



Designing a Blockchain Based Model for Secure and Effective Pharmaceutical Supply Chains

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Abstract: Proposed study represents the blockchain framework using Ethereum tool for pharmaceutical supply chain. Proposed blockchain based pharmaceutical supply chain can trace the drug batches from different stakeholders which makes data more immutable, secure as well as data is decentralized. In the proposed method admin can add the different stakeholders to the secure and decentralized database using Ethereum. Users such as pharmacies, distributor, manufacturer, raw material supplier are added by the admin to the application. Proposed system is designed with smart contract using solidity programming. End user can verify and trace the product using QR code-based verification or product batch number. For maintaining secure and reducing counterfeit risk proposed application provide transparent solution for real time pharmaceutical data. Proposed method is the combination of blockchain technology using Ethereum tool and Django framework for web application where this application provide total security, traceability higher efficiency for product management in supply chain.

Keywords: Decentralization data storage, Pharmaceutical Supply Chain, Drug Traceability, Blockchain, Verification using QR Code, Verification using product ID.

1. INTRODUCTION

The pharmaceutical supply chain is necessary to ensure safety of drugs transportation between manufacturers to the end users. The many parties involved include manufacturers, distributors, pharmacies and regulatory bodies just to mention a few. However, there are a number of issues with the present pharmaceutical supply chain system, such as data manipulation, counterfeit medications, insufficient traceability, and a lack of transparency. These issues pose a serious threat to patient safety and the health of the population as well as undermining operational efficiency.

The availability of inferior and fake medications is one of the main issues with the conventional system. Centralized data storage and poor monitoring procedures make it difficult to monitor the origin and passage of pharmaceuticals throughout the supply chain. Counterfeit drugs can thus easily find their way to the system and have adverse health consequences. Furthermore, the lack of safe data exchange and real-time tracking erodes stakeholder trust and raises the possibility of fraud and mistakes.

Blockchain technology has presented an opportunity as a means to address these problems. It is a decentralized, distributed ledger system which ensures data security, immutability and transparency. Since all the transactions in the blockchain are time-stamped and immutable, it is highly reliable in tracking and verification. Akram et al. [1] argue that blockchain technology can significantly improve the supply chain management in the pharmaceutical industry by improving the level of transparency and reducing the risk of using counterfeit drugs.

The use of blockchain in supply chain management and healthcare has been investigated by a number of researchers. Gruchmann et al. [3] discussed the potential of blockchain to reduce transaction costs and improve coordination among the stakeholders, whereas Clauson et al. [2] noted that blockchain could help to raise visibility and trust in healthcare supply chains. Similarly, Sylim et al. [4] discussed the importance of blockchain in detecting counterfeit and low-quality drugs through safe measures of tracking.

Moreover, Agarwal et al. [5] and Xu et al. [6] presented detailed studies of blockchain-based supply chain systems that can enhance the operational efficiency and data security. While Badhotiya et al. [8] examined the obstacles to blockchain adoption in this field, Bryatov and Borodinov [7] showed how to use Hyperledger Fabric for creating safe pharmaceutical supply chain models. Moreover, Zakari et al. [9] conducted a thorough review, which defines the benefits and limitations of blockchain in the pharmaceutical business. Surjandy et al. [10] also discussed the advantages and challenges of adopting blockchain technology in supply chain management.

The aim of the proposed system would be to develop a blockchain architecture that ensures safe, open, and effective management of pharmaceutical supply chains. The system enables real-time monitoring of medicine batches, safe data transfer among stakeholders, and assuring end-user product authenticity. The method reduces the risk of counterfeit drugs, enhances the confidence of the participants and improves the effectiveness of the supply chain through the integration of blockchain technology. The overall goal of this project is to create a dependable and impenetrable pharmaceutical supply chain system by utilizing blockchain technology. It provides the innovative approach to the existing issues and contributes to the improvement of the quality and safety of healthcare.

1.1 Real-World Application in Pharmaceutical Companies

The proposed blockchain-based supply chain system can be practically implemented in pharmaceutical companies by mapping each stakeholder's role to the workflow:

- a) Admin:** Registers manufacturers, distributors, and pharmacies, supervises transactions, and ensures compliance with regulatory standards.
- b) Manufacturer:** Creates drug batches and records production details immutably on the blockchain, preventing falsification of origin data.
- c) Distributor:** Updates shipment status, enabling real-time tracking of drug movement across regions.
- d) Pharmacy:** Receives batches, verifies authenticity, and marks them as dispensed, ensuring only genuine products reach consumers.
- e) End User:** Verifies the drug using batch ID or QR code, gaining transparency into the entire lifecycle of the medicine.

2. LITERATURE SURVEY

Pharmaceutical supply chain is highly fragmented, and it does not have appropriate traceability, fake and poor transparency. The decentralized and immutable format of block-chain allows tracking drug through end-to-end, sharing data in a secure manner, and communicating among stakeholders. It has been found out that block-chain based systems offer verifiable logs that are not tamper able, real-time tracking and automated checks that increase the integrity of the drug, adherence to the regulations and ultimately make the distribution of medicines safer. [1].

Challenges that impact healthcare supply chains are the complexity of supply chains, risk threat, and patient-safety, and counterfeit medicines and lack of visibility are the major threats. Block-chain provides provenance tracking on a secure level, enhances transparency, and provides medical-device authentication, IOHT integrity, and public-health logistics. Even though the number of use cases has increased, most block-chain projects remain in the pilot phase due to regulatory, technical, and interoperability challenges, however, the technology has a tremendous potential in the secure health-sector supply chains. [2].

The pharmaceutical supply chains in the emerging economies such as Egypt are typified by inefficiencies, high transaction costs and low transparency. In one instance, blockchain is perceived to reduce contracting and processing, coordination, safe delivery of medication, and collaboration among pharmacies, manufacturers and distributors. However, full applications of the block-chain to the developing pharma systems of the countries have barriers: the lack of awareness, culture resistance, and high costs of operations. [3].

The problem of drug counterfeiting in the Philippines, a developing country, is one of the most significant ones due to the absence of traceability in the channels of distribution and the possibility to control the centralized databases. An adult-to-drug tracking system is another area where a suggested pharmacovigilance system (blockchain-based, smart contracts, decentralized storage and modified consensus algorithms) can be used to secure a safe adult-to-drug system between FDA and manufacturers, wholesalers, and retailers. Theonized results reveal that there is enhanced verification, consumer level authentication through QR code, and regulatory oversight is improved to enable drugs to flow in a safer way. [4].

The traditional centralized supply-chain systems lack transparency, traceability and fraud as well as security. The distributed registry of blockchain allows citable transactions, anti-duplicating measures, and opens exchange of information without the intervention of a third party. A review of 97 articles shows that blockchain can be of immense significance in enhancing trust, traceability, and operational integrity in different supply-chain industries, yet there are issues in scalability and technology integration.[human]>A review of 97 articles reveals that blockchain can be of immense value in raising trust, traceability, and operational integrity in the different supply-chain industries but there are problems of scalability and assimilation of technology.

The drug supply chains are susceptible to corruption and falsification of data which is a consequence of centralized authorities in order to gain personal benefits. Blockchain can mitigate these threats by providing distributed, non-temper able data storage, automation via smart-contracts and real-time traceability. It has been suggested that blockchain has the potential to offer transparency, independence, and increased drug authentication and that persistent issues such as scalability, interoperability, and regulatory acceptability continue to exist[6].

Counterfeit drugs like those sold in drug markets like Russia imply that there is inefficiency in the effectiveness of monitoring the origin of drugs and traceability of the products. Hyperledger Fabric systems based on blockchain enable safe identification of drugs, which captures the manufacturing information and all supply-chain transfer routes in an immutable manner. This enhances authentication checking, improved supply-chain management, and helps drug-stores and regulators to prevent the entry of the counterfeits into the market. [7].

3. PROPOSED METHOD

Within the application flow is a proposed system containing four key types of users: Admin, Manufacturer, Distributor, Pharmacy and one End User/Consumer to validate the system. The batch flow is Manufacturer - Distributor - Pharmacy - Dispensed, and the whole system is monitored by the Admin.

3.1. Admin Functionalities: The pharmaceutical supply chain system has the admin as its main controller. The web interface enables the admin to manage participant registration, access to batch registration, and monitor complete batch traceability. The admin is not directly updated on the supply chain like the operational users, but oversees all the work and ensures that drug batches stored on the blockchain are moved.

- a) **Add Participants:** The admin has the ability to add new supply chain members into the system like Distributor, Pharmacy and Manufacturer. Upon registration, the credentials of participants and the specifics of their role are registered on the blockchain, and only authorized users can gain access to and modify supply chain records.
- b) **View Participants:** The list of all registered participants in the system can be seen by the admin. This comprises the name of the participant, password and participant type. This assists the admin to ensure that all the stakeholders are properly registered before the batch movement commences.

- c) **Register Drug Batch:** The administration interface entails drug batch registration page through which a new batch could be generated with drug name, batch description, package image, manufacturing location and unique batch ID. The batch blockchain record is then created.
- d) **Trace Drug Batch:** The admin is able to choose a drug batch ID and see the entire supply chain history of the batch. The presented data consists of the name of the participant, batch ID, drug name, description, update date, stage of the supply chain, location, status, and image.
- e) **See Batch Location on Map:** The admin is also able to access the recorded location of a batch in a Google Map view. This enhances visibility and aids in tracking the geographical flow of the batch through the supply chain.

To strengthen the research contribution, this study extends beyond a conceptual framework by implementing a fully functional prototype integrating Ethereum smart contracts with a Django-based middleware for real-time pharmaceutical supply chain tracking. The system demonstrates end-to-end traceability, secure data exchange, and tamper-proof record management across multiple stakeholders. Unlike basic blockchain demonstrations, the proposed model introduces a multi-layer architecture combining IoT data capture, decentralized validation, and QR-based consumer verification. This practical implementation highlights measurable improvements in transaction transparency, data integrity, and counterfeit prevention, establishing a strong technical and research contribution to blockchain applications in healthcare logistics shown in Figure 1.

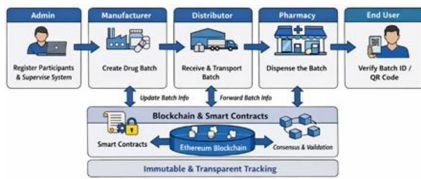


Figure 1. Workflow of the Blockchain Pharmaceutical Supply Chain System

3.2. Manufacturer Functionalities

The first stakeholder in the supply chain is the Manufacturer. The role generates the first batch of drug or owns the batch and transports the batch to the subsequent legitimate step in the chain. The activities of the manufacturer are recorded in the form of blockchain records, which is the point of beginning traceability.

- a) **Gain access to the System:** The manufacturer enters the platform with authorized credentials and as a Manufacturer role. Upon successful login, only actions related to manufacturers are provided.
- b) **See Assigned Drug Batch Records:** The manufacturer has the access to the pertinent batch information such as batch ID, drug name, description, date, current stage, status and package image. This enables the manufacturer to verify the status of the batch and then update it.
- c) **Update Batch to Distributor Stage:** Should the batch be at the stage of Manufacturer, the manufacturer can change its next stage to Distributor. This move creates a new blockchain record that has a new location, date and status, which allows you to track the movement.
- d) **Retain Original Supply Chain Authenticity:** Given that the manufacturer is the original creators of the first valid supply chain record, this position is tasked with ensuring that the registered batch details is accurate and complete, which will be required later to verify.

3.3 Distributor Functionalities

The second stakeholder in the pharmaceutical supply chain that operates is the Distributor. The distributor then notifies the manufacturer after accepting the batch and the system shows that the product is on its way. This assists in continuity of the tracking process in the blockchain approach.

- a) **Sign in to the System:** The distributor logs in to the application with the help of Distributor credentials. Role-based login will only allow valid distributors to make distributor-stage updates.
- b) **See Batch Details:** The distributor has the ability to read the information of the drug batches that have already been recorded in the blockchain, with the previous stage updates. This enables checking of the origin and actual position of the batch prior to going forward.
- c) **Batch update to Pharmacy Stage:** In case the drug lot is already at the Distributor level, the distributor is able to change the lot to the next level which is the Pharmacy level. This generates a fresh unchangeable blockchain statement of the batch movement.
- d) **Record Location of Distribution:** At the stage update, the distributor keys in the present location in such a way that subsequently, the route that the batch has traversed could be checked by the administrators or final consumers. This enhances the openness of transport and distribution.

3.4. Pharmacy Functionalities

The pharmaceutical industry is highly regulated, requiring strict compliance with national and international drug laws. The proposed blockchain-based supply chain system aligns with these regulations through the following mechanisms:

The admin registers participants and supervises all updates, ensuring that only authorized stakeholders (manufacturers, distributors, pharmacies) can interact with the system in compliance with regulatory frameworks.

Each update in the flow (manufacturer → distributor → pharmacy → dispensed → end user verification) is immutably stored on the blockchain, satisfying requirements under laws such as the U.S. Drug Supply Chain Security Act (DSCSA) and the European Falsified Medicines Directive (FMD).

Drug batches are tracked with unique IDs and QR codes, aligning with serialization mandates and enabling regulators to trace the complete lifecycle of medicines.

Regulators can access tamper-proof transaction logs for inspections, ensuring transparency and simplifying compliance audits.

Sequential updates prevent bypassing of stages, reducing the risk of counterfeit drugs entering the supply chain, which directly supports government policies on patient safety.

Smart contracts enforce rules automatically, while cryptographic hashing ensures that drug information cannot be altered, meeting legal requirements for secure data handling.

The third functional stakeholder in the system is the Pharmacy which is the last supply side before the medicine is consumed by the consumer. The pharmacy confirms that it has received the batch and commits an update to the last step in the blockchain record.

- a) **Enter the System:** Pharmacy credentials make the pharmacy enter the system and only access the pharmacy-related stage update functions.
- b) **View Drug Batch Information:** The pharmacy is able to view the entire drug batch data with past changes by the manufacturer and distributor. This can be used to ensure that the received batch is part of a valid chain.
- c) **Update Batch to Dispensed Stage:** As the pharmacy finishes with the supply chain processing, it is updated to the Dispensed stage. This is the final internal supply chain record prior to consumer use and leaves a final blockchain record in the chain of custody.
- d) **Assist Real Drug Delivery:** The pharmacy will also work to certify the end supply stage to ensure that the medicine that gets to the end user is of a proven and approved distribution channel.

3.5. End User / Consumer Functionalities

The End User or Consumer is not a party that adds to block-chain records, yet is the last verifier of the product. The system is used by this role to verify the authenticity and traceability of the drug batch before trust is put on its consumption or purchase.

- a) **Automated Drug Batch Checking:** The consumer is able to input the Drug Batch ID onto the verification page and access the entire history of the medicine stored on the block-chain. It consists of drug name, description, date of update, stage, location, status, and image.
- b) **Checks on the basis of QR-Code:** The consumer is also able to check the medicine by the QR code that was created on each batch. This offers a faster and easier way to retrieve the same traceability information in the block-chain.
- c) **See Entire Supply Chain Path:** The end user will be able to view the flow of the batch between the Manufacturer and Distributor to Pharmacy and then to the status of Dispensed. This creates the assurance that the product has been in the legitimate supply chain.
- d) **Check Batch Location Information:** The consumer will also be able to see the location information recorded and this will help in verifying the location the batch was handled at as it moved. This is another level of trust and transparency.

Overall User Flow of proposed method

- a) Admin registers participants and supervises the system.
- b) Manufacturer creates or initiates the drug batch and updates it to Distributor.
- c) Distributor receives the batch and updates it to Pharmacy.
- d) Pharmacy receives the batch and updates it to Dispensed.
- e) End User verifies the batch using batch ID or QR code.

3.6. Possible Risk and Solution

a) Sequential Update Dependency Risk

The proposed system enforces a strict sequential update mechanism, where each stakeholder (Manufacturer → Distributor → Pharmacy → End User) must update the batch status before the next stage can proceed. While this ensures integrity and prevents unauthorized skipping of stages, it introduces a potential operational risk

b) Security Risks

Unauthorized access or data tampering could undermine trust. The system employs cryptographic hashing, role-based access control, and immutable smart contracts to ensure secure data management and prevent manipulation.

c) Regulatory Risks

Compliance with pharmaceutical standards and government regulations is critical. The immutable blockchain ledger provides transparent auditability, enabling regulators to verify transactions and ensure adherence to compliance requirements.

The proposed blockchain-based pharmaceutical supply chain system is designed to support many users and large datasets. As the number of participants grows (manufacturers, distributors, pharmacies, regulators, and end users), the system ensures scalability through the Multi-User Support. The architecture allows unlimited participants to be registered and managed by the admin, ensuring that new stakeholders can be added without disrupting existing workflows. This capability demonstrates that the system is not restricted to small-scale implementations but can be extended to large supply chains with diverse stakeholders

4. RESULTS

Results for the proposed method using blockchain in the pharmaceutical supply chain.

The home page of proposed method which has multiple options such as Admin Login, Supply chain, QR codes, User Trace, QR verify. Once the admin get login with correct credentials, there are multiple options are shown on the screen of the admin.



Figure 2. View Participant Details

Admin can see all the participants (Figure 2) with specifications such as participant name, password and participant type.

Participant Name	Drug Batch ID	Drug Name	Batch Description	Update Date	Supply Chain Stage	Location	Current Status	Image	View Map
admin	crocin-1	crocin	table related to headache	2026-04-10	Manufacturer	mumbai	Manufacturer		View on Map
admin	crocin-1	crocin	table related to headache	2026-04-10	Distributor	hyderabad	Distributor		View on Map
admin	crocin-1	crocin	table related to headache	2026-04-10	Pharmacy	amserpet	Pharmacy		View on Map

Figure 3 Admin can trace the Batch

Admin can see the complete trace of the batch from different supply chain suppliers. Admin can see complete trace details of each batch such as participant name, drug batch ID, batch description, current status, image and view on map.

Supply chain participant can login to the application using user name, password and user type. These details are added by the admin to the application.

Participant Name	Drug Batch ID	Drug Name	Batch Description	Drug Package Image	QR Code	Download QR Code
admin	crocin-1	crocin	table related to headache			Click Here to Download

User can see and download the QR code from main Page

Admin once add the product, the QR code for product will be generated and stored information in blockchain.

End User Drug/ Batch Verification As shown in Figure 1 End user can verify the drug or batch of the pharmaceutical product. User need to add product ID.

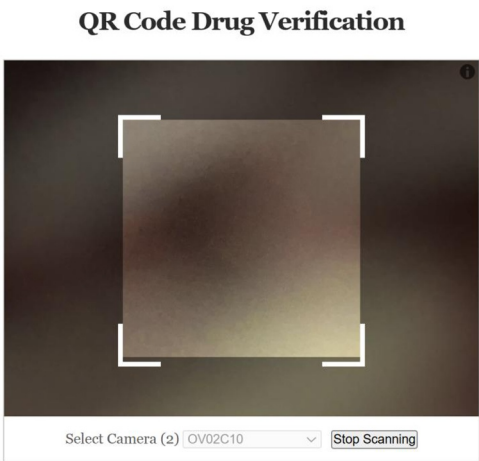


Figure 4. QR code-based tracing

Even user can verify and trace the product using QR code provided by the admin for pharmaceutical product. User can scan the product QR code and get all the details of the product where user can trace the product as shown Figure 4.

4.1. Cost Comparison with Traditional Systems.

The pharmaceutical industry often relies on centralized supply chain management systems, which involve high administrative overhead, manual reconciliation, and third-party audits. While blockchain introduces transaction costs and infrastructure requirements, the overall economic impact is favourable when compared to traditional systems shown in Table 1.

Table 1. Cost Comparison

Traditional System	Blockchain Based System
Multiple databases maintained separately by manufacturers, distributors, and pharmacies.	Smart contracts automate compliance and record-keeping, reducing manual labour and audit costs.
High costs for audits, compliance checks, and counterfeit detection.	Immutable records eliminate repeated verification, lowering administrative expenses.

Table 2. Default Account and Private Keys

Accounts	Private keys
0x8c928c9b113fd7414887a34e8dac5d978e dee279	5ddb3b83b84356c7cf172ec9d51a128ed4b6dd38ad136ec778f09f 9b19a1a10c
0x9f308d5b196ee3036904fe2a20e680e170 8a204e	e7e4adaa79ce5209a4b3e57b978c35f8e79d6674a53fb20af22fbfa1 bd3466b9
0x61274ab25759150ee2dda6853330ce7e4 442f325	42c823a9d86a257f2a6152dfb16a452e27c5aab3744e70562e9a09 8e7b2c768f
0x31c93f456ce5394fd9a5729edf52c3c589c a8d27	0b20fd3f10bbb322e1c30ef38fec85e40c4d34f2e3cfff41e77ed66f 95a3484
0x3d5f17ffd4c82557f546aacb6f208533664 1fde1	598d2aeccf94ee392e96d5f72ba26a046c850d3d11b927c8813969 31bc8ecede

Table 2 shows Blockchain-generated Private keys and default account addresses

Table 3. Implementation Setup

Technology	Element	Description
Blockchain	CPU	Intel® Core™ i5-6200U CPU @2.30GHZ
	Operating system	Windows 10
	Platform	Ethereum
	Language	Solidity
	Framework	Django
	JavaScript runtime environment	Node.js
Machine Learning	Operating System	Windows 10
	Browser	Chrome
	Programming language	Python
	Frontend	HTML, CSS

As shown in Table 3, The implementation uses the Ethereum platform for blockchain operations and the Solidity programming language for smart contract development. Truffle Suite is a comprehensive development environment that facilitates the creation and deployment of smart contracts. Node.js is a JavaScript runtime environment used to enhance the interactivity and responsiveness of blockchain applications. The machine learning aspect of the project was performed using Python, a versatile programming language ideal for data analysis and modelling. Windows 10 serves as the operating system for blockchain and machine learning components. Google Chrome serves as a browser that provides compatibility and accessibility to various web-based features.

5. CONCLUSION

Blockchain technology has become an attractive option to enhance the security, transparency and traceability of pharmaceutical supply chains. It successfully tackles such serious challenges as fake drugs, data manipulations, invisibility, and low trust levels among the stakeholders through decentralized registers, smart contracts, and cryptographic keys. The system provides a record of drug flow between manufacturers and end users which is verifiable and tamper free. Nevertheless, there are still challenges of uncertainty in regulations, interoperability, high cost of implementation and no large-scale deployment. Thus, additional studies, standardization, and stakeholder cooperation are required to make the full potential of blockchain in the pharmaceutical applications of the real world possible.

Further studies can be directed to the application of blockchain with other sophisticated technological solutions like Internet of Things (IoT) and Artificial Intelligence (AI) to create a completely automated and intelligent system of pharmaceutical supply chain. The IoT sensors can be used to monitor drug conditions such as temperature and location in real-time, whereas AI methods can assist in predicting risks, detecting anomalies, and forecasting demand. Moreover, creating single blockchain systems that will make the interaction between platforms such as Ethereum, Hyperledger Fabric, and Quorum possible will be a significant trend. System reliability can be further improved through global standardization, decentralized digital identities implementation, and regulatory compliance based on smart contracts. It is anticipated that in the future blockchain will become a full-fledged digital infrastructure that facilitates secure, efficient, and patient-centred distribution of drugs.

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