Shammy Akter

Implementing Blockchain for Improved Pharmaceutical Transparency and Efficiency in Supply Chain Management

Metropolia University of Applied Sciences

Master of Engineering

Information Technology

Master’s Thesis

Date: 27.11.2024

ACKNOWLEDGMENTS

I would like to thank everybody who assisted me in completing this thesis. First, I am very grateful to my advisor Aarne Klemetti for his guidance, support, and encouragement throughout this journey.

I would also like to thank Ville Jääskeläinen, Principal Lecturer of the Master's Program in Information Technology at Metropolia University of Applied Sciences, for the contribution provided and useful advice, which was of high importance to my work.

At last, I would like to thank my teachers, classmates, and the staff in my department for the support and shared knowledge which helped me a lot during my research

Shammy Akter

27.11.2024

Abstract

Author(s):	Shammy Akter
Title:	Implementing Blockchain for Improved Pharmaceutical Transparency and Efficiency in Supply Chain Management
Number of Pages:	56 pages
Date:	27, November 2024
Degree:	Master of Engineering
Degree Programme:	Information Technology
Professional Major:	Networking and Services
Supervisors:	Aarne Klemetti, Researching Lecturer Ville Jääskeläinen Principal Lecturer

---

Pharmaceuticals supply chain is a clearly defined network that is under pressure from a variety of issues, for example counterfeits, inventory, regulatory, and supply chain opacity. The current key challenges include a centralized model, trust, transparency, risk and security which have led to the consideration of Blockchain technology for solving these problems. This thesis aims at establishing the utility of block chain technology in the increase of transparency and traceability and reduction of the risks in pharmaceutical supply chains. It considers the use of the technology in the fight against fake drugs as well as managing drug stocks, other processes such as compliance and additionally, endears authority and investors. The study uses a literature review followed by case study analysis and simulated prototypes to show how blockchain can be applied to pharmaceutical supply chain, the feasibility of which is proved. Main conclusions suggest that the decentralization of records provided by the blockchain system can effectively monitor drug distribution from the manufacturers supply chain to the end consumer making it easier to eliminate fake medications. In addition, applying smart contracts can help automate such actions as order approval and payment realization, which can misfire anyway. Due to its general features, Blockchain also helps organizations work with compliance by creating compliance audit checklists and maintaining records that cannot be altered, thus saving time and resources that would otherwise need to be spent repeating compliance reports manually. Current papers and articles feature real-life pharmaceutical companies, including Pfizer, Novartis, and Boehringer Ingelheim, and demonstrate their best practices in the use of blockchain and the corresponding benefits for drug traceability and risk reduction. For example, Pfizer's engagement with the MediLedger consortium has shown how blockchain can achieve compliance, for example with the DSCSA while Novartis and IBM has shown how the sharing of real-time data can improve supply chain performance. These examples underscore the need for harmonization and synergy involving blockchain together with other systems and involving all players in the supply chain. Hence, the blockchain application for improving the pharmaceutical supply chain carries certain limitations including scalability constraints, high cost of implementation, and the GDPR related restrictions on personal data management. In order to overcome these challenges, this research offers the following recommendations. Some of these priorities are pilot projects, deploying blockchain with new technologies such as IoT and artificial intelligence, and improving the awareness level and cross-industry cooperation among stakeholders by engaging in industry partners' associations. Further, it is possible to partially address these issues with the help of the use of partially public blockchains and such improvements in consensus algorithms as PoS and sharding. This thesis affirms that blockchain technology will add value to the pharmaceutical supply chain since transparency, fraud and efficiency will improve. However it takes black and white cooperation, proper and effective regulation and dealing with technical issues. This research focuses on the practical approach that can realize the most of blockchain potential in pharma industries and improve supply chain accessibility, reliability and safety.

Keywords: Blockchain, Pharmaceutical Supply Chain, Counterfeit Drugs, Supply Chain Transparency, Smart Contracts, IoT Integration, Supply Chain Efficiency, Regulatory Compliance, Data Privacy, Artificial Intelligence, Drug Traceability, Supply Chain Innovation.

List of Abbreviations:

SCM- Supply Chain Management

WHO- World Health Organization

H1: Hypothesis 1

H2: Hypothesis 2

POMS: Product Ownership Management System.

S.C: Supply Chain

DSCSA: Drug Supply Chain Security Act

GMP : Good Manufacturing Practice

GDP: Good Distribution Practice

IBM: International Business Machines Corporation

SAP: Systems, Applications, and Products in Data Processing

GDPR: General Data Protection Regulation

FMD: Falsified Medicines Directive

I.T : Information Technology

PoS: Proof of Stake

IoT: Internet of Things

A.I: Artificial Intelligence

Table of Contents

1. Introduction

To maintain the integrity of pharmaceutical supply chains, it is essential to confront the ongoing challenges posed by counterfeit medications, deterioration in quality, and insufficient transparency within global trade frameworks (Abd-alrazaq, Alajlani et al. 2021, Bamakan, Moghaddam et al. 2021, Abdullah and Nizamuddin 2023). With the increasing demand for pharmaceutical products and most of all, the reliable and effective distribution of them, more so given the global situation due to the COVID-19 pandemic, new technologies such as blockchain and the Internet of Things are gaining ground as key enablers in enhancing transparency(Badhotiya, Sharma et al. 2021, Bamakan, Moghaddam et al. 2021, Chen, He et al. 2023), accountability(Azzi, Chamoun et al. 2019), and security(Chen, He et al. 2023) across the supply chain. Blockchain(Bocek, Rodrigues et al. 2017, Chang, Iakovou et al. 2020, Bamakan, Moghaddam et al. 2021), as a DLT, has been increasingly accepted in different domains because it can be used to offer immutability of data, transparency(Badhotiya, Sharma et al. 2021, Bamakan, Moghaddam et al. 2021, Chen, He et al. 2023), and security(Chen, He et al. 2023). Integration of this technology into IoT has, importantly, increased the potential of revolutionizing supply chain management in the pharmaceutical industry, making it possible for real-time gathering of data using sensors placed in the shipment (Jamil, Hang et al. 2019, Li, Li et al. 2019, Liu, Barenji et al. 2021).

The pharmaceutical supply chain is naturally labyrinthine, composed of manufacturers, distributors, retailers, and consumers (Buterin 2014, Clauson, Breeden et al. 2018). Its system is spread across very distant geographical regions, which exposes the supply chain to inefficiencies, delays, and vulnerabilities. These challenges have further been exacerbated by global health crises, such as the COVID-19 pandemic, which brought to the fore the imperative of resilient, transparent, and effective supply chain systems to ensure the continuous delivery of critical pharmaceuticals and medical supplies.

One of the most compelling concerns for regulatory agencies across the world, which continues to produce massive economic losses running into billions annually, is the distribution of counterfeit medicines that pose a critical threat to public health (Organization 2017, Clauson, Breeden et al. 2018, Jasmil, Hang et al. 2019, Musamih, Salah et al. 2021, Nawale and Konapure 2021). According to the World Health Organization, the trade in counterfeit medicines accounts for an estimated 50% of all medications sold online, which are believed to be fake. This kind of situation calls for devising new strategies to protect the pharmaceutical supply chain right from the manufacturing point to the final point of sale (Szabo 1996, Organization 2017, Chang and Chen 2020, Svoboda, Ghazal et al. 2021, Regin, Rajest et al. 2022).

The state-of-the-art blockchain is a decentralized ledger technology that provides potentially useful solutions to such problems. Its distributed nature essentially guarantees that data is redundantly stored at many locations, thus unreachable or immune to manipulation through unauthorized changes. Every transaction on this blockchain is validated through consensus mechanisms and linked to the previous transactions, thereby creating an immutable sequence of events that cannot be altered retrospectively (Azzi, Chamoun et al. 2019, Abd-alrazaq, Alajlani et al. 2021, Bamakan, Moghaddam et al. 2021). This, in the pharmaceutical context, means that a drug development product, from its process of manufacturing to distribution and finally to the last customer, is well documented and authenticated; hence, providing a transparent and traceable history of the product. These steps not only prevent such fraudulent practices but also assure customers that the products they receive are authentic, safe, and of high quality(Buterin 2014).

Various scholars have studied the use of blockchain in the pharmaceutical industry to its ability to overcome some of the major challenges. One of the main challenges that blockchain solutions address is the issue of trust between the different parties in the supply chain (Chang, Iakovou et al. 2020). Trust has always been a supply chain issue and more so in the pharmaceutical industry where stakes are high, as well as counterfeit activities (Badhotiya, Sharma et al.

2021). The single, publicly accessible ledger of all transactions between blockchain technologies is what allows manufacturers, distributors, regulators, and consumers to track the authenticity of pharmaceuticals at any point in the supply chain (Bocek, Rodrigues et al. 2017). This makes it possible to remove third-party verification service needs, thus introducing a more efficient and cost-effective way of ensuring product integrity (Bamakan, Moghaddam et al. 2021).

However, the advantages of blockchain extend beyond the mere elimination of counterfeit drugs. Efficiency and automation in pharmaceutical supply chains can be drastically increased by using blockchain-based smart contracts—self-executing agreements whose stipulations are embedded in coded lines (Abdallah and Nizamuddin 2023). These smart contracts eliminate the need for intermediaries, reduce administrative costs, and ensure that agreements set between various stakeholders are implemented in a secure and automated manner (Abd-alrazaq, Alajlani et al. 2021).

For instance, the arrival of a pharmaceutical product at a pre-defined location, or the verification of meeting specific quality standards, can autonomously trigger the next step in the process by a smart contract (Azzi, Chamoun et al. 2019). The next step could be payment, dispatch of the product, or reporting compliance to the regulatory authorities. Other than blockchain, IoT can revolutionize pharmaceutical supply chain management because it enables real-time data on the conditions under which products are transported and stored (Badhotiya, Sharma et al. 2021). IoT sensors—for example, temperature and humidity sensors—can be embedded in packaging or shipment containers to monitor environmental conditions throughout the transportation process (Bamakan, Moghaddam et al. 2021). This data will then be sent to a blockchain, where it can be viewed in real-time by all the authorized parties. By combining IoT with blockchain, pharmaceutical companies can ensure the integrity of their products by not only ensuring authenticity but also ensuring they have been stored and transported at the appropriate conditions (Bocek, Rodrigues et al. 2017).

A good example is the tracking of temperature-sensitive medicines that need refrigeration during transportation, ensuring that they are not exposed to variations in temperature that could alter their quality or effectiveness. Integration of blockchain and IoT in pharmaceutical supply chains could help solve some of the critical problems of a lack of visibility, inefficiencies, and fraud (Buterin 2014). Blockchain has a transparent and immutable record of all transactions and events of the supply chain; then, all parties involved in the process, from manufacturer to consumer, ensure that they have the same information available(Centobelli, Cerchione et al. 2022).

It creates a level of trust and accountability that is impossible to achieve with traditional systems, which will often have multiple, siloed databases and intermediaries (Chang and Chen 2020). Furthermore, the combination of IoT and blockchain can provide top pharmaceutical companies with the ability to track and trace products throughout their whole life cycle, right from production down to delivery, ensuring that any issues related to counterfeit drugs, quality degradation, or environmental factors are detected and acted upon quickly (Chang, Iakovou et al. 2020). Moreover, the inherent characteristic of blockchain technology is decentralized(Chen, He et al. 2023), which means that no single entity has control over the data, further reducing potential risks of data breaches and unauthorized changes(Clauson, Breeden et al. 2018). Unlike in a centralized system, where there is a single point of failure that could threaten the whole network, the distributed nature of blockchain assures that the data is stored on a large number of nodes, making it highly resilient and secure against hacks(Ducrée 2022).

This branch of technology has particularly given the pharmaceutical industry a derivative, owing to the fact that the industry deals with sensitive data pertaining to patient health records and drug traceability data (Funding 2017). For instance, blockchain is able to offer a secure environment for storing or sharing data in an encrypted form, ensuring that only authorized parties can have access while protecting against unauthorized access or tampering (Jamil, Hang et al. 2019). Apart from the technical benefits, the application of blockchain and

IoT in pharmaceutical supply chains could also have huge economic benefits (Li, Li et al. 2019). The key advantages would include reducing fraud, increasing transparency, and automating processes using smart contracts, which would finally help pharmaceutical companies reduce their costs and improve operational efficiency (Liu, Barenji et al. 2021). With the removal of intermediaries and fewer manual processes, for example, operations become streamlined, and error or delay chances are reduced (Marchesi 2023).

With better supply chain visibility, blockchain and IoT can ensure the authenticity and quality of the product, hence building consumer trust—something quite important in an industry where stakes are high and the consequence of failure is colossal (Musamih, Salah et al. 2021). However, several challenges have to be overcome before these technologies are widely adopted in the pharmaceutical industry (Nawale and Konapure 2021). One of the major challenges is the lack of standardization. Blockchain and IoT, though powerful, need interoperability between different platforms and systems to be successfully integrated into pharmaceutical supply chains.

Different companies and organizations in the supply chain may have different systems that could potentially make data exchange and alignment of processes more difficult (Organization 2017). The development of standard protocols and architectures on how to integrate blockchain and IoT will be very important for practicality and feasibility at a global level (Regin, Rajest et al. 2022). However, one of the major issues with blockchain remains its scalability. While blockchain has been proven to work well in smaller-scale applications, scaling it up technologically to handle the huge volumes of transactions and data generated by the pharmaceutical supply chain may prove to be a big challenge. Blockchain networks face the possibility of bottlenecks with any increase in volumes of transactions, especially those using proof-of-work consensus algorithms (Sarkar 2023).

This will require further research into new consensus mechanisms, such as proof-of-stake, and also blockchain scalability solutions, such as sharding

(Svoboda, Ghazal et al. 2021). Another challenge relates to the regulatory environment. While blockchain technology can facilitate better regulatory compliance, its application in the pharmaceutical sector will need to be in line with existing legal laws and regulations (Szabo 1996). In particular, the pharmaceutical industry is subject to strict rules regarding pharmaceutical traceability and validation, and any solution based on blockchain needs to adhere to these very rules.

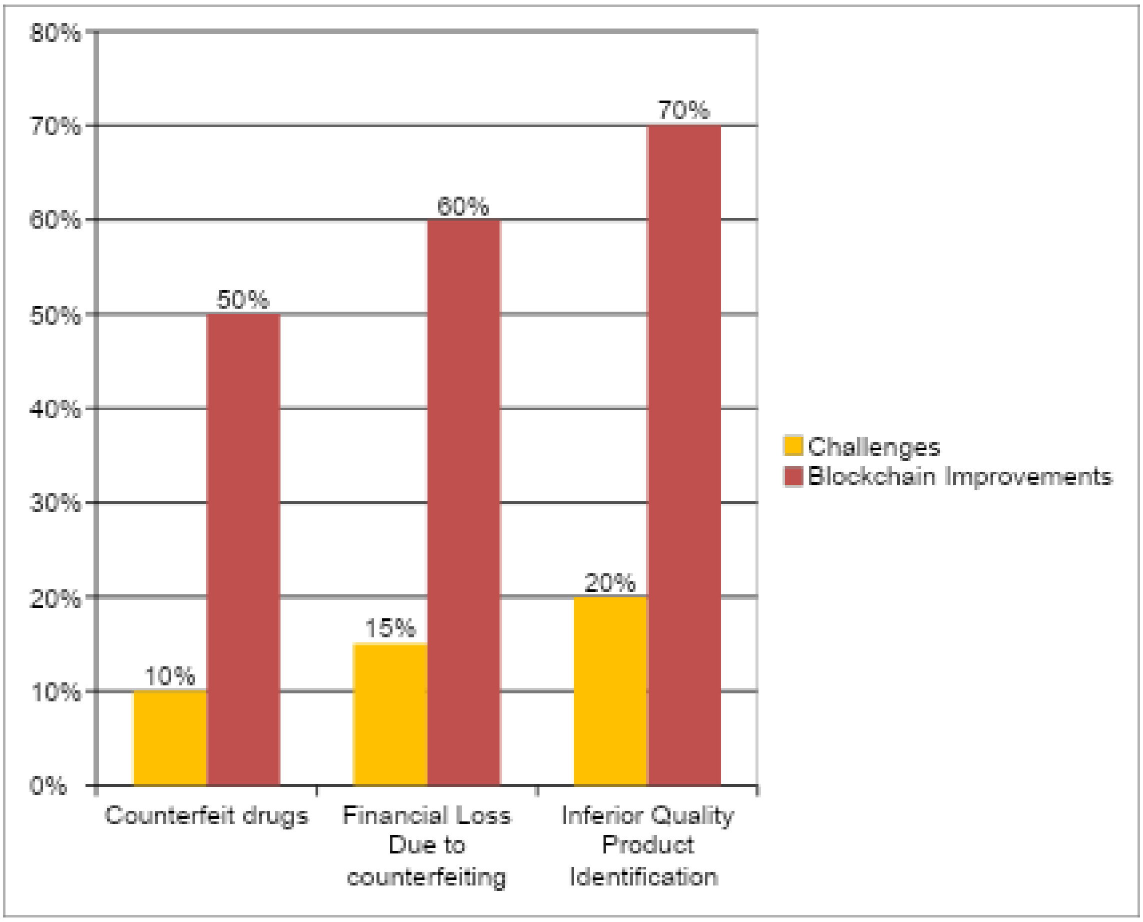
Its application in the pharmaceutical supply chain will, therefore, require regulatory agencies to adapt and make explicit regulations governing the use of blockchain technology. Despite such challenges, the integration of blockchain and IoT in pharmaceutical supply chains has huge potential (Wei, Wang et al. 2020). Through these technologies, pharmaceutical companies can build more transparent, secure, and efficient supply chains for the benefit of both businesses and consumers. This, therefore, is the continued development and adoption of blockchain and IoT solutions that will help address some of the most pressing issues of the pharmaceutical industry today, including counterfeit drugs, quality control, and supply chain inefficiencies. As they mature, the technologies will increasingly shape the future of the pharmaceutical industry and its supply chains (Organization 2017, Clauson, Breeden et al. 2018, Jamil, Hang et al. 2019, Marchesi 2023).

In the last analysis, this convergence of blockchain and IoT technologies holds a transformative opportunity for revolutionizing the pharmaceutical supply chain. It helps to provide enhanced transparency, security, and automation in solving major issues such as fraud, quality degradation, and inefficiency. As the pharmaceutical industry changes due to various global challenges, blockchain, and IoT technologies will be making very important contributions to establishing the authenticity, safety, and integrity of pharmaceutical products for the benefit of consumers, manufacturers, and regulators. Further research into these technologies, along with overcoming the challenges of standardization, scalability, and regulation, will be important for the full potential of these technologies to be realized in the pharmaceutical supply chain.

Supply chain management has different challenges and aspects in the context of managing the vendors of pharmaceutical products, tracking the products, and dealing with the problem of co, counterfeit products. The WHO said that it is approximated that about 10% of medical products in both developed and developing nations are counterfeit or of inferior quality; this is dangerous to consumers and results in financial loss to pharmaceutical companies (World Health Organization, 2017). Blockchain technology could solve these issues due to its ability to improve transparency and trust within supply chains (Kshetri, 2018). Counterfeit drugs are not only risky to the life of the patient, but they also erode consumer confidence in the health systems and defeat global health targets. Several industries and governments cause vast economic losses due to counterfeit pharmaceuticals, these systemic risks prove a hard nut to crack. Several supply chain mechanisms may fail to provide adequate durable traceability and real-time performance capable of mitigating these factors. Additionally, any form of delay in identifying fake products brings the effectiveness of body regulation into a one-step quandary while harmful substandard drugs flood the market.

Blockchain technology provides a unique solution by creating a transparent and decentralized system of recording each movement and every transaction of pharmaceutical products. Every member from the manufacturers to the end consumers can get access to the data that cannot be tampered with further and thus increasing accountability throughout the chain. In addition to fighting counterfeits, blockchain optimizes inventory and automatically completes compliance tasks through smart contracts and minimizes waste to other forms of inefficiency such as intermediaries.

Furthermore, the cases with applying complementary technologies like IoT and AI with blockchain increases the efficiency of the technology. Internet of things, such as temperature recording devices, can monitor drug conditions in real-time, with the information tensor being stored in blockchain. The data collection process can also present a broad advantage to the supply chain since machine learning algorithms can easily identify likely disruptions further to enhancing operations. Therefore, blockchain along with other future technologies offers a complete solution for innovation and protection of pharmaceutical supply chain.This research paper seeks to reveal how blockchain technology can enhance transparency and encourage efficiency in restoring safety in the supply chain of drugs to combat counterfeit medications.



Figuare 1: Impact of Blockchain on Pharmaceutical Supply Chain Challenges Supply Chain Aspects

This thesis explains how Blockchain, an advanced technique in the digital environment, can revolutionize and increase accountability, traceability, and effectiveness in the pharmaceutical distribution network. A few of them are counterfeit medicine and lack of transparency, which have been problems for a long time. Since this technology relies on decentralized consensus, it can easily be a revolutionizing catalyst for the supply chain by presenting a Share perspective. Thus, this research study explores both the application of and the efficiency of a system established on the Blockchain in the pharmaceutical industry.

1.1Aim

This study will assess the current and potential supply chain challenges and opportunities to correct them using blockchain solutions, including fraud, transparency, and medication delays. Blockchain will be discussed in terms of its concepts and the possibility of using it in managing the pharmaceutical supply chain; features of the system to be included are real-time tracking, smart contracts, and IoT (Casino et al., 2019).

1.2 Goal

Therefore, the thesis will show how Blockchain can improve the pharmaceutical pharmaceutical supply chain's reliability, security, and efficiency. An actual blockchain prototype for this study will be established to let manufacturers, distributors, and pharmacies authenticate the products and their conformity in real-time (Saberi et al., 2019).

1.3 Rational of the study

1.3.1 Significance

The results serve the common good by assisting pharmaceutical companies, regulatory authorities, and customers in decreasing the prevalence of counterfeit drugs, increasing confidence in the Med replenishment chain, and guaranteeing that over-the-counter products are authentic. Through the development of blockchain technology, regulatory bodies will be in the position of monitoring compliance(Tijan et al., 2019). In consumers' cases, Blockchain will offer equal visibility and security to guarantee they buy genuine products.

1.3.2 Utilization of Results

Applying blockchain solutions becomes easy due to the flexibility present in integrating them into the supply chains. It is also promising for other fields with comparable issues related to transparency, as this technology may be used in other sectors and fields (Toyoda et al., 2017).

1.3.3 Desired Outcome

In particular, this project will seek to implement a mock deployment of a prototype blockchain application. This system will allow for monitoring transactions and product movements, making audits more accessible and reducing the chances of counterfeiting. The expected result is to achieve shorter and more effective delivery of pharmaceutical products and protect patient and regulatory interests (Hughes et al., 2019).

1.4 Research Questions and Hypotheses

This section will define the specific research questions, such as:

- What are the benefits of using Blockchain to increase transparency in the pharmaceutical supply chain?
- Which factors are potential drivers for the blockchain industry?

Hypotheses will then be formulated to guide the research

H1: There is a perception that the minimal use of blockchain technology lowers the cases of fake pharmaceutical products in the chain.

H2: The use of Blockchain increases supply chain efficiencies within the sphere of pharmaceutical manufacturing and distribution.

2. Literature review

Smart contracts have received massive interest due to their capability in transforming supply chain networks, especially in the healthcare sector. This section discusses relevant literature regarding the use of Blockchain in supply chains, particularly about transparency, efficiency, and counterfeiting.

2.1 Blockchain and Supply Chain Transparency

In detail, Kshetri (2018) assessed how Blockchain supports transparency in different SCM domains, including pharmaceuticals. The paper also discusses how Blockchain effectively decentralizes ledgers; records can be saved in fixed formats that can be viewed at any time to unveil product histories applicable to multiple parties. As pointed out by Kshetri, this aspect could go a long way toward reducing related fraud problems and, at the same time, enhance confidence from suppliers, manufacturers, and customers. According to the author, the ability of Blockchain to offer high transparency and accountability can enable counterfeits to be detected and ensure compliance with industrial standards (Kshetri, 2018).

2.2 The Use of Blockchain in Combating Fake Drugs

Toyoda et al. (2017) pointed out that fake products are one of the most significant issues in the pharma industry, and blockchain systems neutralize them. Consequently, the researchers used a blockchain-based Product Ownership Management System (POMS) that grants product approval at every S.C. process checkpoint. Based on their studies, it was observed that, with the help of the blockchain technology integrated POMS system, it is possible to reduce the risk of counterfeit drug circulation and confidently prove the ownership of products. It can benefit consumers from transparency, especially the security characteristics because using techniques consistent with the characteristics of Blockchain can significantly ensure that the medicines are not fake or dangerous.

2.3 Optimizing the Performance of Pharmaceutical Distribution Networks

According to Saberi et al. (2019), there is a systematic review of Blockchain in the supply chain, and the authors mentioned that Blockchain applies to pharmaceutical industries. Based on this, the authors review different facets of Blockchain and establish that the technology reduces the number of intermediaries and, thereby, the time taken to verify and reconcile transactions. They also note that, due to the utilization of the bright contract concept, which implies actions are only carried out on the condition that requirements have been met, the operation may be enhanced. This work indicates that using blockchain applications in the pharmaceutical system improves dependability and the rate at which products are delivered and minimizes time and cost (Saberi et al., 2019).

The papers under review show that Blockchain can potentially address difficulties in pharmaceutical supply chains. Blockchain has the characteristics to improve some of the issues in the area, reduce them, and provide better tracking and functionality of the supply chain. Based on these results, the current thesis shall extend the understanding of Blockchain's applicability within the pharmaceutical industry.

2.4 Four types of challenges in the pharmaceutical Supply Chain

The supply chain of pharmaceuticals is known to experience countless hurdles that affect its functionality, compliance, and security. Blockchain has therefore been identified as a viable solution to the aforementioned challenges through increase of drug traceability, compliance as well as improving on the credibility of all the stakeholders involved in the process.

2.5 Counterfeit Drugs and Product Authentication

Falsified products are a major concern in the pharma sector because they compromise the health of the end consumer, and are financially burdensome.

Globalization of medicine has been significantly hampered by counterfeiting of medical products which according to the global health organization (WHO) is compensated in low and middle income setting at 10% (World Health Organization, 2017). Counterfeits put consumers' health at risk because they contain wrong and dangerous substances. Blockchain can reduce counterfeit items via an effective record of product history for every transaction made on the network making drugs real as they are being supplied (Dwivedi et al., 2020).

3. Methodology

Smart contracts have received massive interest due to their capability in transforming supply chain networks, especially in the healthcare sector. This section discusses relevant literature regarding the use of Blockchain in supply chains, particularly about transparency, efficiency, and counterfeiting.
The system in which a drug is manufactured, distributed, stored, dispensed and administered to the populace is a linear one but which is filled with many players. The diagram above highlights the flow of goods and information through four main stages:

1. Manufacturers:
Manufacturers play the first link of supply chain by developing proper pharmaceutical products. With the help of blockchain those may include information on the origin of the raw materials used, processing and quality control data. This makes the drugs to have a trail of their source and that they conform to the intended standards.

2. Distributors:
Distributors are in the middle position between a manufacturer and a pharmacy. Drug consignment is made transparent through Blockchain that ensures end to end movement of the consignment is recorded in real time. Authors using smart contracts for payments and delivery confirmations can minimize errors made by people.

The way it works Pharmaceutical Supply Chain Flow: A Blockchain

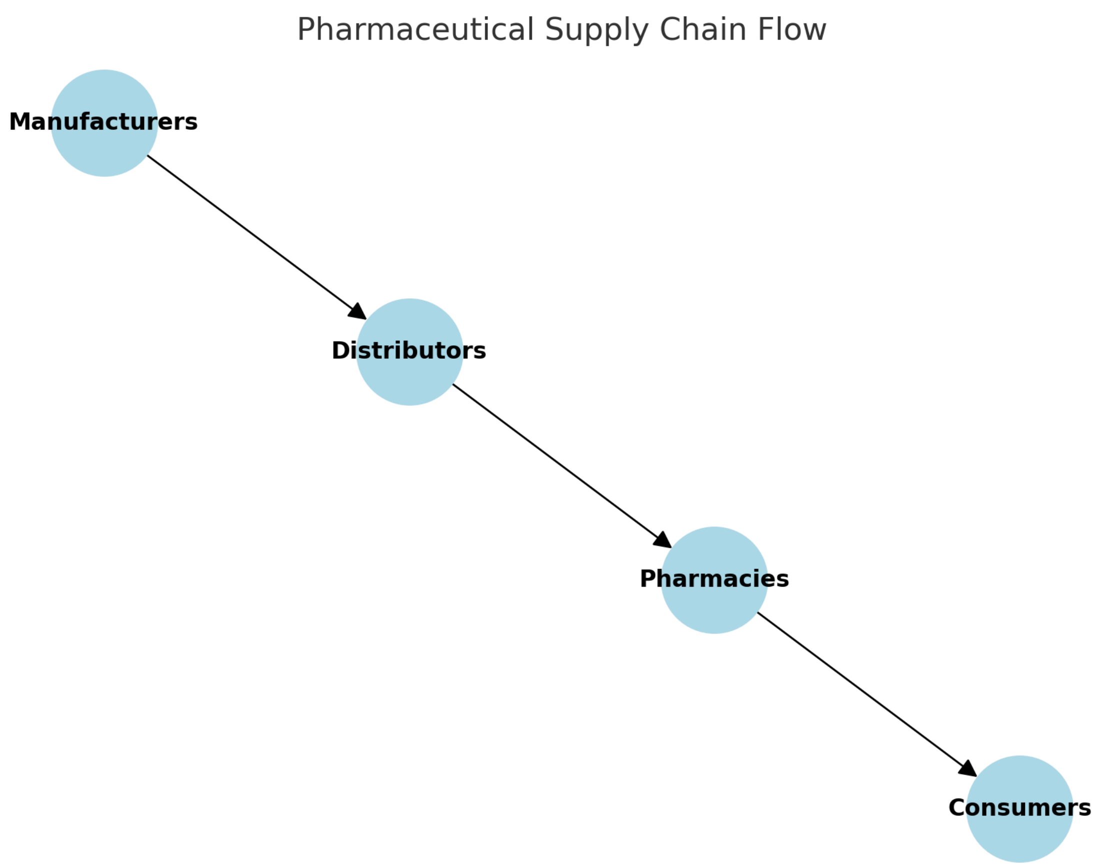


Figure 2 : Working flow chart of distribution of drugs from the manufacturers to consumers.

3. Pharmacies:

Pharmacies are the last stop before the drugs are rendered available to the consumer of the medications. They use blockchain to prove the purity of the drugs they want to use to avoid using substandard drugs in the market. This also saved the record of inventory they do not let it overstocked or under stocked.

4. Consumers:

Consumers also experience improvements in the traceability and transparency produced by blockchain. Through the Blockchain technology, the medications they obtain can be confirmed to be originals, which creates confidence in the chain and enhances the safety of the people.

Significance

Combined with all these stages is blockchain technology that will decentralize and securely identify, analyze, and reduce fraudulent cases, and increase trust among all participants. The flow exemplifies how the concept of blockchain is useful within the guideline of the pharmaceutical channel since it makes the handling of drugs from the manufacturer to the consumer providers more dependable.

3.1 Blockchain and Supply Chain Transparency

In detail, Kshetri (2018) assessed how Blockchain supports transparency in different SCM domains, including pharmaceuticals. The paper also discusses how Blockchain effectively decentralizes ledgers; records can be saved in fixed formats that can be viewed at any time to unveil product histories applicable to multiple parties.

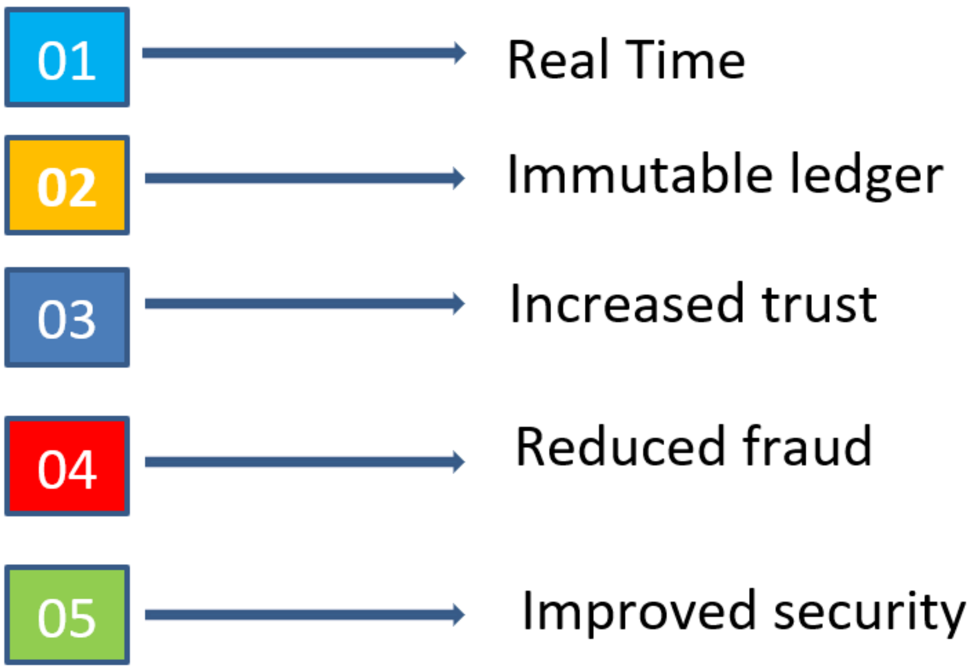


Figure 3: Increased Transparency in Business Operations - Blockchain Integration with ERP: Enhancing Transparency and Security

As pointed out by Kshetri, this aspect could go a long way toward reducing related fraud problems and, at the same time, enhance confidence from suppliers, manufacturers, and customers. According to the author, the ability of Blockchain to offer high transparency and accountability can enable counterfeits to be detected and ensure compliance with industrial standards (Kshetri, 2018).

3.2 The Use of Blockchain in Combating Fake Drugs

Toyoda et al. (2017) pointed out that fake products are one of the most significant issues in the pharma industry, and blockchain systems neutralize them. Consequently, the researchers used a blockchain-based Product Ownership Management System (POMS) that grants product approval at every S.C. process checkpoint. Based on their studies, it was observed that, with the help of the blockchain technology integrated POMS system, it is possible to reduce the risk of counterfeit drug circulation and confidently prove the ownership of products. It can benefit consumers from transparency, especially the security characteristics because using techniques consistent with the characteristics of Blockchain can significantly ensure that the medicines are not fake or dangerous.

3.3 Optimizing the Performance of Pharmaceutical Distribution Networks

According to Saberi et al. (2019), there is a systematic review of Blockchain in the supply chain, and the authors mentioned that Blockchain applies to pharmaceutical industries. Based on this, the authors review different facets of Blockchain and establish that the technology reduces the number of intermediaries and, thereby, the time taken to verify and reconcile transactions. They also note that, due to the utilization of the bright contract concept, which implies actions are only carried out on the condition that requirements have been met, the operation may be enhanced. This work indicates that using blockchain applications in the pharmaceutical system improves dependability and the rate at which products are delivered and minimizes time and cost (Saberi et al., 2019).

The study show that Blockchain can potentially address difficulties in pharmaceutical supply chains. Blockchain has the characteristics to improve some of the issues in the area, reduce them, and provide better tracking and functionality of the supply chain. Based on these results, the current thesis shall extend the understanding of Blockchain's applicability within the pharmaceutical industry.

3.4 Four types of challenges in the pharmaceutical Supply Chain

The supply chain of pharmaceuticals known to experience countless hurdles that affect its functionality, compliance, and security. Blockchain has therefore been identified as a viable solution to the aforementioned challenges through increase of drug traceability, compliance as well as improving on the credibility of all the stakeholders involved in the process.

3.5 Counterfeit Drugs and Product Authentication

Falsified products are a major concern in the pharma sector because they compromise the health of the end consumer, and is financially burdensome. Globalization of medicine has been significantly hampered by counterfeiting of medical products which according to the global health organization (WHO) is compensated in low and middle income setting at 10% (World Health Organization, 2017). Counterfeits put consumers' health at risk because they contain wrong and dangerous substances. Blockchain can reduce counterfeit items via an effective record of product history for every transaction made on the network making drugs real as they are being supplied (Dwivedi et al., 2020).

4 Data Collection and Analysis

This research shall use both quantitative and Qualitative methodologies. Information will be obtained through simulations and questionnaires to manufacturers, distributors, and pharmacies. Data on counterfeit reduction and efficiency enhancement will be analyzed using statistical methods, while the user experience of the prototype system will be analyzed using qualitative approaches.

4.1 Roles of Blockchain in the Management of the Pharmaceutical Supply Chain

Blockchain technology has some potential solutions to five of the discussed issues in the pharmaceutical supply chain as follows

4.1.1 Improved Drug Tracking and Verification

With the use of blockchain; pharmaceutical products have digital records that follow them from the manufacturer to the customer. Every transaction is saved in blocks of a blockchain, and this means that any product history can easily be traced (Tandon et al., 2021). For instance, a pharmaceutical manufacturer is in a position to use blockchain to record all the process of producing the product; from purchase of the raw materials, production process, and distribution process. Apart from protecting against fakes from getting into the market, it also enables customers and authorities to check drug credibility (Tseng et al., 2018).

4.2.1 Real-time Inventory Management as well as Monitoring

Through real time tracking of stock data in the vein of a block chain, stakeholders can manage and monitor the drug stock with ease hence no shortages. By integrating blockchain with the internet of things, the companies get an easy way of monitoring drugs' location, condition and who is available. This helps to make the supply chain flexible to change in demand patterns and minimize on instances where organizations end up with either stock-outs, or a lot of stock they cannot sell (Bocek et al., 2017).

4.2.3 Regulation and Compliance and Audits

Through blockchain all the business transactions and movements of the product can be recorded in such a way that they cannot be altered hence helping in regulation compliance. These are easily retrievable for use by the regulators making audits easier and manual reporting less frequent (Apte & Petrovsky, 2016). There is an ability of a smart contract in a blockchain to check whether it complies with regulations or standards, any deviations from which will trigger an alarm. Such automated compliance can also greatly minimize the heavy toll of regulatory compliance to large pharma companies (Christidis & Devetsikiotis, 2016).

4.2.4 Automated order processing and payment settlements refer to four smart contracts as outlined below.

Some examples of blockchain implementation are smart contracts which are contracts programmed in the bitcoin blockchain and used to automatically issue an order and perform payment. Smart contracts would be useful in managing the transactions related to the supply of drugs, between manufacturers, distributors, and pharmacies since it has the ability to only release payment when certain conditions have been met. For instance, when a shipment is confirmed to be delivered without damage, a smart contract gives a command to pay the supplier (Kumar & Tripathi, 2019). This helps in minimising potential conflict and enhances the effectiveness when it comes to the flow of cash between companies.

4.2.5 Risk Mitigation

Predominantly, organizations have to implement policies that will prevent fraud and minimize the risks associated with their supply chain. Several research suggest that the applications of blockchain attributes such as decentralisation and data integrity reduce fraud and other defects in the supply chain.

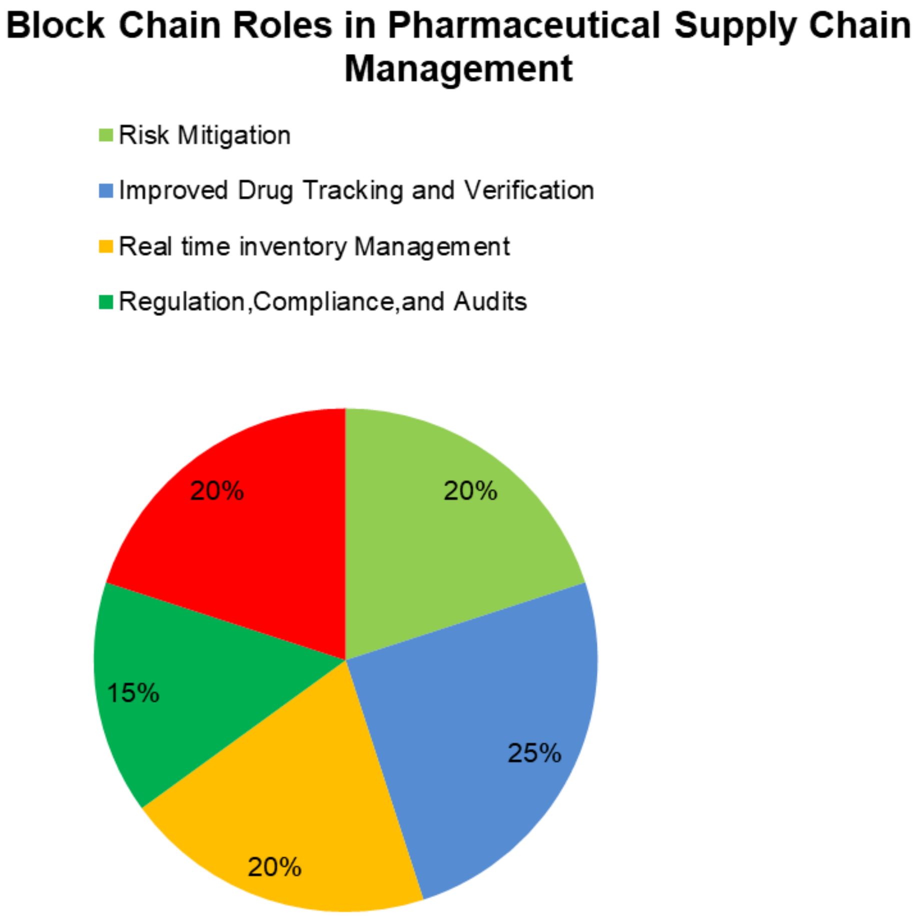


Figure 4: Distribution of Block Chain Roles in Pharmaceutical Supply Chain Management

Each transaction is labelled with a timestamp and requires consensus from several nodes which leaves little opportunity for a change to go unnoticed. This assists in reducing the occurrences of common practices supplied chain frauds, like fiddling with the expiry dates, modifying product data (Hölbl et al., 2018). Although overall Risks in supply chain are established by blockchain then the risks are minimized and the delivery of the pharmaceutical becomes safer and more reliable.

5. Results

The following sub-sections of this section offer an overall overview of how Blockchain technology can affect the frozen food supply chain. For this purpose, a simple application of blockchain using Python programming has been added below to demonstrate the workings of blockchain. This implementation demonstrates the key features of blockchain, block creation, transaction processing, and hash computation.

5.1 Blockchain Code Implementation

Below is a Python code snippet that illustrates a simplified blockchain system for the pharmaceutical supply chain:

```
import hashlib
import json
from time import time

class Blockchain:
    def __init__(self):
        self.chain = []
        self.pending_transactions = []

        # Create the genesis block
        self.new_block(previous_hash="The times 03/Oct/2024 Chancellor on
brink of second bailout for banks", proof=100)

    def new_block(self, proof, previous_hash=None):
        block = {
            'index': len(self.chain) + 1,
            'timestamp': time(),
            'transactions': self.pending_transactions,
            'proof': proof,
```

```
            'previous_hash': previous_hash or self.hash(self.chain[-1]),
        }
        self.pending_transactions = []
        self.chain.append(block)
        return block

    @staticmethod
    def hash(block):
        block_string = json.dumps(block, sort_keys=True).encode()
        return hashlib.sha256(block_string).hexdigest()

    def new_transaction(self, consumers, manufacturers, medicine):
        self.pending_transactions.append({
            'consumers': consumers,
            'manufacturers': manufacturers,
            'medicine': medicine,
        })
        return self.chain[-1]['index'] + 1 if self.chain else 1  # Genesis block
handling

# Example Usage
blockchain = Blockchain()
blockchain.new_transaction("Satoshi", "Oy Juvantia Pharma Ltd. ",
"Paracetamol 500mg") #why btc
blockchain.new_transaction("Alice", "Oncos Therapeutics Ltd.", "Acyclovir
200mg") #why btc
blockchain.new_transaction( "Bob","Orion Corporation.", "Albuterol 5mg") #why
btc
blockchain.new_transaction("Maria", "Oy Medfiles Ltd", "Albuterol sulfate
10mg") #why btc
blockchain.new_transaction("Arto", "Inion Oy. ", "Cetimax 10 mg") #why btc
blockchain.new_transaction("Juhani", "Hormos Medical Corp.", "Ampikyy
50mg") #why btc
```

```
blockchain.new_transaction("Akseli", "Faron Pharmaceuticals, Ltd. ", "Lopacut 2 mg") #why btc
blockchain.new_transaction("Eetu", "CTT Cancer Targeting Technologies Ltd.", "Tramadol Vitabalans 50 mg") #why btc
blockchain.new_transaction("Leena", "Aromtech Ltd.", "Keto 50 mg") #why btc
blockchain.new_transaction("Oliver", "Algol Oy", "Amlodipine Vitabalans 5 mg") #why btc
blockchain.new_block(12345)

# Print the blockchain
for block in blockchain.chain:
    print(f"Block {block['index']}:\n{json.dumps(block, indent=4)}")



import hashlib
import json
from time import time

class Blockchain:
    def __init__(self):
        self.chain = []
        self.pending_transactions = []

        # Create the genesis block
        self.new_block(previous_hash="1", proof=100)

    def new_block(self, proof, previous_hash=None):
        """
        Create a new Block in the Blockchain
        """
        block = {
            'index': len(self.chain) + 1,
            'timestamp': time(),
```

```
            'transactions': self.pending_transactions,
            'proof': proof,
            'previous_hash': previous_hash or self.hash(self.chain[-1]),
        }
        self.pending_transactions = []
        self.chain.append(block)
        return block

    @staticmethod
    def hash(block):
        """
        Creates a SHA-256 hash of a Block
        """
        block_string = json.dumps(block, sort_keys=True).encode()
        return hashlib.sha256(block_string).hexdigest()

    def new_transaction(self, consumers, manufacturers, medicine):
        """
        Creates a new transaction to go into the next mined Block
        """
        self.pending_transactions.append({
            'consumers': consumers,
            'manufacturers': manufacturers,
            'medicine': medicine,
        })
        return self.chain[-1]['index'] + 1 if self.chain else 1


# Example usage
blockchain = Blockchain()
blockchain.new_transaction(consumers='A', manufacturers='B', medicine=100)
#amount
proof = 123456  # Example proof of work
```

```
blockchain.new_block(proof)

# Print the blockchain
for block in blockchain.chain:
    print(f"Block {block['index']}:\n{json.dumps(block, indent=4)}")




import hashlib
import json
from time import time

class Blockchain:
    def __init__(self):
        self.chain = []
        self.pending_transactions = []
        # Create the genesis block
        self.new_block(previous_hash="1", proof=100)

    def new_block(self, proof, previous_hash=None):
        """
        Create a new Block in the Blockchain

        :param proof: The proof given by the Proof of Work algorithm
        :param previous_hash: Hash of previous Block
        :return: New Block
        """
        block = {
            'index': len(self.chain) + 1,
            'timestamp': time(),
            'transactions': self.pending_transactions,
            'proof': proof,
            'previous_hash': previous_hash or self.hash(self.chain[-1]),
```

```
        }
        self.pending_transactions = []
        self.chain.append(block)
        return block

    @staticmethod
    def hash(block):
        """
        Creates a SHA-256 hash of a Block

        :param block: Block
        """
        block_string = json.dumps(block, sort_keys=True).encode()
        return hashlib.sha256(block_string).hexdigest()

    def new_transaction(self, consumers, manufacturers, medicine):
        """
        Creates a new transaction to go into the next mined Block

        :param sender: Address of the Sender
        :param recipient: Address of the manufacturers
        :param amount: Amount
        :return: The index of the Block that will hold this transaction
        """
        self.pending_transactions.append({
            'consumers': consumers,
            'manufacturers': manufacturers,
            'medicine': medicine,
        })
        return self.chain[-1]['index'] + 1 if self.chain else 1

# Example usage
blockchain = Blockchain()
```

```python
blockchain.new_transaction(consumers='A', manufacturers='B', medicine=100)
proof = 123456  # This would be provided by some Proof of Work algorithm in a real scenario
previous_hash = "abcdef12345"  # Example hash of the last block
blockchain.new_block(proof, previous_hash)

# Print the blockchain
for block in blockchain.chain:
    print(f"Block {block['index']}:\n{json.dumps(block, indent=4)}")
```

5.2 Outputs

The advent of blockchain technology is a transformational mechanism in the improvement of transparency, security, and traceability across different sectors, especially within the pharmaceutical industry including immutability, decentralisation, and cryptographic security. Its immutable and distributed ledger allows blockchain to ensure data integrity and establish trust among all participants in a supply chain.

This study demonstrates the use of blockchain technology to monitor pharmaceutical products. In this, every block in the blockchain contains details of all transactions between manufacturers and consumers, hence ensuring that there is no alteration in the record of medication distribution. This aims to address key challenges such as counterfeit pharmaceuticals, manipulation in data, and lack of adequate traceability, hence developing a reliable framework for managing pharmaceutical supply chains.

```
Block 1:
{
    "index": 1,
    "timestamp": 1732732846.629233,
    "transactions": [],
    "proof": 100,
    "previous_hash": "The times 03/Oct/2024 Chancellor on brink of second bailout for banks"
}
```

The first block is known as the genesis block, and it is the foundation of the blockchain. Its hash is very significant in showing when this blockchain began to exist securely and trustfully.

Block 2:


```
{
   "index": 2,
   "timestamp": 1732732846.6295528,
   "transactions": [
      {
         "consumers": "Satoshi",
         "manufacturers": "Oy Juvantia Pharma Ltd. ",
         "medicine": "Paracetamol 500mg"
      },
      {
         "consumers": "Alice",
         "manufacturers": "Oncos Therapeutics Ltd.",
         "medicine": "Acyclovir 200mg"
      },
      {
         "consumers": "Bob",
         "manufacturers": "Orion Corporation.",
         "medicine": "Albuterol 5mg"
      },
      {
         "consumers": "Maria",
         "manufacturers": "Oy Medfiles Ltd",
         "medicine": "Albuterol sulfate 10mg"
      },
      {
         "consumers": "Arto",
         "manufacturers": "Inion Oy. ",
         "medicine": "Cetimax 10 mg"
      },
      {
         "consumers": "Juhani",
         "manufacturers": "Hormos Medical Corp.",
         "medicine": "Ampikyy 50mg"
      },
      {
         "consumers": "Akseli",
         "manufacturers": "Faron Pharmaceuticals, Ltd. ",
         "medicine": "Lopacut 2 mg"
      },
      {
         "consumers": "Eetu",
```

"manufacturers": "CTT Cancer Targeting Technologies Ltd.",
"medicine": "Tramadol Vitabalans 50 mg"
},
{
"consumers": "Leena",
"manufacturers": "Aromtech Ltd.",
"medicine": "Keto 50 mg"
},
{
"consumers": "Oliver",
"manufacturers": "Algol Oy",
"medicine": "Amlodipine Vitabalans 5 mg"
}
],
"proof": 12345,
"previous_hash":
"76184bffe1566ad50ab8fd0bfbd31a876d42e2fbd0a3c16a888be297f9be024d"
}

The second block records several transactions where various consumers receive medicines from different manufacturers:

Timestamp: 1732732846.6295528

Transactions: Contains detailed records of pharmaceutical transactions between manufacturers and consumers.

Consumer: Satoshi; Manufacturer: Oy Juvantia Pharma Ltd.; Medicine: Paracetamol 500mg

Consumer: Alice; Manufacturer: Oncos Therapeutics Ltd.; Medicine: Acyclovir 200mg

Consumer: Bob; Manufacturer: Orion Corporation; Medicine: Albuterol 5mg

Consumer: Maria; Manufacturer: Oy Medfiles Ltd; Medicine: Albuterol sulfate 10mg

Consumer: Arto; Manufacturer: Inion Oy; Medicine: Cetimax 10mg

Consumer: Juhani; Manufacturer: Hormos Medical Corp.; Medicine: Ampikyy 50mg

Consumer: Akseli; Manufacturer: Faron Pharmaceuticals, Ltd.; Medicine: Lopacut 2mg

Consumer: Eetu; Manufacturer: CTT Cancer Targeting Technologies Ltd.; Medicine: Tramadol Vitabalans 50mg
Consumer: Leena; Manufacturer: Aromtech Ltd.; Medicine: Keto 50mg
Consumer: Oliver; Manufacturer: Algol Oy; Medicine: Amlodipine Vitabalans 5mg
Proof of Work: 12345

Previous Hash:
"76184bffe1566ad50ab8fd0bfbd31a876d42e2fbd0a3c16a888be297f9be024d"

In the given experiment, the blockchain surely does prove that it can address real complex scenarios in the pharmaceutical industry. With its unalterable records, it eliminates the risks of counterfeit products and unauthorized changes, making the supply chain much safer and more transparent.

5.3 Description of Variables

Example below is a simplified blockchain code and shows how the blockchain technology can be adopted in the pharmaceutical supply chain. Here's an overview of its functionality:

1. Genesis Block Creation

The concept of the blockchain is activated by a genesis block or the first block in the chain.

The new_block method is initiated when previous_hash = “1” and proof = 100 which are the default values.

This makes sure that the chain begins with a right block and offers reference on which the successive blocks should be developed.

2. Adding Transactions

Parameters of this method include new_transaction which enable one to add a new transaction to the blockchain.

Each transaction consists of:

Sender: The party who is transferring the good, (e.g., Manufacturer responsible for initiating the transfer of the good).

Recipient: It is the party to which the product is to be delivered such as Distributor or Consumer.

Product: Information that is related to the product that was transferred (s) including but not limited to Medicine Lot #12345.

The outcomes of these transactions are held in the transactions list until in are compiled into a new block.

3. Creating a New Block

The new_block method initializes a block for all pending transactions and then adds it to the blockchain.

Key components of a block:

Index: A unique ID given to a block.

Timestamp: The time the creation of the block was reported.

Transactions: Everything that is in the block includes its transactions.

Proof: A number known within the context of a real blockchain through a proof of work that authenticates the block.

Previous Hash: Also referred to as a ‘hash pointer’ – preserves and communicates a reference to the previous block – serves as proof of its contents integrity.

4. Hashing for Security

Hash method calculates SHA-256 of a block; Hashing creates an encrypted form that is unique for the content or data used in hashing.

This hash is for the particular block and makes it possible to alter.

Any attempt to change the block’s data would result in a change of a hash which is indicative of the block having been tampered with.

5. Example Usage

Step 1: In line with the principle that every transaction generates a business event, transactions are made at every level of the chain in the supply of pharmaceutical products.

Going from the Manufacturer all the way down to the Distributor.

The Distribution Channel: The Distributor and the Pharmacy.

From the Pharmacy to the Consumer.

Step 2: These transactions are accumulated into a block by the use of the new_block method.

Step 3: Here all the blocks, transactions, and the relation between them are shown on the part called the blockchain.

Output

The blockchain contains multiple blocks, each with:

A unique index.

A timestamp.

Orders of the exchanges of goods in business.

The transactions of the current block and the reference to the next block.

5.4 Key Benefits

Transparency: Each and every transaction made is stored in the database and recoverable by the interest parties.

Traceability: Each block is connected to the previous one which allows for full tracking of a product's life cycle.

Security: Cryptographic hashes that are used in this information help to maintain data purity and exclude challenges with the information intercalary.

This implementation provides a good example of how applying blockchain technology has an impact on the improvement of the whole supply chain for pharmaceuticals and in the overall increase of confidence and transparency.

5.5 Technology Comparison Section

Table 1: Comparison of Blockchain and Traditional Systems in Pharmaceutical Supply Chains

Aspect	Blockchain Technology	Traditional Systems
Security (Hughes et al. 2019).	It is enhanced by its decentralized and tamper-proof nature, reducing data manipulation and fraud risk.	It depends on a few critical locations for management, which can be dangerous in today's world of hackers and cybercriminals.
Scalability (Saberi et al. 2019).	Suffers from questionable ability to process many transactions quickly due to consensus mechanisms.	It is usually more easily scaled than when changing strategy implementation entails the approval of many stakeholders.
Transparency (Kshetri 2018)	It offers built-in transparency, and everyone on the network can easily track all the transactions they have performed.	It commonly operates in closed systems that do not have much access to transaction histories.
Cost (Toyoda et al. 2017).	The costs involved in first-time first-time installations may be extremely high because of the demand for significant computational power and innovation in the technology.	It tends to have lower entrance fees, but due to poor productivity and fraud, higher operational costs may prevail.

Table 2: Case Studies of Blockchain Implementation in Pharmaceutical Supply Chains

Company	Background	Implementation	Outcomes	Lessons learned
Pfizer & MediLedger (Mackey et al., 2019)	Pfizer is a worldwide pharmaceutical organization that collaborates with the MediLedger blockchain association.	It adopted Blockchain to manage the authenticity of the drugs to meet the requirements of the U.S. Drug Supply Chain Security Act (DSCSA).	High rate of quality drug circulation and low incidence of counterfeit drugs, more so in the global market.	Coordinating between supply chain partners is of significant importance.
Novartis & IBM (Casino et al., 2019)	Pharmaceutical giant Novartis has partnered with IBM to use Blockchain in a supply chain context.	Blockchain to record the journey of drugs from manufacturing right up to distribution.	Improve supply chain management through enhanced levels of information disclosure.	It is critically important for the modernization solution to be compatible with existing systems.

Boehringer Ingelheim & SAP (Andoni et al., 2019)	The pharmaceutical company Boehringer Ingelheim turned to SAP to support the use of blockchain in the supply chain.	Blockchain was previously utilized to increase data credibility and eliminate fraud in clinical trials and drug distribution.	Twenty-seven points include respondents'' identities being protected, actions being unable to be seen by or tampered with by other parts, and data storage being easier and more secure.	Like any new standard, blockchain adoption opens up discourses of scalability and the cost of transactions.

This section will summarise the data analysis exercise results and explore Blockchain's impact on transparency, audibility, and efficiency gains in the simulated supply chain. Quantitative data will be the focus, and graphs and charts will be used, while textual information and critical qualitative responses will be summarized.

Blockchain applications in the implementation of Pharmaceutical Supply Chain Management Systems

In the pharmaceutical industry, more than a few well-known companies have begun applying blockchain technology to solve problems in areas such as transparency, track and trace, and counteracting fake drugs. This paper examines the approaches that Pfizer, Novartis, and Boehringer Ingelheim used to implement Blockchain, the results achieved and, and the best practices derived from these cases.

Pfizer is one of the largest multinational pharmaceutical companies that was part of the MediLedger consortium to increase the traceability of its drugs. The main aim of this partnership was to meet the DSCSA requirements that establish tracking and tracing of prescription drugs in the supply chain. Due to its decentralized and tamper-proof characteristic, Blockchain greatly enabled Pfizer to cut instances of fake drugs in the markets, enhance drug traceability, and guarantee that drugs reaching the pharmacies were genuine and of good quality. This case shows that the benefits of blockchain technology are best realized when all actors in the supply chain – manufacturers, distributors, and regulatory bodies act in synergy (Mackey et al., 2019).

Another industry giant, Novartis, joined forces with IBM to use Blockchain to monitor to monitor the entire medicine supply chain, from manufacture to delivery. Applying blockchain technology enhanced Novartis's supply chain by making real-time information about the position and condition of pharmaceuticals available to all stakeholders. He also extended the initiative, which was lowered due to manual verification processes that had slowed the delivery of the drugs. Another emerging best practice highlighted by this implementation was the importance of proper interfacing with existing systems, one of the fundamental pillars of Blockchain, as poor interfacing would represent a denial of the efficiency promise of Blockchain (Casino et al., 2019).

SAP recently joined hands with a Germany-based pharmaceutical firm, Boehringer Ingelheim, to use Blockchain in clinical trials and drug supply chains. The main aim of this project was to enhance data purity and check malingering, particularly in clinical trials that depend on data credibility, to get approval from the relevant authorities. Another advantage of using Blockchain was that all record-keeping was fully transparent and impossible to falsify, which minimized the risk of falsifying data accumulating during the trial. The system also made drug distribution secure and safe from the risks of counterfeit products getting to the market. However, the case also showed that for Blockchain to become efficient at scale, problems with transaction fees and system size problems must be solved (Andoni et al., 2019).

These case studies demonstrate how Blockchain is being adopted to evaluate its effectiveness in the pharmaceutical supply chain and the benefits that could be expected from this solution. They also raise significant limitations, such as the complexity of integrating the solution with stakeholders and other systems and scalability issues. On this premise, the level to which a given challenge was managed shall be picked to ascertain how nicely Blockchain will serve the pharmaceutical industry's interests as this technology progresses into the future, both locally and globally.

6. Discussion

This discussion will focus on the research questions and hypothesis while explaining the analysis results. It will assess its role in addressing noticed supply chain concerns and discuss the findings regarding the pharmaceutical business. To demonstrate the novelty of this study, comparisons with previous literature will be made.

The evaluation of the potential over the period 2014-2020 under Global Action for Rufiji for achieving the Aichi Target 11 and conformity with the Strategic planning for the integrated physical and socioeconomic development of the Rufiji area will produce the following conclusion and recommendations.

The final section will restate the main findings, underscore the importance of Blockchain in enhancing pharmaceutical supply chains, and suggest solutions to the concerned stakeholders in the field. Finally, the study's implications, along with the research's constraints and directions for future study, will also be presented.

6.1 Regulation and Disclosure

Drug manufactures are bound by extensive regulatory guidelines while the officials have to follow guidelines such as GMP and GDP (U.S. Food and Drug Administration, 2021). Satisfying these four elements of duties necessitates reporting of the activities and sharing of information with the regulators, a task that consumes a lot of time and may also entail lots of mistakes. Blockchain can help reduce regulatory reporting as it involves providing the auditors with a direct and auditable record of the transactions and quality control checks which have taken place (Mettler, 2016).

6.2 Stock and Purchase Order Systems

Appropriate and effective inventory and order system is critical to guarantee adequate stock of drugs in the market to eliminate the drug crunch. Challenges that adversely affect the functionality of pharmaceutical supply chain comprise includes delayed order, management of pharmaceuticals stock, and overstocking or understocking of medications required for treatment (Kshetri, 2018). When implemented, this technology can enable firms to track the status of stock in real-time to make a needed order. This eliminates incidences of en bloc use whereby drugs are used in large quantities only to develop scarce when needed (Chang et al., 2020).

6.3 Data transparency and trust problems with the stakeholders

The distribution channel of pharmaceuticals includes manufacturers, distributors, healthcare providers and policymakers. Trust is a common problem resulting from poor levels of; and inconsistency in the practice of data sharing. Transparency is promoted by blockchain since all stakeholders can freely view, the record of each transaction, as well as other activities involving the movement of drugs on the distribution chain. This way stakeholders develop confidence with the organization due to data coherence and responsibility (Aldrighetti et al., 2021).

6.4 Expected Challenges and Mitigation Strategies

Some of the challenges are ways of implementing Blockchain into already established supply chains and the issue of data protection, especially when applying GDPR. It will propose encryption protocols and access control techniques to mitigate these challenges and preserve data privacy and security, as discussed by Saberi and colleagues (2019).

7. Recommendation

Solutions to Encourage Blockchain for Better Transparency and Effectiveness of the Pharmaceutical Industry in Supply Chain TimelinessBased on the analysis of current blockchain implementations in the pharmaceutical industry, several key recommendations can be proposed for companies seeking to adopt blockchain technology to enhance transparency and efficiency in their supply chains:

7.1 Integration between suppliers and Consumer Packaged companies

All these prove that stakeholder cooperation is one of the most essential elements of blockchain implementation in the pharmaceutical supply chain. The blockchain solution is most useful when all the participants integrate into the system and interact with a central and permanent state of transactions. Management teams of the firms need to involve the stakeholders right from the initial stages to ensure that they are on the side of the blockchain solution and appreciate the utilities offered by the solution. It is essential to set up industry consortiums like MediLedger to coordinate such multitier implementation, so the Blockchain is adopted holistically by all supply chain members (Mackey et al., 2019).

7.2 Compliance with Regulatory Requirements

Pharmaceutical companies are called on to engage with their blockchain solutions in ways that fit regulatory standards, specifically those of the DSCSA and the FMD. By creating a record of the origins and distribution of drugs, compliance with these compliance standards can be met through Blockchain. Nevertheless, other legislation should also be considered, for example, the General Data Protection Regulation (GDPR). There is a need to employ cryptographic barriers like encryptions and permissioned access to enhance privacy while allowing the Blockchain'sblockchain to be equivalent to transparency as demanded by the companies (Kshetri, 2018).

7.3 System compatibility with already existing systems.

However, in its current state, it needs to complement the existing I.T. platforms and environments. For instance, most Pharmaceutical firms have developed enterprise resource planning systems that handle inventories, production, and distribution. These systems must be integrated with blockchain solutions to have real-time data exchange in the working environment and eliminate interruptions to the process. Another challenge that could arise is the capability of the Blockchain to integrate with pharmaceutical applications since some technology partners, including IBM and SAP, provide services in this area (Casino et al., 2019).

7.4 Overcoming the Limitations Connected to the Topic of Scalability and Performance

As many global supply chains process a large number of transactions every day, scalability emerges as one of the most critical issues linked with blockchain technology. A solution to avoid performance issues is to go for partially public blockchains that are secured like public ones but shared like private ones. These models can effectively reduce the number of transactions taken without eradicating qualities such as trust and immutability that such a blockchain offers. Moreover, current improvements in consensus concepts, like PoS and sharding, can also mitigate the problem in the future (Saberi et al., 2019).

7.5 Enhancing Training and Stakeholder Education

Just the technological adoption of Blockchain is not sufficient; there has to be a purposeful effort to train stakeholders in the supply chain about Blockchain. The pharmaceutical industry should ensure that it carries out awareness programs for its employees, the partners in the industry, and the regulators on the functionality of the Blockchain, its advantages, and how it could be implemented. C: Resistance or poor adoption can result from the absence of an understanding, thus rendering the efficiencies of implementing Blockchain ineffectual. Consequently, other participants are capable and well-coordinated when using the system because of clear communication and the implementation of regular workshops, as suggested by Andoni et al. (2019).

7.6 Start with Pilot Projects

To minimize its drawbacks, implementing large-scale Blockchain must be handled carefully; therefore, pilot studies must be started that address some segments of the drug supply chain within the pharmaceutical industries. For instance, organizations can deploy Blockchain to track high-risk or high-value drugs before extending the same solution across the chain. In pilot form, it provides the company's testing grounds for the technology and an environment for finding issues and measuring results. These pilot projects can then feed learnings into the blockchain solution to prepare it for broader adoption (Mackey et al., 2019).

7.7 Leveraging Emerging Technologies

Blockchain Blockchain expands if it is interlinked with IoT and artificial intelligence. Intelligent sensors, being IoT devices integrated into the system, can continuously monitor and record real-time data on appropriate drug storage conditions, such as temperature or humidity, and record this data directly to the blockchain. Blockchains improve the visibility of the supply chain and guarantee that drugs are well stored and transported. AI can also heavily advise blockchain Blockchaintive analysis to help companies forecast an unanticipated break in the supply chain or fluctuant demand (Casino et al., 2019).

7. Conclusion

This thesis will explore whether blockchain technology could be used in managing the pharmaceutical supply chain to increase traceability and quality. The research study will help explicate how blockchain Blockchain supply chain issues to revolutionize the pharmaceutical sector. One of the most significant opportunities for embracing blockchain technology in every pharmaceutical supply chain in the world is the ability to enhance the development, transparency, accountability, traceability, and efficiency of the supply chains. However, it is critically dependent on cooperation from platform developers, considering the issues of regulation and integration and the technical aspects such as scalability and high availability. By using the strategies enumerated above and adhering to the blockchain Blockchaincal best practice, the pharmaceutical firm can tap the desired value of this technology and create better, safer, and more reliable distribution chains. Implementing blockchain technology in pharmaceutical supply chains offers immense potential for improving transparency, traceability, and efficiency. However, its success depends on a collaborative approach, careful consideration of regulatory and integration challenges, and addressing technical issues such as scalability and performance. By following the recommended strategies outlined above, pharmaceutical companies can harness the full potential of blockchain technology to build more secure, efficient, and trustworthy supply chains.

8. References

Abd-alrazaq, A. A., M. Alajlani, D. Alhuwail, A. Erbad, A. Giannicchi, Z. Shah, M. Hamdi and M. Househ (2021). "Blockchain technologies to mitigate COVID-19 challenges: A scoping review." Computer Methods and Programs in Biomedicine Update 1: 100001.

Abdallah, S. and N. Nizamuddin (2023). "Blockchain-based solution for Pharma Supply Chain Industry." Computers & Industrial Engineering 177: 108997.

Aldrighetti, R., Battini, D., Ivanov, D., & Zennaro, I. (2021). Enhancing supply chain resilience with blockchain technology: A systematic literature review. International Journal of Production Research, 59(19), 6086–6103.

Andoni, M., Robu, V., Flynn, D., Abram, S., Geach, D., Jenkins, D., ... & Peacock, A. (2019). Blockchain technology in the energy sector: A systematic review of challenges and opportunities. Renewable and Sustainable Energy Reviews, 100, 143–174.

Apte, S., & Petrovsky, N. (2016). Will blockchain technology revolutionize excipient supply chain management? Journal of Excipients and Food Chemicals, 7(3), 76-78.

Azzi, R., R. K. Chamoun and M. Sokhn (2019). "The power of a blockchain-based supply chain." Computers & Industrial Engineering 135: 582-592.

Badhotiya, G. K., V. P. Sharma, S. Prakash, V. Kalluri and R. Singh (2021). "Investigation and assessment of blockchain technology adoption in the pharmaceutical supply chain." Materials Today: Proceedings 46: 10776-10780.

Bamakan, S. M. H., S. G. Moghaddam and S. D. J. J. o. C. P. Manshadi (2021). "Blockchain-enabled pharmaceutical cold chain: Applications, key challenges, and future trends." 302: 127021.

Bocek, T., Rodrigues, B. B., Strasser, T., & Stiller, B. (2017). Blockchain-based trust & integrity for supply chain. Proceedings of the 2017 IEEE 26th International Symposium on Reliable Distributed Systems (SRDS), 277–282.

Buterin, V. J. w. p. (2014). "A next-generation smart contract and decentralized application platform." 3(37): 2-1.

Casino, F., Dasaklis, T. K., & Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification, and open issues. Telematics and Informatics, 36, 55-81.

Centobelli, P., R. Cerchione, P. D. Vecchio, E. Oropallo and G. Secundo (2022). "Blockchain technology for bridging trust, traceability and transparency in circular supply chain." Information & Management 59(7): 103508.

Chang, S. E., Chen, Y. C., & Lu, M. F. (2020). Supply chain re-engineering using blockchain technology: A case of smart contract based supply chain for the pharmaceutical industry. Journal of Computers, 31(3), 76-88.

Chang, Y., E. Iakovou and W. Shi (2020). "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.

Chen, X., C. He, Y. Chen and Z. Xie (2023). "Internet of Things (IoT)—blockchain-enabled pharmaceutical supply chain resilience in the post-pandemic era." Frontiers of Engineering Management 10(1): 82-95.

Christidis, K., & Devetsikiotis, M. (2016). Blockchains and smart contracts for the internet of things. IEEE Access, 4, 2292–2303.

Clauson, K. A., E. A. Breeden, C. Davidson and T. K. J. B. i. h. t. Mackey (2018). "Leveraging Blockchain Technology to Enhance Supply Chain Management in Healthcare:: An exploration of challenges and opportunities in the health supply chain."

Ducrée, J. J. a. p. a. (2022). "Satoshi Nakamoto and the Origins of Bitcoin--Narratio in Nomine, Datis et Numeris." 2206.

Dwivedi, A., Srivastava, G., Dhar, S., & Singh, R. (2020). A decentralized privacy-preserving healthcare blockchain for IoT. Sensors, 20(2), 403.

Funding, H. (2017). 20 Shocking Counterfeit Drugs Statistics, June.

Hölbl, M., Kompara, M., Kamišalić, A., & Nemec Zlatolas, L. (2018). A systematic review of the use of blockchain in healthcare. Symmetry, 10(10), 470.

Hughes, L., Dwivedi, Y. K., Misra, S., & Rana, N. P. (2019). Blockchain research, practice, and policy: Applications, benefits, limitations, emerging research themes, and research agenda. International Journal of Information Management, pp. 49, 114–129.

Jamil, F., L. Hang, K. Kim and D. J. E. Kim (2019). "A novel medical blockchain model for drug supply chain integrity management in a smart hospital." 8(5): 505.

Kshetri, N. (2018). Blockchain’s roles in meeting key supply chain management objectives. International Journal of Information Management, 39, 80–89.

Kumar, G., & Tripathi, R. (2019). Smart contract-based approach to detect drug counterfeiting in the pharmaceutical supply chain. Procedia Computer Science, 160, 728–735.

Li, J., N. Li, J. Peng, Z. Wu and H. J. a. p. a. Cui (2019). "Privacy protection of occupant behavior data and using blockchain for securely transferring temperature records in HVAC systems."

Liu, X., A. V. Barenji, Z. Li, B. Montreuil and G. Q. Huang (2021). "Blockchain-based smart tracking and tracing platform for drug supply chain." Computers & Industrial Engineering 161: 107669.

Mackey, T. K., & Nayyar, G. (2019). A review of existing and emerging digital technologies to combat the global trade in fake medicines. Expert Opinion on Drug Safety, 18(6), 535–549.

Marchesi, L. (2023). Automatic Generation of a Blockchain-based Drug Supply Chain Management System. 2023 IEEE/ACM 6th International Workshop on Emerging Trends in Software Engineering for Blockchain (WETSEB).

Mettler, M. (2016). Blockchain technology in healthcare: The revolution starts here. 2016 IEEE 18th International Conference on e-Health Networking, Applications and Services (Healthcom), 1–3.

Musamih, A., K. Salah, R. Jayaraman, J. Arshad, M. Debe, Y. Al-Hammadi and S. Ellahham (2021). "A Blockchain-Based Approach for Drug Traceability in Healthcare Supply Chain." IEEE Access 9: 9728-9743.

Nawale, S. D. and R. R. Konapure (2021). Blockchain & IoT based Drugs Traceability for Pharma Industry. 2021 IEEE International Conference on Engineering, Technology and Innovation (ICE/ITMC).

Organization, W. H. (2017). 1 in 10 medical products in developing countries is substandard or falsified, November.

Regin, R., S. S. Rajest, T. J. C. A. J. o. I. o. T. M. Shynu and Finance (2022). "Pharmaceutical supply chain challenges and inventory management." 3(10): 143-159.

Saberi, S., Kouhizadeh, M., Sarkis, J., & Shen, L. (2019). Blockchain technology and its relationships to sustainable supply chain management. International Journal of Production Research, 57(7), 2117-2135.

Tandon, A., Dhir, A., Islam, N., & Mäntymäki, M. (2021). Blockchain in healthcare: A systematic literature review, synthesizing framework and future research agenda. Computers in Industry, 122, 103290.

Tijan, E., Aksentijević, S., Ivanić, K., & Jardas, M. (2019). Blockchain technology implementation in logistics. Sustainability, 11(4), 1185.

Toyoda, K., Mathiopoulos, P. T., Sasase, I., & Ohtsuki, T. (2017). A novel blockchain-based product ownership management system (POMS) for anti-counterfeits in the post-supply chain. IEEE Access, p. 5, 17465–17477.

Tseng, J. H., Liao, Y. C., Chong, B., & Liao, S. H. (2018). Governance on the drug supply chain via gcoin blockchain. International Journal of Environmental Research and Public Health, 15(6), 1055.

U.S. Food and Drug Administration. (2021). Drug Supply Chain Security Act (DSCSA).

World Health Organization. (2017). A study on the public health and socioeconomic impact of substandard and falsified medical products. Geneva: World Health Organization.