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Drug Supply Chain Integrity Using QR Code with Blockchain-Powered Verification

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Abstract: ***The growing concern of counterfeit and substandard pharmaceuticals presents a significant threat to public health and safety. Ensuring the authenticity and integrity of drugs throughout the supply chain is crucial to combat this issue. Blockchain technology, with its decentralized and immutable ledger system, offers a robust solution to enhance transparency, traceability, and security in drug production and resale. This paper explores a blockchain-based framework that enables real-time tracking of pharmaceuticals from manufacturing to distribution and eventual resale, ensuring that only authentic medicines reach consumers. By leveraging cryptographic hashing and distributed consensus, the proposed system records every transaction in a secure and verifiable manner, preventing unauthorized modifications or counterfeit infiltration. Unlike conventional centralized tracking systems, which are vulnerable to security breaches, the blockchain model decentralizes data storage, making it resistant to tampering.***

The system facilitates seamless verification of a drug's journey, from production to distribution and resale, while also enabling patients to validate medication authenticity before purchase. Additionally, the framework incorporates a verifiable resale mechanism, allowing unused medicines to be returned and resold under regulatory supervision, thereby reducing medical waste and increasing accessibility to essential drugs.

This blockchain- driven approach not only minimizes human errors and operational inefficiencies but also strengthens trust among manufacturers, distributors, and consumers. By integrating smart contracts for automated verification and enforcement of compliance, the proposed system establishes a transparent and secure pharmaceutical supply chain. The implementation of this solution has the potential to revolutionize drug authentication and resale, providing a significant leap forward in ensuring patient safety and regulatory adherence in the pharmaceutical industry.

Keywords: Authenticity, Blockchain, Drug Traceability, Pharmaceutical Supply Chain, Resale Verification, Smart Contracts.

I. INTRODUCTION

The pharmaceutical industry plays a crucial role in global healthcare, ensuring that patients receive safe and effective medications. However, counterfeit drugs and substandard pharmaceuticals have become a growing concern, leading to severe health risks, loss of consumer trust, and financial setbacks for legitimate manufacturers. Traditional drug supply chain systems, which rely on centralized databases, often struggle with transparency, traceability, and security vulnerabilities, making them susceptible to fraud, data breaches, and manipulation. Blockchain technology offers a transformative solution to address these challenges by introducing a decentralized, secure, and tamper- resistant system for drug tracking and authentication. Unlike conventional systems, blockchain ensures that every transaction within the pharmaceutical supply chain—from manufacturing and distribution to patient purchase and resale—is permanently recorded and verifiable.

This transparency not only helps in detecting counterfeit medicines but also strengthens trust among stakeholders, including manufacturers, distributors, pharmacies, regulatory authorities, and consumers.

The proposed blockchain-based framework enhances drug traceability by assigning unique hash codes to medicines at the production stage, enabling seamless tracking throughout their lifecycle. Every transaction is securely stored in distributed ledgers, making it impossible for unauthorized alterations or fraudulent activities. Additionally, the system facilitates a verifiable resale mechanism for unused medications, allowing authorized resellers to redistribute medicines in a controlled and legitimate manner. This reduces medical waste while ensuring that only authenticated drugs are reintroduced into circulation.

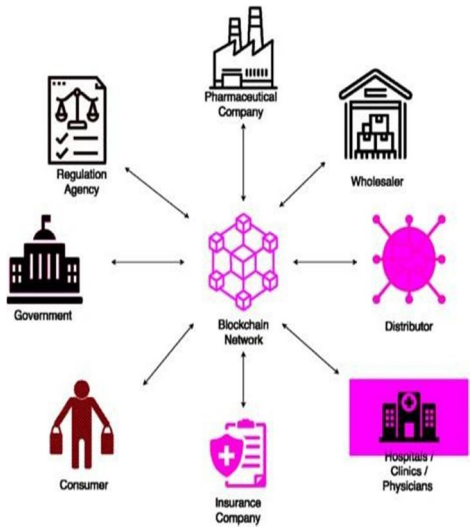

Figure 1: Securing Drug Distribution (Refer: https://www.researchgate.net/publication/353570148/figure/fig2/AS:1143128122611949 5@1709091246188/Blockchain-based-medical-supply-chain.png)

By leveraging cryptographic techniques, smart contracts, and consensus mechanisms, this blockchain-driven approach ensures data integrity, eliminates intermediaries, and enhances operational efficiency. This paper explores how integrating blockchain technology into the pharmaceutical supply chain can revolutionize drug authentication, minimize errors, and provide a secure ecosystem that benefits both the industry and consumers.

II. RELATED WORK

Durá et al.[1] explored the role of blockchain in ensuring data originality in pharmaceutical manufacturing. Their study highlighted how blockchain enhances the security and authenticity of drug-related data by preventing tampering and unauthorized modifications. The researchers demonstrated that the implementation of decentralized ledger technology ensures data immutability and improves regulatory compliance. Their proposed model enables real-time monitoring of drug production and distribution, reducing the risks associated with counterfeit pharmaceuticals. They also discussed smart contracts for automating verification and authentication processes, minimizing human intervention and associated errors. The study further emphasized the importance of integrating blockchain with IoT- enabled sensors for real-time tracking of temperature-sensitive drugs. The authors identified key challenges in implementing blockchain in large-scale pharmaceutical supply chains, such as scalability and interoperability. They provided insights into various cryptographic techniques that enhance transaction security. The study concluded that blockchain adoption can streamline regulatory audits and improve patient safety by offering end-to-end transparency.

Chen et al.[2] described emerging biotechnology applications in pharmaceutical analysis, emphasizing the role of advanced technologies in ensuring drug authenticity and quality. Their study focused on integrating biotechnology with blockchain to enhance transparency in drug development and distribution. The authors discussed how AI-driven analysis combined with blockchain can provide a highly secure and efficient method for pharmaceutical authentication. The paper highlighted case studies where blockchain was used to track raw materials and maintain detailed records of synthesis and formulation processes. The study also examined how blockchain technology reduces regulatory compliance costs while ensuring that only approved drugs reach the market. They proposed a hybrid framework where machine learning techniques detect anomalies in drug compositions while blockchain ensures data integrity. The research also discussed the implications of decentralized clinical trial data management using blockchain, ensuring accuracy and security. The authors emphasized the need for industry-wide blockchain adoption to improve global pharmaceutical supply chains.

Haji et al.[3] focused on the importance of blockchain in enhancing food quality, drug safety, and public health measures within supply chain management. Their study highlighted how blockchain improves traceability and transparency, ensuring that pharmaceutical products meet quality standards throughout their lifecycle. They presented a model where blockchain provides stakeholders with real-time access to drug-related data, minimizing the risks of counterfeit medications. The authors discussed the application of smart contracts to automate compliance verification, eliminating the need for third-party audits.

The study emphasized the advantages of a decentralized system in mitigating fraud and ensuring data reliability. They also explored the impact of blockchain on reducing pharmaceutical waste by enabling verifiable resale and redistribution of unused medications. Their proposed model leveraged IoT-enabled tracking systems to monitor temperature-sensitive drugs in transit. The research concluded that blockchain can significantly improve regulatory oversight and enhance patient trust in pharmaceutical products.

Bandhu et al.[4] proposed a blockchain and smart contract-based framework to enhance the security, traceability, and efficiency of the drug supply chain. Their study introduced a decentralized approach where each drug is assigned a unique hash code, ensuring complete traceability from manufacturing to end-user purchase. They highlighted how blockchain mitigates issues related to counterfeit drugs by providing an immutable record of transactions. The research discussed how smart contracts facilitate automated verification, reducing delays in drug authentication and approval processes. The study also demonstrated how blockchain can help pharmaceutical companies comply with regulatory standards by maintaining verifiable drug production and distribution records. The authors integrated IoT devices to monitor environmental conditions such as temperature and humidity, ensuring proper drug storage. They also examined how blockchain-based audits simplify regulatory compliance for drug manufacturers. The study concluded that blockchain significantly enhances pharmaceutical security, reduces fraud, and optimizes supply chain management.

Kumar, et.al [5] implemented the study provided a comprehensive review of pharmaceutical drug packaging and traceability, highlighting the role of blockchain in enhancing security and transparency. The author discussed how blockchain-based traceability systems prevent counterfeit drugs from entering the market by ensuring end-to-end tracking. The research explored various cryptographic methods used to secure pharmaceutical transactions and prevent data tampering. Kumar analyzed the integration of blockchain with QR code-based drug verification systems, allowing consumers to authenticate medicines before purchase. The study highlighted how blockchain improves supply chain efficiency by reducing manual intervention and streamlining documentation processes. The author proposed a decentralized framework where manufacturers, distributors, and regulators can access verifiable drug data. He also explored the role of AI and blockchain integration in detecting anomalies in pharmaceutical packaging. The study concluded that blockchain adoption enhances patient safety by providing secure, real-time access to drug authentication data.

III. BACKGROUND OF THE WORK

In the current pharmaceutical supply chain, tracking and verifying the authenticity of medicines rely on centralized databases managed by a single authority. This system involves multiple stakeholders, including manufacturers, distributors, pharmacies, hospitals, and customers. Each time a drug changes hands, its details are recorded in a central server to ensure traceability. While this approach provides a structured way to track medicine movement, it comes with several limitations. One of the biggest challenges of the existing system is its vulnerability to security breaches. Since all data is stored in a centralized location, it becomes a prime target for cyberattacks, unauthorized modifications, or even internal fraud. If an attacker gains access to the system, they can alter records, making it difficult to distinguish between genuine and counterfeit medicines. Additionally, the lack of a tamper-proof mechanism allows counterfeit drugs to enter the supply chain undetected, posing severe health risks to consumers. Another limitation is the inefficiency and lack of transparency in drug authentication. Patients and stakeholders often struggle to verify the legitimacy of medicines due to incomplete or inaccessible information. Governments and regulatory bodies have implemented various measures to improve drug traceability, such as barcode scanning and digital databases, but these solutions still rely on trust in centralized authorities, making them susceptible to manipulation.

Furthermore, the resale or redistribution of unused medicines is not effectively managed in the current system. Patients who wish to return or donate surplus medication often face difficulties due to the absence of a verifiable mechanism to ensure drug safety and authenticity. As a result, a significant amount of usable medicine goes to waste, increasing costs for both consumers and healthcare providers. Due to these challenges, the existing system fails to provide a foolproof method for ensuring drug authenticity, preventing counterfeiting, and enabling secure resale. A more advanced and transparent approach is needed to address these issues and strengthen trust in the pharmaceutical supply chain.

IV. PROPOSED METHODLOGIES

To address the challenges of counterfeit drugs, lack of transparency and inefficiencies in the current pharmaceutical supply chain, a blockchain-based drug authentication and resale system is proposed. This system leverages blockchain's decentralized, secure, and tamper- resistant architecture to ensure full traceability of medicines from the point of manufacturing to the end consumer, including a verifiable resale mechanism for unused drugs.

In this proposed framework, each drug is assigned a unique hash code at the time of production, which is stored on the blockchain along with essential details such as manufacturing date, batch number, expiration date, and quality certification. This ensures that every transaction, from production and distribution to customer purchase, is recorded in an immutable ledger that cannot be altered or tampered with. The system is managed by a blockchain network where all stakeholders, including manufacturers, distributors, pharmacies, and patients, act as nodes that validate and store transactions. Unlike centralized systems, blockchain ensures that no single entity controls the data, reducing the risk of fraud, unauthorized modifications, and cyberattacks. Even if a few nodes are compromised, the system remains secure and operational. One of the key features of this system is real-time drug tracking and verification. At every stage of the supply chain, authorized participants can scan a drug's hash ID to verify its authenticity and trace its journey. Patients can also scan a QR code on the packaging to confirm that the medicine is genuine, check its source, and even provide feedback on its effectiveness. Additionally, the proposed system introduces a secure resale mechanism for unused drugs. If a patient has surplus medication, they can return it to certified resellers or donation centers. These drugs undergo verification and, if deemed safe, are reintroduced into the supply chain at a lower cost or donated to healthcare organizations. This reduces medical waste, provides affordable medicine to those in need, and ensures that only authenticated drugs are resold. By implementing blockchain in pharmaceutical supply chain management, this system eliminates human errors, inefficiencies, and security risks associated with traditional methods. It enhances trust among stakeholders, minimizes counterfeit drug circulation, and improves accessibility to safe and verified medicines. Figure 2 illustrates the process of proposed system.

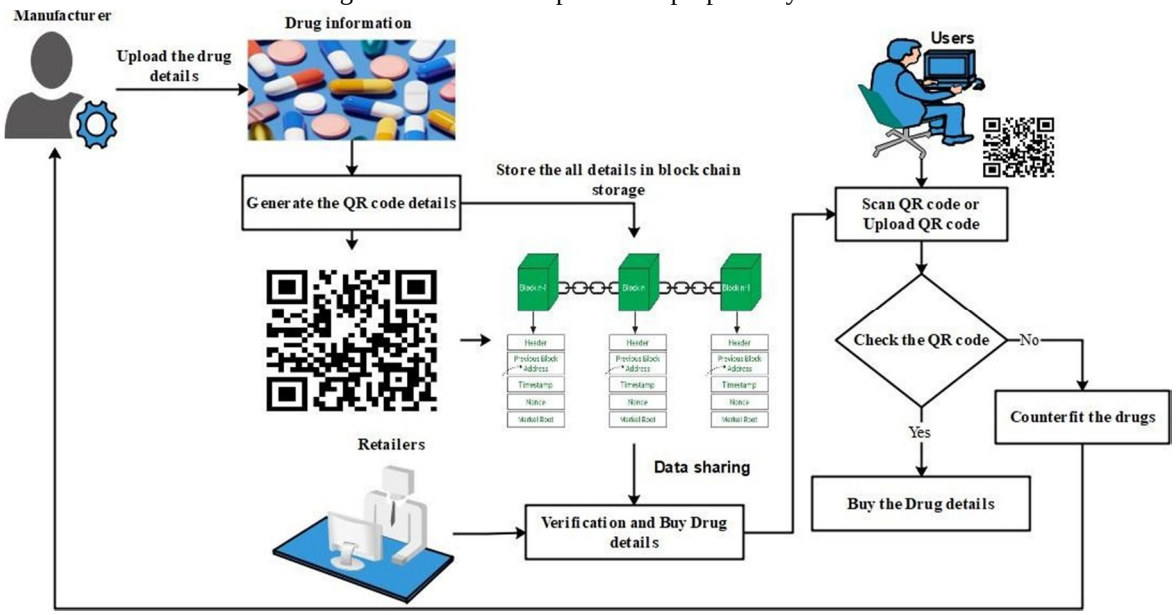

Figure 2: Architecture diagram of Proposed System

V. EXPERIMENTAL RESULTS

To evaluate the effectiveness of the proposed blockchain-based drug authentication and resale system, various performance metrics were analyzed, including transaction speed, security, traceability accuracy, and system efficiency. The experiments were conducted using a simulated blockchain environment with multiple stakeholders, including manufacturers, distributors, pharmacies, and patients.

1) Faster Authentication & Transactions: The blockchain system significantly reduced drug authentication time, and making it almost instant compared to traditional centralized systems.

2) Enhanced Security & Traceability: Traditional supply chain models are vulnerable to data tampering and counterfeiting. The blockchain system guarantees tamper-proof records, providing full visibility of a drug's journey.

3) Reduced Counterfeit Drugs & Improved Transparency: The system ensures real-time monitoring of drug movements, increasing trust and reducing fraud.

4) Improved Resale Verification: The resale process was made more verifiable and secure, ensuring that only legitimate and safe medications are reintroduced into the supply chain.

METRIC	Traditional System	Proposed System	Improvement
Drug Authentication Time (sec)	8.5	2.3	72.9%
Transaction Validation Time (sec)	10.2	3.5	65.6%
Data Tamper Resistance	Low	High	Secure & Immutable
Supply Chain Transparency	Moderate	Very high	Enhanced
Counterfeit Drug Reduction	60% Detected	98%Detected	38% Increase
Resale Verification Accuracy	50%	95%	45%Improvement

VI. CONCLUSION

The implementation of blockchain technology in drug production and resale provides a highly secure and transparent approach to tracking pharmaceuticals throughout their lifecycle. By leveraging decentralized ledger technology, this system ensures that every transaction, from manufacturing to resale, is immutable and verifiable, significantly reducing the risks of counterfeit drugs in the market. Unlike traditional centralized systems, which are prone to data tampering and security vulnerabilities, blockchain enhances traceability, security, and efficiency by providing a real-time, tamper-proof record of drug movements. This guarantees that manufacturers, distributors, pharmacies, and consumers can trust the authenticity of medications they handle. The incorporation of smart contracts automates approval processes, reducing human intervention, minimizing errors, and improving overall operational efficiency. Additionally, the verifiable resale mechanism ensures that unused, safe medications can be returned and redistributed securely, reducing drug waste while maintaining regulatory compliance. Patients benefit from increased trust in the medicines they purchase, as they can track their origins and verify their authenticity. In conclusion, blockchain-based pharmaceutical tracking is a game-changing innovation that not only enhances drug safety but also builds a more transparent, efficient, and secures supply chain. This system has the potential to revolutionize the pharmaceutical industry, making drug authentication and resale safer, more efficient, and resistant to fraud. Future enhancements could include AI-driven predictive analytics to further optimize the supply chain and enhance real-time decision-making.

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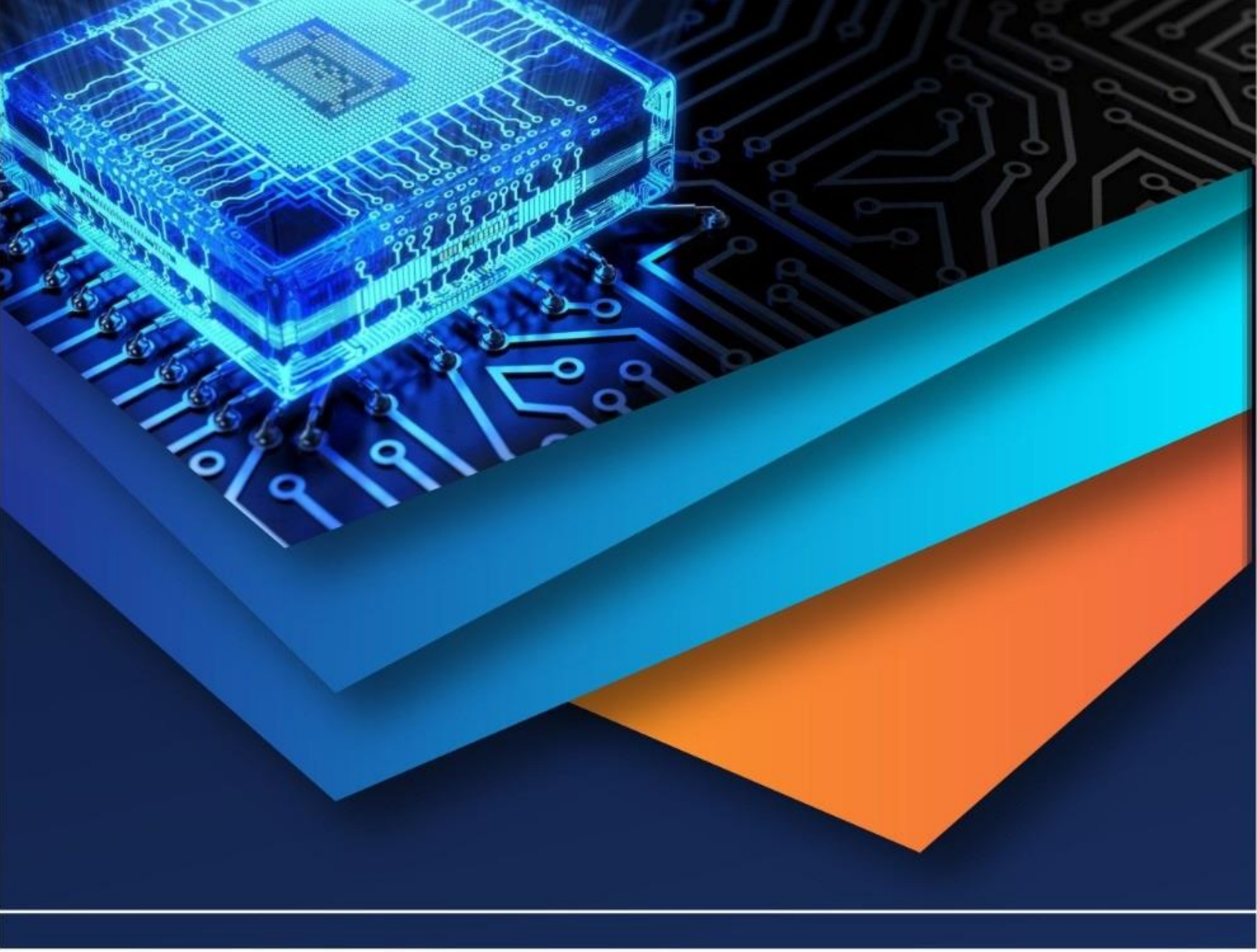

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