

Article

Securing Drug Distribution Systems from Tampering Using Blockchain

Mamoona Humayun ^{1,*}, Noor Zaman Jhanjhi ², Mahmood Niazi ³, Fathi Amsaad ⁴ and Isma Masood ⁵

¹ Department of Information Systems, College of Computer and Information Sciences, Jouf University, Sakakah 42421, Saudi Arabia

² School of Computer Science (SCS), Taylor's University, Subang Jaya 47500, Malaysia; noorzaman.jhanjhi@taylors.edu.my

³ Department of Information and Computer Science, Interdisciplinary Research Center for Intelligent Secure Systems, King Fahd University of Petroleum and Minerals, Dhahran 31261, Saudi Arabia; mkniazi@kfupm.edu.sa

⁴ School of Information Security and Applied Computing, Eastern Michigan University, Ypsilanti, MI 48197, USA; fathi.amsaad@emich.edu

⁵ Department of Computer Science, Shaheed Zulfikar Ali Bhutto Institute of Science and Technology, Islamabad 46000, Pakistan; dr.isma@szabist-isb.edu.pk

* Correspondence: mahumayun@ju.edu.sa

Abstract: The purpose of this study is to overcome coordination flaws and enhance end-to-end security in the drug distribution market (DDM). One of the major issues in drug market coordination management is the absence of a centralized monitoring system to provide adequate market control and offer real-time prices, availability, and authentication data. Further, tampering is another serious issue affecting the DDM, and as a consequence, there is a significant global market for counterfeit drugs. This vast counterfeit drug business presents a security risk to the distribution system. This study presents a blockchain-based solution to challenges such as coordination failure, secure drug delivery, and pharmaceutical authenticity. To optimize the drug distribution process (DDP), a framework for drug distribution is presented. The proposed framework is evaluated using mathematical modeling and a real-life case study. According to our results, the proposed technique helps to maintain market equilibrium by guaranteeing that there is adequate demand while maintaining supply. Using the suggested framework, massive data created by the medication supply chain would be appropriately handled, allowing market forces to be better regulated and no manufactured shortages to inflate medicine prices. The proposed framework calls for the Drug Regulatory Authority (DRA) to authenticate users on blockchain and to monitor end-to-end DDP. Using the proposed framework, big data generated through drug supply chain will be properly managed; thus, market forces will be better controlled, and no artificial shortages will be generated to raise drug costs.

Keywords: drug distribution; blockchain; tampering; mathematical modeling; big data; counterfeit medicines



Citation: Humayun, M.; Jhanjhi, N.Z.; Niazi, M.; Amsaad, F.; Masood, I. Securing Drug Distribution Systems from Tampering Using Blockchain. *Electronics* **2022**, *11*, 1195. <https://doi.org/10.3390/electronics11081195>

Academic Editor: Manohar Das

Received: 20 March 2022

Accepted: 8 April 2022

Published: 9 April 2022

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1. Introduction

Blockchain, in essence, has become an alternative name for cryptocurrency. However, it is a lot more than that. It is an ecosystem that has integrated a modular sense of entity comprised of various nodes that work in compliance for efficient data management [1,2]. Blockchain is a comparatively new technology, yet most new businesses integrate their interactions with the scheme of work. However, many governments across the globe have adopted the technology for efficient management of their resources and their data [3–5]. The government of Sweden is using blockchain technology (BCT) to create digitalized land records [6]. Similarly, Estonia and Georgia are also using the technology for the

same purpose. The scheme of work for the technology has enabled it to be accessible to multi-contingent partnerships, so governments are also using it [7].

The DRA is one of the key governmental bodies facing many challenges, such as using different harmful chemicals to make fake medicines, the trade of illegal medications, etc. [8,9]. The manual management of the system makes it hard to manage such issues efficiently. Such issues can be mitigated by employing BCT. Digitalized blockchain systems will make it hard to hide fake medicines and to evade national and civic duties such as taxation [10]. The distributed ledger technology (DLT) allows us to record every transaction, allowing for a centralized system for efficient and better resource management [11]. Further, it will also help mitigate the tampering issue during the distribution chain because it may be nearly impossible to forge a transaction in a blockchain [12,13]. Increased digital processing power, rapid growth in cybercrime, and the rise of bitcoin and cryptocurrency are key reasons for using BCT [14].

The pharmaceutical industry is one of the key sectors that need to be regulated for optimization to become a part of the global trade mechanisms. To achieve this, there is a need to mobilize the resources to ensure that one of the most important economic sectors can be regulated for optimization [15,16]. Although the drug distribution system has improved a lot in the past few decades, there is still a need to improve the market dynamics of authentication, availability, and real-time price management of medicines. The lack of a central management system enables loopholes to turn into market failures and structural inefficiencies [17]. These inefficiencies create drug shortages, credibility issues, and much more. Such issues are the leading causes of macroinstability and market failures.

As technology advances, the current social structure of society does not align with the technological pace. Therefore, new measures need to be taken to readjust the dynamics [18,19]. To come up with a solution, the BCT is undoubtedly the foremost. It is a solution to restructure our sense of security with brands by automating the ledger. The proposed framework is driven by the motivation to solve these automation issues. Therefore, as the pharmaceutical industry is the foremost in the war against any disease, it must be optimized by making it free of human error and fraud, which BCT can ensure. The medicine industry can regularize itself and receive benefits from BCT. A generalized solution is needed for regularization that can change the dynamics of the medical industry.

Considering the importance of BCT for drug distribution, this research work proposes a secure framework for drug distribution. The proposed framework is evaluated with the help of mathematical modeling and a case study. The proposed framework will help consumers and industry on multiple levels. Government regulators can use this to track the import and export of medicines and determine illegal stocks. On the other hand, doctors and consumers can also follow the availability of drugs in the market. At the Manufacturer's and dealer's end, they can also use the proposed solution to know about the effectiveness of any formula. The proposed solution will also help the logistics and inventory-management systems for long-term coordination. The proposed solution's horizon of use would be far spread across different segments of society. Each of the segments would equally ensure a modernized take on the healthcare system, ranging from the market component to the direct healthcare participants, with the application catering to the needs of all. The system will allow all the participants to keep track of the medicine to reduce the likelihood of fake medicine and ensure authenticity to avoid tampering. BCT will allow the efficient allocation of resources by monitoring and controlling DRA. Below is a brief overview of our contribution:

1. Using BCT for processing real-time data of the drug market;
2. Recording all the transactions under blockchain technology;
3. Minimizing medicine hoardings through regulatory governance by DRA;
4. Ensuring security of drug distribution through BCT;
5. Ensuring coordination in the drug market;
6. Ensuring availability of updated information about medicine for authentication purposes at all times.

The remaining paper is organized as follows: Section 2 provides the details of existing related work to provide an overview of the current state of the art; Section 3 outlines our proposed framework and its evaluation using mathematical modeling and a case study; followed by Section 4, which discusses the insights gained from evaluation of the proposed framework; finally, the paper is concluded in Section 5 by providing insights into future directions.

2. Literature Review

This section will provide an overview of the existing studies to better understand the role of Blockchain in drug distribution and to know the current state of the art.

The study [15] suggested and built a revolutionary medicine supply-chain-management and recommendation system (DSCMR) based on blockchain and machine learning (ML). The proposed approach is divided into a blockchain-based medicine supply-chain-management and an ML-based drug-recommendation system for customers. The system is implemented utilizing Hyperledger fabrics in the first module, which can continually monitor and track the medication delivery process in the smart pharmaceutical business. The N-gram and LightGBM models, on the other hand, are utilized in the ML module to propose top-rated or best drugs to pharmaceutical sector clients. Using a well-known publicly accessible drug-review dataset from the University of California, Irvine: an open-source machine-learning repository, these models were trained. Furthermore, the ML module is connected with this blockchain system through the REST API. Several experiments were also carried out to evaluate the proposed system's efficiency and usability.

The primary goal of the study [20] was to discuss how Blockchain might fit the needs of a cold pharmaceutical chain. They examined the present constraints of the blockchain-enabled pharmaceutical chain to acquire a thorough understanding of the current research issues and to define future study paths. This research depicts the numerous ways in which BCT might aid in the achievement of pharmaceutical cold-chain goals. Furthermore, many case studies of blockchain-based pharmaceutical and medical enterprises that address these difficulties for a variety of objectives are highlighted.

Using BCT, study [21] provides a good drug-delivery paradigm. A user-centered design and a qualitative methodology are used in model development. The study's findings led to the development of a blockchain-based medication delivery scheme that has been independently verified. Several desirable properties of this design include its capacity to provide all of the above-mentioned benefits while also being decentralized, secure, traceable, automated, and impervious to human error. Using this paradigm, the government can better protect the public's health and safety by guaranteeing that its pharmaceuticals are of high quality.

Blockchain applications in healthcare are discussed in paper [22]. The existing pharmaceutical supply-chain-management challenges are highlighted, and how Blockchain may be utilized to provide traceability and visibility to medication supply and tackle the issue of counterfeiting is described in depth. An explanation is given of how the blockchain's identification system works and how it may be used to securely communicate medical data while protecting the patient's personal information. In addition, it outlines several approaches, blockchain types, and third-party solutions that may be utilized to construct a blockchain-based pharmaceutical supply chain. The proposed system's work is illustrated using an example that demonstrates how a wide range of participants may utilize the system.

Paper [23] proposes Drugledger, a scenario-oriented blockchain system for drug traceability and regulation that reconstructs the whole service architecture by splitting service providers into three separate service components and secures the authenticity and privacy of traceability data. With its peer-to-peer design, Drugledger is more robust than conventional systems. Furthermore, Drugledger could prune its store effectively, resulting in a stable and acceptable blockchain storage. Moreover, algorithms based on the enhanced UTXO process in Drugledger are meant to represent actual drug supply-chain logic (e.g.,

package, unpackage, repackage, etc.). It is a comprehensive study of how a blockchain system may be constructed for drug traceability and regulation from technological and practical standpoints.

The pharmaceutical supply chain's safety has become a critical problem for public health, which is a group effort. To handle safe medication-supply-chain data, paper [24] proposes a revolutionary drug supply-chain-management system based on Hyperledger Fabric and BCT. The suggested solution tackles this challenge by executing drug-record transactions on a blockchain to construct a smart healthcare environment with a medication supply chain. A smart contract has been established to provide time-limited access to patients' electronic medication data and electronic health information. In order to show the usability and effectiveness of the planned platform, a number of tests were conducted. Finally, Hyperledger Caliper evaluated the developed system's performance in terms of transactions per second, transaction latency, and resource consumption.

The paper [25] studies the current literature and blockchain applications for the healthcare sector. Additionally, this paper suggests numerous processes for the healthcare ecosystem, all of which use BCT for improved data management. Various medical workflows, including sophisticated operations such as surgery and clinical trials, have been devised and executed utilizing the Ethereum blockchain platform. This also involves accessing and managing a vast volume of medical data. The cost of implementing the medical smart-contract system for healthcare management has been evaluated via a feasibility analysis that has been extensively reported in this article. This effort would assist numerous stakeholders engaged in the medical system in delivering higher-quality healthcare services at a lower cost.

The paper [26] proposed a paradigm for a decentralized ledger system to improve the robustness, security, and convenience of medication-history management. The authors went into further depth about their framework's design, demonstrated a demonstration network as a proof of concept, and discussed possible implementation scenarios in the e-prescription business. They discussed the present challenges associated with drug data transmission and the insecure nature of centralized networks and how the suggested method addresses these concerns. This framework is noteworthy, but there are various ways in which it might be expanded. First, it may be combined with current ADE research to give prescribers decision guidance based on a patient's drug history. Second, in addition to monitoring prescriptions, this network may be used to collect and standardize patient-reported outcomes. This may be accomplished by enhancing a patient's client's functionality to enable them to submit transactions.

The authors of paper [27] suggest a strategy based on the Ethereum blockchain that uses smart contracts and decentralized off-chain storage to provide efficient medication tracking and to monitor patients' compliance with a doctor's prescription. This smart contract ensures data provenance, eliminates the need for an intermediary, and provides all interested parties with a secure and immutable transaction history. Additionally, the authors describe the system architecture and precise algorithms that regulate the suggested approach's operational principles. Additionally, they give an assessment of the approach's usefulness in enhancing traceability within medication supply chains, including testing and validation, as well as an analysis of the approach's costs and security.

The study [28] attempts to explain a solution to India's counterfeit pharmaceutical issue by suggesting a robust electronic health network based on BCT. The proposed solution is based on the blockchain network's ability to track medicinal logistical needs from manufacture to patient. If counterfeit medication is brought into the system at any point, it will be quickly identified, and its further penetration will be halted. The system is simulated on a Hyperledger Fabric platform, and its performance is compared to that of other available approaches. The results indicate that although the system is computationally costly, it provides a dependable solution to the problem of counterfeit pharmaceuticals.

The above explanation demonstrates that BCT is extensively employed in the pharmaceutical business to facilitate medicine delivery, combat counterfeiting, manage data and

supply chains, ensure security, and monitor medication. While some of these significant benefits have been realized, these issues persist in various ways. Further, consensus making and trust building is also inevitable for the success of DDS [29–32]; lack of trust among stakeholders involved in DDS affects the quality of product, its delivery and distribution. This demonstrates the necessity for a generalized solution capable of resolving the aforementioned challenges and assisting in improving the medication delivery process by making it more resilient and secure. To address this gap, this paper provides a blockchain-based framework to provide end-to-end security of DDP by making it transparent under the supervision of DRA and adding all supply-chain actors as members of blockchain.

3. Proposed Methodology

This section provides details of the proposed framework. The proposed framework provides a generalized and integrated solution that will assist the supplier, transporter, manufacturer, wholesaler, distributor, pharmacist, and the DRA to assess real-time data to better manage the drug distribution process. Moreover, the proposed framework will allocate a registration number to the registered sellers and producers to increase the viability and reliability of the seller. Blockchain will ensure the recording of the transaction between two parties in a verifiable manner. The ability of blockchain systems to be decentralized, distributed, transparent, and immutable can be used as an efficient tool to identify counterfeit medicine [33–35].

As shown in Figure 1, the proposed framework consists of many entities such as suppliers, transporters, manufacturers, wholesalers, distributors, pharmacists, and customers connected through a decentralized network. Each of these supply-chain entities is a node on the public blockchain. Each of these nodes has its account [36], which is used for representing its identity. DRA will be the owner of the blockchain and will control and monitor end-to-end DDP for ensuring the security and quality of drugs.

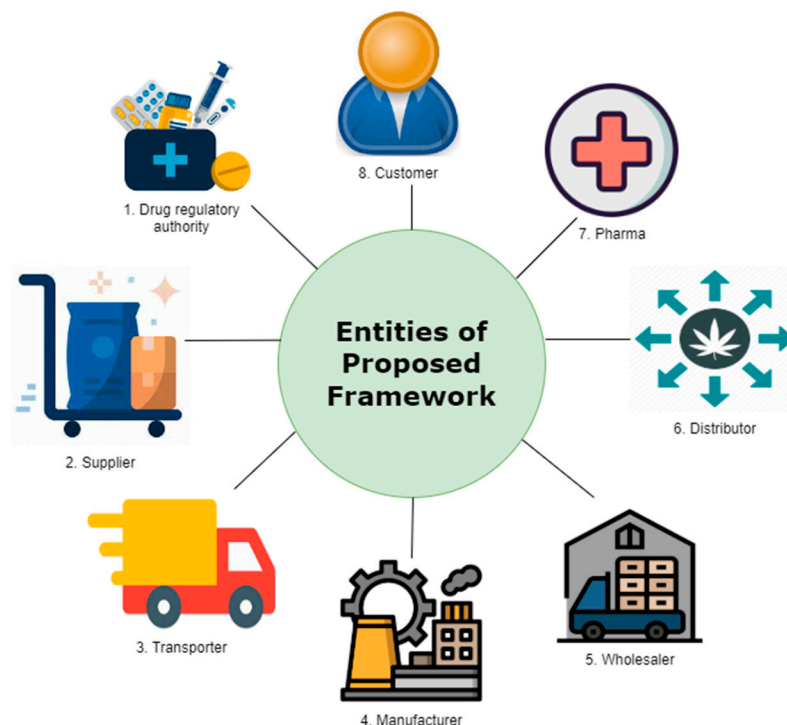


Figure 1. Key entities of the proposed framework.

3.1. Entities of the Proposed Framework

The specific roles and functionalities of each entity are discussed in subsequent sections and are also summarized in Figure 2.

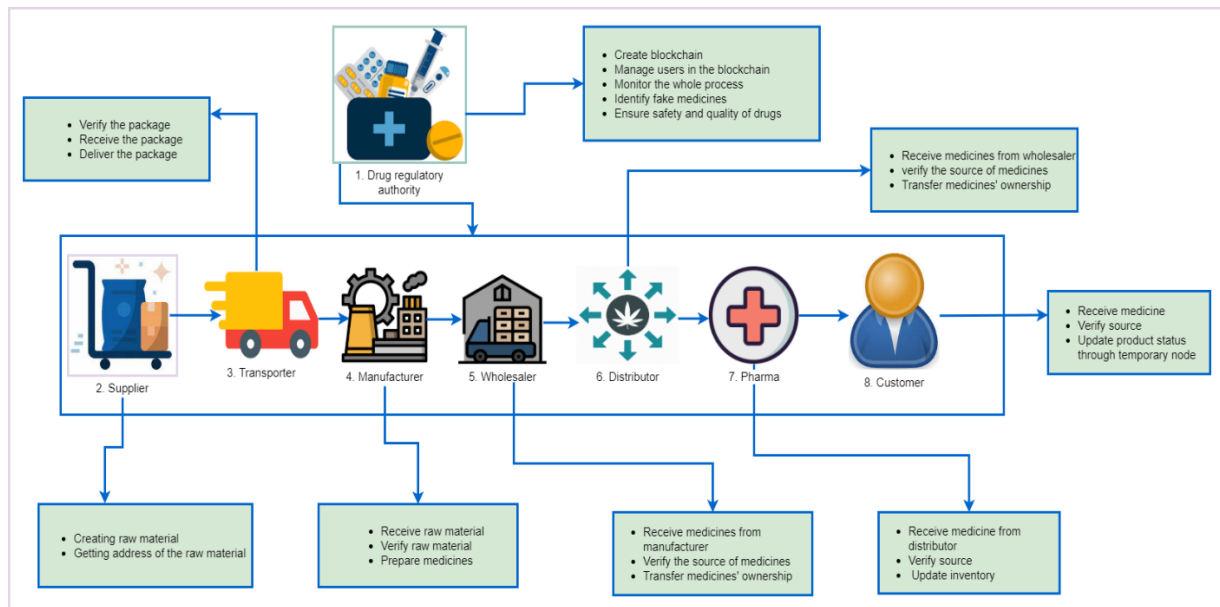


Figure 2. Key responsibilities of the entities involved in the proposed framework.

3.1.1. DRA

DRA is the one who creates the blockchain, manages all the stakeholders, monitors the overall process of drug distribution, and ensures the safety and quality of drugs. Management of the blockchain by DRA will enable DRA to monitor and control overall DDP.

3.1.2. Transporter

The role of the transporter is to verify the package (raw material or medicine), pick the package from an entity (based on transporter type), and deliver the product to an entity. The transporter entity has multiple instances, such as transferring the data from supplier to manufacturer, from manufacturer to wholesaler, and from wholesaler to distributor.

3.1.3. Supplier

The supplier in the proposed architecture is the entity that creates a raw material and obtains the addresses of the raw materials created. All the data of the raw material are recorded properly using big-data management techniques. The manufacturer ensures the authenticity of the raw material supplied after receiving it and updates its ledger.

3.1.4. Manufacturer

The manufacturer entity receives the raw material from the supplier via the transporter, verifies the source of the product received, and creates a new medicine using received raw materials.

3.1.5. Wholesaler

This entity receives the medicine from the manufacturer via the transporter, verifies the source of the medicine, and transfers the ownership of the drug. Wholesalers take the drugs in bulk and store records in the ledger. The maintenance of big data related to drugs is properly managed through blockchain to ensure the authenticity of received drugs by the distributor.

3.1.6. Distributor

This entity of the proposed system is responsible for receiving the medicine from the wholesaler via the transporter, verifying the source of the medicine, and transferring the

ownership of the drug. The distributor is responsible for handling orders given by the pharmacist and delivering drugs on time.

3.1.7. Pharmacist

The pharmacist entity receives the medicines from the distributor via the transporter, verifies the source of the product received, and enters the accepted drugs in the record.

3.1.8. Customer

The customer will receive medicines from pharmacist, will verify the source of medicine through a temporary node, and will also update the product status through a temporary blockchain link.

3.2. Smart Contract Design

Smart contracts are nothing more than computer programs registered on a blockchain and executed when specific conditions are met [37]. Smart contracts are becoming more popular. They are often used to automate the execution of an agreement so that all parties may be confident in the completion of the agreement immediately, without the involvement of an intermediary or the loss of time [38]. Aside from that, they may automate a process by triggering the next action when particular conditions are met. The smart contracts included in the proposed architecture are as follows:

3.2.1. Supply-Chain Contract

This contract is deployed by the DRA. It consists of many entities associated with the supply chain, i.e., supplier, transporter, manufacturer, wholesaler, distributor, pharmacist, and customer. None of the entities without a particular role can access a specific function. This helps increase the security and accessibility of data stored or queried from the blockchain.

3.2.2. Raw-Material Contract

A respective supplier deploys the raw-material contract. Once a raw material is created physically, it is added to the chain by the supplier who made it. While creating a raw material to be added to the chain, data such as the address of the supplier, date, time, address of transporter, transaction-contract address, etc., are requested from the supplier. It also contains events that can compute the whereabouts of the package in real time. The receiver (manufacturer) address is later updated based on the event request–response mechanism. It also stores the current status of the medicine, i.e., which entity currently has the raw material.

3.2.3. Medicine Contract

The respective manufacturer deploys the medicine contract. Once a medicine is created physically, it is then added to the chain by the manufacturer who created the medicine. While creating medicine to be added to the chain, data such as the address of the raw material used to create the medicine, date, time, address of transporter, transaction-contract address, etc., is requested from the manufacturer. It also contains events that can compute the whereabouts of the package in real time. The wholesaler's and distributor's addresses are updated later based on the event request–response mechanism. It also stores the current status of the medicine, i.e., which entity currently has the package.

3.2.4. Transaction Contract

The transaction contract is deployed automatically by the raw-material and medicine smart contracts whenever created. The contract takes data such as the date, time, sender address, receiver address, location, transaction hash, and the hash of the previous transaction.

3.3. Proposed Framework

This section aims to provide the proposed framework and its workings in detail. Our proposed framework entities and their roles are already discussed in previous sections. Here, we will explain how the proposed framework will work and how it will secure the drug distribution system from tampering

According to the proposed framework mentioned in Figure 3, DRA will initiate the process and participate in the whole DDP to make it transparent. Every block in the chain consists of the sender address, receiver address, and the previous block's hash. It will be a decentralized P2P network managed by DRA. Whenever there is a new block, it is automatically distributed to all network members. Each node must perform its own verification to ensure that the block has not been tampered with. Each node then adds this block to its blockchain once it has been thoroughly checked. The benefits of the proposed system involve time reduction, resilience, security, counterfeit and fake medicine detection, and collaboration. The suggested approach uses smart contracts, which are free computer programs that run in the background and check for criteria such as simplification, verification, and enforcement. All transactions will be recorded in a secure and transparent digital ledger created by BCT. It enables DRA to keep track of all drugs in a tamper-proof manner. Using BCT to record transactions may make confirming and transferring ownership more safe and more accessible. The suggested framework will also aid in tracking drugs as they transit through a supply-chain network. The detailed working of the proposed approach is shown in Algorithm 1.

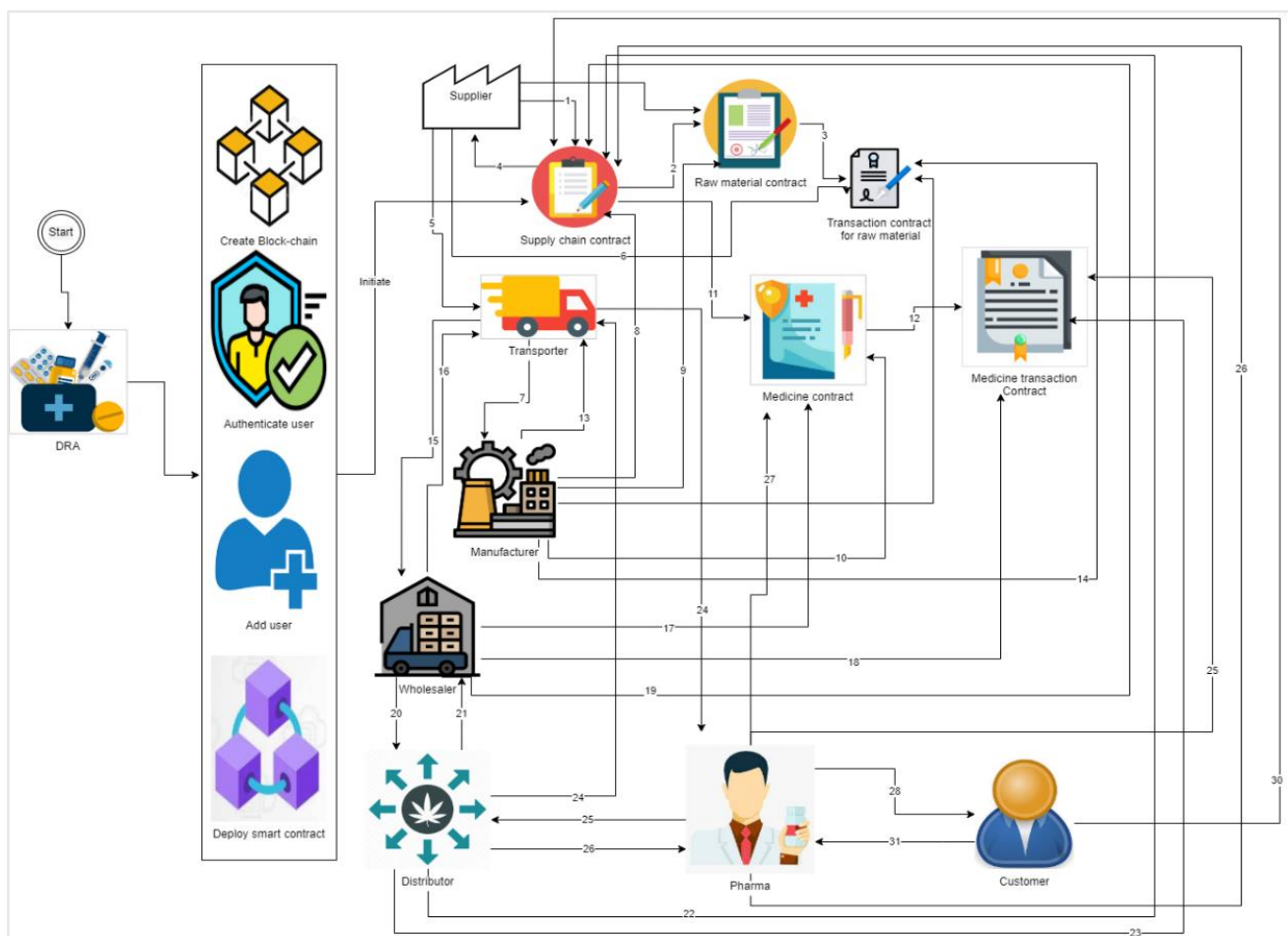


Figure 3. Proposed framework for handling end-to-end DDP and supply-chain big data.

Algorithm 1

Let SC = smart contract; BCE = blockchain entities; RM = raw material; RMC = raw-material contract; TC = transaction contract; NCRM = newly created raw material; Sp = supplier; T = transporter; Tr = transaction; M = manufacturer; Md = medicines; MC = medicines contract; Ws = wholesale; Dr = distributor; Cs = customer; Ph = pharmacists; DRA = drug regulation authority; PS = product status; NCM = newly created medicine

1. Begin
2. $Deploy(SC) \leftarrow DRA$
3. $Authenticate(BCE) \leftarrow DRA$
4. $Register(BCE) \leftarrow DRA$
5. $Register(RM) \leftarrow Sp$
6. $Sp \rightarrow Deploy(RMC) \rightarrow NCRM$
7. *if Register(RM) = true : next ? Go to step 5*
8. $Sp \rightarrow Transfer(RM) \rightarrow T$
9. $(Update(PS) \&\& Create Tr(TC)) \leftarrow Sp$
10. $T \rightarrow Transfer(RM) \rightarrow M$
11. $VerifySource(RM) \leftarrow M$
12. $Register(Md) \leftarrow M$
13. $(Update(PS) \&\& Create Tr(TC)) \leftarrow M$
14. *if Register(Md) = true : next ? Go to step 12*
15. $M \rightarrow Deploy(MC) \rightarrow NCM$
16. $Deploy(TC) \rightarrow M$
17. $M \rightarrow Transfer(Md) \rightarrow Ws$
18. $VerifySource(Md) \leftarrow Ws \text{ via } T$
19. $(Update(PS) \&\& Create Tr(TC)) \leftarrow Ws$
20. $Ws \rightarrow Transfer(Md) \rightarrow T$
21. $T \rightarrow Transfer(Md) \rightarrow Dr$
22. $VerifySource(Md) \leftarrow Dr$
23. $(Update(PS) \&\& Create Tr(TC)) \leftarrow Dr$
24. $Transfer(Md) \rightarrow T$
25. $T \Rightarrow Receive(Md) \leftarrow Ph$
26. $VerifySource(Md) \leftarrow Ph$
27. $(Update(PS) \&\& Create Tr(TC)) \leftarrow Ph$
28. $Ph \Rightarrow Receive(Md) \leftarrow Cs$
29. $VerifySource(Md) \leftarrow Cs$
30. $Update(PS) \leftarrow Cs$
31. End

3.4. Mathematical Modeling

The objective function of the proposed framework is to optimize DDP and reduce tampering. Thus, our objective function can be modeled in Equations (1) and (2). Table 1 lists the notations used for mathematical modeling.

$$OBF1 = Optimize(DDP) \quad (1)$$

$$OBF2 = Minimize(T) \quad (2)$$

The optimization of DDP is achieved when $(E_1, E_2, E_3, \dots, E_n)$ perform all the operations successfully by registering products and verifying the source using smart contracts.

$$DDP = \left| \overbrace{E_1, E_2, E_3, \dots, E_n}^{DRA} + \overbrace{A_1, A_2, A_3, \dots, A_n}^{DRA} + \overbrace{P_1, P_2, P_3, \dots, P_n}^{DRA} + TC \right| \quad (3)$$

Table 1. Notations used in mathematical modeling.

Notations	Used for
OBJ	Objective function
DDP	Drug distribution process
T	Tampering
$E[i]$	An array of blockchain entities
A_i	Assets
TC	Transaction contract
P_i	Package including (data, hash, previous hash)
SR	Supply of raw material
TR	Transportation of raw material
MM	Manufacturing of medicine
TM	Transportation of medicines
DM	Distribution of medicine

The DDP process will be implemented under the supervision of *DRA*, which is responsible for all E_i , A_i , P_i and TC to make the DDP process secure and transparent.

The situation when the invader tries to inject false data or intends to break the chain is modeled in the equations below:

$$T = E_1 + \varepsilon, E_1 + \varepsilon, E_2 + \varepsilon, E_3 + \varepsilon \dots \dots E_n + \varepsilon \quad (4)$$

where ε is the invader who tries to become part of the communication between entities. In such a situation, *DRA* will identify the invader and will not allow it to enter the blockchain.

The second way of tampering is when the invader tries to attack the assets, which are drugs in our case; in such a situation the invader will try to add fake medicines in the supply chain process, as shown in Equation (4). Where $f_1, f_2, f_3 \dots \dots f_n$ are the fake or counterfeit medicines:

$$T = A_1 + f_1, A_2 + f_2, A_3 + f_3 \dots \dots A_n + f_n \quad (5)$$

The third way of tampering is to make some changes in the packages that might be changed either in the hash or the actual data, as shown in Equation (6):

$$T = P_1 + H_1|D_1, P_2, H_2|D_2, P_3 + H_3|D_3 \dots \dots P_n + H_n|D_n \quad (6)$$

where $H_1, H_2, H_3 \dots \dots H_n$ represent the change made in the original hash value, and $D_1, D_2, D_3 \dots \dots D_n$ represent the change made in the data by the invader. The *DRA* will continuously monitor the blockchain. Thus, any such interference will be immediately noticed and rectified.

In our case, the optimization of DDP will be achieved, as mentioned in Equation (7):

$$Optimization(DDP) = \sum_{i=1}^n SR_i \sum_{j=1}^n TR_j \sum_{k=1}^n MM_k \sum_{l=1}^n TM_l \sum_{m=1}^n DM_m \quad \text{subject to } {}^m_c DRA \quad (7)$$

According to Equation (7), DDP can be optimized if the supply of raw material, transportation of raw material, manufacturing of medicines, transportation of drugs, and distribution of drugs is carried out properly and securely, and this can only be achieved through continuous monitoring and control by *DRA*.

In the same way, minimization of tampering will also be achieved if the whole DDP is end-to-end secure, and this can be only achieved when *DRA* is monitoring and controlling all of the supply-chain activities, as mentioned in Equation (8).

$$\text{Minimization}(T) = \sum_{i=1}^n SR_i \sum_{j=1}^n TR_j \sum_{k=1}^n MM_k \sum_{l=1}^n TM_l \sum_{m=1}^n DM_m \quad \text{subject to } {}^m_c DRA \quad (8)$$

3.5. Case Study

The case study is a hypothetical application situation in which detailed DDP elements are presented in order to better understand the concept's potential. The pharmaceutical industry ABC offers a diverse portfolio of brands aimed towards the pharmaceutical industry's consumer and retail markets. The industry ABC must continually simplify and improve its operations to stay competitive in a highly competitive market with the availability of low-cost medications widely available through regular transporters and distributors. Engineering and design, research, manufacture, worldwide sourcing, importation, and distribution are all part of ABC's vertically integrated business model. This enables ABC to create new goods and send them for approval by physicians. It also allows for design modifications and custom designs from a single unit to thousands of units. The supply chain is made up of three warehouses: warehouse A produces raw materials; warehouse B receives raw materials from warehouse A via the transporter and manufactures pharmaceuticals; and warehouse C markets the medications to different distributors. Even though the industry ABC is thriving, its medications are not only marketed locally, but also exported to other countries. There are many reports of tampering and counterfeit drugs on a daily basis. The firm is making every effort to improve its process, but monitoring the end-to-end DDP in its present manual configuration is impossible. The suggested framework may assist the DDP and trade business to improve its connections with its suppliers both locally and worldwide. The industry ABC will use the proposed approach to verify all blockchain entities, allowing any manipulation in the DDP to be detected immediately.

BCT will provide all stakeholders with clear visibility, allowing them to make faster choices and actions. The use of blockchain generates a chain of events or transactions between the end customer, the manufacturer, and the supplier. A part of a blockchain that can communicate directly with the company's sales staff and suppliers would ensure that the pharmacies have the merchandise they need when they need it. The manufacturing process will be traceable from the source of raw materials to the components (as shown in Figure 4) and the quality assurance and tests that have been completed if the suggested framework is used. Furthermore, blockchain may be used in supply-chain management to monitor medicine supply. This degree of transparency establishes a relationship between the manufacturer and the external stakeholders, who are all collecting and exchanging data that can be transferred further down the supply chain. The proposed framework addresses the problem of not knowing when a purchase order for items will arrive and the qualities and data of the objects included inside it. Blockchain will be used within the organization to offer ties between the client's order and the final produced items for the customer. The proposed framework will allow it to see where things are stored in a warehouse, how they were inspected, and if they were assigned to the client's order. This traceability also aids inventory management by ensuring that there is sufficient stock on hand to fulfill a request. In addition, the suggested framework connects the pharmacist's order to the warehouse and transportation provider. Pharmacists receive their orders in whole, on schedule, and from the proper warehouse due to this chain's record keeping and connecting. Blockchain is anticipated to become an appealing and cost-effective choice due to the lack of other viable options to tackle the challenge of supply-chain communications. In addition, the proposed framework enables transparency for sales reps, who will have access to pertinent information such as the components being utilized, the supplier from whom they are sourced, the needed lead times, and stock availability.

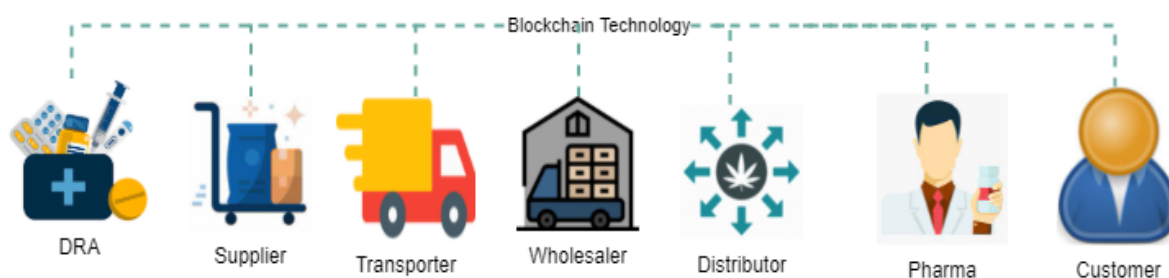


Figure 4. Traceability using blockchain.

4. Discussion

The nonavailability of a centrally regulated drug-management system has caused significant issues such as a shortage of medicine in the market and the lack of any mechanism to authenticate medicines. The Drug Regulatory Act is an inclusive act and caters to a wide variety of users and executive authorities; however, lack of coordination amongst the actors causes massive disruptions in the market. To cater to such disruptions and lack of centrally regulated drug-management mechanisms, a BCT-based framework is proposed that makes the entire DDP process transparent, secure, and traceable. BCT allows the DRA to maintain market functionalities while also seeking to ensure that the authenticity of the medicine is kept under check. The proposed solution eliminates the threat of fake engagements. It will help the DRA and the intended users, including suppliers, transporters, manufacturers, wholesalers, and distributors.

Using tracking systems, authenticity checks, and brand registration, the proposed framework offers an integrated approach to the supplier, the transporter, the manufacturer, the wholesaler, distributor, pharmacists, customer, and the regulatory authority to assess real-time data for better management of the sector. Furthermore, this will be advantageous for companies since it will enable them to forecast their demand ahead of time. Apart from that, the framework will allow governments to provide a registration number to registered sellers and producers in order to improve the viability and credibility of the vendor using BCT. The blockchain will guarantee that all transactions between two parties are recorded verifiably. According to the World Health Organization, because of the capabilities of blockchain systems to be decentralized, distributed, transparent, and immutable, they may be utilized as an effective method for identifying counterfeit medicines. Our proposed framework outperforms the existing solution by providing end-to-end security of DDS. Paper [39] has presented a blockchain-based solution for DDS; however, this paper does not include the pharmacist entity in the list of recommended entities, despite the fact that a security breach may occur between the pharmacist and the consumer. Furthermore, the blockchain owner is considered to be the one who is accountable for maintaining the blockchain in this study; however, our suggested framework involves DRA and considers it the owner of the blockchain to make the whole DDP more transparent.

The proposed framework was evaluated with the help of mathematical modeling and a case study. The insights obtained from the case study show that the security and traceability features of the proposed system make the DDP process transparent and tamper-free.

5. Conclusions and Future Work

The absence of a centralized drug monitoring system causes coordination failure and creates a huge market for fake and counterfeit medicines. This study aims to optimize DDP and to reduce tampering in the drug market by providing a centralized monitoring system with end-to-end connectivity and security. A blockchain-based solution is proposed to address the challenges such as coordination failure, secure drug delivery, and pharmaceutical authenticity. To optimize the drug distribution process (DDP), a drug distribution framework is presented, which is monitored and controlled by DRA, and all entities in the drug supply chain are part of the blockchain. The proposed framework is evaluated using mathematical modeling and a real-life case study. According to our findings, the

proposed approach helps to maintain market equilibrium by guaranteeing that there is adequate demand while maintaining supply. Using the suggested framework, massive amounts of data created by the medication supply chain would be appropriately handled, allowing market forces to be better regulated and no manufactured shortages to inflate medicine prices. The proposed framework calls for the Drug Regulatory Authority (DRA) to authenticate users on blockchain and to monitor end-to-end DDP. This will make DDP resilient and tamper-proof.

In the future, we are planning to implement the proposed system using open-access blockchain to know its effectiveness.

Author Contributions: Conceptualization, M.H. and I.M.; methodology, M.H.; formal analysis, N.Z.J. and M.N.; investigation, M.H.; data curation, M.H. and I.M.; writing—original draft preparation, M.H.; writing—review and editing, M.H., M.N. and N.Z.J.; visualization, F.A.; supervision, N.Z.J.; project administration, M.N.; funding acquisition, F.A. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Deanship of Scientific Research at Jouf University under grant No (DSR-2021-02-0331).

Conflicts of Interest: The authors declare no conflict of interest.

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