El Cezeri
Journal of Science and Engineering
ISSN: 2148-3736

Research Article

Unveiling the Power of Blockchain in Pharmaceutical Supply Chains: Strengthening Security and Improving Drug Traceability

Vandani Verma[1a]
[1] Department of Mathematics, Amity Institute of Applied Sciences, Amity University, Noida, India
vandaniverma@yahoo.com

DOI : 10.31202/ecjse.1338782
Received: 07.08.2023Accepted: 13.05.2024
How to cite this article:
Vandani Verma " Unveiling the Power of Blockchain in Pharmaceutical Supply Chains: Strengthening Security and Improving Drug Traceability ", El-Cezeri Journal of Science and Engineering, Vol: 11, Iss:2, (2024), pp.(142-151).
ORCID: 0000-0003-4175-9227

Abstract : Pharmaceutical supply chains involve multiple stakeholders at various stages, beginning with the API source, moving on to the medication manufacturer, packaging and distribution firms, administrative regulators, hospitals, pharmacies, and finally the patient. Because of the difficulty in tracking and ensuring authenticity, counterfeit drugs are more likely to penetrate the distribution system. Increasing counterfeit medicinal products in the market pose a potential threat to the pharmaceutical supply chain and to the lives of innocent people. There is a need for technology that could provide privacy, trust, transparency, security, authorization, and authentication to clients and show proof of the origin of products. Due to significant qualities such as decentralization, transparency, a trust-free environment, anonymity, and immutability, blockchain-based drug traceability provides a viable answer to this problem. Blockchain technology provides an efficient and cost-effective option for improving various drug traceability functions and procedures to assure appropriate identification. Blockchain is being employed in other areas of the pharmaceutical sector, such as packaging and supply chain activities. This paper describes the challenges in the pharmaceutical supply chain and how blockchain combined with the pharmaceutical supply chain can be a problem solver. We also review a blockchain architecture for product traceability in the pharmaceutical supply chain system.

Keywords : Blockchain Architectures, Drug Traceability, Healthcare, Information Sharing, Pharmaceutical Supply Chain, Security

1 Introduction

Cryptography serves as the fundamental basis for the blockchain system. The advent of blockchain technology, which offers a reliable and transparent framework for the storage and dissemination of information, is presenting novel opportunities to tackle significant issues pertaining to data privacy, security, and integrity across various domains, such as healthcare. Messages were encoded millennia ago as a protective measure against potential adversaries. The literature of the 1980s and 1990s featured numerous articles that posited the integration of cryptography with secure data chains and the initiation of digital currencies. In the year 1982, David Chaum [1] introduced the concept of digital currency and blind signatures, which enable individuals to affix their signature to a document, asserting their ownership while simultaneously concealing the information contained within the document. Subsequently, in 1990, David founded DigiCash [2], a cryptographic system that utilized both private and public keys, as well as signatures, to generate an untraceable form of digital currency. Regrettably, DigiCash faced financial insolvency and was officially declared bankrupt in 1998. Adam Back is credited with the establishment of hash cash, a proof-of-work system created to restrict the spread of unsolicited emails, colloquially called spam, in 1997. Prior to sending an email, the sender would be required to verify their ability to solve a computational puzzle, thereby consuming computational resources and heightening the expenses associated with sending out large volumes of spam emails. This innovative approach was subsequently expounded upon in a scholarly article published in 2002 [3]. In 1998 [4], the concept of "bit gold" was put forth as a decentralized form of digital currency. It involved a combination of proof-of-work and a network of computers that recognized the legitimacy of the proof-of-work and incorporated it into the subsequent problem, along with a timestamp. However, it is important to note that bit gold was purely theoretical and never attained the status of a genuine currency. In 1998, another article [5] was published that elucidated the fundamental principles of digital currencies, such as Bitcoin, and this research is referenced in Satoshi Nakamoto's seminal Bitcoin paper. It was the extensive efforts undertaken from the 1980s to the 2000s that established the foundational framework for Bitcoin and the underlying blockchain technology. In 2008, Satoshi Nakamoto [6] outlined in his article the process of Bitcoin creation and the linking of transaction blocks into chains. With Satoshi Nakamoto's establishment of the Bitcoin network and its inaugural blockchain in 2009, the concept became a tangible reality. This foundational blockchain

played a crucial role in Bitcoin, thwarting double spending and serving as a decentralized public ledger for all transactions within the Bitcoin network. Nakamoto further solidified this by mining the inaugural block on the Bitcoin network, famously dubbed the "genesis block." In blockchain technology, all records, whether they be transactional or medical, are stored in blocks. Once a block reaches its capacity with data, it becomes part of the chain of preceding blocks, and a new block is generated for subsequent data entries. This immutable nature ensures that once added to the blockchain, blocks cannot be altered, with any modifications requiring notification to all previous users. The scalability and decentralized nature of blockchain technology make it invaluable for improving supply chain processes, enhancing the global economy, and promoting project sustainability. Every aspect of the supply chain, from raw materials to transportation logistics to human resources, can be efficiently tracked using blockchain technology. Numerous studies [7], [8], and [9] have suggested alterations and devised novel methodologies to enhance and implement a diverse range of applications, such as smart contracts, supply chain management, and healthcare. This article discusses the possibilities and limitations of blockchain technology for drug tracing in the pharmaceutical supply chain. The main contributions of our study are as follows:

- We explore the issues of the pharmaceutical supply chain without blockchain.
- We analyse the suitability of Blockchain properties for drug tracing by giving an overview and several architectural designs.
- We discuss solutions in pharmaceutical supply chain management leveraging blockchain technology.
- We review thorough implementation of Blockchain solutions in pharmaceutical supply chains, launched as the eZTracker Platform by Zuellig Pharma.
- We investigate a Blockchain SCMS use case for COVID-19 vaccine distribution.

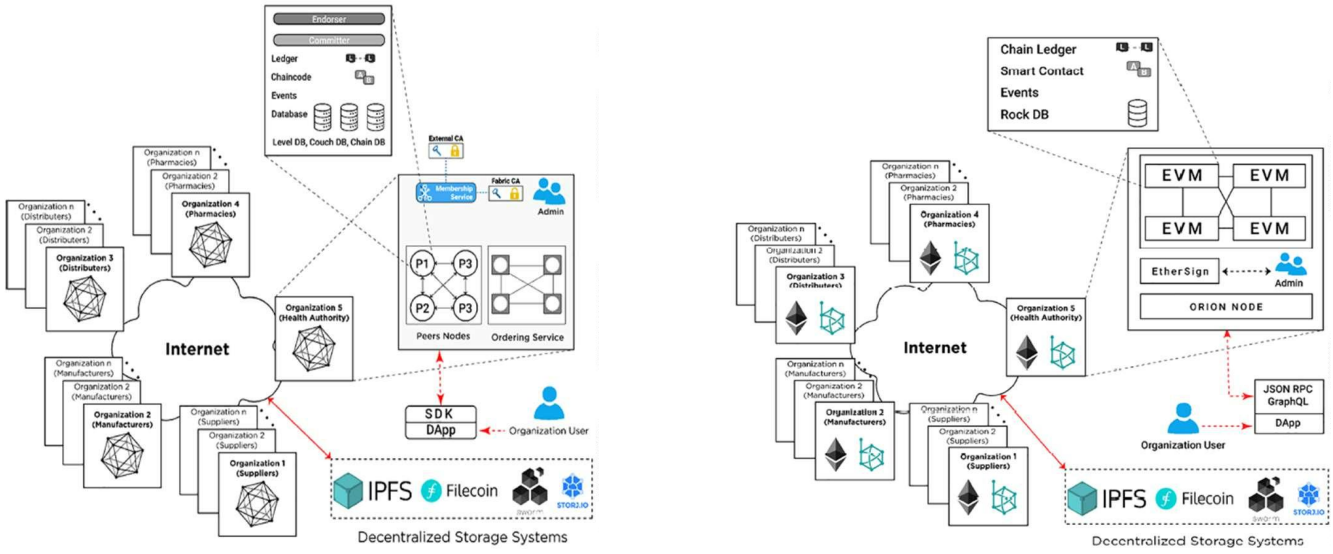
2 Challenges in Pharmaceutical Supply Chain Management System

- Counterfeit Drug Prevention: Products that are purposefully manufactured and have their identity labelled to appear to be genuine and the sale of fake medications harms both patients and the pharmaceutical industry as these may be harmful or ineffective to patients. Avoiding counterfeiting that can only be accomplished by identifying illegal intermediaries or determining provenance is a big challenge.
- Product Distribution: In supply chain management, goods are exchanged between several parties, none of whom are aware of any previous exchanges that took place. The drug supply chain lacks the infrastructure to ensure comprehensive manufacturer-to-end user tracking. Drugs are initially given to wholesalers by the manufacturer, who then give them to hospitals or pharmacies and the absence of process transaction tracking in classical supply chain is challenging its effective implementation.
- Tracking and Tracing: Quality assurance and tracking of all stages of drug production from manufacturer to consumer has always posed a challenge. Deaths have resulted from the distribution of substandard and counterfeit drugs, prompting governments around the globe to incorporate trace and track systems to monitor pharmaceuticals supply chains.
- Safety and Security: Classical drug supply chain management characteristics cannot broadcast necessary information securely and reliably. Data can be easily removed, altered, and tampered with in many cases. Keeping data safe from alteration, removal, and modification while sending it securely and reliably all over the network is a bigger challenger to users.
- Inaccurate Stock Data: A lack of visibility into inventory or stock data is one of the most serious issues in the supply chain. Healthcare facilities, manufacturers, and vendors would lack up-to-date inventory information. Many hospitals, for example, are unaware of the number of resources they have or will require during the covid-19 pandemic. Hospitals that use antiquated software to manage inventory, procurement, shipping, and other operations may struggle to meet timelines.
- Quality Priority: Because medicines deal with people's lives, quality is the most important factor to consider. The major function of a supply chain is to retain the product's quality so that it is effective until it is consumed by the customer. For example, maintaining proper temperature and humidity levels. Many systems do not provide such assurance.

3 Characteristics and Architecture of Blockchain for Drug Traceability

In this section, we discuss the characteristics of blockchain in context with drug traceability and two further architectures with these characteristics as proposed by Uddin et al. [7]. Following are the characteristics of block chain:

- Immutability: Immutability is a core pillar of blockchain technology, ensuring the integrity of the digital ledger by making it immutable. Unlike traditional money transfer systems, which allow transaction details to be easily tampered with and require the involvement of trusted third parties to ensure data integrity, blockchain works on the principle that each block is intricately linked to its predecessor, significantly reducing the likelihood of block alteration.



(a) Hyperledger Fabric Blockchain Architecture **(b) Hyperledger Besu Blockchain Architecture**

Figure 1: Blockchain Architecture [7]

- Decentralization: Decentralisation is a distinguishing feature of blockchain networks, which eliminates the need for a trusted third party or central authority to supervise transactions. This decentralised distributed ledger solution efficiently overcomes issues such as single-point failures and dependency on third parties to ensure transaction integrity.
- Heightened Security: After transaction details are hashed, appended to a block, and made public, altering the transaction information becomes impossible without modifying the hash value. This is because the blockchain relies on irreversible hashes for all its data. Thus, anyone attempting to alter data would need to compromise every block across the entire network.
- Distributed Ledgers: All details regarding a transaction and its participants are distributed among all involved parties. This ensures that any malicious alterations to a transaction can be readily detected, promoting transparency, and making the system resistant to tampering.

A distributed ledger technology called Hyperledger Fabric [7] (Fig. 1a as presented in [7]) provides reliable solutions with high degrees of secrecy, resilience, adaptability, and scalability. By enforcing trust between several parties without requiring mining, it preserves desired blockchain characteristics like block immutability and avoids double spending through the use of smart contracts. It is perfect for intricate supply chain systems because of its transaction throughput, which may approach several thousand transactions per second. The Hyperledger Fabric medication traceability architecture [7] incorporates a blockchain-based supply chain system that protects privacy, confidentiality, and data security. The notion of channels separates business logic from data privacy regulations across stakeholders. A permissioned private blockchain network is formed, with a Health Authority registering organisations and users through the membership service provider. This protects privacy and secrecy by decentralising identity management. At its heart, Hyperledger Fabric consists of peer nodes that store ledger copies and execute smart contracts, while an ordering service receives, orders, and broadcasts transactions for validation. The transaction processing approach consists of four phases: proposal, endorsement, ordering, and execution, which ensures determinism and dependability in updating the ledger's state. Hyperledger Fabric's principles provide safe and transparent transaction management for many parties in the pharmaceutical supply chain, reducing hazards such as counterfeit pharmaceuticals.

To execute medication-related traceability transactions on a Hyperledger Besu network [7] (Fig. 1b as presented in [7]), a Distributed App (DApp) sends signed private transaction requests to a Hyperledger Besu EVM node. These transactions include recipient addresses (or privacy group IDs), sender addresses, and transaction types. Privacy groups, denoted by unique IDs, grant access to certain data exclusively to designated accounts or nodes. The DApp interface transmits transactions to Orion via a Private Transaction Handler, which distributes them to the appropriate Orion nodes. Orion nodes record transactions in a state database and provide the transaction hash to the Private Transaction Handler. Additionally, Privacy Marker Transactions (PMT) are generated, mined into blocks, and broadcasted. The Mainnet Transaction Processor executes PMTs, which are then executed and committed to the private world state on nodes that have the relevant precompiled smart contract. Nodes without a contract ignore the marker transaction.

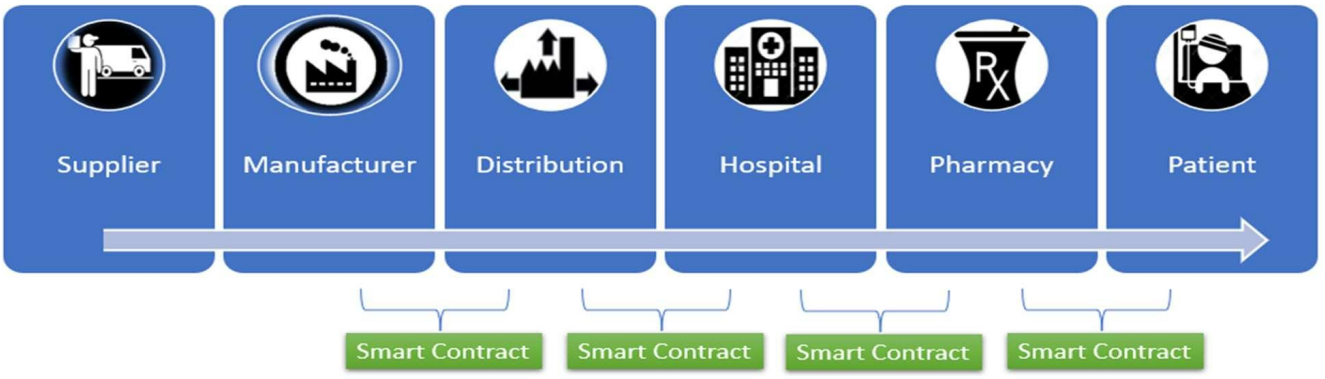


Figure 2: Blockchain for Product Traceability

4 Pharmaceutical Supply Chain Management System with Blockchain

The pharmaceutical supply chain comprises of several stakeholders, like a supplier, manufacturer, distributor, retailer, pharmacy, and at last, the consumer (patient). Product distribution frequently necessitates sophisticated packing, unpacking, and repacking methods, making drug authenticity, and tracking incredibly hard. Since medicine deals with humans' lives, quality is of the utmost importance, and it's not only the quality while manufacturing but also maintaining the quality of the products so that they are efficient until the time they are consumed by the patient, and so it's the responsibility of the manufacturer to store the drugs at the right temperature, ensuring that the storage humidity is right, depending on the storage requirement for the product. Also, in the pharma industry, whenever there is a product on the shelf-life, and it is not sold, either because it is expired, or it is near expiration, or because it may have quality issues, the supply chain (Fig. 2) ensures the pickup of these products from the complex network of thousands of retailers, distributors, and wholesalers and disposes of them. This scenario also offers a chance for the counterfeit drug industry, where they can buy these expired drugs and reprint their expiry labels to sell them into the market.

This scenario of the introduction of counterfeit drugs into the market poses a challenge to bringing all the supply chain (raw material-producing companies, manufacturers, distributors, and then the different channels through which they call the hospital and clinic) and, at the end, the patient together, as they tend to be a fragmented ecosystem altogether. The first challenge is to share information between parties when there's no standard mechanism for data transfer and a lack of trust, as people don't want to share data ownership. Lack of information and communication between parties create entry points for illicit products from outside the system. The second challenge is to track a product's activity from end to end along the supply chain so that information is passed over consistently and is being recorded in a timely manner, making it accessible to whoever needs access to that data. Then, the third challenge is: how do you give drug supply information to a patient so that a patient is able to verify it through a mobile phone, investigate the supply chain, and decide before purchasing the medicine or getting vaccinated? Thus, a verified block chain-based pharmaceutical supply chain is the solution to these challenges. Several studies have been done towards implementing blockchain in the pharmaceutical supply chain; some of the relevant ones are listed in the table 1

Each participating entity uploads its transaction to the blockchain network (depending on the finished activity). At the first stage, many manufacturers send raw materials to the producer and record their transactions on the block chain network. This transaction contains information such as the raw material's name, quantity, and quality, as well as the supplier's location.

When the manufacturer receives the raw materials, smart contracts are activated, and appropriate action is taken. All network authorities have access to the network and can check the validity and history of any medicine at any time. Similarly, the manufacturer interacts with the network at the next level, and so on. Thus, in a block chain network, various aspects of the supply chain are recorded, and every new transaction in the network is recorded in an immutable block that is time-stamped to keep track of the exact product in the end-to-end chain and ensures that the block's details are not tampered with. At last, when the drugs are delivered to the patient, he can trace the drug through a mobile app that allows him to scan a data matrix QR code on the medication (Fig. 3) and be able to trace right the way back to the origin of that product and provides information like where it was manufactured, where it came from, where it's been, how long it was in certain locations, where it was stored in the right temperature controls, and that it's been through a supply chain and being handled in the correct way, so it transforms a patient's mobile phone into a cloud-based verification tool.

5 Review of eZTracker designed by Zuellig Pharma[31]

Recognizing the need for blockchain networks in the pharmaceutical and healthcare industries (Table 1), Zuellig Pharma: a professional services firm, has created a platform that would serve as the foundation for a complete plant-to-patient supply

Table 1: Blockchain in Healthcare Supply chain Management

S. No.	Reference	Key Findings
1	Wu et al. [10]	Introduced a delivery structure comprised of several private distributed ledgers and a blockchain public ledger, as well as its implementation.
2	Jochumsen et al. [11]	Using a literature review and expert interviews, this study investigates the impact of Blockchain on the pharmaceutical supply chain. The authors have interviewed various Co-Founder and Executive Director pharmaceutical industry experts, including project managers to conduct this study.
3	Clauson et al. [12]	Using Blockchain technology, the study explores several difficulties (such as product identity, traceability, verification, detection, and etc) as well as prospects for improvement in the healthcare supply chain.
4	Tseng et al. [13]	The system's objective is to reduce the likelihood that fake medications will enter the supply chain for real ones. The double-spending prevention feature of the Gcoin Blockchain was used by the authors of this study to address the issue of fake medications. The Gcoin Blockchain has created and is maintaining an immutable, transparent, and secure database of drug supply chain transaction data that is consensus driven.
5	Hossein et al. [14]	The authors created a Blockchain-based architecture that uses multiple system miners to validate and protect patient data in the healthcare industry. Also, investigated several barriers to using Blockchain in IoT to protect patients' privacy. Concerns expressed included network overhead imposed by the Proof of Work consensus technique and a limited number of transactions recorded in the Blockchain network.
6	Bryatov et al. [15]	A pharmaceutical supply chain architecture is built using the Blockchain Hyperledger Fabric technology. They have highlighted drug counterfeiting as a severe problem in the supply chain and proposed a comprehensive plan to address it.
7	Jamil et al.[16]	According to the authors, the pharmaceutical supply chain's safety has become a serious concern to public health. Using Hyperledger Fabric, they demonstrated pharmaceuticals supply chain management. They also created a smart contract to allow patients to obtain electronic prescription data and electronic health information for a limited period.
8	Drosatos et al. [17]	Provide a thorough overview of the scope and constraints of Blockchain technology in the biological field. Most research focuses on how to integrate, maintain the integrity of, and control access to patient data related to health records. Medical research, clinical trials, the pharmaceutical supply chain, and medical insurance are just a few of the other interesting and cutting-edge applications that are emerging.
9	Yang et al. [18]	Presents an architecture that integrates Blockchain technology into global electronic health records with the use of smart contracts. The proposed system is practical for health providers to implement, without affecting record management effectiveness and interoperable with current e-healthcare systems.
10	Jayaraman et al. [19]	Highlights the potential benefits of combining IoT and Blockchain Technology for the healthcare supply chain. The study investigated how IoT-based Blockchain design, with its smart contract's capability, can address challenges and problems in the healthcare supply chain, including product recalls, supply constraints, expiry monitoring, and fake goods.
11	Tijan et al. [20]	This article delves into the application of Blockchain technology in logistics and supply chain management. Blockchain technology could aid in a variety of supply chain tasks such as tracking objects, tracking orders, vouchers, bills, and transactions, and so on.
12	Abou-Nassar et al. [21]	Proposed a Blockchain-based Decentralized Interoperable Trust framework (DIT) for a healthcare IoT system using smart contracts to boost trust. To ensure trustworthy communication, the system leverages a ripple chain, which verifies nodes depending on underlying interoperable structure.
13	Fekih et al. [22]	An overview of blockchain, particularly as it relates to healthcare, is provided in this article. Electronic Medical Records, Remote Patient Monitoring, Pharmaceutical Supply Chain, Health Insurance Claims, and other healthcare-related use cases and challenges were highlighted.
14	Reda et al. [23]	The healthcare and pharmaceutical supply chain architecture described in this article uses blockchain technology to ensure that real medications get to the people who need them most.
15	Y. L. Chang et al. [24]	Analysed blockchain applications in the maritime, transportation, food, pharmaceutical, and manufacturing supply chains to highlight the key challenges for blockchain implementation.
16	Houtan et al. [25]	Proposed a new model based on the Ethereum network and patient health records. Study includes patients' digital identity, records management, patient data, and decentralised applications for autonomous clinical operation.
17	Alghazwi et al. [26]	The literature on the use of blockchain for genome. They divided searches into commercial and non-commercial categories and predicted several challenges, including constraints to Implementation, interoperability, smart contract security, data privacy, and verifiability, among others.
18	Xiao et al. [27]	To replace the traditional healthcare system, researchers created a consortium Blockchain-based health chain. A consortium of hospitals, insurance companies, and government agencies that may be able to solve the traditional supply chain problems.
19	Cerny et al. [28]	General overview of the challenges associated with the use of blockchain technology in the supply chain. The article makes a distinction between conventional supply chains and supply chains built on blockchain technology. The lack of traceability, a lack of real-time information, the provenance of commodities, counterfeit goods, and other issues related to supply chain.
20	Sunmola et al. [29]	The study examined two different case studies to conduct a literature review on the application of Blockchain technology in traditional supply chains and its deployment in pre-adoption, adoption, and post-adoption stages.
21	Musamih et al. [30]	Authors demonstrated a Blockchain-based drug traceability solution for pharmaceutical supply chain through built in app DApp (Decentralized application) using various Ethereum smart contracts for permission. As a system stakeholder, they followed FDA (Food and Drug Administration) standards and regulations.

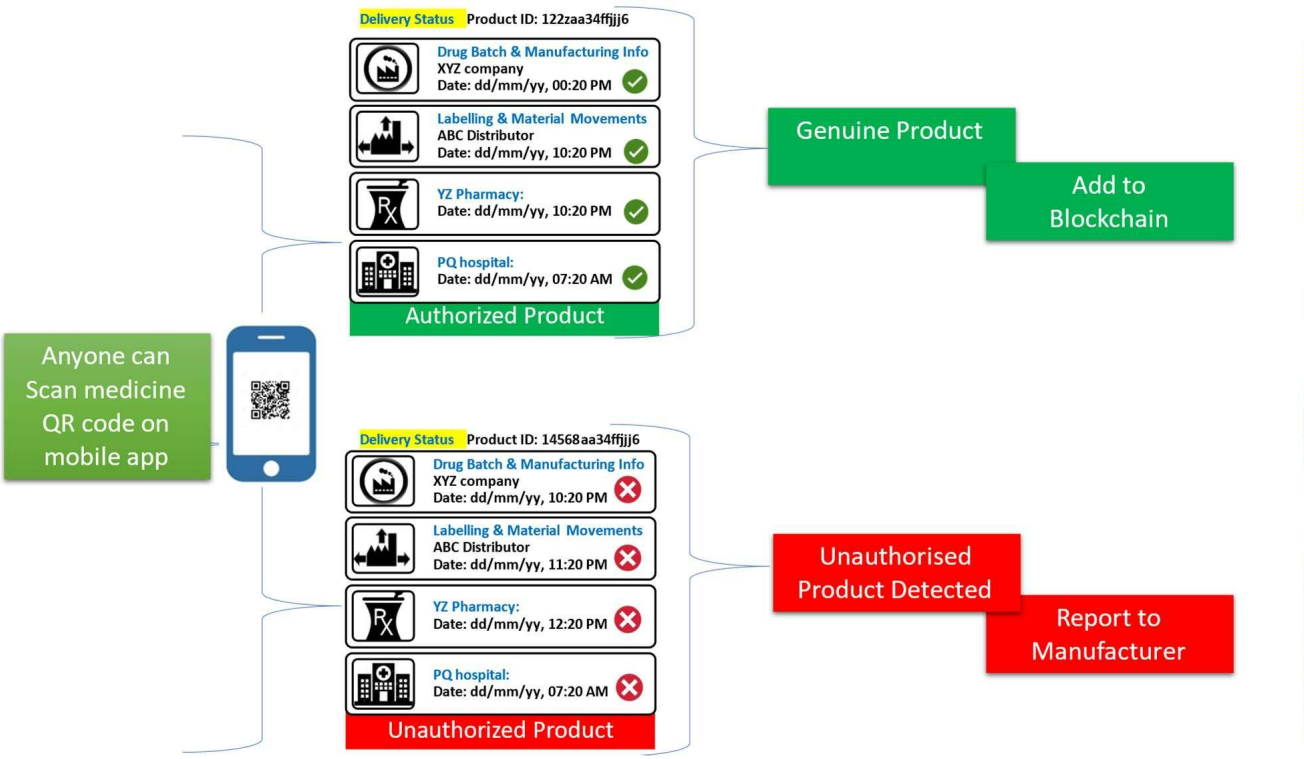


Figure 3: Product Traceability by Patient

chain information network. A one-of-a-kind platform designed with the following goals in mind to create a resilient blockchain network where:

- Supply Chain Concerns and Importance: One out of every ten pharmaceutical products sold in developing nations is fake, costing the region of SEA alone an estimated 2.6 billion USD in lost revenue every year, in addition to posing serious risks to patient safety.
- Pharmaceutical Industry Traceability: Grey markets or parallel imports of drugs are common. Beyond shrinking profit margins for pharmaceutical companies, the greater risks come from endangering public health by failing to comply with regional regulatory approval and labelling requirements.
- Margin erosion because of supply chain inefficiencies: Due to inefficient supply chains and inadequate storage conditions, the pharmaceutical industry loses an average of 4.5percent of its potential revenue.
- Inflated costs and a long-time lag for product recalls: In the last ten years, the average product recall has cost medical device manufacturers USD 10 million (excluding brand damage).
- Harsher penalties and stricter health policies regarding patient safety: Authorities around the world are increasing their scrutiny to ensure that supply chain practices do not jeopardise patient safety.

5.1 Collaboration Challenges with Information Exchange:

Challenge 1: Due to a lack of information and communication between supply chain parties and the lack of a data transfer mechanism, illegal products from outside the system may enter the system.

Challenge 2: Even when information is transmitted, activities are not consistently associated with product / package identities, limiting the effectiveness of sharing. In a system with interconnected feedback loops, efforts to optimise the supply chain are hampered by a lack of end-to-end information.

Challenge 3: Patients lack access to and no way to utilise the supply chain's information regarding product movement and provenance.

5.2 eZTracker Solution to challenges

eZTracker is a blockchain-based solution that gives pharmaceutical manufacturers transparency and traceability over their goods' movements throughout the distribution network. eZTracker turns patients' mobile devices into instant validation tools by tracking the unique QR code. Within seconds, a medication's code can be traced back to its manufacturer and country of origin,

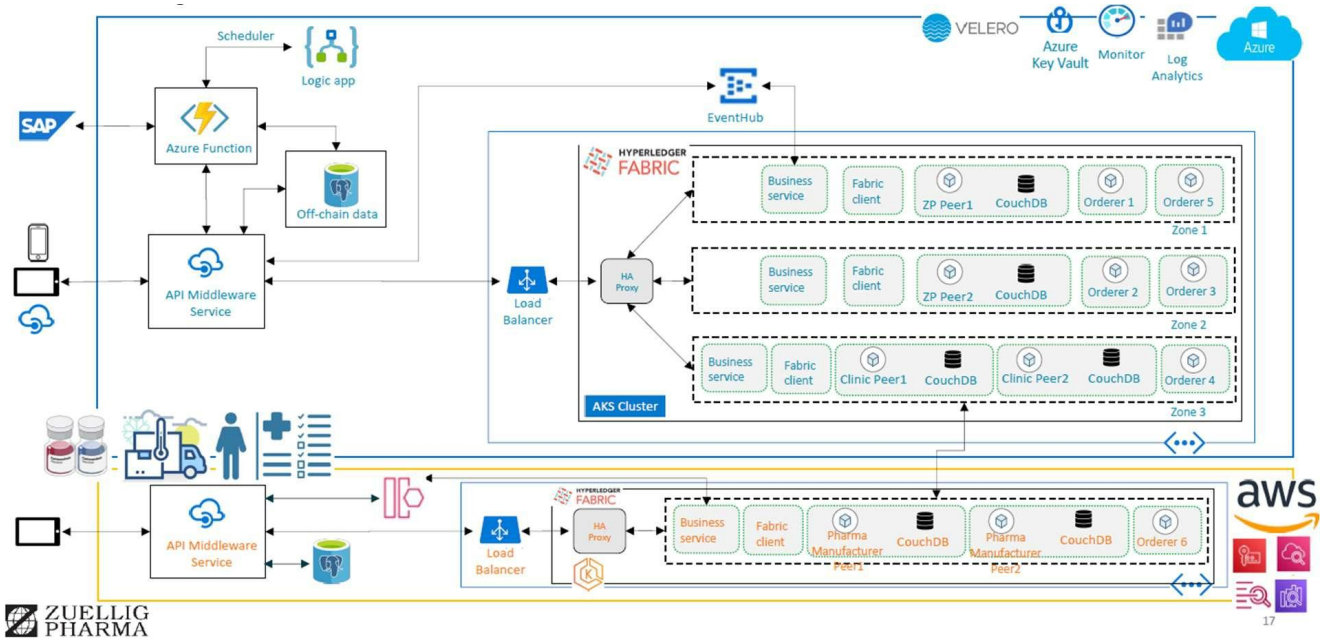


Figure 4: Zuellig Pharma Drug Traceability Blockchain Architecture [31]

which enables them to confirm the provenance and authenticity of their purchase, raising the bar for compliance and quality control to increase patient safety. Zuellig Pharma [31] has designed a material tracker (Fig. 4.) using Hyperledger blockchain technology in which the manufacturer shares material information, including batch information, expiry data, and all other data, with the blockchain that fits the evidence for traceability purposes. Now, this data will be shared along with the blockchain network with all the participants, including the distributor (like Azure Farmer or the other distributor, hospitals, clinics, as well as the other end users). So, when the product reaches the warehouse of Pharma Company, they will also feed in more information in the blockchain, like the shipping date of the medicine to the client, to the hospital, or to the clinic. Zuellig Pharma blockchain also manages the repo repository by storing patient information and patient vaccination details; some details are not shared in the blockchain because of privacy and confidentiality. Salient Features of [31] Participants host and operate their own "Node," which keeps their data safe in their own surroundings.

- Before being fed into the Node, every data point on product movements is confirmed by Smart Contracts and heavily encrypted.
- Participants can choose what data on their Node is recorded on the ledger ("on-chain") and what information is accessible to others.
- Smart Contracts and APIs allow users to "virtually" query ledger data across Nodes without transferring real data.

6 Blockchain SCMS for COVID-19 Vaccine Distribution

Blockchain technology may be the best option for managing COVID-19 vaccine distribution. An efficient allocation of a COVID-19 vaccine would necessitate global agreement on its delivery as well as a transparent, verifiable, and timely supply management system. Blockchain technology may be appropriate to handle such a difficult task, letting all countries and participating associations to be nodes in a network that can visualise immutable and real-time records [32]. The system could keep tabs on important details like vaccine production, distribution, and stock, as well as vaccine-related supplies (like needles, glass vials, and refrigeration units), both within and between nations. It could also keep tabs on the vaccine's quality by keeping track of its batch number, producer, expiration date, and temperature control. To minimise loss and waste, the system should also enable measurement of these two factors.

Blockchain technology, when combined with internet of things ('IoT') technology, could also be used to monitor the COVID-19 vaccine rollout [33](e.g. temperature sensors). Because each vaccination has varied storage needs, temperature and storage duration monitoring is crucial for the COVID-19 vaccine distribution chain. Temperature and other sensitive data could be tracked using blockchain technology throughout vaccination batch shipping and storage. The system would function by placing smart IoT sensors on shipping containers that would gather, store, and transfer data to the blockchain. Other authorised parties could then instantly examine this information on the blockchain, allowing hospitals, distributors, and regulators to confirm that the vaccinations were carried and stored securely and effectively. Many additional possible benefits of blockchain

in the context of pharmaceutical supply chains include the ability to locate problems, limitations, and restrictions rapidly and effectively, as well as eliminate the possibility of double computation through instantaneous transactions. As previously discussed, blockchain could help with quickly recognising troublesome products (such as defective, inaccurately stored, or counterfeit products) and efficiently expelling them from the supply chain.

7 Benefits of Blockchain in Pharmaceutical Supply Chain Management System

- Material Traceability for Pharma Manufacturers: Using blockchain technology, key farmer manufacturers can track the products from the plant down to the patient. Other things like managing inventory visibility and auto-replenishments are basically ways to strengthen trust and really allow them to give a stamp of approval that the products that they have are going through an easy tracker. Customers are assured that these are genuine products; they've been through a genuine supply chain, and they've been handled in the correct way. Block chain also helps in reducing waste and cost with higher demand and inventory visibility. Strengthen brand trust and reduce revenue loss by identifying "grey trade" occurrences.
- Quality Assurance for Patients: Blockchain provides comprehensive traceability from production to the point of reaching the patient, effectively preventing the introduction of counterfeit drugs or medical devices into the ecosystem. In cases where targeted recalls or inspections are necessary, blockchain facilitates swift and precise actions. Furthermore, quality parameters are documented by certifying agencies on the shared ledger, significantly reducing the risk of data tampering. Thus, the prescriber of the drug can verify it at any time, and people will have the right drugs anytime they need them, building confidence that they can go ahead and take that genuine medication, but also the quality. Thus, block chain empowers patients with the quality-related data of each box of medication, creating a sense of security that medication is quality-assured and genuine. Allow for more effective and accurate adverse event reporting and product recalls.
- Efficiency for Healthcare Organizations: Generate business efficiencies by minimizing inefficiencies in inventory management. Allow for more efficient and secure payment processing for pharmaceutical companies and other sub-distributors and wholesalers.

8 Results and Discussion

The pharmaceutical supply chain faces challenges such as counterfeit drugs, inefficient distribution, and quality maintenance. Numerous studies [7, 10-31] have been conducted to resolve this with the help of blockchain technology by ensuring transparency, traceability, and security throughout the supply chain process. With blockchain, each transaction is recorded on an immutable ledger, addressing issues like counterfeit drug introductions and inefficient recalls. The use of Hyperledger Fabric technology, Hyperledger Besu Network, and initiatives like Zuellig Pharma's eZTracker blockchain solutions provide transparency and traceability, enabling manufacturers to track product movements and consumers to verify the authenticity of their medications. By utilising Hyperledger blockchain technology, eZTracker ensures the integrity of data related to product movements, batch information, and expiration dates, enhancing traceability and accountability across the supply chain. In terms of COVID-19 vaccine distribution, blockchain provides an effective and transparent alternative for managing vaccine allocation and supply chain logistics. Real-time monitoring of temperature-sensitive vaccinations is now possible thanks to the integration of IoT technology and blockchain, ensuring adherence to storage regulations and minimising waste. Furthermore, blockchain enables the fast identification of defective items, which improves the overall safety and efficiency of pharmaceutical supply chains. Overall, blockchain technology offers various advantages for pharmaceutical supply chain management, such as increased traceability, quality assurance, and operational efficiency. By adopting blockchain-based systems like eZTracker, stakeholders may minimise risks, increase transparency, and assure the supply of safe and legitimate pharmaceuticals to patients worldwide by just scanning through the mobile app. Thus, these technological advancements significantly reduce counterfeit medicine and provide patients with legitimate drug supply information.

9 Conclusion

Blockchain qualities like decentralisation, immutability, increased security, and distributed ledgers allow for the safe traceability of medications from producers to end-user patients, lowering the possibility of counterfeit drugs entering the market. The paper discusses various architectural advancements in blockchain technology that can be used in the pharmaceutical supply chain to reduce counterfeit medicine. One of the proposed solutions is for consumers, i.e., patients may use smartphone applications to scan QR codes on pharmaceuticals to learn about their origins, production information, and supply chain trip, boosting confidence and trust in pharmaceutical supply chains. Blockchain's immutability and decentralisation provide data integrity and security, providing answers to issues such as counterfeit medication prevention, product distribution, and erroneous stock data. The paper also reviews Zuellig Pharma's eZTracker technology and demonstrates blockchain's disruptive potential by enabling transparency and traceability across the supply chain. Looking ahead, blockchain technology promises to revolutionise healthcare supply chain management, notably in COVID-19 vaccine delivery, by enabling real-time tracking, monitoring, and verification to guarantee equal access and minimise waste.

Competing Interests

The authors declare that they have no conflict of interest.

References

[1] David Chaum. Blind signatures for untraceable payments. In David Chaum, Ronald L. Rivest, and Alan T. Sherman, editors, *Advances in Cryptology*, pages 199–203, Boston, MA, 1983. Springer US. ISBN 978-1-4757-0602-4.

[2] David Chaum and Sandra Roijakkers. Unconditionally-secure digital signatures. In *Advances in Cryptology-CRYPTO'90: Proceedings 10*, pages 206–214. Springer, 1991.

[3] Adam Back et al. Hashcash-a denial of service counter-measure. *Available at : http://www.hashcash.org/papers/hashcash.pdf*, 2002.

[4] Nick Szabo. Bit gold: towards trust-independent digital money. *Recuperado de: https://web.archive.org/web/20140406003811/http://szabo.best.vwh.net/bitgold.html*, 1998.

[5] Wei Dai. B-money-an anonymous, distributed electronic cash system, 1998.

[6] Satoshi Nakamoto. Bitcoin: A peer-to-peer electronic cash system. *Available at https://bitcoin.org/bitcoin.pdf*, 2008.

[7] Mueen Uddin, Khaled Salah, Raja Jayaraman, Sasa Pesic, and Samer Ellahham. Blockchain for drug traceability: Architectures and open challenges. *Health informatics journal*, 27(2):14604582211011228, 2021.

[8] Sanjeev Kumar Dwivedi, Ruhul Amin, and Satyanarayana Vollala. Blockchain based secured information sharing protocol in supply chain management system with key distribution mechanism. *Journal of Information Security and Applications*, 54:102554, 2020.

[9] Seyednima Khezr, Md Moniruzzaman, Abdulsalam Yassine, and Rachid Benlamri. Blockchain technology in healthcare: A comprehensive review and directions for future research. *Applied sciences*, 9(9):1736, 2019.

[10] Haoyan Wu, Zhijie Li, Brian King, Zina Ben Miled, John Wassick, and Jeffrey Tazelaar. A distributed ledger for supply chain physical distribution visibility. *Information*, 8(4):137, 2017.

[11] Magnus Lyster Jochumsen and Atanu Chaudhuri. Blockchain's impact on supply chain of a pharmaceutical company. In *EUROMA Conference*, volume 6, 2018.

[12] Kevin A Clauson, Elizabeth A Breeden, Cameron Davidson, and Timothy K Mackey. Leveraging blockchain technology to enhance supply chain management in healthcare:: An exploration of challenges and opportunities in the health supply chain. *Blockchain in healthcare today*, 2018.

[13] Jen-Hung Tseng, Yen-Chih Liao, Bin Chong, and Shih-wei Liao. Governance on the drug supply chain via gcoin blockchain. *International journal of environmental research and public health*, 15(6):1055, 2018.

[14] Koosha Mohammad Hossein, Mohammad Esmaeil Esmaeili, Tooska Dargahi, et al. Blockchain-based privacy-preserving healthcare architecture. In *2019 IEEE Canadian conference of electrical and computer engineering (CCECE)*, pages 1–4. IEEE, 2019.

[15] SR Bryatov and AA Borodinov. Blockchain technology in the pharmaceutical supply chain: Researching a business model based on hyperledger fabric. In *Proceedings of the International Conference on Information Technology and Nanotechnology (ITNT), Samara, Russia*, volume 10, pages 1613–0073, 2019.

[16] Faisal Jamil, Lei Hang, KyuHyung Kim, and DoHyeun Kim. A novel medical blockchain model for drug supply chain integrity management in a smart hospital. *Electronics*, 8(5):505, 2019.

[17] George Drosatos and Eleni Kaldoudi. Blockchain applications in the biomedical domain: a scoping review. *Computational and structural biotechnology journal*, 17:229–240, 2019.

[18] Guang Yang, Chunlei Li, and Kjell E Marstein. A blockchain-based architecture for securing electronic health record systems. *Concurrency and Computation: Practice and Experience*, 33(14):e5479, 2021.

[19] Raja Jayaraman, Khaled Salah, and Nelson King. Improving opportunities in healthcare supply chain processes via the internet of things and blockchain technology. *International Journal of Healthcare Information Systems and Informatics (IJHISI)*, 14(2):49–65, 2019.

[20] Edvard Tijan, Saša Aksentijević, Katarina Ivanić, and Mladen Jardas. Blockchain technology implementation in logistics. *Sustainability*, 11(4):1185, 2019.

[21] Eman M Abou-Nassar, Abdullah M Iliyasu, Passent M El-Kafrawy, Oh-Young Song, Ali Kashif Bashir, and Ahmed A Abd El-Latif. Ditrust chain: towards blockchain-based trust models for sustainable healthcare iot systems. *IEEE access*, 8:111223–111238, 2020.

[22] Rim Ben Fekih and Mariam Lahami. Application of blockchain technology in healthcare: a comprehensive study. In *The Impact of Digital Technologies on Public Health in Developed and Developing Countries: 18th International Conference, ICOST 2020, Hammamet, Tunisia, June 24–26, 2020, Proceedings 18*, pages 268–276. Springer, 2020.

[23] Moulouki Reda, Dominique Bernard Kanga, Taif Fatima, and Mohamed Azouazi. Blockchain in health supply chain management: State of art challenges and opportunities. *Procedia Computer Science*, 175:706–709, 2020.

[24] Yanling Chang, Eleftherios Iakovou, and Weidong Shi. Blockchain in global supply chains and cross border trade: a

critical synthesis of the state-of-the-art, challenges and opportunities. *International Journal of Production Research*, 58 (7):2082–2099, 2020.

[25] Bahar Houtan, Abdelhakim Senhaji Hafid, and Dimitrios Makrakis. A survey on blockchain-based self-sovereign patient identity in healthcare. *IEEE Access*, 8:90478–90494, 2020.

[26] Mohammed Alghazwi, Fatih Turkmen, Joeri Van Der Velde, and Dimka Karastoyanova. Blockchain for genomics: a systematic literature review. *Distributed Ledger Technologies: Research and Practice*, 1(2):1–28, 2022.

[27] Yonggang Xiao, Bin Xu, Wenhao Jiang, and Yunjun Wu. The healthchain blockchain for electronic health records: development study. *Journal of medical Internet research*, 23(1):e13556, 2021.

[28] Mikuláš Černỳ, Marián Gogola, Stanislav Kubal'ák, and Ján Ondruš. Blockchain technology as a new driver in supply chain. *Transportation Research Procedia*, 55:299–306, 2021.

[29] Funlade T Sunmola, Patrick Burgess, and Albert Tan. Building blocks for blockchain adoption in digital transformation of sustainable supply chains. *Procedia Manufacturing*, 55:513–520, 2021.

[30] Ahmad Musamih, Khaled Salah, Raja Jayaraman, Junaid Arshad, Mazin Debe, Yousof Al-Hammadi, and Samer Ellahham. A blockchain-based approach for drug traceability in healthcare supply chain. *IEEE access*, 9:9728–9743, 2021.

[31] Daniel Laverick and Zhang Haisheng. A blockchain-enabled solution to drive material traceability along the pharmaceutical supply chain in asia. pages 1–20. ., 2021.

[32] Manan Shukla, Jianjing Lin, and Oshani Seneviratne. Blockiot: blockchain-based health data integration using iot devices. In *AMIA Annual Symposium Proceedings*, volume 2021, page 1119. American Medical Informatics Association, 2021.

[33] H Schofield and L Thasarathakumar. Blockchain, covid-19 and the pharmaceutical supply chain. *PharmExec*, 2021.