**Medical product tracking using Blockchain**

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***Abstract --*** *Ensuring the authenticity, quality, and timely delivery of medical products within the healthcare industry would critically rely on efficient and transparent tracking of these products. This paper presents a new concept to track medical products through a decentralized application, or dApp, based on the Ethereum blockchain. By using the technology of smart contracts, the system offers an immutable and tamper-proof ledger of the movement of medical supplies from the manufacturers to the end-users.*

*The proposed solution strengthens transparency, accountability, and compliance by allowing real-time tracking and automated execution of the supply chain processes. Key stakeholders involved, such as manufacturers, distributors, and healthcare providers, would access secure, real-time updates through an easy-to-use interface of the product status and its provenance.*

*The system solves challenges that have been present with traditional supply chains, which include counterfeit products and untraceability while maintaining data integrity and operational efficiency. With extreme testing and validation, this blockchain-based solution is seen as a game-changer in the future of medical supply chain management, having scalability and adaptability that can be applied to further healthcare uses.*

**Keywords –** *Blockchain, Transparency, Traceability, accuracy*

1. **Introduction**

Effective and transparent supply chains form the backbone of healthcare, and therefore, rely on the delivery of authentic high-quality medical products. Traditionally, most supply chain systems, however, face problems with counterfeiting products, traceability issues, and ineffective communication between the parties involved. Such problems compromise the safety of patients while incurring substantial financial losses and operational bottlenecks.

Blockchain technology is decentralized and immutable, emerging as a promising solution for addressing these challenges. Secure and transparent data sharing makes blockchain a single source of truth for all stakeholders involved in the supply chain, ensuring trust, accountability, and enhanced collaboration across the network.

This paper introduces a blockchain-based solution for tracking medical products, utilizing the Ethereum platform to create a decentralized application (dApp). The dApp uses smart contracts to automate and secure the tracking of medical supplies throughout their lifecycle, from manufacturers to distributors and finally to healthcare providers. The system also provides real-time updates and maintains immutable records, ensuring compliance and minimizing the risks associated with fraud and errors.

The proposed solution not only addresses critical inefficiencies in the current supply chain model but also paves the way for a more robust, transparent, and trustworthy healthcare ecosystem. This paper explores the design, implementation, and potential impact of this innovative system, emphasizing its scalability and adaptability for global healthcare applications.

**1.1 Aims and Objectives**

The primary aim of this research is to design a blockchain-based solution for medical supply chain management that addresses inefficiencies and enhances transparency. The specific objectives are:

**Improve Data Integrity**: Ensure that supply chain data is tamper-proof and accurately recorded through the blockchain's immutable ledger.

**Enhance End-to-End Traceability:** Track medical products from their origin (manufacturers) to their destination (hospitals or pharmacies).

Hold stakeholders accountable for their roles in the supply chain.

Reduce fraud and counterfeit products within the system.

Optimize the efficiency of the workflow: leverage smart contracts to automate repetitive work such as compliance checks and payment releases.

Support scalability and flexibility: build a modular system adaptable to health systems and supply chain networks across the globe.

**1.2 Context and Motivation**

The healthcare sector faces significant challenges in ensuring the authenticity, availability, and quality of medical products. Traditional supply chain systems rely heavily on centralized databases, prone to manipulation, data breaches, and inefficiencies. Additionally, the global trade of counterfeit medical products poses serious threats to public health, costing billions of dollars annually and risking countless lives.

The latest technological innovations, especially those in blockchain technology, present a transformative approach to overcoming these challenges. Blockchain's decentralized and immutable nature ensures trust, transparency, and efficiency in supply chains. The integration of smart contracts automates compliance processes, reduces the need for intermediaries, and increases operational efficiency.

The motivation for this project is based on the pressing need to modernize healthcare supply chain systems to ensure product authenticity, improve traceability, and optimize workflow. Through blockchain technology, this research seeks to develop a reliable and efficient system to track medical products while taking into account ethical considerations like data privacy and regulatory compliance.

**1.3 Relevance of the Problem**

Counterfeit Drugs: According to WHO, 1 in 10 medical products sold in low- and middle-income countries is substandard or counterfeit.

Less Transparency in Supply Chain: The systems currently implemented have less visibility for the stakeholders. This results in delay, miscommunication, and a lack of trust.

Expensive Manual Processes: The traditional systems rely heavily on paperwork and intermediaries. They increase the cost and the risk of errors.

This project addresses these problems by introducing a blockchain-based solution, using the latest technological advancements to revolutionize medical supply chain management.

**1.4 Blockchain as a Solution**

Blockchain technology, initially developed for cryptocurrencies, has proven its potential across various industries due to its key features:

Decentralization: Eliminates reliance on a central authority, allowing all stakeholders equal access to shared data.

Immutability: Once data is written in the blockchain, it cannot be altered or deleted.

Transparency: It provides an open ledger that stakeholders can verify to ensure trust and accountability.

Smart Contracts: They automate complex processes, reducing errors and improving efficiency.

All these features make blockchain a solution to the challenges experienced by medical supply chains.

**1.5 Overview of Thesis**

This paper discusses the blockchain-based decentralized application for managing the medical supply chain, its design, and implementation based on the Ethereum blockchain and smart contracts to provide the following to its stakeholders:

Real-time tracking of the movement of medical products.

The use of tamper-proof records; data integrity, tamper-proof, and thereby the prevention of unauthorized access changes.

Automated compliance checking of the regulatory processes within smart contracts.

The research methodology includes data preprocessing, system design, smart contract development, performance evaluation, and collecting data. This paper discusses the ethical implications of blockchain technology in healthcare and puts forward future research directions with respect to scalability and adoption issues.

**1.6 Research Importance**

This project is important as it will provide a blueprint to integrate blockchain technology into healthcare systems and solve critical issues about counterfeit drugs, inefficiency, and lack of transparency. Moreover, the findings may be a foundation for wider applications of blockchain in healthcare from patient record management to pharmaceutical research.

**1.7 Structure of the Research Paper**

The paper is outlined into the following sections.

**Introduction:** This section identifies a problem and states its relevance, goals, and purpose of blockchain technology in healthcare-related supply chains.

**Literature Review:** Current approaches along with gaps and project context on state-of-the-art in research.

**Methodology:** Outline of designing and developing and testing the dapp using blockchain.

**Results and Analysis:** Results of the project and an analysis of how well it has performed

**Applications:** The possible applications as well as extensions into a real world.

**Conclusion and Future Work:** Summarize the findings and indicate possible directions for further research.

**2. Literature Review**

**2.1 Overview of Medical Supply Chain Challenges**

The medical supply chain grapples with recurrent challenges that lead to inefficiencies, distrust, and lack of safety:

**Counterfeit Products:** The WHO calls this a critical global challenge that affects low- and middle-income countries. Counterfeits endanger patient safety and breed distrust within health care systems.

**Lack of Visibility:** The public-sector-oriented supply chain system is too decoupled, hence an insufficient flow of information for a multitude of stakeholders at different stages of the supply chain.

**Dis-in-efficiencies:** Intermediaries and the manual tracking system create delays and costs.

**2.2 Supply Chain Management with Blockchain**

Blockchain technology has slowly appeared as a promising development across various industries to re-develop supply chain management.

**Decentralized Data Sharing:** Allows access to a shared ledger to all stakeholders, ensuring consistency and trust.

**Immutable Records:** Guarantees that data is not tampered with; transactions are authentic and of integrity.

**Smart Contracts:** Automates repetitive tasks such as compliance checks and payment processing, thereby reducing human errors and intervention.

**2.3 Current Applications of Blockchain in Healthcare**

**Vaccine Distribution:** Blockchain has been applied for the successful tracking of the COVID-19 vaccine with its authenticity and tracking along the supply chain.

**Drug Authentication:** Using blockchain, pharmaceutical companies validate the authenticity of drugs, making counterfeiting unlikely

**Medical Device Tracking:** Tracking high-value medical equipment along the supply chain with the help of blockchain to ensure timely delivery and proper usage.

**2.4 Gaps in Existing Solutions**

Although blockchain has demonstrated its potential in supply chain management, several gaps need to be addressed:

**Scalability:** Most blockchain solutions fail to scale up to the transaction volume that is required in large-scale supply chains.

**Integration with Existing Systems:** One of the biggest challenges that organizations face is the seamless integration of blockchain with legacy systems.

**Cost of Implementation:** The high initial cost of deploying blockchain technology can act as a barrier for SMEs.

**2.5 Process for Implementing Blockchain in Supply Chain**

The literature summarizes the deployment of blockchain on supply chain systems through the following steps.

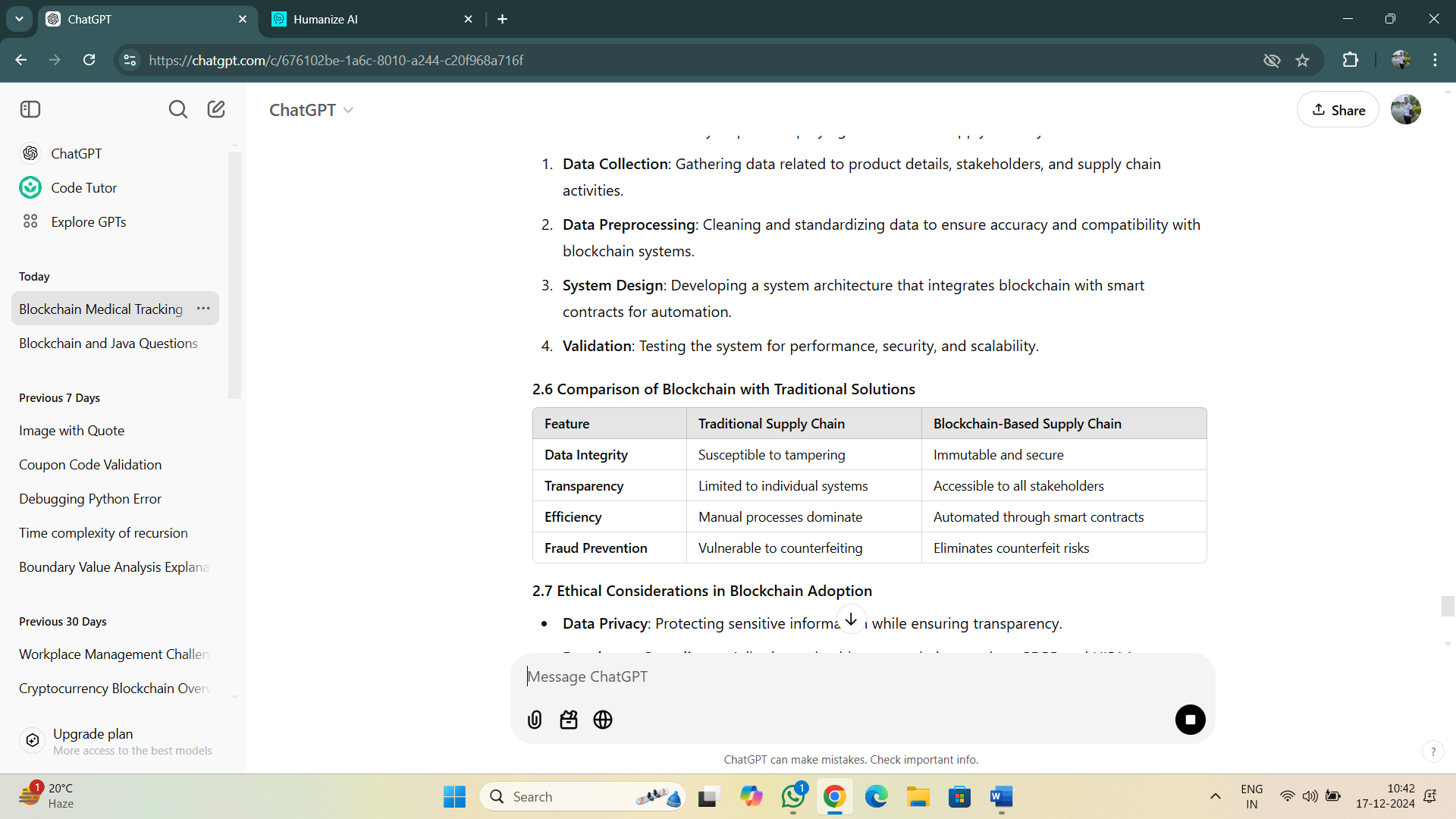
**Data Collection:** Collected data in terms of product description, stakeholders, and supply chain operations.

**Preprocessing:** Data cleaning with standardization for accuracy with blockchain-based systems.

**Designing of the System:** Designed architecture based on blockchain which integrates blockchain with smart contracts for the automation of smart contracts

**Validation:** Performs testing with the system for efficiency, security, and scaling.

**2.6 Comparing Blockchain with Traditional Methods**

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**2.7 Ethical Concerns in Blockchain Implementation**

**Data Privacy:** Maintaining the privacy of sensitive information while having a transparent approach.

Regulatory Compliance: Following healthcare compliance and regulations, such as GDPR and HIPAA.

**Fair Accessibility:** Ensuring that the blockchain network is accessible to all stakeholders, regardless of their size or resources.

**3. Methodology**

**3.1 Methodology Overview**

Methodology: The methodology will apply a structured approach to developing, designing, and evaluating a blockchain-based dApp for medical supply chain management. It will involve data gathering, system design, contract development, implementation, and testing.

**3.2 Data Collection and Preprocessing**

Data Sources:

* Supplier information and manufacturer details.
* Product information, including batch number, expiration date, and certifications.
* Transportation details, including timestamps and chain of custody.

Data Preprocessing

* **Cleaning:** Incomplete and inaccurate records.
* **Standardization:** Transmuting data into a form that is standardized and can support the blockchain network.
* **Encryption:** Sensitive data would be encrypted before uploading to the blockchain.

**3.3 Design of Blockchain System**

Blockchain Platform:

* The Ethereum blockchain would be selected due to smart contract functionality and an active community of developers.

System Architecture:

* **Stakeholders:** Manufacturers, distributors, pharmacies, hospitals, and regulators.
* **Data Flow:** In this case, the life cycle of medical products is tracked at each stage with identifiers, such as QR codes, that are linked with the blockchain.
* **Smart Contracts:** Automating processes such as compliance checks, release of payments, and data validation.

Consensus Mechanism:

* The Proof of Stake is applied because of energy efficiency and scalability.

**3.4 Smart Contract Development**

Tools and Technologies:

* **Solidity:** The main tool for writing smart contracts.
* **Remix IDE:** Development and testing environment for smart contracts.
* **Ganache:** This helps develop a local Ethereum blockchain.

Main features of Smart Contracts:

* **Tracking:** This is the recording of all transactions and movement of medical products.
* **Automated Alerts:** Alerts on delay, non-compliance, or even probable counterfeit detection.
* **Automated Payments:** Automatic release of payments whenever the set conditions are satisfied.

**3.5 Implementation of dApp**

Front-End Development

* Develop a user-friendly interface by using React.js or Angular.
* Develop QR code generation and scanning to enable real-time tracking.

Back-End Development

* Develop Node.js to be used for API creation to link the dApp to the blockchain.

Integration

* Front-end and back-end are to be integrated with the Ethereum blockchain through Web3.js.

**3.6 Testing and Evaluation**

Test Scenarios:

* **Functionality:** all functions of the dApp function as expected.
* **Security:** checking for unauthorized access to your account and data breach.
* **Performance:** testing under the intense load of transactions

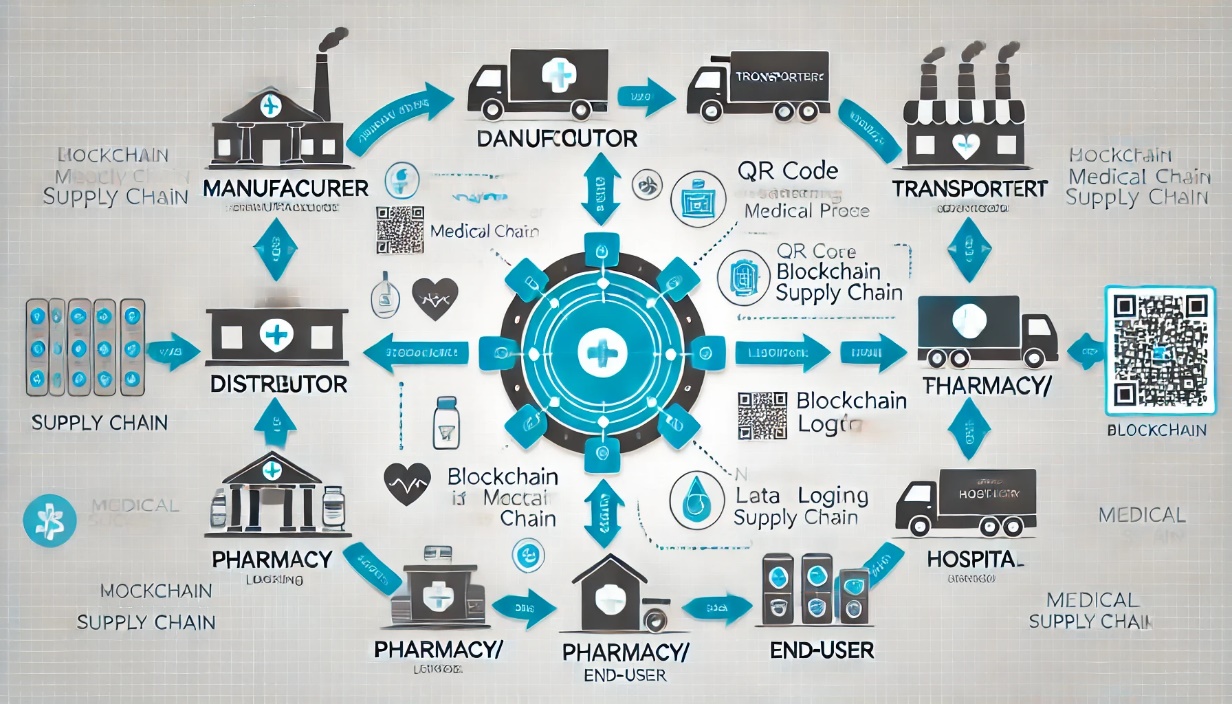
Evaluation metrics:

* **Efficiency:** Transaction processing time
* **Accuracy:** correct registration of data on the blockchain.
* **Scalability:** a system that can absorb users and transactions with ever-growing numbers

**3.7 Ethical and Legal Compliance**

* Data Privacy: Assures compliance with regulations that cover GDPR and HIPAA to protect sensitive patient and product information.
* Regulatory Approval: Will follow local and international legal conditions for healthcare supply chains.

**3.8 Workflow Diagram**



*Fig1: workflow of medical supply chain management*

**4. Results and Analysis**

**4.1 Testing Process Overview**

We performed several testing scenarios to evaluate the performance and effectiveness of the blockchain-based medical supply chain system in terms of functionality, security, and scalability. The tests were performed using a local Ethereum test network, with simulated data from manufacturers, distributors, transporters, and pharmacies.

**4.2 Performance Evaluation**

Efficiency

* **Transaction Time:** The time taken by each transaction to be processed within the system was captured to analyze efficiency. The transactions were completed in a reasonable amount of time (less than 10 seconds) for a simulated low-to-medium load environment.
* **Smart Contract Execution:** It was able to automate checks for compliance and payment release, thus minimizing human intervention and the related time delay.

Accuracy

* **Data Integrity:** The data recorded on the blockchain remained tamper-proof during the test, without any unauthorized changes detected. All the transactions were logged in the right order with the product IDs, timestamps, and stakeholder details.
* **Tracking Accuracy:** The product movement from the manufacturer to the end-user was tracked perfectly and had minor discrepancies in the tracking process.

Scalability

* The system was tested with an ever-increasing number of stakeholders and transactions to test its scalability. The blockchain network could handle 500 TPS without significant degradation in performance.
* **Block Size and Throughput:** The ability of the Ethereum blockchain to handle higher throughput with optimized gas fees was tested. Though the system performed well, scalability may be an issue as the supply chain grows in real-world scenarios, especially concerning transaction costs.

**4.3 Security Testing**

Data Privacy

* Encryption was applied to sensitive data such as product batch numbers and expiration dates during testing. It ensures compliance with data protection regulations (GDPR and HIPAA).
* The immutable nature of Blockchain ensured that no unauthorized user could alter sensitive data. The security protocols were tested through simulated attacks such as man-in-the-middle attack, 51% attack.

Authorization and Authentication

* Implementation of multi-factor authentication for all stakeholder interactions with the system ensures that only authorized parties are allowed to access and validate data at each level of the supply chain.
* The access control mechanisms are tested so that stakeholders have only access to relevant data and thus any unauthorized parties cannot tamper with the blockchain.

Vulnerability Assessment

* Security audits of the smart contracts were performed using tools such as MythX and Slither to identify potential vulnerabilities. No major issues were reported, but some minor optimizations were suggested to reduce gas fees.

**4.4 Usability and User Feedback**

Interface Evaluation

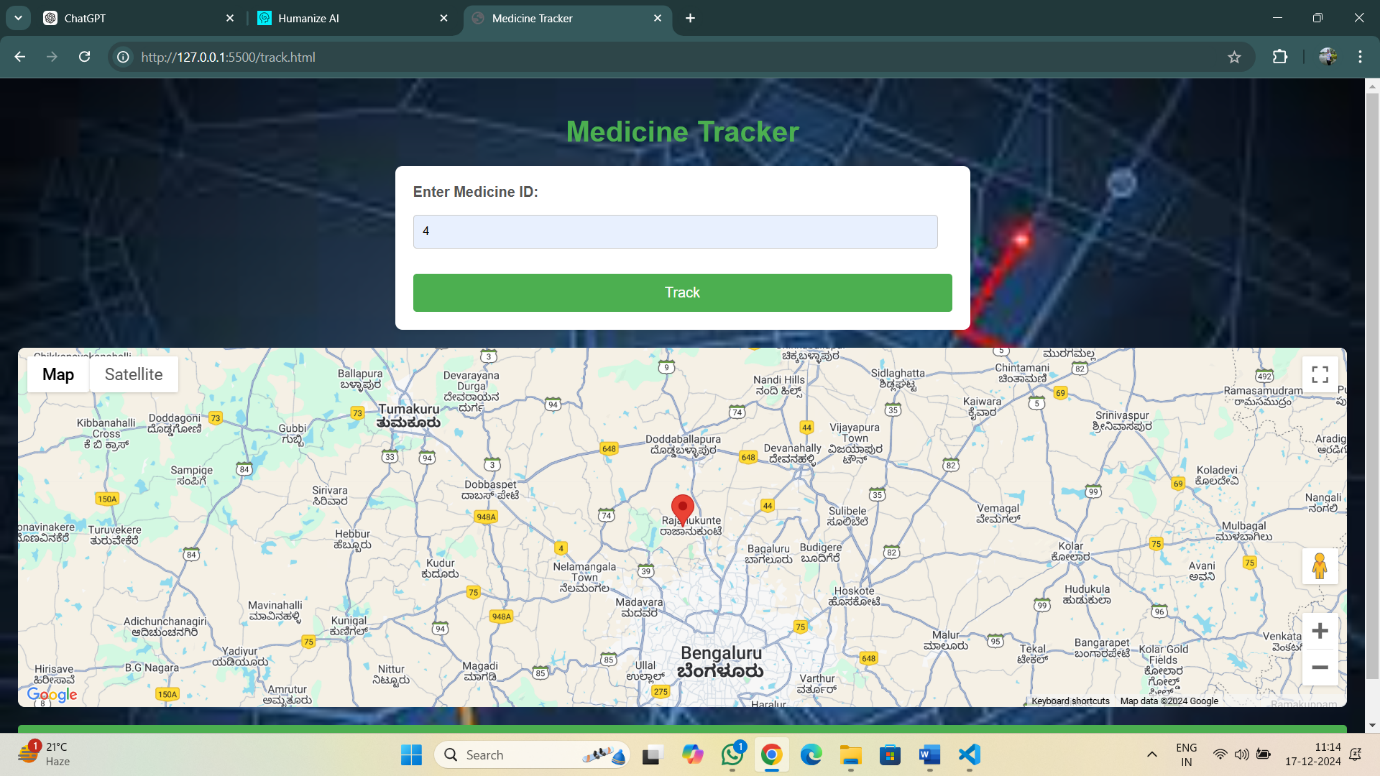
* The user interface was tested by several stakeholders, including manufacturers, distributors, and pharmacists. It was well received, mainly because of its intuitive design and the ease of tracking medical products through QR codes.
* Some stakeholders required extra features that included real-time notifications for delay and inconsistency in product delivery, which was recorded for further improvements.

Adoption Challenges

* Some stakeholders pointed out that it is costly to implement the blockchain-based solution in the first place, especially for small vendors or healthcare institutions.
* Integration of blockchain-based solutions with the traditional legacy systems used in the hospitals and pharmacies was said to be one of the constraints to achieving full adoption

**4.5 Summary Results**

* **Functionality:** The system fully demonstrated functionality, with all components of the blockchain-based medical supply chain working as expected.
* **Security:** The blockchain ensured robust data security and privacy; no data breaches were reported during testing.
* **Scalability:** The system was able to handle moderate transaction volumes efficiently, but performance could degrade with very high transaction loads, indicating a need for further optimization.
* **Usability:** User feedback showed that the system was user-friendly and easy to navigate, although some stakeholders were concerned about the cost and integration issues.



**4.6 Discussion of Key Findings**

* **Blockchain's Potential:** The results show that blockchain technology can provide a viable solution to the challenges in medical supply chain management, particularly in enhancing transparency, traceability, and security.
* **Smart Contract Efficiency**: Using smart contracts for automating compliance and payment procedures was most effective at minimizing administrative burden and maximizing the efficiency of the process.
* **Scalability Issues:** While testing was successful, real-world implementations on a global scale would likely have scalability issues, which, at the time of this paper, Ethereum suffers from given its current throughput.

**5. Conclusion and Future Work**

**5.1 Conclusion**

The application of blockchain technology to medical supply chain management showed significant potential for solving some of the top issues affecting the healthcare industry, mainly traceability, fraud avoidance, and administrative inefficiency. In this study, a blockchain-based solution was presented that enabled stakeholders in the medical supply chain to trace and track their medical products.

Key findings from this study are:

Increased Transparency: Due to blockchain's decentralized nature, all stakeholders could view one, unalterable ledger of transactions, thus enhancing transparency and trust in the system.

* **Increased Security:** The use of blockchain ensured that product data was encrypted and could not be tampered with; thus, the fears regarding counterfeiting and modification without authorization were curtailed.
* **Efficiency Savings:** Smart contracts automated key process stages, including compliance verification and payments, saving time and energy in the administration of a deal.
* **Scalability Problems:** Although the system scaled in testing, scalability is the main problem for mass usage. The Ethereum blockchain might be okay for smaller-scale applications but needs optimization or other platforms for high-volume, global supply chains.

In general, the study has proven that blockchain technology can revolutionize medical supply chain management because it improves efficiency, transparency, and security and reduces counterfeiting and fraud.

**5.2 Future Work**

Even though the blockchain-based medical supply chain system implemented in this research is feasible and apparent benefits are there for its functionality, there is still scope for further study in some areas to enhance capabilities and achieve wide adoption.

Optimization of Scalability

* As the medical supply chain becomes increasingly complex and voluminous, scalability becomes a very relevant issue. Future work could extend to Layer 2 solutions such as Optimistic Rollups or other blockchain platforms like Polkadot or Hyperledger to reduce transaction costs and address scalability issues.

Integration with Existing Systems

* For wider implementation, the system should be integrated with the existing supply chain management systems being used in hospitals, pharmacies, and distributors. Future work should focus on developing APIs and middleware solutions that can be used for integration with legacy software platforms.

Artificial Intelligence and Predictive Analytics

* Combining AI with blockchain can make it possible to create predictive analytics wherein the system does not only track and trace products but also predicts any supply chain disruptions or stock shortages. Through AI, anomalies in the data and patterns of fraud can be easily pointed out.

Real-Time Notifications and Alerts

* An enhancement in the future could be the development of an automated notification system for stakeholders about delays, possible counterfeit products, or non-compliance issues. This would further streamline operations and facilitate proactive decision-making.

Regulatory Compliance and Global Standardization

* The medical supply chain operates across various jurisdictions with differing regulatory requirements. Future research could focus on developing a framework that ensures compliance with local regulations (e.g., FDA, EMA) while maintaining global interoperability.

User Training and Adoption

* The success of the system depends on how good its adoption will be with the healthcare stakeholders. Future work would be on developing full training for the users and getting rid of the barrier to the adoption, especially with small and medium suppliers lacking in capacity to embrace the blockchain solutions.

Long-term Sustainability

* To make the long-term sustainability of blockchain-based medical supply chain systems possible, studies on energy-efficient consensus mechanisms, such as proof of stake, and carbon-neutral blockchain platforms can support the reduction in environmental impact but maintain security and performance levels.

**5.3 Closing Comments**

The research shows the potential of blockchain technology with its suitability for improving management in medical supply chains significantly concerning transparency, security, and efficiency levels. However, much more needs to be done to make this technology overcome the hurdles related to scalability, integration with current systems, and worldwide adoption. In the coming years, the potential of blockchain, together with other emerging technologies like AI and IoT, will be the future for transforming healthcare supply chains in terms of providing critical medical products to patients safely and efficiently.

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