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Blockchain-Based Supply Chain Management For Enhanced Traceability

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Abstract:

The pharmaceutical industry faces persistent challenges in ensuring the authenticity and safety of drugs within the healthcare supply chain. Counterfeit drugs, inefficient traceability systems, and lack of transparency pose significant threats to public health and industry integrity. Therefore, this research explores the implementation of blockchain technology to revolutionize drug traceability in healthcare supply chains. The main aim is to design and implement a blockchain-based drug traceability system, focusing on enhancing transparency, security, and real-time tracking. Key objectives include developing a decentralized ledger for transparent transactions, ensuring data immutability to prevent tampering, and enabling seamless interoperability across the supply chain entities. In addition, it employs a systematic approach, encompassing the analysis of existing traceability systems, the design of a blockchain-based solution, and the development of a prototype for testing and validation. Smart contracts and cryptographic techniques are utilized to secure transactions and ensure the integrity of supply chain data. Further, the introduction of blockchain technology in healthcare supply chain management offers a transformative solution to the longstanding challenges faced by traditional drug traceability systems. By leveraging blockchain's decentralized and immutable ledger, the pharmaceutical industry can establish a transparent, secure, and real-time traceability system, enhancing patient safety and overall supply chain efficiency.

Keywords: Blochchain Technology, Decentralized, Supply chain, Traceability, Smart Contracts, Transparency, Immutable Ledger, Security, Pharmaceutical industry, Cryptographic techniques, Efficiency.

1.INTRODUCTION

Healthcare supply chain is a complex network of several independent entities that include raw material suppliers, manufacturer, distributor, pharmacies, hospitals and patients. Tracking supplies through this network is non-trivial due to several factors including lack of information, centralized control and competing behaviour among stakeholders. Such complexity not only results in in-efficiencies such as those highlighted through COVID-19 pandemic but can also aggravate the challenge of mitigating again, counterfeit drugs as these can easily permeate the healthcare supply chain. Counterfeit drugs are products deliberately and fraudulently produced and/or mislabelled with respect to identity and/or source to make it appear to be a genuine product. Such drugs can include medications that contain no active pharmaceutical ingredient (API), an incorrect amount of API, an inferior-quality API, a wrong API, contaminants, or repackaged expired products. Some counterfeit medications may even be incorrectly formulated and produced in substandard condition. According to the Health Research Funding Organization, up to 30% of the drugs sold in developing countries are counterfeit. Further, a recent study by World Health Organization (WHO) indicated counterfeit drugs as one of the major causes of deaths in developing countries, and in most cases the victims are children. In addition to the adverse impact pharmaceutical industry. In this respect, the pharmaceutical industry. In this respect, the annual economic loss to the US pharmaceutical industry due to counterfeit medicine is estimated around $200 billion.

The pharmaceutical industry has been plagued by issues related to counterfeit drugs, diversion, and theft in the supply chain. Drug traceability in healthcare supply chains is crucial for ensuring patient safety and regulatory compliance. Traceability involves tracking the movement of drugs from manufacturers to consumers, verifying the authenticity of products, and detecting and preventing counterfeit drugs. These problems can lead to serious health risks for patients and financial losses for pharmaceutical companies. Traditional paper-based and centralized electronic systems have limitations in ensuring the integrity and security of supply chain data. Blockchain technology offers a promising solution to address these challenges by providing a decentralized, immutable, and transparent ledger for tracking drug transactions. Blockchain technology has shown potential in transforming various industries, including healthcare, by providing secure and transparent transaction records. Ensuring the authenticity and integrity of drugs is essential to safeguard public health. Drug traceability is necessary to comply with regulations, prevent counterfeiting, streamline recalls, optimize inventory management, and enhance overall supply chain efficiency. Blockchain technology offers a decentralized and tamper-proof solution, addressing the need for a reliable drug traceability system

The primary problems in traditional drug traceability systems include data inconsistencies, lack of real-time tracking, vulnerability to tampering, and limited transparency. Counterfeit drugs entering the supply chain, inaccurate information about drug origins, and delays in identifying the source of contaminated or substandard drugs are significant concerns.

2. LITERATURE SURVEY

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Corrado et al., Supriya, Djearamane and Jamal et al.[1] have proposed solutions for traceability but they use a centralized database which makes tampering goods information relatively easy and difficult to detect. In addition to that, the use of different types of centralized databases can result in the proposed solutions to have lack of interoperability and scalability. Mettler [2] have discussed the use of blockchain based approach for various issues in healthcare sector with no technical details or specific application.

Kurki [3], presented the advantages of blockchain technology in pharmaceutical supply chain. However, similar to only conceptual discussion was provided.

Muniandy and Ong Tze Ern [4] proposed a traceability system using Ethereum for anticounterfeiting. The proposed solution employs smart contract however it lacks implementation or evaluation which limits understanding the contribution.

Huang et al. [5] proposed a drug traceability system, Drugledger, which reflects the practical drug transaction logic in the supply chain, and generates both authenticity and privacy of stakeholders' traceability information without losing the resilience of the system. Drugledger completes its workflow based on the expanded UTXO data structure, especially that of package, repackage, and unpackage. However, recent studies such as have highlighted concerns with the use of UTXO data structure with respect to its weakness in programmability, high storage cost, and low state space utilization.

Faisal et al. [6] proposed a Hyperledger-based solution for drug traceability in the pharmaceutical supply chain. Authors report increase in the performance in terms of throughput and minimizes latency of the proposed system with less utilization of resources, however their solution was not rigorously tested and was implemented in a small-sized network. This effort also highlighted the challenge of achieving scalable solutions with blockchain which has received significant attention in recent literature such as.

Similar concerns are valid for the approach adopted by Hulseapple [7] who developed a private blockchain concurrently with the Bitcoin, which is used as a ledger to hash certain data to secure the transactions in chain. Every product has its own permanent record on their blockchain, making it impossible to manipulate with the private keys. The system was designed to protect every stage of product transfer in the supply chain, creating a trustless system of transparency.

In addition to the above, a number of active projects exist which are focused at exploring use of distributed ledger technologies to achieve traceability within pharmaceutical supply chain. For instance, Arsene [8] involves leading companies including IBM, Cisco, Accenture, Intel, Bloomberg, and Block stream where every drug is issued with a timestamp, making it traceable with its origin and manufacturer details.

Similarly, MediLedger [9] investigates use of blockchain to provide a solution compliant with the DSCSA regulation to increase interoperability in the industry.

Farmatrust project [10] aims to improve traceability in pharmaceutical industry based on Quorum blockchain with future plans to accommodate other platforms such as Ethereum and Hyperledger. The use of Quorum blockchain presents challenges such as lack of transaction ordering of transactions and policy enforcement which limits it widespread use.

3. PROPOSED METHODOLOGY

This research presents an Ethereum blockchain-based approach leveraging smart contracts and decentralized off-chain storage for efficient product traceability in the healthcare supply chain. The smart contract guarantees data provenance, eliminates the need for intermediaries and provides a secure, immutable history of transactions to all stakeholders. Additionally, the proposed system presents the system architecture and detailed algorithms that govern the working principles of our proposed solution.

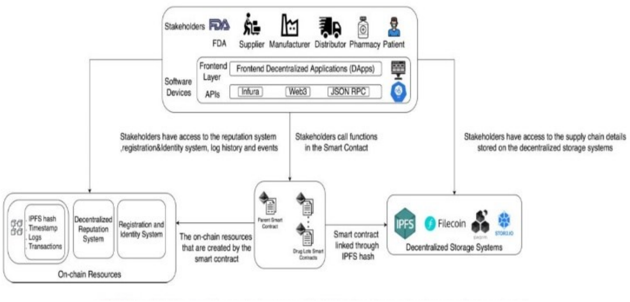

Figure 1: System architecture

Overview:

In summary, the project provides a Django-based web interface for users to interact with a blockchain-enabled system managing drug-related data. It covers aspects of user authentication, product management, and tracing updates using Ethereum smart contracts. Here is a more detailed overview:

- Blockchain Integration: The project leverages the Ethereum blockchain for storing and retrieving drug-related information. The web3 library is used to interact with the Ethereum blockchain through a local node (http://127.0.0.1:9545). Smart contracts deployed on the Ethereum blockchain are utilized to store and manage data.
- Contract Details: The smart contract details are stored in a JSON file named 'Drug.json'. The contract's ABI (Application Binary Interface) is loaded from this file, enabling communication with the deployed contract on the blockchain.
- Global Variables: Global variables like details, username, contract, and product_name are used to store and share data across different parts of the application.
- Views: The project consists of several views implemented in Django, each associated with a specific HTML template. Views include functionalities like rendering pages ('index', 'Login', 'Register', 'AddProduct'), user login, user registration, and product tracing updates.
- User Authentication: The project handles user authentication, with a distinction between regular users and an admin user (username: admin, password: admin). User login details are verified against the data stored in the Ethereum blockchain.

  Security Product Management: Users can add new drug products through the 'AddProduct' view. The product details, including name, price, quantity, description, and an associated image, are stored on the blockchain.
- Tracing Updates: The project allows users to update tracing information for specific drug products. This includes details

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such as the drug name, price, quantity, description, image, last update date, and current tracing information.

- Security Considerations: The project handles user authentication, but security aspects such as password hashing and protection against common web vulnerabilities (e.g., SQL injection, cross-site scripting) are not explicitly addressed in this code snippet. It's important to enhance security features for a production-level application.
- User Interface: HTML templates (e.g., 'index.html', 'Login.html', 'Register.html') are used to render the user interface for different views.
- File Handling: The project involves file handling, such as saving and displaying images associated with drug products.
- Date Handling: The 'datetime' library is used to capture and display dates, including the last update date for products

Applications:

Blockchain technology has a wide range of potential applications across various industries. Some examples of how blockchain is currently being used, or has the potential to be used, include:

- **Cryptocurrencies:** Blockchain technology is the foundation of cryptocurrencies like Bitcoin and Ethereum, which use blockchain to enable peer-to-peer transactions without the need for a centralized intermediary.
- **Supply chain management:** Blockchain technology can be used to create transparent and secure supply chain systems, allowing participants to track and verify the origin and authenticity of products.
- **Identity verification:** Blockchain technology can be used to create secure and tamper-proof digital identity systems, allowing individuals to prove their identity without the need for a centralized authority.
- **Voting systems:** Blockchain technology can be used to create secure and transparentvoting systems, ensuring the accuracy and legitimacy of election results.
- **Healthcare:** Blockchain technology can be used to create secure and transparent healthcare systems, enabling secure sharing of patient data and facilitating drug traceability.
- **Finance:** Blockchain technology can be used to create more efficient and secure financial systems, allowing for faster and cheaper transactions while reducing the risk of fraud and corruption.
- **Real estate:** Blockchain technology can be used to create more transparent and secure real estate transactions, allowing for faster and more efficient transfer of ownership.

Advantages:

Ethereum provides several advantages over other blockchain platforms and traditional systems. Here are some of the main advantages of Ethereum:

- **Smart Contracts:** Ethereum's main innovation is the ability to create smart contracts, which are self-executing contracts with the terms of the agreement between buyer and seller being directly written into lines of code. This allows for secure and automated execution of complex agreements without the need for intermediaries or third parties.
- **Decentralization:** Ethereum is a decentralized platform, which means that it is not controlled by any single entity or organization. This provides a level of trust and transparency, as there is no single point of failure or vulnerability.
- **Interoperability:** Ethereum's blockchain is open-source and allows for interoperability with other blockchain platforms, making it easier to integrate with existing systems and applications.
- **Programmable:** Ethereum's blockchain is programmable, which means that developers can create custom applications and smart contracts that meet their specific needs. This allows for more flexibility and customization than traditional systems.
- **Security:** Ethereum's blockchain is secured through cryptographic algorithms and consensus mechanisms, making it resistant to hacking and fraud. Additionally, smart contracts on the platform are auditable and transparent, which helps to reduce the risk of fraud and corruption.
- **Tokenization:** Ethereum enables the creation and exchange of tokens, which can represent assets, securities, or other digital assets. This makes it possible to create new business models and revenue streams that were previously not possible.

Overall, Ethereum provides a powerful and flexible platform for developers to build decentralized applications and execute complex smart contracts in a secure, transparent, and decentralized manner.

4. EXPERIMENTAL ANALYSIS

Fig 1 shows the homepage of the pharmacy system. It likely serves as the entry point for users, providing an overview of the platform's services and functionalities. The description highlights a "Login link," which suggests that users need to log in to access certain features. This homepage is crucial for establishing the initial impression and guiding users towards the appropriate sections of the system.

Fig 1: GUI of homepage

Fig 2 depicts the login screen for regular users of the pharmacy system. It likely features fields for username and password, allowing users to access their accounts. This interface is essential for user authentication and ensuring that only authorized individuals can access their personal information or place orders. The login screen's simplicity suggests a straightforward access point for authorized users to manage and track drug information within the supply chain. The pre-filled "admin" username might indicate a development or initial setup phase, highlighting the need for secure user credentials in a production environment

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Fig 2: User Login Screen as admin

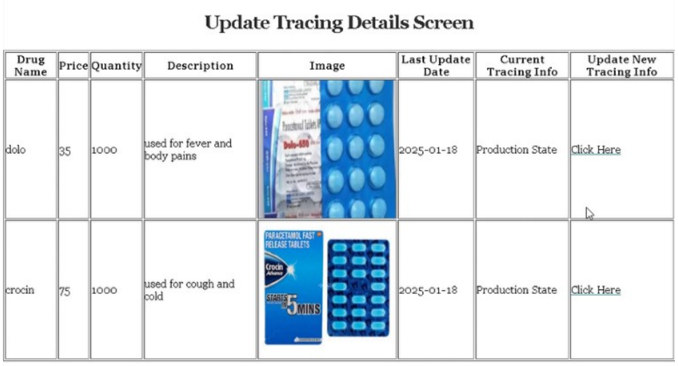
Fig 3 shows the interface is specifically for administrators of the pharmacy system. It provides a separate login portal, distinct from the regular user login. The description mentions that administrators can "click on 'Add New Drug' link to add new product details" after logging in. This indicates that administrators have elevated privileges to manage the product catalog and perform other administrative tasks

Figure3: GUI of admin login

Fig 4 interface is used by administrators to add new drug products to the system's catalog. The description explains that administrators can "add all Drug details" and "upload image" of the product. This suggests that the interface includes fields for product name, description, price, dosage, and other relevant information, as well as an option to upload product images. This functionality is crucial for maintaining an up-to-date and comprehensive product catalog.

Fig 4 : Add New Product Screen

Fig 5 GUI presents a table-based view of existing tracing details for a drug. The table likely includes columns for tracing type, details, and potentially other relevant information. This interface allows users to view and possibly edit the recorded tracing data. The "Update" functionality suggests that changes to tracing information can be made, but the system may also maintain a history of modifications, ensuring accountability and transparency.


Update Tracing Details Screen

Drug Name	Price	Quantity	Description	Image	Last Update Date	Current Tracing Info	Update New Tracing Info
dolo	35	1000	used for fever and body pains		2025-01-18	Production State	Click Here
crocin	75	1000	used for cough and cold		2025-01-18	Production State	Click Here

Fig 5: Update Traicing Details Screen

Fig 6 interface enables users to record the tracing details for a specific drug. The user selects a "Tracing Type" from a dropdown or list, such as batch number, manufacturing date, or location, and then enters the corresponding details. The "Store current tracing data to Blockchain" button indicates that this information is also recorded on the blockchain, further emphasizing the system's focus on secure and transparent tracking. This functionality is crucial for maintaining a comprehensive and auditable history of drug movement and handling

Fig 6: Add Drug Tracing Details Screen

This image depicts a user interface for a system designed to manage drug traceability within the healthcare supply chain, leveraging blockchain technology. The prominent header, "Drug Traceability in HealthCare Supply Chain using Blockchain Technology," clearly defines the system's purpose. The interface features buttons for "Add New Drug," "Update Tracing Details," and "Logout," suggesting core functionalities related to drug management and tracking. A central graphic with the heading "Blockchain in Pharma" reinforces the system's focus on blockchain technology within the pharmaceutical context. The "Tudip" logo at the bottom right likely identifies the software developer.

The message "Tracing details updated" at the bottom of the screen indicates a successful data modification, suggesting the system allows users to record and track changes in drug information throughout the supply chain. The overall design implies a user-friendly interface aimed at healthcare professionals.

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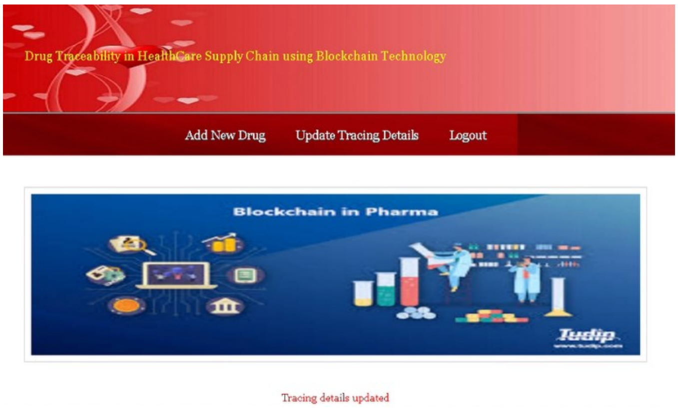


Fig 7: GUI of Tracing Details Uploaded

Fig 8 shows the GUI which is designed for new users to create accounts within the pharmacy system. It presents a simple form with fields for entering signup details. The user is expected to input their information and then click a button to submit the form. The text description mentions that "in above screen user is entering signup details and then press button to get below output," implying that upon successful submission, the system will provide some form of confirmation or proceed to the next step, such as logging the user in or displaying a welcome message. This screen is crucial for onboarding new users and granting them access to the system's functionalities.

Figure 8: New User Signup Screen

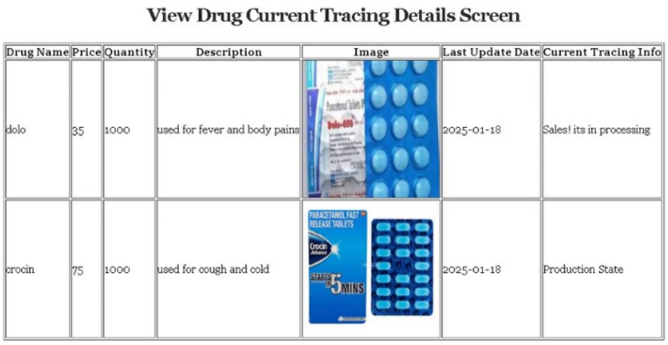
Fig 9 interface is for existing users to log in to the pharmacy system. It features a straightforward login form, presumably with fields for username and password. The description states, "In above screen user is login and after login will get below output," suggesting that upon successful login, the user will be redirected to their account dashboard or a specific page within the system. This screen is essential for granting access to registered users and ensuring that only authorized individuals can access sensitive information or perform actions within the system.

Fig 9: User Login Screen

Fig 10 shows the user interface after a successful login. The description mentions, "In above screen in blue colour text we can see user details saved in Blockchain and now click on "View Drug & Tracing Details" link to get all product details." This indicates that the system utilizes blockchain technology to store user details securely and immutably. The "View Drug & Tracing Details" link suggests that the user can access a catalogue of products and their associated tracing information, highlighting the system's emphasis on transparency and traceability. This screen represents the user's entry point into the system's core functionalities after successful authentication. Login Screen

Fig 10: GUI of User login

Fig 11 GUI presents a table-based view of drug tracing details. It allows users to see comprehensive information about a specific drug, including product details and its tracing history. The table format likely includes columns for various tracing attributes like batch number, manufacturer, current location, and timestamps. This interface is crucial for ensuring transparency and accountability in the drug supply chain, allowing users to verify the authenticity and track the movement of pharmaceutical products. The description mentions that "any user can know current tracing and manufacturer details of any drug," highlighting the system's focus on providing accessible and verifiable information to a wide range of stakeholders.



View Drug Current Tracing Details Screen

Drug Name	Price	Quantity	Description	Image	Last Update Date	Current Tracing Info
dolo	35	1000	used for fever and body pains		2025-01-18	Sales! its in processing
crocin	75	1000	used for cough and cold		2025-01-18	Production State

Fig 11: View Drug Current Tracing Details Screen

5. CONCLUSION

In this article, we have investigated the challenge of drug traceability within pharmaceutical supply chains highlighting its significance especially to protect against counterfeit drugs. We have developed and evaluated a blockchain-based solution for the pharmaceutical supply chain to track and trace drugs in a decentralized manner. Specifically, our proposed solution leverages cryptographic fundamentals underlying blockchain technology to achieve tamper-proof logs of events within the supply chain and utilizes smart contracts within Ethereum blockchain to achieve automated recording of events that are accessible to all participating stakeholders.

The future scope of the provided Django application is extensive and includes enhancements in security measures, such as secure password handling and HTTPS implementation, the introduction of user profiles and permissions, and the establishment of an audit trail system for tracking user activities. Additional improvements involve refining the user interface, developing a mobile application, and exploring integration with external APIs to enrich drug-related information. Consideration should be given to decentralized identity solutions, compliance with data privacy regulations, and optimization of performance through caching mechanisms and profiling. The application's evolution may also involve community engagement, documentation enhancement, cross-blockchain compatibility, and the integration of machine learning for predictive analytics. Scalability considerations and internationalization/localization features further contribute to the application's adaptability and robustness in the pharmaceutical and blockchain domains..

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