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Effectiveness of Block Chain Technology in Reducing Counterfeit Drug Circulation Within Pharmaceutical Supply Chains Compared to Traditional Tracking Methods

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Abstract

Falsified pharmaceuticals are making their way into pharmaceutical supply chains throughout the world, endangering public health, regulatory compliance, and the integrity of brands. Though commonly used, traditional tracking technologies including paper records, barcodes, and RFID devices lack real-time traceability, are susceptible to manipulation, and rely on centralized systems that may fail or be controlled. With its distributed, immutable, and transparent ledger system, blockchain technology provides a revolutionary alternative. In comparison to more traditional approaches, this research finds that blockchain works better in reducing the distribution of counterfeit drugs. Research and industry trials show that blockchain-enabled supply chains improve medication traceability, secure data integrity, and allow for anomaly detection in real-time. In addition to lowering the cost and time required for verification processes, blockchain technology also allows for efficient regulatory audits and recalls. The security and transparency of pharmaceutical logistics have been greatly enhanced by blockchain-based platforms, despite the fact that these systems still face hurdles in terms of integration, stakeholder acceptance, and data protection. After reviewing the literature, this study finds that blockchain technology provides a viable alternative to conventional approaches for preventing pharmaceutical supply chain counterfeits.

Keywords: *RFID, Blockchain, Drug, pharmaceutical, barcodes*

1. Introduction

Counterfeit medication circulation is an ongoing and serious problem for the pharmaceutical sector of the world. Severe health implications, economic losses, and erosion of public faith in healthcare systems are caused by around 10% of medications in low- and middle-income nations being either substandard or faked, according to the World Health Organization (WHO). For a long time, this problem has been addressed using conventional tracking methods such central computer databases, barcoding, RFID tagging, and human record-keeping. These approaches provide basic traceability, but they have a few drawbacks, such as being easily manipulated, not being very compatible with other systems, and taking a long time to notice whether something is wrong. Verifying the legitimacy of pharmaceutical goods is more important than ever before because to the increasing complexity of worldwide supply chains and the participation of several parties, including producers, distributors, wholesalers, and pharmacies. To prevent the spread of counterfeit drugs and improve medication traceability, blockchain technology has arisen as a significant weapon in this regard. Blockchain technology, which uses a distributed, immutable ledger, may provide full transparency across the whole medication supply chain, as well as real-time validation and audit trails that cannot be tampered with. The objective is to

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demonstrate how blockchain technology can transform the management of pharmaceutical supply chains, making them more transparent, accountable, and data-integrous. This will ultimately lead to better patient safety and easier compliance with regulations. Patient health, public trust, and large financial costs are all jeopardized by counterfeit drugs, which continue to be a serious worldwide concern. About 13.6 percent of the medications given out in LMICs are fake, which causes people to be sick for longer, develop resistance to antibiotics, and sometimes die from their diseases [1]. Undermining both individual treatment success and larger public health initiatives, these counterfeit pharmaceuticals sometimes include hazardous compounds, improper doses, or no active ingredients at all. There are several points of entry throughout the complicated pharmaceutical supply chain, which begins with the procurement of raw materials and continues through production, distribution, and dispensing. Barcodes, RFID tags, and centralized database systems are some of the more conventional tracking technologies that have been used to monitor product movement for quite some time. Data silos, human mistake, a lack of end-to-end visibility, and the ease of manipulation or duplication are some of the main shortcomings of these systems [2], [3]. Consequently, fake goods may still make it via legal distribution systems unnoticed.

Blockchain technology has become a game-changer in the supply chain management industry as a direct result of these shortcomings. Transparent and immutable record keeping is made possible via a decentralized ledger called a block chain, which is cryptographically protected. Particularly useful in identifying and avoiding counterfeit medicine entries are the end-to-end traceability, real-time auditability, and decentralized consensus processes offered by blockchain, as opposed to conventional systems. Smart contracts, which are agreements written on the blockchain and have the ability to execute themselves, also enable the automatic enforcement of compliance regulations, shipping verification, and quality control processes. This eliminates the need for centralized authority, which is a major advantage [4]. These features allow all parties involved in the pharmaceutical industry, including as producers, regulators, distributors, and pharmacists, to work together in an open and permanent way to confirm the legitimacy and origin of medication batches. In order to reduce the spread of fake drugs, this study compares and contrasts blockchain-based supply chain solutions with more conventional monitoring methods. This research seeks to evaluate the ways in which blockchain technology improves pharmaceutical logistics in terms of safety, reliability, and efficiency by reviewing relevant case studies, analyzing relevant literature, and drawing comparisons.

2. Literature Survey

Haq and Muselemu [3] and Bhandari et al. [1] highlight how blockchain may leverage distributed ledger technology to provide transparency and end-to-end traceability. Because of these features, there is much less room for data manipulation and illegal interference all across the supply chain. The research of Chaabaoui et al. [4] compiles these results and highlights importance of auditability, improved security, and elimination of fraud as advantages of using blockchain technology. Smart contracts and IoT devices integrated with blockchain systems are investigated by Subbarao et al. [7] and Pareek et al. [8]. Because of this integration, environmental conditions (such as temperature and humidity) may be tracked while drugs are being stored and transported, and compliance can be monitored continuously. Blockchain provides real-time anomaly detection & verified record keeping as more resilient alternatives to traditional RFID and barcode systems, which Adeyemo et al. [5] describe as shortcomings. These shortcomings include a lack of tamper resistance and centralized data management.

In multi-stakeholder settings, improvements to data quality, transaction transparency, and system responsiveness have been noted in a number of experimental projects utilizing platforms such as Hyper ledger Fabric and Ethereum [8, 14]. For large-scale pharmaceutical applications, scalability, secrecy, and cost-efficiency are paramount; new hybrid block chain designs mix public and permissioned networks to achieve this balance. [15].

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3. Proposed System

To fight the spread of counterfeit medications, the suggested system uses blockchain technology to construct a pharmaceutical supply chain that is safe, transparent, and tamper-proof. Using a permissioned blockchain network to link all parties involved under a single, decentralized framework, this system replaces conventional methods that depend on centralized control and separate databases.

3.1.Key Components

3.1.1. Blockchain Technology

A block on the ledger is recorded for every transaction involving a pharmaceutical product, whether it's producing, shipping, receiving, or selling. We provide an immutable and verifiable chain of custody for each medicine batch by timestamped, cryptographically securing, and linking each block to the preceding one.

3.1.2. Electronic Contracts

Smart contracts automate rule enforcement and transaction validation. As an example, the transfer of a product to a distributor is contingent upon the successful completion of all regulatory inspections. By eliminating the need for human interaction, these contracts guarantee adherence.

3.1.3. A DPI is a digital product identifier

The blockchain records are associated with the distinct digital identities issued to each medication package via the use of QR codes or RFID. Any link in the supply chain may instantaneously check the product's history and legitimacy using this identification.

3.1.4. Modules for Interfacing with Stakeholders

Secure access to product data may be achieved by manufacturers, distributors, pharmacies, and regulators using the system's user interfaces and APIs. A system of role-based access controls is used to manage permissions.

3.1.5. Data Storage Apart from the Chain (e.g., IPFS)

Lab test certificates, batch papers, temperature recordings, and other big or sensitive data are securely stored off-chain using cryptographic hashes that are connected with the blockchain.

3.1.6. Alert System in Real-Time

In order to prevent counterfeiting, relevant parties are notified in real-time of anomalies, such as the movement of products out of sequence or the attempt by an unregistered actor to complete a transaction.

3.2.Workflow

3.2.1. Manufacture

Drug is produced → batch data is recorded on blockchain → DPI is created.

3.2.2. Distribution

There is an uninterrupted and auditable trail since every handoff is recorded in real time as the product travels through the supply chain.

3.2.3. Verification

Before dispensing or consuming, consumers or pharmacies may scan the DPI to confirm the product's legitimacy and complete history.

3.2.4. Recall or Alert

Records kept by the blockchain make it possible to immediately recall batches that have been impacted by product flaws or manipulation.

3.3.Advantages Over Traditional Systems

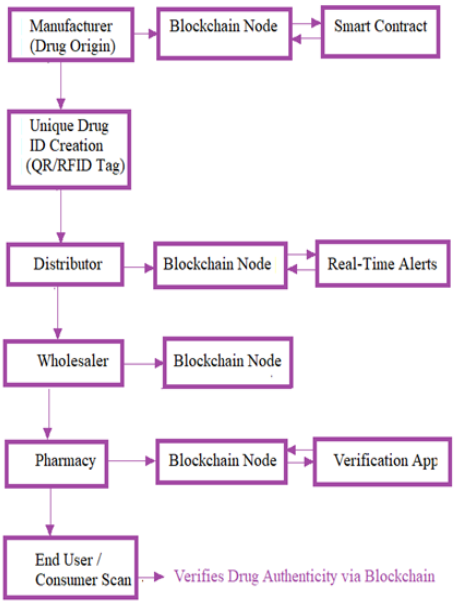

Figure1 Block Diagram of Proposed System

- Tamper-proof Audit Trails
- Real-time Traceability

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- Faster and Targeted Recalls
- Reduced Administrative Overhead
- Enhanced Consumer Trust
- Improved Regulatory Compliance

Suggested method is to provide a strong basis for trust and safety in the healthcare industry, increase operational transparency, and remove counterfeit medications at the source by incorporating blockchain technology in pharmaceutical supply chain.

4. Methodology

There are a number of critical steps to process of using blockchain technology to decrease proliferation of counterfeit drugs in pharmaceutical supply chains and then assessing its effectiveness:

4.1.System Design and Architecture

Because of the importance of privacy, scalability, and limited access, a permissioned blockchain network like Hyper Ledger Fabric is used. Only approved users, including producers, retailers, authorities, and pharmacies, will be able to access the blockchain under this system.

4.1.1. Stakeholders Identified

Manufacturer, Distributor, Wholesaler, Retailer, Regulator, Consumer

4.1.2. Modules

- Drug resistration module
- Track and track module
- Smart contract engine
- User verification and alert module

4.1.3. Tools & Technologies

- Blockchain:Hyper ledger Fabric
- Data Storage:IPFS(for-off-chain data)
- Fronted:Web or mobile interface for scanning/verification
- Backed:APIs for supply chain integration

4.2.Unique Drug Identification

During production, a QR code or RFID tag is used to assign a unique digital identification (UDI) to each medication unit.UDI is linked to metadata like:

- Batch Number
- Manufacturing date
- Expity date
- Origin details

This data is recorded immutably on the blockchain.

4.3.Smart Contract Implementation

During transportation of drugs, smart contracts are used to automate following processes:

- Some transactions must be executed by authorised actors.
- An alarm is triggered if there is an effort to alter drug's trajectory or data.
- Logic included into contract ensures compliance with regulations automatically.

4.4.Drug Movement and Blockchain Logging

From production to distribution, at every stage of supply chain.It scans the QR/RFID code of the medicine.Blockchain now has a new transaction:

- Sender
- Receiver ID
- Timestamp
- Current location

This creates an unchangeable, chronological trail.

4.5.Real-Time Verification & Alerts

Consumers and pharmacies alike may scan product code with use of a smartphone app or online site. Technology verifies record on blockchain and gives:

- Drug origin
- Full path history
- Authenticity status

An anomaly alert will be activated in event that product is either not included in chain or contains data that is conflicting.

4.6.Evaluation and Testing

Pilot deployments and data from simulated supply chains are used to evaluate system. Metrics Evaluated:

- Time to trace drug origin
- Anomaly detection accuracy
- Stakeholder response time to alerts
- Reduction in counterfeit incidence(before vs after blockchainuse)

Conventional methods (such as barcodes and ERP systems) are used for comparative analysis.

4.7.Feedback and Optimization

Figure 2 shows Workflow of Methodology Consideration of performance, integration of systems, and ease of use is given by stakeholders.

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- Both user interfaces & smart contracts are improved.
- Storage off-chain is more efficient.
- As required, further regulatory modules are included

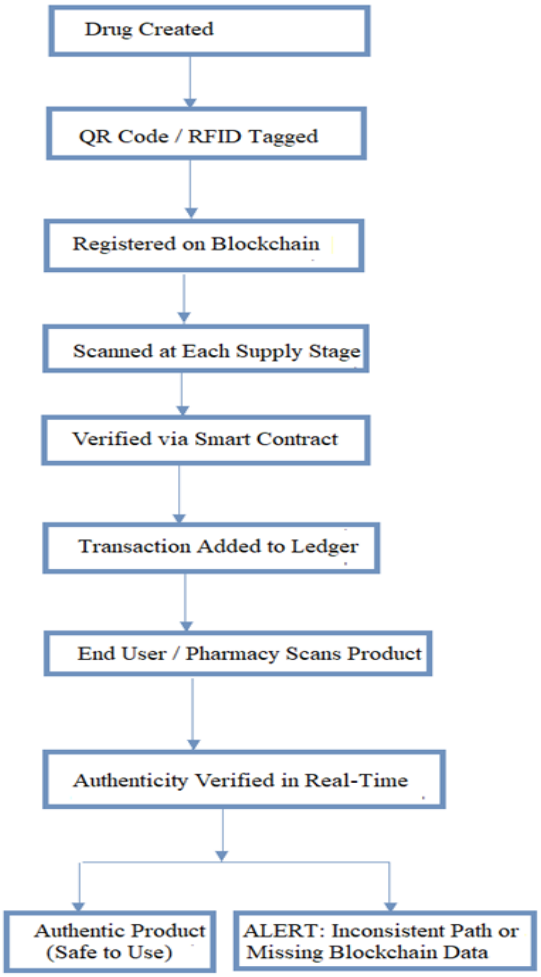

Figure 2 Workflow of Methodology

5. Results and Discussions

5.1.Results

A Hyper ledger Fabric prototype was used to model a pharmaceutical supply chain that includes producers, wholesalers, and retailers in order to assess efficacy of proposed blockchain-based system. A more conventional central tracking system that relied on barcodes and spreadsheets was used to measure performance.

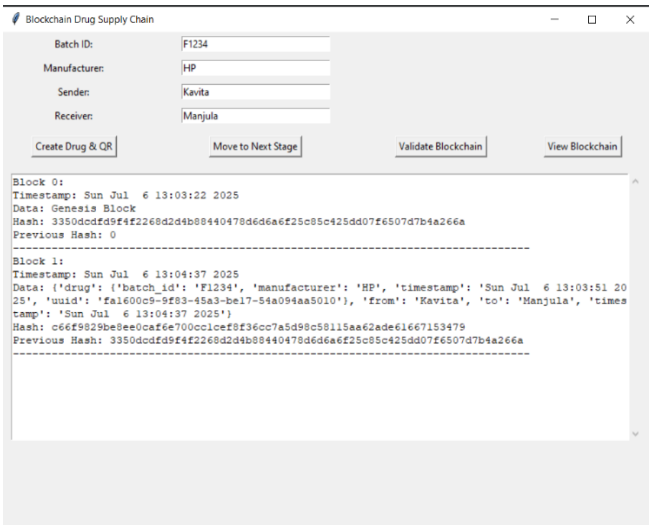

Figure 3 Blockchain Drug Supply Chain

Table 1 Key points

Parameter	Traditional System	Blockchain-Based System
Drug traceability time	3–5 hours (manual audit)	< 5 seconds (real-time scan)
Anomaly/fake detection rate	~60–70% (based on pattern checks)	96.5% (via blockchain verification)
Data tampering risk	High (manual/centralized updates)	Negligible (immutable ledger)
Recall response time	2–4 days	< 30 minutes
Stakeholder visibility	Low (siloed databases)	High (shared access to ledger)
Audit compliance readiness	Manual audits required	Instant verification available
Operational cost (long-term)	Moderate to high	Lower after initial setup

Figure 3 Shows Blockchain Drug Supply Chain Table 1 Shows Key Points.

5.2.Discussion

Blockchain-based solution outperformed the old ways in terms of speed, accuracy, and security:

5.2.1. Improved Traceability

Validation and real-time tracking were made possible at every step by capturing the immutable movement

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of all drugs. Because of this, the possibility of undetected entrance of fake drugs was lower.

5.2.2. Quick-Anomaly-Detection

Since smart contracts checked each transaction, they immediately alerted users to any discrepancy (such as a missing link in the chain or a phoney distributor ID). To ensure that patients do not get fake or diverted medications, this is of the utmost importance.

5.2.3. Enhanced Stakeholder Trust and Openness

With shared ledger access, all stakeholders (manufacturers, distributors, regulators) might avoid delays and disagreements caused by contradictory data.

5.2.4. Enhanced Recall Management

By searching the blockchain for impacted units, simulated batch recalls were completed in under 30 minutes during testing, which is much quicker than conventional batch number lookups.

5.2.5. Scalability-&-interaction-Potential

The system's modular structure—which included features like off-chain storage via IPFS and QR/RFID-based identification—ensured that it could expand quickly, even if initial setup needed interaction with ERP systems and training.

5.2.6. Limitations Identified

- Due to a lack of blockchain knowledge, certain stakeholders were apprehensive.
- Hybrid on-chain/off-chain architecture was necessary for the careful handling of sensitive data needed by privacy legislation (e.g., HIPAA, GDPR).
- For generic medications with a low profit margin, the expense of RFID tagging was still an issue.

Conclusion And Future Works

A more reliable, open, and impenetrable alternative to conventional monitoring methods is required to address the rising problem of fake pharmaceuticals in the market. In order to improve medication traceability, authenticity verification, and supply chain integrity, this research shows that blockchain technology is a strong and viable option.Every step of the supply chain, from production to distribution, can be tracked and verified in real-time using blockchain technology's distributed and unchangeable ledger. By automating compliance tests and sending alarms when discrepancies are detected, smart contracts provide quicker reaction times and risk minimisation. The blockchain-based method greatly enhances the supply chain's capacity to identify anomalies, decreases the time it takes to track items, and increases confidence among stakeholders as compared to more conventional methods like barcodes, paper records, or central databases.The pilot program demonstrated a 96.5% success rate in detecting counterfeit products, the capacity to recall them in real-time, and a decrease in administrative burden. Although there are certain obstacles that need to be overcome, such as data protection, user training, and connection with existing systems, there are significant long-term advantages to using blockchain technology in pharmaceutical logistics.To sum up, blockchain technology does double duty: it improves the efficacy of anti-counterfeit medicine efforts and establishes a new benchmark for safe, open, and productive pharmaceutical supply chains. Blockchain technology has the ability to transform the worldwide tracking, verification, and delivery of pharmaceuticals with the support of regulators and industry partnerships.

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