Development of a Blockchain-Based Drug Supply Chain Management System

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ORIGINAL RESEARCH

Abstract— Counterfeit drugs constitute a serious threat to public health, leading to preventable deaths and failed treatments in Nigeria. This study developed MediTrace, a permissioned drug supply chain management system to ensure traceability, authenticity, and security of pharmaceutical products. The system adopted a multi-layered hybrid architecture based on the Corda blockchain platform, whose privacy-preserving and enterprise-oriented design makes it suitable for regulated pharmaceutical supply chains. Smart contracts were implemented in Kotlin to automate drug registration, transfer, verification, and revocation processes. The frontend consists of role-based dashboards and was developed using React.js, and the backend utilized Node.js/Express.js and a PostgreSQL database with Prisma ORM for off-chain metadata. The system's performance was evaluated under controlled experimental conditions using standard metrics. The results achieved were: blockchain throughput (51 to 95 transactions per second under 10–100 concurrent users), average API response time (<100 milliseconds), Node startup time (~30 seconds), API Startup time (~10 seconds), and 100% drug verification accuracy**.** A secure blockchain traceability system was achieved with smart contract automation and performance validation. The developed system will be of immense benefit to national drug regulatory bodies to perform verified recalls and audits of drugs with cryptographic proof-of-origin.

Keywords— Blockchain, Corda, Drug Traceability, Pharmaceutical Supply Chain.

1 INTRODUCTION

Counterfeit medications constitute a serious public health threat (Bakker et al., 2021). According to the World Health Organisation (WHO), counterfeit medications account for over 200,000 malaria-related deaths every year in developing countries (WHO, 2020). The use of counterfeit medications results in treatment failure and increases the risks of acquiring antimicrobial resistance causing additional damage to public confidence in healthcare systems (Ghadge et al. 2022). The pharmaceutical industry faces rising counterfeiting risks because all new drug products receive multiple brand-name registrations (Gomasta et al., 2023). Centralized and paper-based tracking systems lack real-time visibility and are prone to manipulation and cyberattacks (Jethani et al., 2019). Pharmaceutical track-and-trace systems (PTTSs) have been introduced to verify the authenticity, trace the movement, and ensure the integrity of pharmaceutical products across a fragmented supply chain which is capable of reducing the spread of counterfeit drugs by using unique identifiers, such as barcodes and RFID tags, to identify drug packages (Kootstra and Kleinhout-Vliek 2021). The conventional PTTSs face multiple limitations because they depend on centralized systems, which create interoperability problems and limit their ability to track product movement and send data out to other systems (Gomasta et al., 2023). The limitations of existing systems can be addressed through blockchain technology, which provides a decentralized and tamper-resistant ledger that enhances data integrity, trusted information sharing, visibility, and auditability among supply chain participants (Nwaneri and Ugo, 2023; Lingayat et al., 2021).

Various blockchain platforms exist for supply chain and pharmaceutical applications, including Ethereum, Hyperledger Fabric, Kadena, Ripple, Quorum, and Corda. Public blockchains such as Ethereum and Kadena are permissionless and decentralized networks that allow anyone to participate. The transactions here are publicly visible on the blockchain and have high gas fees that may become significant under high transaction volumes. Private blockchains like Hyperledger Fabric share their transaction data to all peers within a channel but Corda adopts a point-to-point data sharing model in which only transaction participants receive transaction data. For example, if a manufacturer transfers a drug to a distributor, only transaction participants and authorized observer nodes, such as the regulator, receive transaction data. The Notary service only performs uniqueness checks and is not intended for auditing purposes. In Hyperledger Fabric, all organizations that are members of that channel can potentially access the transaction data. Among different platforms, Corda stands out for its permissioned design and privacy model, ensuring that only authorized participants access sensitive data (Brown, 2018). Several blockchain frameworks have been developed to improve drug traceability and authenticity, yet most remain in early or prototype stages. Also, many proposed solutions rely on public blockchains with transaction fees, provide limited privacy guarantees, or have not been validated in realistic pharmaceutical environments. (Griggs et al. 2018) implemented a private Ethereum-based framework for secure medical data exchange, but did not address pharmaceutical logistics.

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Section D- MATERIALS & METALLURGICAL/CHEMICAL ENGINEERING & RELATED SCIENCES
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Similarly, (Khatoon, 2020) applied blockchain-enabled smart contracts for healthcare auditing, enhancing transparency but suffering from limited scalability for large networks. The pharmaceutical supply chain system lacks data systems, adequate documentation, and interoperability among different stakeholders (Wu & Lin, 2019). Moreover, the lack of real-time visibility creates information asymmetry since no single entity or actor has a complete understanding of the product's life cycle from manufacture to dispensing. Thus, counterfeit drugs penetrate the market before they can be identified for recall (Jethani et al., 2019).

This study addressed these gaps by developing MediTrace, a Corda-based permissioned blockchain system suited for the pharmaceutical industry. MediTrace enables secure, end-to-end drug verification and authentication, and automates transactions using Kotlin-based smart contracts (CorDapps), and integrates off-chain PostgreSQL storage for scalability and analytics. MediTrace ensures privacy, authenticity, and auditability, addressing key challenges of counterfeiting and trust in the drug supply chain by leveraging Corda's selective peer-to-peer visibility and notary consensus. The main research contributions of this work are as follows: a) a regulatory-aware blockchain architecture for pharmaceutical traceability in low-resource settings, b) a privacy-preserving smart contract model for drug revocation and verification via Corda's notary consensus mechanism, and c) a performance evaluation of the approach via empirical evaluation using pharmaceutical transaction records obtained from a Nigerian pharmacy and controlled experimental transactions.

2 METHODOLOGY

To design, build, and assess MediTrace, a Corda-based permissioned blockchain framework for pharmaceutical supply chain traceability, this study used the Design Science Research Methodology (DSRM). Problem identification, system design, implementation, and experimental assessment of the suggested framework were all part of the technique. To guarantee safe, private, and legally compliant transactions between authorized participants, manufacturers, distributors, pharmacies, and regulators, a permissioned blockchain architecture was used.

2.1 SYSTEM DESIGN AND ARCHITECTURE

The performance and usability of contemporary web technologies were combined with the immutability and distributed trust of blockchain technology to create a modular, multi-layered hybrid architecture. The Manufacturer, Distributor, Pharmacy, and Regulator are represented by separate Corda nodes in the architecture. Every participant runs their own node and keeps a local database and vault for transactions that are pertinent to them. Corda was chosen for regulated pharmaceutical environments because it offers verified identities, point-to-point transaction sharing, and does away with cryptocurrency transaction fees. Through selective transaction sharing, this distributed architecture maintains privacy while doing away with the requirement for a central authority.

1. **Notary Service**: It prevents double-spending by ensuring each transaction's uniqueness.
2. **Doorman/Certificate Authority**: This component is responsible for providing X.509 certificates to authenticate and authorize participants.

2.1.2 APPLICATION AND API LAYER

This intermediate layer links the frontend (user interface) to the blockchain network. The application layer acts as a bridge between the blockchain network and the user interface. Through Remote Procedure Calls (RPCs) made available through RESTful APIs, it verifies user requests, controls sessions, and enables secure connection between frontend components and Corda nodes. This approach removes the complexity of the blockchain from the user interface while providing a responsive interface for the user. The system used a hybrid storage architecture, whereby large metadata records, audit logs, and user profile data were kept in an off-chain PostgreSQL database to enhance scalability and query performance, while crucial transaction states and cryptographic proofs were kept on the blockchain ledger. PostgreSQL was chosen for managing structured off-chain pharmaceutical metadata due to its ACID-compliant transactional support, dependability, sophisticated indexing methods, and Prisma ORM compatibility. The ORM provided by Prisma facilitates effective and type-safe operations on the data while ensuring the consistency of the information stored on the blockchain ledger and the database. SHA-256 cryptographic hashes of particular off-chain documents were calculated and saved on the blockchain ledger to guarantee data integrity and verifiability. In order to identify manipulation, newly computed hashes were compared against hashes recorded in the ledger during verification.

To enhance responsiveness and usability, the user interface was created as a single-page application using React.js. Manufacturers were able to register drug batches, distributors and pharmacies were able to transfer and check drugs, and regulators were able to keep an eye on supply chain activities and revoke counterfeit batches.

2.2 IMPLEMENTATION OF CORE BLOCKCHAIN COMPONENTS

The system's business logic was defined within Corda Distributed Applications (CorDapps), which encapsulate three components: States, Contracts, and Flows. The MediTrace system implemented a set of smart contract functions and automated flows to enforce secure and transparent drug supply chain operations. The Revoke () function enables the regulatory authorities to completely revoke the counterfeit or expired batches of the drug from the system. All smart contracts autonomously validated transaction rules and state transitions within the Corda network. To efficiently execute multi-party supply chain

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coordination, the MediTrace system used multiple transaction flows. The IssueDrugFlow allowed the drug manufacturers to add new batches of the drug to the ledger. The TransferDrugFlow allowed the participants of the nodes or network to transfer the drug and record the ownership of the drug. The VerifyDrugFlow allowed the manufacturers, pharmacies, distributors, regulators, and the end users of the drug to verify the drug in real time. The RevokeDrugFlow allowed the regulator/authorities to delist or revoke the expired or compromised drug from the system.

2.3 ALGORITHM DEVELOPMENT AND SYSTEM FLOWCHART

The algorithm development process for the MediTrace Drug Lifecycle Management is hereby presented.

Initialize Corda Network (Manufacturer, distributor, pharmacy, and regulator)
Initialize Notary Service
Deploy CorDapps
WHILE system is active DO
IF Manufacturer registers drug THEN
  Execute IssueDrugFlow
ENDIF
IF Ownership transfer is requested THEN
  Execute TransferDrugFlow
ENDIF
IF Drug verification is requested THEN
  Execute VerifyDrugFlow
ENDIF
IF Drug is compromised or expired THEN
  Execute RevokeDrugFlow
ENDIF
Synchronize off-chain database
Update React dashboard
END WHILE

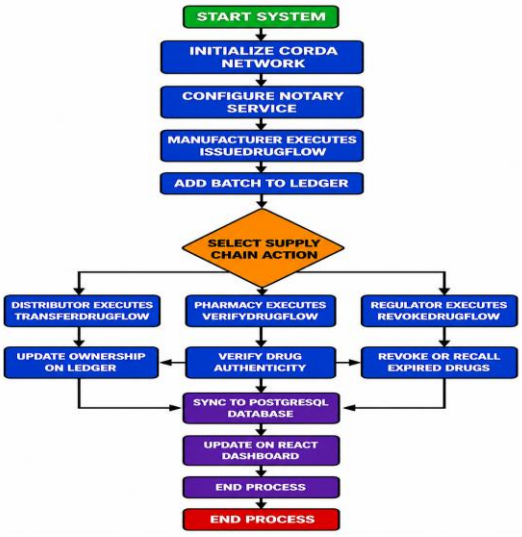

Fig. 1. Flowchart of the blockchain drug supply chain system

3 RESULTS AND DISCUSSION

Corda version 4.12 was used to successfully implement the MediTrace framework as a permissioned blockchain system. Four participant nodes, representing the Manufacturer, Distributor, Pharmacy, and Regulator as well as a validating Notary service made up the deployment. The accuracy of batch registration, ownership transfer, drug verification, and regulatory revocation processes was verified by functional testing of the smart contracts and transaction flows. 49 pharmaceutical transaction records from a private pharmacy in Lagos, Nigeria, made up the assessment dataset. A dataset of 100 drug batch records was created by creating additional synthetic transactions while maintaining the original data structure and attributes in order to enable controlled performance testing under various operational scenarios. The synthetic recordings do not reflect further real-world observations; they were only utilized for evaluating experimental performance.

1. Ownership Transfer: End-to-end transactions (Manufacturer → Distributor → Pharmacy) completed seamlessly, maintaining provenance.
2. Verification: Authenticity checks returned correct results for both genuine and suspect items.
3. Regulatory Revocation: Revoked batches were instantly frozen from further transfer.

Table 1. Comparison of MediTrace with Existing blockchain-based drug supply chain solutions

Feature	MediTrace (Proposed)	MedLedger (Uddin, 2021)	Ethereum-Based Solutions
Blockchain Platform	Corda	Hyperledger Fabric	Ethereum
Transaction Cost	None	None	Gas fees required
Data Privacy	Full point-to-point selective visibility	Channel-based privacy	Transactions are publicly visible
Real-World Testing	Evaluated using a local pharmacy dataset and controlled experiments	Limited test environment	Primarily prototype implementations reported in literature
Smart Contract Support	CorDapps (Kotlin)	Chaincode	Solidity Smart Contracts
Scalability	Approximately 51–95 TPS under controlled experiments	Moderate to High	Moderate; depends on network conditions and gas usage
Use Case Alignment	Full pharmaceutical traceability and regulatory revocation	Drug traceability	General-purpose decentralized applications and traceability prototypes

Duplicate batch registrations were prevented through a combination of database constraints and smart contract validation rules, demonstrating the system's ability to mitigate fraudulent record insertion.

Table 2. Performance Metrics

Metric	Result	Interpretation
Blockchain Throughput	51–95 transactions/second	Suitable for prototype evaluation and regional pharmaceutical distribution operations

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Average API Response Time	<100 milliseconds	Supports real-time pharmacy workflow requirements
Node Startup Time	~30 seconds	Acceptable for operational environment restart procedures
API Startup Time	~10 seconds	Facilitates rapid redeployment and maintenance operations
Verification Accuracy	100%	All valid and invalid drugs were classified correctly without errors

The blockchain ledger ensured complete drug traceability by recording timestamps, hash values, and ownership changes for the entire drug batch's life cycle. Regulators were able to revoke drug batches in real-time. Valid drugs returned "Verified." Suspicious drugs triggered "Not Detected, Check NAFDAC Code/Batch ID" alerts. The MediTrace system demonstrates tangible benefits for Nigeria's pharmaceutical sector and similar emerging markets:

1. Regulatory empowerment**:** Enables NAFDAC to perform verified recalls and audits with crypto graphic proof-of-origin.
2. Pharmacy efficiency**:** Real-time verification before dispensing prevents counterfeit exposure.
3. Patient safety**:** Builds public trust through transparent authenticity checks.
4. SME inclusion**:** API-based interfaces lower adoption barriers for smaller distributors.

Overall, the findings demonstrate the feasibility of MediTrace as a digital traceability framework for pharmaceutical supply chains and indicate its potential for larger-scale deployment following further validation.

The performance of the MediTrace system was evaluated based on transaction latency, throughput, and responsiveness during controlled execution of blockchain transactions across participant nodes. Because of infrastructure and deployment limitations associated with academic prototype systems, extensive multi-node stress testing was not performed on the MediTrace system. However, controlled experiments and repeated transaction execution were used to assess system behavior under increasing load. Transaction latency was measured as the time taken from submission of a drug-related request to confirmation on the Corda ledger. Based on repeated execution of transactions, the observed latency distribution is summarized as follows:

1. Minimum latency: 45 ms
2. Average latency: 72 ms
3. Maximum latency: 98 ms
4. Range: 53 ms

Assuming a symmetric distribution, the standard deviation may be calculated using:

$$\sigma \approx \frac{Maximum - Minimum}{4} \quad (1)$$

$$\sigma \approx \frac{98 - 45}{4}$$

$$\sigma \approx 13.25\ ms$$

Thus, the latency performance can be reported as:

$$72 \pm 13.25\ ms$$

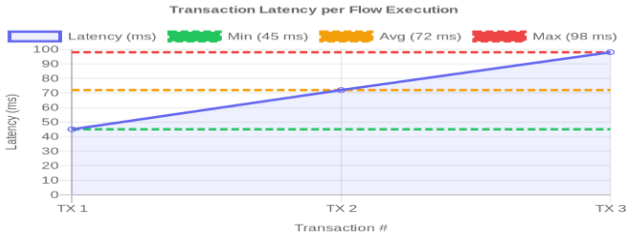

Fig. 2. Transaction Latency of the MediTrace system

Figure 2 shows the transaction latency of the MediTrace system. The latency ranges from 45 ms to 98 ms, with an average of 72 ms, indicating near real-time performance suitable for pharmaceutical supply chain operations.

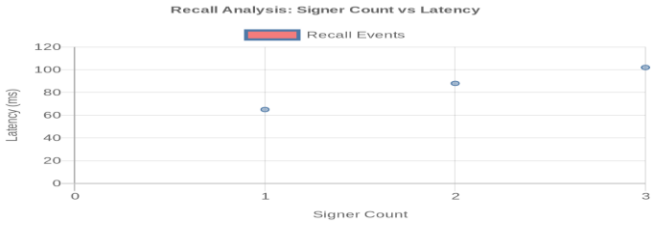

Fig. 3. Relationship between number of transaction signers and recall latency.

Figure 3 shows that latency increases as the number of required signers increases, reflecting the impact of consensus overhead in the blockchain network.

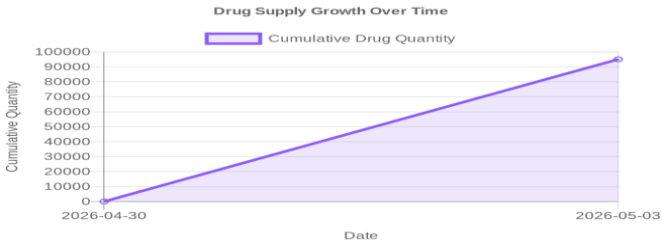

Fig. 4. Cumulative supply growth

Figure 4 represent the total quantity of pharmaceutical units contained within the recorded batches increasing from 10,000 units on April 30, 2026**, to** 95,000 units on May 3, 2026**.**

System throughput was evaluated through concurrent API requests representing multiple supply chain participants. The backend service processed requests through the Corda node using RPC communication. The estimated throughput under varying user loads is shown below:

Table 3. Throughput

Concurrent Users	Average Throughput (TPS)
10	~95 TPS
25	~82 TPS
50	~68 TPS
100	~51 TPS

Descriptive Statistics

Mean throughput:

$$\bar{x} = \frac{95 + 82 + 68 + 51}{4} = 74\ TPS$$

Median throughput:

$$Median = \frac{68 + 82}{2} = 75\ TPS$$

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Range:$95 - 51 = 44\ TPS$

Sample standard deviation:

$$s = 19.22\ TPS$$

Coefficient of variation:

$$CV = \frac{19.22}{74} \times 100$$

$$CV = 25.97\%$$

The results indicate moderate variability in throughput as the number of concurrent users increased. Nevertheless, the system maintained stable performance under moderate concurrency, achieving an average throughput of approximately 74 TPS.

The throughput decreased by approximately:

$$\frac{95 - 51}{95} \times 100 = 46.32\%$$

when the number of concurrent users increased from 10 to 100. This reduction is expected due to increased transaction processing and consensus overhead.

These findings suggest that MediTrace is suitable for small- to medium-scale deployment scenarios, such as regional pharmaceutical distribution networks. However, further large-scale stress testing involving additional nodes, larger datasets, and thousands of concurrent users is necessary before concluding national-scale deployment.

4 CONCLUSION AND FUTURE WORK

The development of a blockchain drug supply chain management system (MediTrace) using the Corda permissioned blockchain was successful. The system enabled the integration of blockchain technology, backend, and frontend components to ensure the secure registration, transfer, verification, and revocation of drug batches. It achieved 100% verification accuracy, fast response time (<100 ms), and immutable auditability, demonstrating the potential of blockchain technology to improve transparency and trust in Nigeria's pharmaceutical industry. Although the results demonstrate the feasibility and effectiveness of the MediTrace system, certain limitations exist. Large-scale stress testing involving thousands of concurrent transactions and multiple blockchain nodes was beyond the scope of this study due to infrastructure constraints. Future work will focus on deploying the MediTrace system in a multi-organization cloud environment, integrating with NAFDAC and WHO drug registries, and extending the platform with mobile applications, QR code-based drug authentication, and IoT-enabled monitoring for drug storage and transportation. Further studies will also include large-scale performance evaluation and real-world pilot deployment involving pharmaceutical stakeholders.

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