintaining drug quality in transit
[11]	Mackey et al. (2019)	Blockchain in pharma SCM	Case studies on pharma supply and blockchain use	Provides empirical insight into blockchain effectiveness
[12]	Alzahrani & Bulusu (2018)	Anti-counterfeit via blockchain + NFC	Combines blockchain and NFC for authentication	Ensures drug authenticity and traceability

[13]	Khan et al. (2021)	Blockchain & smart contracts in SCM	Systematic review on automation & traceability	Explores smart contract automation in drug tracking
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Table 1

3. DRUG SUPPLY CHAIN CHALLENGES

The pharmaceutical supply chain is a complex and multi-layered system, and its proper functioning is crucial for ensuring patient safety and the availability of essential medicines. However, several significant challenges compromise the integrity and efficiency of the drug supply chain. These challenges can be broadly categorized into the following subtopics:

1. Counterfeit Drugs

One of the most pressing challenges in the pharmaceutical supply chain is the prevalence of counterfeit drugs. These falsified medicines are often manufactured with substandard or incorrect ingredients, or they may contain no active ingredients at all. Counterfeit drugs pose a serious risk to public health and are responsible for thousands of deaths globally each year. The World Health Organization (WHO) reports that approximately 10% of medical products in low- and middle-income countries are either substandard or counterfeit [1]. The increasing globalization of the pharmaceutical industry, combined with the lack of visibility across the entire supply chain, makes it difficult to detect and eliminate these fake medicines.

2. Lack of Transparency

Transparency is crucial for tracking products throughout the pharmaceutical supply chain. However, many existing supply chain systems operate in silos, with different stakeholders—including manufacturers, distributors, wholesalers, and retailers—maintaining separate databases that are often disconnected. This fragmented system creates information gaps, making it difficult to trace the origins and movements of pharmaceutical products in real time [2]. The lack of end-to-end

visibility contributes to inefficiencies and delays in the detection of counterfeit drugs and recalls of defective products.

3. Regulatory Compliance

The pharmaceutical industry is highly regulated, and companies must comply with stringent regulations designed to ensure the safety, efficacy, and quality of drugs. Regulations such as the U.S. Drug Supply Chain Security Act (DSCSA) and the European Union's Falsified Medicines Directive (FMD) require pharmaceutical companies to implement tracking systems for their products [3]. However, meeting these regulatory requirements is a costly and time-consuming process for companies, especially those that operate globally. The lack of harmonization between different regulatory frameworks further complicates compliance efforts, leading to increased operational burdens.

4. Inefficient Product Recall Processes

In the event of safety concerns or quality issues, pharmaceutical companies must initiate product recalls. The efficiency of the recall process is critical to protecting public health. However, due to the fragmented nature of the supply chain and the lack of real-time information sharing between stakeholders, recalls are often delayed or incomplete. The inability to track specific batches of drugs accurately can result in delays that endanger patients' lives, as affected products may remain in circulation [4]. This inefficiency is compounded by the absence of integrated systems that allow quick identification and retrieval of compromised products.

5. Supply Chain Disruptions

The pharmaceutical supply chain is vulnerable to a range of disruptions, from natural disasters and political instability to labor strikes and

transportation issues. The COVID-19 pandemic, for instance, exposed the fragility of global pharmaceutical supply chains, leading to shortages of essential drugs and active pharmaceutical ingredients (APIs) [5]. The reliance on a small number of suppliers for critical components further exacerbates the risks, leaving supply chains prone to bottlenecks and delays. Such disruptions not only affect drug availability but also increase costs for pharmaceutical companies.

6. Data Integrity and Security Concerns

The digital systems used to manage the pharmaceutical supply chain are susceptible to cyberattacks, data breaches, and other security vulnerabilities. Hackers may target these systems to manipulate records or steal sensitive information, which could have catastrophic consequences for the industry [6]. Moreover, ensuring the integrity and accuracy of the data generated throughout the supply chain is challenging. Any inconsistencies or errors in data entry can lead to confusion, mismanagement of stock, or failure to comply with regulations. The lack of standardized data-sharing protocols between stakeholders further complicates these issues.

7. Fragmentation of Stakeholders

The pharmaceutical supply chain involves multiple players, including manufacturers, logistics providers, wholesalers, pharmacies, hospitals, and regulatory authorities. Each of these entities operates independently, often using different systems for tracking, verifying, and managing inventory. This fragmentation creates inefficiencies in communication and collaboration, as stakeholders are not always aligned in terms of goals, practices, or technology [7]. The resulting disconnects hinder the flow of information and make it more difficult to address supply chain challenges in a coordinated manner.

4. BLOCKCHAIN TECHNOLOGY IN DRUG SUPPLY CHAIN

Blockchain technology is rapidly gaining traction as a transformative solution for addressing the

many challenges faced by the pharmaceutical supply chain. Blockchain, by its nature, is a decentralized, distributed ledger that enables secure, transparent, and immutable record-keeping across various participants in a network. Its potential to improve traceability, enhance security, and streamline compliance has made it an ideal candidate for integration into the drug supply chain [1].

1. Enhanced Traceability and Transparency

One of the most significant advantages of blockchain technology in the pharmaceutical supply chain is its ability to provide end-to-end traceability. Each transaction or movement of a pharmaceutical product can be recorded on a blockchain, creating an immutable record that can be accessed by all authorized stakeholders, including manufacturers, distributors, wholesalers, pharmacies, and regulatory agencies. This increased transparency allows for real-time monitoring of the movement and handling of drugs throughout the entire supply chain [2].

By tracking drugs from the point of production to the point of sale or consumption, blockchain ensures that each step in the supply chain is verifiable. This helps to prevent the introduction of counterfeit drugs, as each stakeholder can verify the authenticity of a product through its digital record [3]. In the event of a product recall or regulatory audit, blockchain's traceability allows for quick identification of the affected products, reducing the time it takes to address quality or safety issues.

2. Improved Security and Reduced Counterfeiting

Blockchain's cryptographic security measures make it a powerful tool for combating counterfeit drugs. Counterfeit drugs, which are often ineffective or harmful, pose a significant threat to public health. Blockchain technology can reduce the risk of counterfeit drugs entering the supply chain by creating a tamper-proof record of transactions [4]. Once data is recorded on the blockchain, it cannot be altered without the consensus of the network, making it extremely

difficult for malicious actors to falsify information or introduce counterfeit products.

Additionally, blockchain can integrate with advanced technologies such as Internet of Things (IoT) devices, including smart packaging and sensors, to monitor the conditions under which drugs are stored and transported. These devices can record data on temperature, humidity, and other environmental factors, which is then securely stored on the blockchain. This ensures that drugs are not only genuine but also maintained under optimal conditions throughout the supply chain [5].

3. Smart Contracts for Regulatory Compliance

Another important application of blockchain in the pharmaceutical supply chain is the use of smart contracts. Smart contracts are self-executing contracts with the terms of the agreement written into code. These contracts can automate various processes in the supply chain, such as verifying regulatory compliance, processing payments, and triggering product recalls when certain conditions are met [6].

For instance, smart contracts can be programmed to enforce the requirements of regulatory frameworks such as the Drug Supply Chain Security Act (DSCSA) in the United States or the European Union's Falsified Medicines Directive (FMD). As a drug moves through the supply chain, the smart contract can automatically check whether the product meets the necessary regulatory standards. If a product does not meet the required criteria, the smart contract can block its progression through the supply chain, preventing the sale of non-compliant or substandard drugs [7].

4. Efficiency and Cost Reduction

The implementation of blockchain technology can also lead to significant cost savings for pharmaceutical companies by reducing inefficiencies, eliminating intermediaries, and automating manual processes. Blockchain's ability to provide a single, shared source of truth across all stakeholders minimizes the need for costly reconciliation and verification procedures [8]. By reducing paperwork and administrative overhead, blockchain can streamline operations and allow

companies to focus resources on critical activities, such as drug development and patient care.

Furthermore, the real-time sharing of information across the blockchain network allows for faster and more accurate decision-making. This enhanced visibility enables companies to optimize inventory management, reduce waste, and minimize the risk of stockouts or overstocking [9].

5. Data Privacy and Security

While blockchain's transparency is one of its key benefits, it also raises concerns about data privacy, especially when it comes to sensitive medical or business information. Blockchain networks can address these concerns through the use of permissioned blockchains, where access to data is restricted to authorized participants. Permissioned blockchains allow organizations to maintain control over their data while still benefiting from the transparency and security offered by blockchain technology [10].

In addition, advanced encryption techniques can be used to protect sensitive information, ensuring that only the necessary parties have access to specific data, such as patient details or proprietary business information.

5. CASE STUDIES AND IMPLEMENTATIONS

Several real-world implementations and case studies have demonstrated how blockchain technology can revolutionize the pharmaceutical supply chain, enhancing security, transparency, and efficiency. The following case studies illustrate the application of blockchain in tracking drug authenticity, reducing counterfeiting, and improving overall supply chain management.

1. MediLedger: Blockchain for Pharmaceutical Supply Chain Compliance

MediLedger is one of the most prominent examples of blockchain implementation in the pharmaceutical industry. The MediLedger Project, developed by Chronicled and supported by major pharmaceutical companies like Pfizer and Genentech, is designed to help companies comply with the U.S. Drug Supply Chain Security Act

(DSCSA). The DSCSA mandates that pharmaceutical companies implement track-and-trace systems to secure the drug supply chain and prevent counterfeit drugs from reaching consumers [1].

MediLedger uses a permissioned blockchain to provide a decentralized platform where pharmaceutical companies, distributors, and other stakeholders can record and verify the movement of drugs through the supply chain. The project facilitates secure, real-time data sharing without revealing proprietary business information. By utilizing smart contracts, MediLedger automates compliance checks, ensuring that only authorized entities can handle and distribute drugs.

The success of the MediLedger Project demonstrates the viability of blockchain in ensuring regulatory compliance, reducing paperwork, and improving the traceability of pharmaceutical products.

2. Pfizer and Biogen: Clinical Supply Chain Tracking

In 2019, pharmaceutical giants Pfizer and Biogen partnered with blockchain startup ClinTex to explore how blockchain technology could be used to improve the efficiency of clinical trials and supply chain management. Their collaboration focused on using blockchain to monitor the distribution of clinical trial drugs, ensuring that the correct medications reached the right patients without tampering or counterfeiting [2].

By leveraging blockchain, Pfizer and Biogen aimed to create an immutable record of drug transactions, enabling them to track and trace the movement of clinical trial supplies from manufacturers to clinical sites. The use of blockchain also ensured that trial participants received accurate and unaltered medications, enhancing the integrity of clinical trials.

This case study highlights how blockchain can be applied beyond the commercial drug supply chain, extending to the clinical trial process, where transparency and traceability are equally critical.

3. IBM and Walmart: Food and Drug Supply Chain Collaboration

IBM's blockchain-based solution, IBM Food Trust, is a blockchain network that tracks the movement of food products to ensure safety and authenticity. Although originally designed for the food industry, the technology has been extended to the pharmaceutical industry to address the challenges of counterfeit drugs and supply chain inefficiencies. IBM has collaborated with Walmart and other major companies to implement this technology for the secure tracking of pharmaceuticals [3].

In this implementation, blockchain provides a single, immutable ledger that records every transaction along the pharmaceutical supply chain. This helps to streamline the recall process by allowing companies to quickly identify and remove compromised products from the market. Furthermore, the real-time visibility of drug movements ensures compliance with regulatory requirements and reduces the risk of counterfeit drugs entering the market.

The success of IBM Food Trust in the food industry and its extension into the pharmaceutical sector demonstrates the versatility of blockchain in enhancing supply chain security and transparency across multiple industries.

4. SAP Blockchain for Pharmaceutical Tracking

SAP, a global leader in enterprise software, has integrated blockchain technology into its pharmaceutical supply chain management solutions. SAP's blockchain solution is designed to provide pharmaceutical companies with end-to-end visibility and traceability of drug shipments. This helps companies meet regulatory requirements, prevent counterfeit drugs, and improve overall supply chain efficiency [4].

SAP's blockchain platform allows stakeholders to track and trace products in real time, ensuring that drugs are stored and transported under optimal conditions. The platform also offers seamless integration with existing enterprise resource planning (ERP) systems, allowing companies to incorporate blockchain without overhauling their existing infrastructure.

In one notable case, SAP worked with a major pharmaceutical company to implement blockchain for tracking the distribution of vaccines. This ensured that vaccines were stored at the correct temperature throughout the supply chain, reducing waste and ensuring the efficacy of the products.

5. VeChain: Blockchain for Drug Traceability in China

VeChain, a blockchain platform that focuses on supply chain management, has partnered with pharmaceutical companies and government agencies in China to implement blockchain solutions for drug traceability. The platform utilizes IoT devices and blockchain to monitor the conditions under which drugs are stored and transported, ensuring that they remain within the required parameters for safety and efficacy [5].

In one case study, VeChain partnered with the China-based pharmaceutical company BrightCode to track the movement of vaccines. Each vaccine was assigned a unique digital identifier, which was recorded on the blockchain. IoT sensors were used to monitor the temperature and humidity conditions during transportation, and this data was also stored on the blockchain. The result was an immutable and transparent record of the vaccine's journey from production to administration.

VeChain's success in China demonstrates how blockchain and IoT technologies can be integrated to ensure the safety and authenticity of pharmaceutical products, especially in regions where counterfeit drugs are a significant concern.

6. Modum: Blockchain for Cold Chain Monitoring

Modum is a blockchain-based solution provider that focuses on cold chain monitoring in the pharmaceutical supply chain. Cold chain logistics are critical for the transportation of temperature-sensitive medications, such as vaccines and biologics, which must be stored under specific temperature conditions to maintain their efficacy. Modum combines IoT sensors with blockchain technology to monitor the temperature of pharmaceutical shipments in real time. The data from the IoT sensors is recorded on a blockchain, creating a tamper-proof record of the shipment's

conditions. If the temperature deviates from the required range, the blockchain automatically alerts the stakeholders, allowing them to take corrective action [6].

Modum's solution has been successfully implemented by pharmaceutical companies to ensure the safe transport of sensitive drugs. By providing real-time visibility and verifiable data, Modum's blockchain solution helps to reduce waste, prevent product recalls, and improve the overall reliability of the cold chain.

CONCLUSION

The pharmaceutical supply chain faces numerous challenges, including the proliferation of counterfeit drugs, lack of transparency, inefficiencies in tracking, and regulatory complexities. These issues pose serious risks to patient safety and erode trust in the healthcare system. Blockchain technology offers a promising solution to these challenges by providing a secure, transparent, and decentralized platform that can enhance the security and traceability of the drug supply chain. Through its inherent features—such as immutability, cryptographic security, decentralized data management, and real-time tracking—blockchain ensures the authenticity of pharmaceutical products and improves visibility across the supply chain. This technology helps stakeholders, including manufacturers, distributors, and regulatory authorities, to verify the origin, handling, and quality of drugs, thereby reducing the risks of counterfeit products entering the market. Real-world implementations of blockchain in pharmaceutical supply chains, as discussed in this review, demonstrate the technology's potential to streamline operations, meet regulatory requirements, and provide an added layer of security. Despite certain challenges, such as scalability, privacy concerns, and the need for integration with existing systems, blockchain is well-positioned to revolutionize the pharmaceutical industry. The adoption of blockchain can lead to enhanced patient safety, better regulatory compliance, and improved overall efficiency of the drug supply chain.

In conclusion, Blockchain technology offers a transformative approach to addressing the vulnerabilities of the pharmaceutical supply chain. As the technology continues to mature, its widespread implementation can play a crucial role in ensuring the safe and secure delivery of pharmaceutical products globally, thus safeguarding public health and increasing trust in the system.

REFERENCES

- [1] S. Dasaklis, F. Casino, and C. Patsakis, "Blockchain in Supply Chain Management: State of the Art and Outlook," *Logistics*, vol. 2, no. 1, pp. 1-16, Feb. 2019, doi: 10.3390/logistics2010018.
- [2] F. Casino, T. K. Dasaklis, and C. Patsakis, "A Systematic Literature Review of Blockchain-Based Applications: Current Status, Classification, and Open Issues," *Telecommunication Systems*, vol. 71, no. 3, pp. 1-31, Dec. 2019, doi: 10.1007/s11235-019-00591-6.
- [3] M. Reyna, C. Martín, J. Chen, E. Soler, and M. Díaz, "On Blockchain and its Integration with IoT: Challenges and Opportunities," *Future Generation Computer Systems*, vol. 88, pp. 173-190, Nov. 2018, doi: 10.1016/j.future.2018.05.046.
- [4] X. Xu, L. Chen, F. Bu, W. Xu, and M. Sun, "Blockchain-Based Identity Management for Secure Access in IoT and Supply Chain Networks," *IEEE Access*, vol. 9, pp. 123-138, Jan. 2021, doi: 10.1109/ACCESS.2020.3047662.
- [5] Y. Liu, K. Li, M. Zhou, and Z. Zhao, "Design and Implementation of Blockchain-Based Drug Traceability System in Pharmaceutical Supply Chain," *IEEE Access*, vol. 7, pp. 51085-51093, April 2019, doi: 10.1109/ACCESS.2019.2907894.
- [6] K. Salah, N. Nizamuddin, R. Jayaraman, and M. Omar, "Blockchain-Based Solution for the Traceability of Pharmaceutical Supply Chain," *IEEE Access*, vol. 7, pp. 225-233, May 2019, doi: 10.1109/ACCESS.2018.2889204.
- [7] C. Bocek, B. B. Rodrigues, T. Strasser, and B. Stiller, "Blockchains Everywhere - A Use-case of Blockchains in the Pharma Supply-Chain," in *Proceedings of the IEEE International Conference on Blockchain*, Halifax, Canada, 2017, pp. 1-7, doi: 10.1109/ICBC.2017.7983683.
- [8] H. Kamilaris, A. Fonts, and F. X. Prenafeta-Boldú, "The Rise of Blockchain Technology in Agriculture and Food Supply Chains," *Trends in Food Science & Technology*, vol. 91, pp. 640-652, Dec. 2019, doi: 10.1016/j.tifs.2019.07.034.
- [9] S. D. Agrawal, R. Singhal, and A. Shukla, "Using Blockchain Technology for Enhancing Traceability and Security of the Pharmaceutical Supply Chain," *International Journal of Pure and Applied Mathematics*, vol. 119, no. 15, pp. 1259-1267, 2018.
- [10] Z. Chen, L. Xu, and Q. Zhou, "A Blockchain-Based Supply Chain Quality Management Framework," *IEEE Access*, vol. 8, pp. 219530-219541, Nov. 2020, doi: 10.1109/ACCESS.2020.3042196.
- [11] S. Mackey, S. Diwakar, and C. Perez, "Exploring Blockchain Technology in Pharmaceutical Supply Chain Management," *Blockchain in Healthcare Today*, vol. 2, pp. 1-9, March 2019, doi: 10.30953/bhty.v2.43.
- [12] A. Y. Alzahrani and A. Bulusu, "Block-Supply Chain: A New Anti-Counterfeiting Supply Chain Using NFC and Blockchain," in *Proceedings of the 1st Workshop on Cryptocurrencies and Blockchains for Distributed Systems*, Munich, Germany, 2018, pp. 30-35, doi: 10.1145/3211933.3211939.
- [13] A. Khan, M. Salah, M. Yaqoob, M. Uddin, S. Iqbal, and R. Jayaraman, "Blockchain-Based Tracking and Smart Contracts in Supply Chain Management: A Systematic Review," *IEEE Access*, vol. 9, pp. 13465-13477, Jan. 2021, doi: 10.1109/ACCESS.2021.3051789.

