How to Cite:
Alshameri, M. S., Alotaibi, S. S., Almutairi, N. H., Bahari, N. G. M., Almutairi, A. Z., Alharbi, F. N., Almasad, M. N., Alqarni, Z. A., & Almazroa, M. N. (2022). Pharmaceutical supply chain management: Ensuring quality and security in the distribution of medicines. *International Journal of Health Sciences*, *6*(S10), 1644–1658. https://doi.org/10.53730/ijhs.v6nS10.15027

Pharmaceutical supply chain management: Ensuring quality and security in the distribution of medicines

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***Abstract*---**Background: The globalization of pharmaceutical supply chains has exposed significant vulnerabilities, enabling counterfeit medications to infiltrate the market. These counterfeit drugs not only fail to aid in the recovery of patients but also pose serious health risks due to their inferior quality. The World Health Organization (WHO) reports that in developing nations, approximately 10% of medications consumed by patients are counterfeit. This alarming statistic, coupled with the estimated annual loss of over $200 billion faced by US pharmaceutical companies, underscores the urgent need for an

effective monitoring solution to safeguard against counterfeiting. Aim of Work: The primary aim of this study is to develop a robust drug supply chain management and recommendation system (DSCMR) that leverages blockchain technology and machine learning to ensure the integrity of medications throughout the supply chain while providing consumers with effective medication recommendations. Methods: The proposed DSCMR comprises two main modules: Blockchain-Based Drug Supply Chain Management: This module uses Hyperledger Fabric to create a secure and transparent system for monitoring and tracing the delivery of medications through the supply chain. This technology ensures that all transactions are recorded and verifiable, enhancing trust in the pharmaceutical process. Machine Learning-Based Medicine Recommendation System: This module employs N-gram and LightGBM models to analyze data from a well-known drug evaluation dataset available in the UCI machine learning repository. The machine learning model recommends the highest-rated or most effective medications to consumers based on this analysis. The integration of this module into the blockchain system is achieved through a REST API. Results: Extensive testing was performed to evaluate the effectiveness and usability of the proposed system. The results demonstrate that the blockchain component significantly enhances the traceability and security of the drug supply chain, while the machine learning module successfully provides accurate medication recommendations, improving patient outcomes and user experience. Conclusion: The integration of blockchain technology with machine learning offers a promising solution to counter the pervasive issue of counterfeit medications in the pharmaceutical industry. By ensuring transparent tracking and accurate recommendations, the DSCMR system can potentially transform drug supply chain management and enhance patient safety and satisfaction.

***Keywords*---**Blockchain, Machine Learning, Drug Supply Chain, Healthcare, Hyperledger Fabric.

Introduction

The presence of counterfeit medications poses a significant and formidable obstacle for the global pharmaceutical business. One difficulty that emerges is: what is the definition of a counterfeit drug? As to the World Health Organization (WHO), a medicine that is produced deceitfully, mislabeled, of inferior quality, concealing its origin or identity, and not adhering to established standards is classified as fake or counterfeit **[1]**. According to the study conducted by the World Health Organization (WHO), in developing nations, 1 out of every 10 drugs used by consumers is counterfeit and of poor quality **[2]**. The assertion made by the World Health Organization (WHO) may not be flawless or comprehensive due to the lack of precise estimations or information about counterfeit pharmaceuticals. The use of this substandard and non-conventional medication yields adverse consequences and has the potential to elevate mortality rates. Counterfeit pharmaceuticals may have some authentic components; however, the

quantity of these components is not appropriate and may be either insufficient or excessive. Additionally, they may contain harmful contaminants that are introduced during the manufacturing process. Consequently, the use of counterfeit drugs may lead to severe health complications in humans.

Occasionally, counterfeit medication manufacturers use the emblem of a well-known and respected pharmaceutical business to facilitate the smooth entry of their products into the market, bypassing obstacles. Hence, these medications have a significant impact on the sales of widely used and costly prescriptions such as antibiotics, cancer treatments, opioids, and various cardiac medications. Additionally, they are associated with many adverse effects and may lead to more severe health problems. As previously stated, around 10-15% of pharmaceuticals globally are counterfeit. However, in underdeveloped nations, the prevalence of counterfeit drugs is higher, reaching over 30%. The yearly mortality rate caused by malaria is around 0.7 million, with counterfeit medications accounting for over 0.2 million of those fatalities **[3]**. As you are aware, the growing use of technology also facilitates the proliferation of counterfeit pharmaceuticals in the market. As technology advances, the proliferation of counterfeit pharmaceuticals is likewise growing steadily. According to the FBI and International Anti-Counterfeiting Coalition (IACC), counterfeiting is a major criminal enterprise in the 21st century, and it is expanding fast with the introduction of new counterfeit pharmaceutical producers into the market **[4,5].**

Currently, every individual has the fundamental entitlement to access improved healthcare services. Due to the proliferation of new ailments, the market has seen a constant influx of pharmaceuticals, each with its own unique name and labeling. These drugs provide immediate relief to the sufferer from excruciating pain. The usage of these pharmaceuticals is associated with several drawbacks rather than benefits, since the legitimacy of the manufacturing organizations is unregistered or unknown, and they fail to adhere to the prescribed requirements. The World Health Organization (WHO) has recorded several fatalities in underdeveloped nations as a result of the use of counterfeit medications, with a significant proportion of these victims being youngsters **[3,6]**. According to the figures, US pharmaceutical businesses experience an annual revenue loss of around $200 billion owing to the presence of counterfeit pharmaceuticals **[1].** While these treatments may not facilitate the patients' recovery from the sickness, they do possess several perilous side effects. These medications pose a significant risk to human health. The distribution of these counterfeit pharmaceuticals occurs via intricate networks, making it challenging to identify them.

The United States dedicates around $3.2 trillion to the healthcare industry, with a quarter of this expenditure specifically allocated to the administration of a safe supply chain process **[7,8]**. There are limited expert opinions and suggestions to address and prevent issues with counterfeit drugs. These include implementing a secure and transparent process for drug delivery and supply chain, improving control and management of the drug market at the pharmacy, distributor, and hospital levels, and utilizing advanced technologies to consistently track drugs at every stage of the supply chain **[9,10]**. Based on the aforementioned considerations, it is crucial to prioritize safe medicine supply chain management in order to effectively address this problem. To prevent the circulation of

counterfeit pharmaceuticals, a highly efficient system is required to monitor and track the whole drug delivery process, starting from the supplier's raw materials to the manufacture, distribution, and ultimately reaching the pharmacy, clinics, and consumers. Moreover, Blockchain is the most recent advancement in computing that has the capability to manage the supply chain and trace the goods. The Blockchain has the ability to safeguard the supply chain process and effectively monitor the delivery **[11,12]**.

Blockchain is an innovative technology that utilizes the consensus mechanism developed by Satoshi Nakamoto in 2008. Its primary purpose is to securely keep the transaction history of a popular cryptocurrency called Bitcoin **[13]**. The blockchain offers a sophisticated digital ledger software for storing data records and transaction logs in the form of organized blocks. In a more explicit manner, it is a database that is both secure and distributed. Each transaction's digital information, including its time, date, price, and the people involved, is kept in a block. The information is dispersed over the blockchain network, with several autonomous nodes participating in transaction validation without any knowledge or trust between them. Each block in the network has two hash codes: the preceding hash code and the current hash code. The previous hash code corresponds to the block that comes before, whereas the current hash code pertains to the block itself. Furthermore, in the event that any information inside a block is modified, it is essential to update all the corresponding information associated with that block. All the blocks inside the network are securely interconnected and safeguarded via transaction codes and cryptographic codes. Another crucial aspect is the implementation of robust mathematical techniques that empower miner nodes to verify these blocks without compromising the integrity of their own data. Once the validation process is complete, the blocks may be seamlessly incorporated into the blockchain network. The blockchain technology guarantees security and transparency, which is why it is implemented **[14].**

The blockchain network is a growing sequence of several blocks that hold information in accordance with predefined criteria. Within the network, several miner nodes exist to append new blocks to the chain, hence facilitating transactions. These nodes function autonomously and adhere to a unified protocol. The blockchain network is a decentralized system that stores comprehensive data on transactions and participants, while also maintaining a complete record of historical information. The functionality of a blockchain network is categorized into three types: private, public, and consortium blockchain, accordingly. In permission-less or public blockchain networks, there is no administrative node responsible for monitoring and managing transactions. However, all miner nodes or participants have the ability to verify and authenticate transactions. The miner nodes may also participate in the consensus process, and consensus is achieved by validating the information among the nodes **[16,17]**. For instance, the networks of Ethereum and Bitcoin, among others. In the consortium blockchain network, the administration node is responsible for managing both the data and transactions. Administrators have the ability to manage data via the use of both public and private access. Certain data may be made publicly available, while other data is only accessible to select private parties in accordance with commercial agreements. These networks are

somewhat centralized and can handle both public and private data. For example, the Hyperledger Fabric platform, among others. In a private blockchain network, all the data and transactions recorded inside the network are exclusively accessible to authorized participants and not publicly available. The information and data are only shared with authorized members of the network. Only the admin node has the authority to add authorized members to the network, which has a similarity with the consortium network in one respect. For example, Hyperledger and multichain networks are mentioned in reference **[18].**

Blockchain technology is the optimal choice for managing and safeguarding the pharmaceutical medication supply chain. Several pharmaceutical businesses are now using blockchain technology in their supply chain management, while others are actively transitioning to blockchain owing to its wide range of capabilities **[11,19]**. Industries are interested in adopting blockchain technology because it offers a distributed and decentralized electronic ledger. This ledger allows all nodes in the network to see and verify transaction information. Additionally, the consensus method of the network enables it to keep only verified information in the repository and resolve the issue of duplicate transactions. In addition, the chance of network failure is very low due to the high number of working nodes that are over the failure threshold. Furthermore, the fault tolerance of the network is quite good.

This publication presents the use of Hyperledger fabric, a blockchain technology, for the purpose of ensuring the security of medicine supply chain management. It has the ability to continuously monitor and trace the process of delivering drugs in order to address problems related to counterfeiting. The objective is to not only address the issue of safe medicine delivery, but also to provide the most appropriate medication to the consumers. In order to achieve this objective, we developed a recommendation system based on machine learning. The system was trained using a dataset of drug user evaluations that was acquired using web crawling.

The dataset includes comments and ratings provided by customers depending on their illness state. In addition, the dataset is used to train machine learning models such as N-gram and LightGBM. These models are then used to provide recommendations for the most optimal and efficient pharmaceuticals to the system's users. The proposed system operates as follows: a novel drug supply chain system is created using blockchain technology. The participants in this system include suppliers, manufacturers, distributors, pharmacies, hospitals, and clinics. They utilize a blockchain network to store and share information related to drug delivery in a secure and efficient manner.

The system offers a user-friendly web interface for managing and monitoring drug-related activities. In addition, we have used the Hyperledger composer REST API to provide communication between web apps and the blockchain network. The suggested method achieves the validation and authentication of transaction requests by establishing rules in the access control policy and history. This study utilizes Couch-DB as a storage solution for a substantial volume of transaction records. Couch-DB is the optimal choice for addressing the issue of data redundancy and ensuring that each node in the blockchain network has its own

dedicated storage. The end result allows users, such as patients, to trace the origin of the drug with authenticity. Another benefit of our system is its ability to use machine learning algorithms to suggest the most effective and highly-rated medications to system users. In addition, the machine learning module is seamlessly incorporated into the blockchain network, allowing members of the system to utilize both functionalities simultaneously. then, the models may also acquire knowledge from the comments and ratings submitted via the client web application, and then adjust the suggestion outcomes.

Literature Review

Blockchain is a groundbreaking technology that securely stores and transfers data in a transparent and resilient way. This is feasible as a result of the use of distributed ledger technology. The blockchain has the complete capacity to render any organization safe, efficient, transparent, and decentralized. Since the emergence of Bitcoin brought the blockchain into public attention, academics have been continuously working to expand the use of blockchain technology beyond financial domains **[13].** Out of these non-financial sectors, the healthcare business has had a significant influence on the blockchain technology. The research on producing blockchain-assisted apps is very fresh and progressing quickly. Consequently, researchers in the healthcare business have been diligently striving to stay abreast of the latest developments in this area. We provide an overview of the present blockchain applications in the healthcare business, offering insight into the emerging area of blockchain technology and its potential for future growth in the healthcare sector **[17,20]**.

Currently, blockchain applications have expanded beyond cryptocurrencies and are being used across other sectors such as agriculture, healthcare, finance, education, transportation, supply chain, and more **[21-26]**. In 2018, a blockchain-based system called agriBlockIoT was created for managing and tracing the supply chain in agriculture. This system has the capability to effectively oversee the whole supply chain of food goods and accurately track their origins. The AgriBlockIoT solution was created using two distinct blockchain network platforms: Hyperledger Fabrics and Ethereum. Additionally, both networks are being compared in terms of latency and transactions per second **[27].** The system guarantees that data and information produced by various sensors are saved securely, in a way that cannot be changed, and is easily understood. In the same year, **[28]** integrated radio frequency identification (RFID) sensor technology and blockchain technology to establish an internal wood chain traceability system based on blockchain architecture. This system effectively traces information and wood quality, integrating relevant data into an online system. By utilizing blockchain technology, the system ensures secure storage of data information and transaction records through feature removal and distributed storage.

In 2019, authors **[29]** proposed a food safety traceability system that utilizes blockchain technology and electronic product code (EPC). This system leverages the traceability, time stamping, and tamper resistance features of blockchain to accurately record valid data across the entire food supply chain. By enabling data sharing and specific tracking, it effectively detects and prevents food safety issues

by addressing concerns such as data tampering, trust in information interaction, and information leakage. In contrast to the previous focus on ensuring traceability of agricultural goods, this also applies to wood, food, and medicine. An imitation traceability system is necessary. In 2016, a quality traceability system for traditional Chinese medicine (TCM) was developed. This system is capable of monitoring and recording changes in external factors such as production and distribution processes, as well as the intrinsic quality of TCM, in a retrospective manner **[30].** In 2018, a comparative study **[31]** suggested a system for collecting, storing, analyzing, and managing data in supply chains. This system aims to guarantee that diverse actors in the supply chain can effectively work together by promoting interoperability of various criteria.

The traceability systems for medication have their benefits, but they cannot simultaneously achieve decentralized data storage. There are three essential criteria: informationization, the availability of complete and tamper-proof information, and the protection of information privacy. The decentralized and distributed storage qualities of blockchain technology provide distinct benefits for traceability systems, ensuring the dependability of data. The attributes of information transparency and absolute data integrity, together with the features of technological traceability and resistance to data tampering, may effectively address challenges in the supply chain such as counterfeiting and substandard products. Blockchain technology enables anti-tampering measures and time stamping of data. The features may serve as proof and provide accountability, facilitating the resolution of conflicts among different parties. In this research **[26]**, a blockchain-assisted medicine traceability system is presented to address the issue of counterfeit drugs in the market by leveraging the technological benefits of blockchain and addressing the deficiencies of the existing medical anti-counterfeiting traceability system.

Blockchain networks are used to enhance the security of the healthcare business by developing electronic medical records (EMR) solutions. The features of blockchain, such as decentralization, immutability, data traceability, dependability, smart contracts, security, and privacy, align with the needs of electronic medical records **[32,33].** Guardtime, a Dutch business specializing in data security, has created a system that uses blockchain technology to verify the identity of patients. Every citizen of the nation will get a card that utilizes blockchain technology to connect electronic medical record (EMR) data with one another. Every time a transaction is initiated on the blockchain network, a hash code is issued to each update. Thanks to blockchain technology, the audit records in the Electronic Medical Records (EMR) system are immune to tampering and cannot be modified. Existing healthcare databases might use tamper-resistant logs to maintain information status **[34]**. When writing a transaction in a block, any modifications in the database, such as registered entries, will be given a timestamp and password. The blockchain technology guarantees the integrity and security of medical data **[35].**

Another application in the field of electronic medical records (EMR) is MedRec, a collaborative initiative between MIT Laboratories **[36].** MedRec facilitates the safe and transparent exchange of healthcare data between different parties. This blockchain application is specifically developed to safeguard the proxy rights of

every patient and their right to be informed about others' access to their healthcare data. Patients may use the blockchain to distribute these authorizations, allowing them to disclose their data for the sake of future study. All the locations and data transaction records are stored on the blockchain network. Simultaneously, in order to get genuine engagement, it is important to have accompanying software support. Another instance is the Gem Health Network, which was created by Gem, an American firm, using the Ethereum blockchain technology. It enables several medical professionals to access and use the shared data stored on the network **[37]**.

Several similar platforms exist, such as Healthbank, which focuses on empowering patients to have complete control over their data using blockchain technology. Medicalchain has developed a blockchain-based platform that facilitates the sharing of patient medical records. Healthcoin **[38]** aims to create a worldwide electronic medical records system. Furthermore, several entities involved in diverse initiatives and endeavors focused on the blockchain technology include Factom, HealthCombix, Patiententory, SimplyVital, IBM Watson, BurstIQ, Bowhead, QBRICS, Nuco, and others. While problem-solving approaches are essential, they encounter many challenges at the implementation level. The primary obstacles in EMR systems are the interaction across various EMR solutions, blockchain security, scalability, and data privacy. The pharmaceutical sector often encounters a significant issue that may directly impact patients: the proliferation of counterfeit or substandard medications. The issue has been effectively addressed by the use of blockchain technology **[39-41]**. Remote patient monitoring has become feasible as a result of the advent of internet of things (IoT) sensors and smartphone devices. These devices have the capability to gather a substantial quantity of biological data, allowing medical personnel to conveniently assess the patients' state and give instructions about medication, among other things. Blockchain technology offers sufficient characteristics to accomplish this goal **[42, 43].**

The authors **[44]** have developed a system based on blockchain technology to ensure the secure distribution of biopharmaceutical goods. This system employs stochastic simulation to guide the blockchain network. It is capable of safeguarding biopharmaceutical items against counterfeiting, fraud, theft, and temperature diversion. The suggested solution enhances the efficiency, transparency, security, and dependability of the supply chain process. The system's smart contracts were established using the proof of authority (PoA) technique. Ultimately, the system has the capability to provide immediate and ongoing surveillance for dispersed data streams inside the blockchain network. The findings demonstrate that the system's performance is acceptable. This work presents a proposed system for managing and monitoring medication distribution in the pharmaceutical business, as suggested by the authors **[45]**. Various technologies, including as RFID and electronic product code information service (EPCIS), have been used to secure the medication supply chain. The research environment was established by using two theoretical frameworks: collective action theory and transaction cost theory. They established several regulations for all the parties involved in the medicine distribution procedure. The illicit trade of counterfeit medications is a significant challenge for both pharmaceutical firms and health organizations. Despite the efforts of worldwide health groups, the sales

of these pharmaceuticals continue to escalate. In this study, the author **[46]** suggests a system that utilizes blockchain technology to ensure the traceability of pharmaceuticals and to regulate the supply chain process. This system allows every participant to monitor and verify the delivery of drugs at each step. The suggested method has been developed solely based on a case study.

The authors **[47]** have suggested an Ethereum-based blockchain network to monitor the transportation of items in this study. The system has the capability to effectively oversee and monitor the logistics of various products during transportation using intelligent containers. This system has been created using smart contracts to facilitate transactions between the sender and recipient of the goods, eliminating the need for a third party. This study **[48]** provides a comprehensive overview and analysis of the present methodologies and strategies pertaining to the medication supply chain. It may also elucidate the many mechanisms by which counterfeit pharmaceuticals infiltrate the market and the financial impact they have on the real makers. Improper supply chain mechanisms are a significant factor contributing to medication counterfeiting. Subsequently, a blockchain-driven system has been created to provide safe end-to-end (E2E) transportation of drugs. However, no specific information is provided on the real-time outcomes and execution of this system. The article **[49]** addresses the problem of drug counterfeiting and proposes solutions to ensure that customers have access to genuine medications. The blockchain offers a resolution to this problem by guaranteeing the characteristics of traceability, security, and transparency.

A blockchain-based system has been developed and implemented, using QR code security measures to enhance drug security. Subsequently, the genuine medications produced by the authorized brand have been securely given to the clients. This is another instance **[50]** of blockchain's potential in enhancing the supply chain process. The supply chain refers to the process of delivering goods from the producer to customers. It is crucial to ensure that the quality of the items is maintained along this supply process. Fraudulent activities and corruption may infiltrate the supply chain process, leading to the introduction of counterfeit items. This method addresses the problem of counterfeit products and utilizes blockchain technology to provide a safe and transparent supply chain.

The authors of this article have created a program that links the Ethereum-based blockchain network with other information systems used by businesses. This system has the capability to safely communicate information across its partners. The blockchain facilitates the provision of enhanced data access, data integrity, data visibility, and authenticity assistance to partner organizations throughout the exchange of information. Furthermore, a simulation environment has been created specifically for the supply chain scenario. This environment carries out various statistical operations to assess the accuracy and effectiveness of the system. The simulation results demonstrate that the blockchain system is the most effective tool for ensuring the security of the supply chain process and fostering trust among various organizations. Additionally, it has the potential to enhance system performance and mitigate instances of fraud or wrongdoing inside firms.

This study **[52]** proposes a blockchain-based system called Drugledger for tracing pharmaceuticals. This technology guarantees the genuineness, protection, confidentiality, and capacity to track data. The system's design is based on a service-oriented mechanism, which is superior to the standard peer-to-peer (P2P) architecture. Drugledger offers a reliable and effective solution for storing the medication supply chain process. The study provided in this article offers a methodical and pragmatic approach to how the blockchain system may effectively monitor and oversee the medication supply chain process. This paper introduces CounterChain, a blockchain-based system designed to address the issue of counterfeit drugs in the drug supply chain. The technology is described in reference **[53]**. It enhances the visibility of pharmaceuticals at every stage of the distribution process and ensures that customers get genuine and unaltered goods. Additionally, the CounterChain may enhance the degree of confidence among suppliers, manufacturers, retailers, and distributors, since they are the primary stakeholders involved. As a result, the system has the capability to prevent the entry of counterfeit medications into the supply chain.

Therefore, blockchain technology is used not only in healthcare, banking, agriculture, cryptocurrency, and other industries, but also in every field. A multitude of researchers are now working on building blockchain applications in several domains, including smart grid, vehicle-to-grid, connected cars, edge computing, cloud computing, and cyber-physical systems **[54,55]**.

Summary of Drug Supply Chain Management (SCM) Procedure at Smart Pharma

The decentralized and distributed nature of blockchain technology has enhanced the security and anonymity of the medication supply chain in the pharmaceutical business. Figure 1 illustrates the comprehensive mechanism of drug supply chain management and recommendation (DSCMR), including participants and a blockchain network. Users are able to effectively oversee and modify all actions within the supply chain. The blockchain-based system stores data pertaining to system users such as suppliers, manufacturers, distributors, pharmacies, hospitals, physicians, and patients. The components of the DSCMR systems are drugs, raw materials, orders, and record repositories. Every system user is given a client application-based front-end interface, which allows them to conveniently carry out transactions and interact with the blockchain network. Throughout the whole DSCMR operation, all pertinent system participants may monitor the progress of medication administration via the use of the client application. Alternatively, there exists a data storage pool, which serves as a distinct data repository, sometimes referred to as stored-off blockchain. This tool is highly effective for data analytics and visualization. It is not only useful for this system, but also for medical institutes and their projects. In our system, we have utilized a store-off storage pool for the machine learning module. The machine learning model suggests the most suitable drug to our customers. Furthermore, system users are granted authorization to access comprehensive information on pharmaceuticals, raw materials, and other pertinent facts such as expiry date, price, manufacturing date, and so forth.

In order to ensure the consistency of the distributed ledger, the system includes peer nodes that are responsible for executing the consensus process. The first supplier transports the unprocessed material to the pharmaceutical firm in our system. Every participant in the system is provided with a web application portal, via which they may log in and carry out transactions. Assume that a manufacturer places an order for raw material. Any peer node in the network has the ability to verify the transaction. Once the transaction is validated, the supplier gets the order. Subsequently, once the raw material order is prepared for delivery, the supplier proceeds with the confirmation of the order. However, only the customer who does a thorough examination of a company's pharmaceutical data may carry out operations that are specifically designated as authorization regulations inside the blockchain network. If a doctor wishes to make an order with a drug firm, they may use our suggested blockchain system by following the identical processes outlined in the aforementioned example. First, the doctor's authentication is performed. Then, the transaction proposal is submitted. The manufacturers verify the transaction and then confirm the transaction of the doctor. Finally, the order status is sent to the doctor via a successful transaction event message.

Summary and Prospects for Future Research

Blockchain technology has revolutionized the conventional supply chain process into a more resilient, automated, secure, traceable, and transparent approach. It guarantees that the whole supply chain process is entirely secure and effectively prevents counterfeit pharmaceuticals from entering the system. The primary objectives and innovation of our suggested scheme include the integration of a blockchain and machine learning-powered system, including two modules: the drug supply chain system and the medication recommendation system. The system has used machine learning algorithms and blockchain technologies in the field of healthcare, yielding outstanding outcomes. We conducted many tests to evaluate the performance of our system, using performance metrics such as throughput, transaction reaction time, and latency. The simulation results of our technology demonstrate encouraging performance. This approach aids pharmaceutical businesses in mitigating the issue of counterfeit medications and achieving a substantial growth in their company. For future endeavors, we want to enhance the scale of the network and deploy it in real-time inside pharmaceutical businesses to assess the effectiveness and accuracy of our system. In addition, we will enhance the accuracy and recommended outcomes of our machine learning algorithms.

References

1. Williams, L.; McKnight, E. The real impact of counterfeit medications. US Pharm. 2014, 39, 44–46.
2. Newton, P.N.; Green, M.D.; Fernández, F.M.; Day, N.P.; White, N.J. Counterfeit anti-infective drugs. Lancet Infect. Dis. 2006, 6, 602–613. [Google Scholar] [CrossRef]
3. WHO. Growing Threat from Counterfeit Medicines. Available online: https://www.who.int/bulletin/volumes/88/4/10-020410/en/ (accessed on 12 February 2020).

4. Justice, C. Activities of the Institutes Comprising the United Nations Crime Prevention and Criminal Justice Programme Network; Economic and Social Council: New York, NY, USA, 2003.
5. Roxanne, E.; Lisa, D.; George, P. Anticounterfeiting in the fashion and luxury sectors: Trends and strategies. In Anti-Counterfeiting—A Global Guide; 2013; Available online: https://iccwbo.org/content/uploads/sites/3/2016/11/WTR-Anti-counterfeiting-2015-A-Global-Guide-featuring-BASCAP-Intermediaries-Report.pdf (accessed on 1 January 2020).
6. Harris, J.; Stevens, P.; Morris, J. Keeping it Real: Combating the Spread of Fake Drugs in Poor Countries; International Policy Network: Londn, UK, 2009. [Google Scholar]
7. Metcalf, D.S.; Bass, J.; Hooper, M.; Cahana, A.; Dhillon, V. Blockchain in Healthcare: Innovations that Empower Patients, Connect Professionals and Improve Care; CRC Press, Taylor & Francis Group: Boca Raton, FL, USA, 2019.
8. Akunyili, D. Fake and counterfeit drugs in the health sector: The role of medical doctors. Ann. Ib. Postgrad. Med. 2004, 2, 19–23.
9. Dégardin, K.; Roggo, Y.; Margot, P. Understanding and fighting the medicine counterfeit market. J. Pharm. Biomed. Anal. 2014, 87, 167–175.
10. Blackstone, E.A.; Fuhr, J.P., Jr.; Pociask, S. The health and economic effects of counterfeit drugs. Am. Health Drug Benefits 2014, 7, 216.
11. Khatoon, A. A Blockchain-Based Smart Contract System for Healthcare Management. Electronics 2020, 9, 94.
12. Soundarya, K.; Pandey, P.; Dhanalakshmi, R. A Counterfeit Solution for Pharma Supply Chain. EAI Endorsed Trans. Cloud Syst. 2018, 3.
13. Nakamoto, S. Bitcoin: A Peer-to-Peer Electronic Cash System. 2008. Available online: https://bitcoin.org/bitcoin.pdf (accessed on 12 September 2019).
14. Jamil, F.; Hang, L.; Kim, K.; Kim, D. A Novel Medical Blockchain Model for Drug Supply Chain Integrity Management in a Smart Hospital. Electronics 2019, 8, 505.
15. Khan, P.W.; Byun, Y.; Namje, P. A Data Verification System for CCTV Surveillance Cameras Using Blockchain Technology in Smart Cities. Electronics 2020, 9, 484.
16. Viriyasitavat, W.; Hoonsopon, D. Blockchain characteristics and consensus in modern business processes. J. Ind. Inf. Integr. 2019, 13, 32–39.
17. Pandey, P.; Litoriya, R. Securing E-health Networks from Counterfeit Medicine Penetration Using Blockchain. Wirel. Pers. Commun. 2020.
18. Hyperledger. Hyperledger Blockchain. Available online: https://www.hyperledger.org/ (accessed on 10 January 2020).
19. Wu, X.; Lin, Y. Blockchain recall management in pharmaceutical industry. Procedia CIRP 2019, 83, 590–595.
20. Bryatov, S.; Borodinov, A. 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, 24–27 April 2019.
21. Lin, Y.P.; Petway, J.R.; Anthony, J.; Mukhtar, H.; Liao, S.W.; Chou, C.F.; Ho, Y.F. Blockchain: The evolutionary next step for ICT e-agriculture. Environments 2017, 4, 50.
22. Rabah, K. Challenges & opportunities for blockchain powered healthcare

systems: A review. Mara Res. J. Med. Health Sci. 2017, 1, 45–52.
23. Amin, A.D. Blockchain technology in banking and finance sector: Its effects and challenges. CARE J. 2020, 31, 349–358.
24. Chen, G.; Xu, B.; Lu, M.; Chen, N.S. Exploring blockchain technology and its potential applications for education. Smart Learn. Environ. 2018, 5, 1.
25. Astarita, V.; Giofrè, V.P.; Mirabelli, G.; Solina, V. A Review of Blockchain-Based Systems in Transportation. Information 2020, 11, 21.
26. Tseng, J.H.; Liao, Y.C.; Chong, B.; Liao, S.W. Governance on the drug supply chain via gcoin blockchain. Int. J. Environ. Res. Public Health 2018, 15, 1055.
27. Caro, M.P.; Ali, M.S.; Vecchio, M.; Giaffreda, R. Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. In Proceedings of the 2018 IoT Vertical and Topical Summit on Agriculture-Tuscany (IOT Tuscany), Tuscany, Italy, 8–9 May 2018; pp. 1–4.
28. Figorilli, S.; Antonucci, F.; Costa, C.; Pallottino, F.; Raso, L.; Castiglione, M.; Pinci, E.; Del Vecchio, D.; Colle, G.; Proto, A.R.; et al. A blockchain implementation prototype for the electronic open source traceability of wood along the whole supply chain. Sensors 2018, 18, 3133.
29. Lin, J.; Shen, Z.; Zhang, A.; Chai, Y. Blockchain and IoT based food traceability for smart agriculture. In Proceedings of the 3rd International Conference on Crowd Science and Engineering, Singapore, 28–31 July 2018; pp. 1–6.
30. Xu, Q.; Aung, K.M.M.; Zhu, Y.; Yong, K.L. A blockchain-based storage system for data analytics in the internet of things. In New Advances in the Internet of Things; Springer: Berlin, Germany, 2018; pp. 119–138.
31. Bocek, T.; Rodrigues, B.B.; Strasser, T.; Stiller, B. Blockchains everywhere-a use-case of blockchains in the pharma supply-chain. In Proceedings of the 2017 IFIP/IEEE Symposium on Integrated Network and Service Management (IM), Lisbon, Portugal, 8–12 May 2017; pp. 772–777.
32. Dubovitskaya, A.; Xu, Z.; Ryu, S.; Schumacher, M.; Wang, F. Secure and trustable electronic medical records sharing using blockchain. AMIA annual symposium proceedings. Am. Med. Inform. Assoc. 2017, 2017, 650
33. Jamil, F.; Ahmad, S.; Iqbal, N.; Kim, D.H. Towards a Remote Monitoring of Patient Vital Signs Based on IoT-Based Blockchain Integrity Management Platforms in Smart Hospitals. Sensors 2020, 20, 2195.
34. Guardtime. Guardtime. Available online: https://guardtime.com/blog/dutch-government-deploys-guardtime-s-ksi-blockchain-for-integrity-assurance/ (accessed on 12 March 2020).
35. Fu, J.; Wang, N.; Cai, Y. Privacy-Preserving in Healthcare Blockchain Systems Based on Lightweight Message Sharing. Sensors 2020, 20, 1898.
36. Ekblaw, A.C. MedRec: Blockchain for Medical Data Access, Permission Management and Trend Analysis. Ph.D. Thesis, Massachusetts Institute of Technology, Cambridge, MA, USA, 2017
37. Prisco, G. The Blockchain for Healthcare: Gem Launches gem Health Network with Philips Blockchain Lab. Bitcoin Magazine, 26 April 2016.
38. HealthCoin. HealthCoin. Available online: https://www.f6s.com/healthcoin/ (accessed on 23 February 2020).
39. Hang, L.; Choi, E.; Kim, D.H. A novel EMR integrity management based on a medical blockchain platform in hospital. Electronics 2019, 8, 467.
40. Clauson, K.A.; Breeden, E.A.; Davidson, C.; Mackey, T.K. Leveraging

blockchain technology to enhance supply chain management in healthcare. Blockchain Healthc. Today 2018.
41. Liu, X.; Wang, W.; Guo, H.; Barenji, A.V.; Li, Z.; Huang, G.Q. Industrial blockchain based framework for product lifecycle management in industry 4.0. Robot. Comput. Integr. Manuf. 2020, 63, 101897.
42. Sloan, B.; Finnegan, S.; Kennedy, P. Remote Patient Monitoring System. U.S. Patent App. 16/442,433, 2 January 2020.
43. Ali, M.S.; Vecchio, M.; Putra, G.D.; Kanhere, S.S.; Antonelli, F. A Decentralized Peer-to-Peer Remote Health Monitoring System. Sensors 2020, 20, 1656.
44. Xie, W.; Wang, B.; Ye, Z.; Wu, W.; You, J.; Zhou, Q. Simulation-based Blockchain Design to Secure Biopharmaceutical Supply Chain. In Proceedings of the 2019 Winter Simulation Conference (WSC), National Harbor, MD, USA, 8–11 December 2019; pp. 797–808.
45. Liu X, Barenji AV, Li Z, Montreuil B, Huang GQ. Blockchain-based smart tracking and tracing platform for drug supply chain. Computers & Industrial Engineering. 2021 Nov 1;161:107669.
46. Ouf S. A Proposed Architecture for Pharmaceutical Supply Chain Based Semantic Blockchain. International Journal of Intelligent Engineering & Systems. 2021 May 1;14(3).
47. Hasan, H.; AlHadhrami, E.; AlDhaheri, A.; Salah, K.; Jayaraman, R. Smart contract-based approach for efficient shipment management. Comput. Ind. Eng. 2019, 136, 149–159.
48. Sahoo, M.; Singhar, S.S.; Sahoo, S.S. A Blockchain Based Model to Eliminate Drug Counterfeiting. In Machine Learning and Information Processing; Springer: Berlin, Germany, 2020; pp. 213–222.
49. Kumar, R.; Tripathi, R. Traceability of counterfeit medicine supply chain through Blockchain. In Proceedings of the 2019 11th International Conference on Communication Systems & Networks (COMSNETS), Bengaluru, India, 7–11 January 2019; pp. 568–570.
50. Azzi, R.; Chamoun, R.K.; Sokhn, M. The power of a blockchain-based supply chain. Comput. Ind. Eng. 2019, 135, 582–592.
51. Longo, F.; Nicoletti, L.; Padovano, A.; d'Atri, G.; Forte, M. Blockchain-enabled supply chain: An experimental study. Comput. Ind. Eng. 2019, 136, 57–69.
52. Huang, Y.; Wu, J.; Long, C. Drugledger: A Practical Blockchain System for Drug Traceability and Regulation. In Proceedings of the 2018 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData), Halifax, NS, Canada, 30 July–3 August 2018; pp. 1137–1144.
53. Chitre, M.; Sapkal, S.; Adhikari, A.; Mulla, S. Monitoring Counterfeit Drugs using CounterChain. In Proceedings of the 2019 International Conference on Advances in Computing, Communication and Control (ICAC3), Mumbai, India, 20–21 December 2019; pp. 1–6.
54. Shu, H.; Qi, P.; Huang, Y.; Chen, F.; Xie, D.; Sun, L. An Efficient Certificateless Aggregate Signature Scheme for Blockchain-Based Medical Cyber Physical Systems. Sensors 2020, 20, 1521.
55. Kim, M.; Park, K.; Yu, S.; Lee, J.; Park, Y.; Lee, S.W.; Chung, B. A secure charging system for electric vehicles based on blockchain. Sensors 2019, 19, 3028

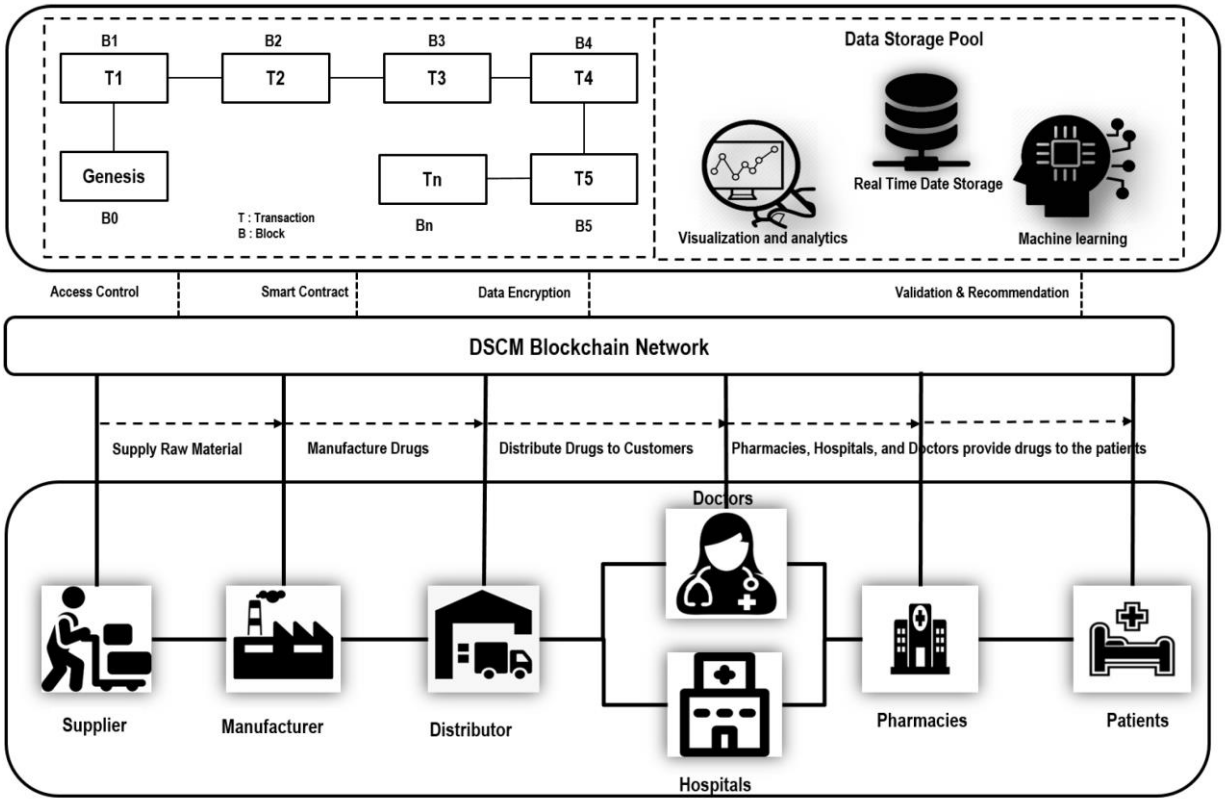

Figure 1. An examination of the drug supply chain management (DSCM) system using blockchain technology