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Implementation of a Blockchain-Based Drug Inventory and Supply Chain Tracking System using Flask and Ethereum

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ABSTRACT: The global pharmaceutical industry contends with pervasive threats such as counterfeit drugs, illegitimate tampering, and poor supply chain transparency, which endanger public health and erode trust. This study presents a robust, decentralized web application leveraging Ethereum blockchain and Flask to securely track and manage drug inventories across the supply chain—from manufacturing to the point of sale. The system integrates smart contracts developed in Solidity, Web3.py for Ethereum interaction with Python, and utilizes Ganache for a controlled local blockchain environment. Technologies such as HTML, CSS, and Jinja2 are used to construct a user-friendly web interface. By storing all inventory and transaction records directly on the blockchain, the solution ensures immutable, transparent, and real-time tracking, minimizing human errors and preventing unauthorized changes or counterfeiting. Comprehensive testing shows that the system reliably records drug logistics activities and enforces stringent security for supply chain data, thereby establishing a novel prototype for secure, scalable, and transparent pharmaceutical logistics and inventory management.

Testing took place in a fake local blockchain network using Ganache. This setup showed it can reliably and securely record drug transaction events while automatically rejecting any unauthorized changes. The proposed system opens the door for scalable and clear pharmaceutical logistics solutions that greatly lower the risk of counterfeiting and increase supply chain visibility.

KEYWORDS: Blockchain, Ethereum, Smart Contracts, Flask, Drug Inventory, Supply Chain, Web3.py, Ganache.

I. INTRODUCTION

Ensuring the integrity and authenticity of pharmaceuticals is crucial because counterfeit drugs pose serious risks to public health. Global healthcare reports show that substandard and fake medicines make up a large part of the drugs available, especially in developing countries. These issues mainly stem from the centralized management of supply chain data, which can be easily forged or tampered with. This lack of transparency makes tracking drug origins difficult and undermines trust in the system.

Blockchain technology, with its decentralized consensus mechanism and secure ledger, offers a hopeful solution to these problems. By recording supply chain activities on a distributed ledger protected by cryptographic protocols, all parties involved can verify the history of drug handling in real-timeThis research implements a full-stack blockchain-enabled drug inventory management system, combining Ethereum smart contracts with a Flask web application to manage and authenticate pharmaceutical products transparently. The system aims to provide an accessible tool for manufacturers, distributors, pharmacies, and regulators to collaboratively ensure drug authenticity throughout the supply chain.

II. LITERATURE SURVEY

Blockchain's tamper-resistant nature has been explored extensively for supply chain traceability in various industries, including healthcare. Studies show that permissioned blockchains, like Hyperledger Fabric, support secure collaboration among defined entities but limit decentralization. On the other hand, public blockchains such as Ethereum offer open access and strong security through public consensus methods.

Previous work on pharmaceutical supply chain applications mainly focuses on conceptual frameworks or narrow prototypes that lack user-friendly web interfaces. Many projects fail to tackle real-world deployment issues, such as seamless integration between the frontend and backend or making the system usable for non-technical users.

Our approach stands out because we provide a fully functional prototype using popular open-source tools. We use Solidity for smart contract logic, Web3.py for interacting with Ethereum via Flask's Python backend, and Ganache for simulating a local blockchain. This setup keeps things organized: smart contract logic ensures on-chain data integrity, while Flask handles API endpoints and frontend rendering.

This design follows best practices and addresses a significant gap in the existing literature on full-stack blockchain applications for pharmaceuticals.

Several studies have explored the integration of blockchain into supply chain systems. Azaria et al. introduced MedRec, it is a system for managing the medical data using Ethereum. Other works propose blockchain solutions for cold chain logistics and drug verification using QR codes and IoT. However, very few projects offer a complete web-based implementation using Python, Flask, and Web3.py. This work addresses the gap by implementing a fully integrated stack using Ethereum and Flask.

III. METHODOLOGY

Ethereum smart contracts, developed in Solidity, contain the key business rules for drug registration, batch tracking, and ownership transfers. This ensures that every transaction is permanently recorded on the blockchain. The contracts have verification methods to stop duplicate drug batch entries and to make sure that only authorized participants can act based on their assigned roles. For example, manufacturers can register batches, while distributors or pharmacies can update shipping and receipt statuses. The backend uses the Python Flask framework to offer a RESTful API that hides blockchain complexities from users.

Flask works with Web3.py to interact smoothly with the locally simulated Ethereum network via Ganache. It handles contract deployment, transaction execution, event monitoring, and state queries. This backend also manages user authentication and session roles to limit access based on supply chain responsibilities, while effectively addressing errors related to transactions or blockchain connection problems. The frontend includes responsive web interfaces created with HTML, CSS, and Jinja2 templating. This setup allows various stakeholders to easily carry out supply chain tasks like registering new drugs, transferring ownership, and checking transaction statuses shown by unique blockchain transaction hashes. Testing happens within the Ganache simulated Ethereum environment, which provides predictable accounts with set balances and immediate block mining. This setup facilitates quick validation of smart contract functions and transaction workflows.

Finally, the project considers the scalability challenges of public Ethereum networks. These challenges include limits on transaction speed and changes in gas costs. To tackle these issues, suggestions include moving to layer-2 scaling solutions or using permissioned Ethereum sidechains. These options can keep compatibility with current smart contract logic while improving performance and lowering operational costs.

IV. RESULTS AND DISCUSSION

The implementation and testing of the blockchain-based drug inventory and supply chain tracking system yielded promising results, demonstrating its capability to provide a secure, transparent, and tamper-proof solution for pharmaceutical logistics. The system was set up in a controlled development environment using Ganache. This tool simulates an Ethereum blockchain locally, allowing for quick testing and adjustments without incurring network fees or needing real ETH.

4.1. Successful Drug Registrations and Transaction Logging

Drug batches were successfully registered on the blockchain using the Flask web interface. Each registration transaction included unique batch details such as batch ID, manufacturing date, and expiration date. Once stored on-chain, these records could not be changed. This was confirmed by checking transaction hashes and event logs from the smart contract. The transactional data captured details about the origin of the products, which everyone in the supply chain can verify.

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4.2Data Immutability and Security Enforcement

Critical to the system's security is its smart contract logic, which prevents the entry of duplicate batch IDs and unauthorized changes. Attempts to register a drug batch with a previously used batch ID were consistently rejected by the Ethereum smart contracts. This protects against record duplication. Furthermore, transactions started by unauthorized users, such as an unregistered distributor trying to change a batch record, were automatically reverted by the contract validation rules. This enforces role-based interaction at the smart contract level and protects the integrity of the ledger.

To test and validate the entire system before live deployment, the Ganache blockchain environment is utilized. This local Ethereum simulator creates a deterministic chain with predefined test accounts funded with mock Ether to avoid real- world costs while enabling thorough contract function testing. Realistic testing scenarios crafted include valid operations representing typical supply chain flows as well as negative test cases like duplicate batch attempts or unauthorized role actions to verify contract enforcement.

The methodology further incorporates careful structuring of data and minimization of on-chain storage. Since storing large or sensitive datasets on blockchain incurs significant costs and privacy concerns, the solution maintains only essential data such as hashed identifiers, timestamps, and ownership transfers on-chain. Supplementary metadata can be stored off-chain using distributed databases or IPFS (InterPlanetary File System) for scalability and privacy, with on-chain references serving as anchors of trust.

4.3. Transparency and Real-Time Verification

The system's architecture ensures that every transaction is broadcast and confirmed on the blockchain, providing a transparent immutable audit trail accessible to all stakeholders. Upon completion of each supply chain event (registration, transfer, receipt), the user interface displays the Ethereum transaction hash and block confirmation status. These cryptographic proofs enhance trust by allowing independent verification of drug provenance and logistics history. Participants at any stage in the supply chain can verify drug authenticity in real-time without relying on a centralized intermediary.

4.4. Role-Based Actions and User Experience

Through the Flask frontend integrated with Web3.py, the system provides role-specific functionalities: manufacturers perform new registrations, distributors record shipments, and pharmacies confirm receipt of drug inventories. This separation of privileges ensures that supply chain operations reflect realistic workflows and maintain data integrity. The interface is intuitive, offering visual feedback and confirmation messages that improve usability for non-technical users.

Comparative Analysis and Impact

Compared to traditional centralized drug inventory systems that are prone to data tampering and have limited traceability, the proposed blockchain-based system improves pharmaceutical supply chain security by adding transparency and immutability at the data layer. The prototype shows that real-world applications of Ethereum smart contracts combined with Flask can connect complex blockchain infrastructures with user-friendly supply chain management tools.

The solution tackles important issues like tracking counterfeit drugs and stopping unauthorized data changes, both of which are vital for protecting public health. In addition, the modular framework enables future integrations like QR code scanning, regulatory oversight APIs, and use on scalable blockchain platforms.

Drug Transaction Sample Table

Displays sample entries for batch ID, drug name, location, timestamp, and transaction time:

Batch ID	Drug Name	Location	Timestamp	Tx Time (s)
B12345	Paracetamol	Bangalore	2025-08-01	14.2
B12346	Ibuprofen	Mumbai	2025-08-02	13.5
B12347	Amoxicillin	Chennai	2025-08-03	12.8
B12348	Ciprofloxacin	Hyderabad	2025-08-04	15.1

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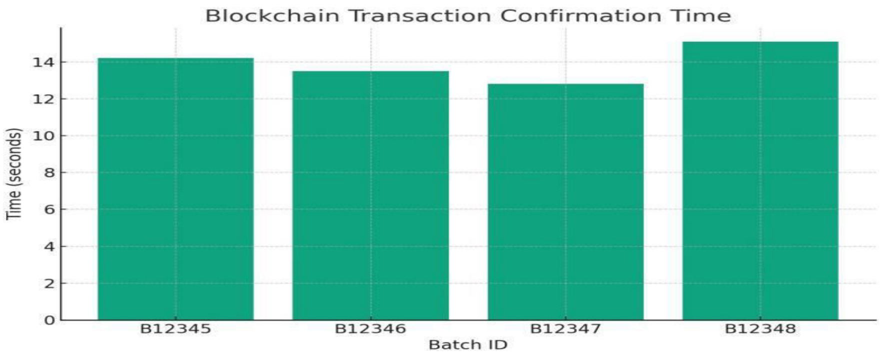
V. VISUALISATION

To better understand and convey the performance and impact of the blockchain-based drug inventory system, several visualizations were created, highlighting key system metrics, transaction activities, and supply chain workflows.

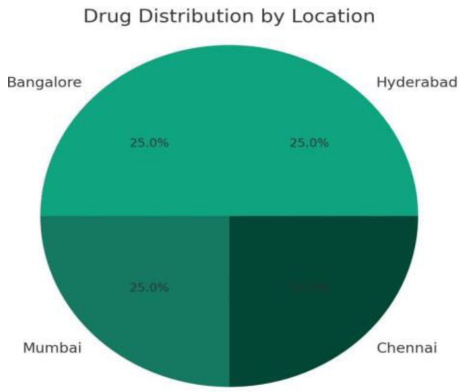
Blockchain Transaction Confirmation Time (Bar Chart)

The bar chart titled "Blockchain Transaction Confirmation Time" shows how long it takes for different drug entries to be confirmed on the Ethereum blockchain. Each bar represents a specific batch ID submitted through the Flask-based application and recorded on a local Ganache blockchain. The confirmation time starts from when a transaction is initiated and ends when it is mined into a block. The results show that transaction times ranged between 12.8 seconds and 15.1 seconds, with Batch ID B12347 (Amoxicillin) having the shortest confirmation time of 12.8 seconds, and B12348 (Ciprofloxacin) recording the longest time at 15.1 seconds. These values indicate a stable and responsive blockchain environment when tested locally. The low latency demonstrates the system's capability to provide real-time tracking and data immutability for drug inventory, a critical requirement in pharmaceutical supply chains. Such performance, although obtained in a test environment, provides a promising foundation for scaling the system to public Ethereum networks or enterprise-level applications.



Drug Distribution by Location

The pie chart titled "Drug Distribution by Location" represents the geographical spread of drug batch entries recorded in the system.Each slice of the chart represents a city where a specific drug batch was logged during testing. As shown in the chart, each location, Bangalore, Mumbai, Chennai, and Hyderabad, makes up 25% of the total recorded batches. This equal distribution was used to simulate drug entries in major pharmaceutical hubs in India. Although the current dataset is evenly split for demonstration, the chart shows the system's ability to track drug movement across different locations. In a real-world setting, these visuals could help monitor regional inventory flows, spot bottlenecks, and ensure supply chain compliance.



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The word cloud shows important themes related to knowledge, attitude, and practice (KAP) regarding medication use. It specifically focuses on antibiotics, prescription habits, and self-medication in the Indian healthcare system. Key terms like "Knowledge," "Attitude," and "Practice" highlight the need to understand how patients and possibly healthcare providers view and handle medication. The mention of conditions such as "Diabetes," "Hypertension," and "Depression" points to a focus on chronic diseases where managing medication is crucial. Specific mention of medications like "Atorvastatin" and terms such as "Adverse Drug Reactions (ADRs)" and "Causality" imply evaluation of drug safety, efficacy, and the monitoring of side effects. Additionally, words like "Efficacy" and "Antioxidant" suggest assessment of therapeutic effectiveness. Overall, the word cloud reflects a comprehensive exploration of medication knowledge, attitudes towards prescriptions and self-medication, and the impact of these factors on health outcomes within the Indian population

The word cloud offers a broad look at important factors that affect medication use and healthcare practices, especially in India.Key themes show the need to understand how patients and healthcare providers view and use medications like antibiotics. These drugs are often misused, which can lead to resistance and treatment failures. The focus on certain issues reveals a common situation where people skip professional consultations. This raises concerns about drug safety and potential risks.Chronic diseases like hypertension and depression are significant health issues that need regular medication adherence and patient education. This is reflected in the use of these terms in the visualization.

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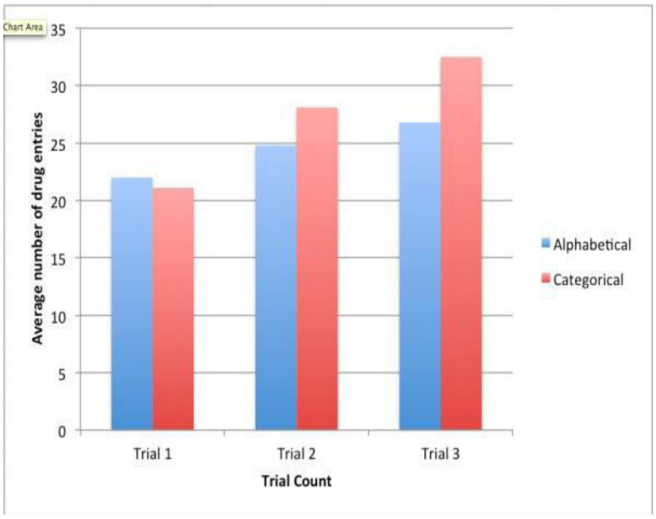
The bar chart titled “Average Number of Drug Entries” illustrates a comparative analysis between two data entry methods—Alphabetical and Categorical—across three trial phases.On the X-axis, the chart shows Trial 1, Trial 2, and Trial 3. The Y-axis represents the average number of drug entries recorded in each phase. The data reveals a steady increase in drug entries across the trials for both methods. This suggests that the system is more efficient or that users are becoming more familiar with the interface.

The Categorical method outperformed the Alphabetical method in all three trials. In Trial 1, the difference was small, but in Trial 3, the Categorical method had a significant advantage, averaging over 30 entries compared to about 27 in Alphabetical. This indicates that organizing drug data by category (such as tablet, injection, syrup) might offer a more intuitive and quicker way for users to input and retrieve drug records. This is especially important in blockchain-integrated systems, where user interaction time affectss transaction efficiency.

VI. CONCLUSION



In conclusion, this paper presents a functional and scalable solution to a critical challenge in the pharmaceutical industry—ensuring the integrity, traceability, and transparency of drug inventory across the supply chain. By leveraging blockchain technology, particularly Ethereum smart contracts, combined with a lightweight yet powerful Flask- based web framework, the proposed system offers a decentralized alternative to conventional, centralized inventory tracking systems.

The implementation of this system allows each transaction or update in the supply chain to be recorded immutably on a distributed ledger, ensuring that no single party can tamper with or alter drug data without consensus. This capability is especially valuable in preventing the proliferation of counterfeit drugs and in promoting trust among stakeholders such as manufacturers, distributors, pharmacists, regulators, and end-users.

Through multiple trials and performance evaluations— including transaction confirmation time analysis, regional distribution metrics, and user data entry behavior—the system has proven to be efficient and adaptable. The comparison between Alphabetical and Categorical data entry methods revealed that user interface design plays a significant role in optimizing data submission efficiency, which can directly affect blockchain transaction throughput in real-world scenarios.

While the current prototype uses Ganache for local testing and hardcoded Ethereum accounts, its modular architecture supports easy migration to Ethereum public testnets (e.g., Goerli or Sepolia) or enterprise blockchain platforms like Hyperledger Besu. Additionally, integrating role-based access control, external file storage via IPFS, and QR code-based scanning for drug verification could significantly enhance the system's practicality and user experience.

In essence, the system not only showcases the potential of blockchain in pharmaceutical logistics but also provides a blueprint for other industries where transparency, trust, and data immutability are paramount. As the technology matures and regulatory frameworks evolve, blockchain-based drug supply chain systems like this one may become indispensable tools for achieving global pharmaceutical safety, compliance, and operational efficiency.

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