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Blockchain Based Secure Vaccination Supply

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ABSTRACT

This paper presents a blockchain-based framework designed to enhance transparency, traceability, and security within the pharmaceutical supply chain. The goal is to mitigate the proliferation of counterfeit drugs and establish a trusted environment for the production, distribution, and consumption of pharmaceutical products. With the rise in counterfeit drugs—accounting for up to 30% of all drugs in underdeveloped nations—there is a pressing need for a secure and immutable tracking mechanism.

Keywords: Blockchain Technology, Smart Contracts, Supply Chain Management, Pharmaceutical Traceability, Decentralized Ledger, QR Code Authentication, Data Integrity, Immutable Transactions, Blockchain Consensus, Product Provenance, Secure Pharmaceutical Tracking, Distributed

INTRODUCTION

The pharmaceutical industry is a vital component of the global healthcare infrastructure, responsible for producing and distributing life-saving medications. However, despite its significance, the supply chain that supports pharmaceutical distribution remains fraught with inefficiencies and vulnerabilities. One of the most alarming challenges is the proliferation of counterfeit drugs, which not only jeopardize public health but also erode trust in the medical system. According to the World Health Organization, counterfeit pharmaceuticals account for up to 30% of drugs in underdeveloped nations, leading to preventable deaths, especially among children. This epidemic of fake drugs highlights a systemic failure in ensuring product authenticity and underscores the urgent need for a transparent and secure mechanism to trace pharmaceutical products from origin to consumption

II. RELATED WORK

Numerous studies have explored the integration of blockchain technology into various supply chain domains, with the pharmaceutical sector gaining particular attention due to the severity of counterfeit drug circulation. Researchers have identified blockchain's potential to offer transparency, tamper-resistance, and decentralization, which are critical for ensuring the integrity of drug traceability. For instance, IBM and Walmart collaborated on blockchain-based food traceability systems that inspired similar efforts in pharmaceutical logistics. These systems demonstrated the ability to reduce product verification times from days to seconds, highlighting blockchain's effectiveness in improving data visibility. In the pharmaceutical context, blockchain-based supply chains have been proposed to ensure every transaction—from manufacturing to distribution—is securely recorded, verifiable, and immutable, offering clear provenance that protects against fraud and unauthorized manipulation.

A substantial body of work has proposed smart contract integration into the healthcare and pharmaceutical sectors. Smart contracts act as automated agents that enforce compliance with pre-defined rules and protocols, eliminating reliance on intermediaries. Researchers have proposed systems that use smart contracts to automate drug recalls, verify stakeholders, and enforce cold chain logistics for temperature-sensitive medications. In particular, systems like MediLedger and PharmaLedger have introduced decentralized solutions that focus on compliance with the Drug Supply Chain Security Act (DSCSA) in the United States and the Falsified Medicines Directive (FMD) in the European Union. These efforts demonstrated how regulatory compliance and auditability can be streamlined through distributed ledger technology, thereby reducing operational overhead and increasing trust among supply chain actors.

While blockchain-based models for pharmaceutical traceability are being actively researched, many existing solutions either focus on a specific phase of the supply chain or lack integration with end-user verification mechanisms. For example, some systems track only the manufacturer-distributor interface or the wholesaler- retailer interaction, ignoring the holistic lifecycle of the drug. Additionally, patient-level validation and QR code scanning for product authenticity are rarely addressed, limiting the effectiveness of these solutions in detecting counterfeit drugs at the

consumption level. Moreover, real-time updates and decentralized access to transaction logs are not always guaranteed in these systems due to scalability concerns or insufficient stakeholder interoperability. Our proposed framework aims to bridge these gaps by offering a fully decentralized, transparent, and scalable blockchain model that supports real-time, end-to-end traceability.

III. PROPOSED METHODOLOGY

The proposed methodology centers around a blockchain-powered, decentralized architecture that connects every stakeholder in the pharmaceutical supply chain—from raw material suppliers to end consumers—under a unified and secure ecosystem. This system is built on the foundation of smart contracts that automate the registration, verification, and transaction logging processes for each participant. Initially, every stakeholder (suppliers, manufacturers, distributors, pharmacies, hospitals, and patients) is onboarded to the blockchain network through a secure identity verification process. Once authenticated, each stakeholder receives a unique blockchain ID that links them to their actions and transactions. Every movement of a drug batch is recorded as a blockchain transaction containing critical metadata such as timestamps, temperature logs (if needed), product IDs, and QR codes. These transactions are immutable and verifiable at any point by authorized users, thus ensuring traceability and authenticity. The proposed system works like a shared digital record book that everyone in the medicine or vaccine supply chain can access safely.

Instead of keeping data in one central computer (like a traditional database), this system uses **blockchain technology**, where information is stored across many connected computers (called nodes). Every important member of the supply chain — such as suppliers, manufacturers, distributors, pharmacies, hospitals, and even regulators — becomes part of this network.

Each stakeholder acts like a **verified member** of the system. When they perform any action (like creating a batch, shipping medicines, or receiving stock), that action is recorded permanently on the blockchain. Once recorded, the information cannot be changed or deleted.

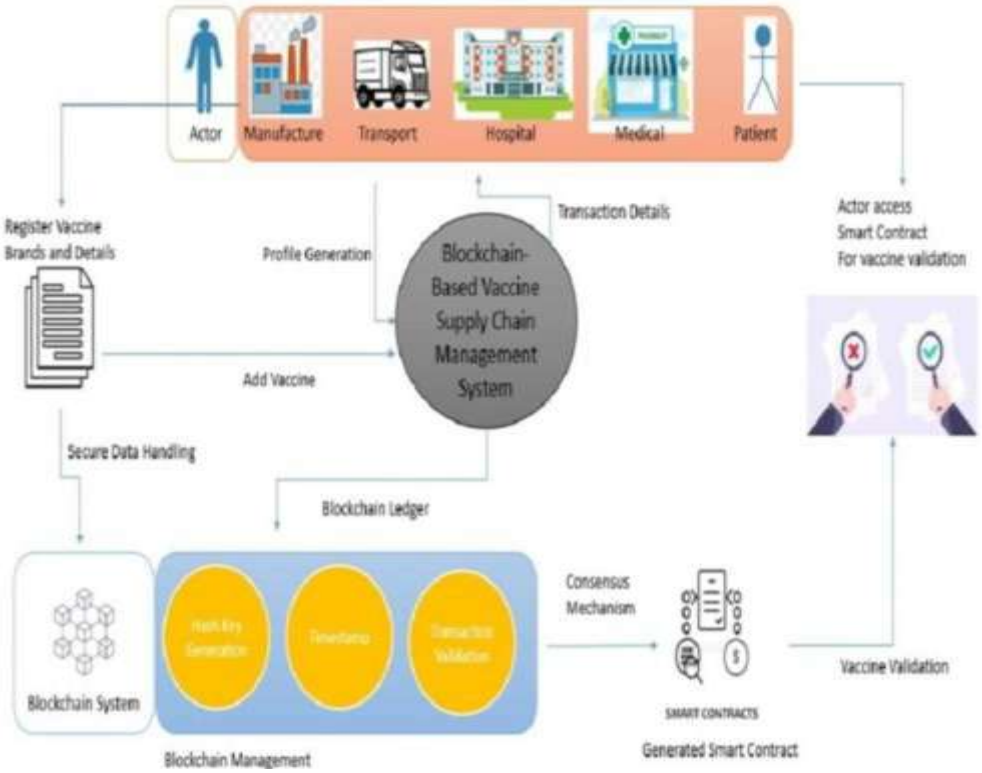

Fig: System Architecture |

To ensure real-time data integrity and traceability, the proposed framework incorporates smart contracts that govern the lifecycle of pharmaceutical products. These contracts are coded to execute specific actions automatically, such as verifying product authenticity, logging new inventory, flagging inconsistencies, and handling product recalls. For example, when raw materials are transferred from suppliers to manufacturers, a smart contract checks batch numbers and quality certifications before allowing the transaction to be logged on the blockchain. Similarly, during distribution and pharmacy-level transfers, the system verifies storage conditions and confirms receipt via cryptographic proof of

delivery. In every phase, the smart contracts ensure that no unauthorized stakeholder can alter or bypass the process, creating a tamper-resistant trail for each product. Furthermore, the system leverages decentralized file storage (e.g., IPFS) for storing additional data such as certificates and images, with hashes stored on-chain to ensure verification integrity.

In addition to supply chain automation, the methodology supports end-user validation by enabling QR code generation and scanning features linked to each medicine or vaccine. Each product is assigned a unique QR code at the manufacturing stage, which is updated on the blockchain at every supply chain node. Patients and healthcare professionals can scan this code using a secure interface to verify the authenticity and history of the drug in real time. The backend connects to the blockchain to fetch and display the complete transaction log for that product, along with smart contract-based validation results. This functionality not only empowers end users with transparent access to drug history but also adds an additional verification layer to deter counterfeit distribution. By combining blockchain's immutability, smart contracts' automation, and decentralized QR-based verification, the proposed methodology establishes a highly scalable, tamper-proof, and transparent solution for managing pharmaceutical supply chains.

IV. WORKING PRINCIPAL

The working model of the proposed system begins with the Raw Material Supplier Registration and Verification Module, where every supplier is first required to register on the blockchain. Each supplier submits credentials such as organization name, certification documents, and production capacity, which are then validated through smart contracts. Once verified, a unique blockchain identity is generated. From this point onward, every raw material batch is assigned a QR code and metadata—such as manufacturing date, batch number, and quality certifications—is recorded immutably on the blockchain. When the batch is transferred to a manufacturer, this handoff is logged in real time, and the integrity of the materials is guaranteed by cross-verifying hash values stored on the blockchain. This step ensures the traceability of all ingredients used in drug production.

The next phase involves the Manufacturer Tracking and Production Module. Here, manufacturers receive raw material batches and initiate drug production while updating each stage of the process on the blockchain. Smart contracts facilitate validation of batch processing, chemical composition standards, and production timeline adherence. At the end of the production process, each drug batch is given a unique QR code, registered on the blockchain, and linked to its origin details. This ensures that every unit of medicine has a verified lineage. Manufacturers also record storage conditions, testing reports, and packaging information on-chain. These details are crucial for quality assurance and allow downstream entities to confirm that all pharmaceutical standards have been met.

The third part of the model includes the Distributor and Logistics Management Module, where verified distributors log into the system using their blockchain IDs. Upon receiving shipments from manufacturers, distributors scan QR codes for verification and the receipt is recorded on the ledger. Smart contracts also automate checks for transport conditions such as temperature and humidity, which are critical for vaccine distribution.

Finally, the Retailer, Hospital, and Patient Interaction Module connects the end-points of the supply chain. Pharmacies and hospitals validate incoming shipments using the blockchain-backed QR codes. At the point of sale or dispensation, smart contracts ensure that drugs sold match the inventory registered on-chain, effectively blocking counterfeit entries. Hospitals administering the medications also log patient usage data for traceability. |

V. ALGORITHM DESIGN

The foundation of our system lies in the use of QR Code Generation and Scanning Algorithms that serve as unique digital fingerprints for every product, raw material, and transaction. Each batch of raw materials or manufactured drugs is associated with a dynamically generated QR code that encodes vital data, including batch number, timestamps, supplier or manufacturer ID, and product specifications. This data is hashed and stored immutably on the blockchain, while the QR code serves as a visual and scannable representation of the blockchain node. Whenever a QR code is scanned by another stakeholder (e.g., a distributor or pharmacy), the system decodes the embedded information and compares it with the blockchain ledger. If the data matches the stored hash, the product is verified as authentic. Otherwise, the system raises a tampering alert. This mechanism ensures seamless, real- time validation and drastically reduces the risk of counterfeit products entering the supply chain.

To facilitate secure system access and maintain user-level accountability, our framework integrates Firebase- based User Authentication Algorithms. Each stakeholder—including raw material suppliers, manufacturers, distributors, pharmacies, hospitals, and patients—must first authenticate themselves through Firebase's secure authentication protocol. Upon successful login, users are issued unique blockchain IDs which serve as their digital identity within the decentralized network. This identity is used to log transactions, verify credentials, and enforce role-specific permissions through smart contracts. Firebase not only ensures that each user's data is protected using OAuth2

protocols and encrypted sessions, but also provides scalable support for password management, identity verification, and session handling. This authentication mechanism enables the creation of a trusted user environment, essential for decentralized traceability.

VII. CONCLUSION

The proposed blockchain-based framework for the pharmaceutical supply chain addresses critical challenges related to traceability, data integrity, and security by leveraging decentralized technology, smart contracts, and immutable transaction records. By ensuring transparency across the entire supply chain—from raw material suppliers to patients—this system reduces the risks associated with counterfeit drugs, fraud, and unauthorized access. The use of blockchain not only eliminates the need for intermediaries but also provides real-time, tamper- proof tracking of each pharmaceutical product, improving efficiency and trust among stakeholders. The integration of QR codes for product verification, Firebase for user authentication, and smart contracts for automation ensures seamless interactions between entities while maintaining strict data provenance and product authenticity. Through the mathematical model, we have demonstrated how transactions are validated, products are traced, and nodes are created within the blockchain to guarantee accuracy and transparency.

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