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ECC - Blockchain-based Identification and Tracking in Pharmaceutical Supply Chain

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Abstract:

The escalating global crisis of counterfeit pharmaceuticals has intensified the urgent need for robust traceability and transparency in pharmaceutical supply chains. Traditional centralised database systems remain vulnerable to data manipulation and lack interoperability among stakeholders, compromising patient safety and resulting in significant economic losses. This paper proposes a comprehensive blockchain-enabled pharmaceutical supply chain monitoring system that integrates Ethereum smart contracts, Elliptic Curve Cryptography (ECC), and blockchain-based environmental condition recording. The proposed system ensures secure product tracking, role-based access control, immutable record keeping, and transparent verification of storage conditions. By enabling consumers to verify product authenticity and temperature compliance, the system enhances trust, accountability, and regulatory compliance across the pharmaceutical supply chain.

Keywords **—Blockchain, Pharmaceutical Supply Chain, Elliptic Curve Cryptography, Smart Contracts, Drug Traceability, Temperature Monitoring.**

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I. INTRODUCTION

The pharmaceutical industry requires strict control over product authenticity, storage conditions, and traceability to ensure patient safety. However, existing centralised supply chain systems lack transparency and are susceptible to data manipulation, counterfeit drug insertion, and poor environmental monitoring during transportation. Once data is altered or lost, it becomes difficult to identify accountability among supply chain participants.

Blockchain technology offers a decentralised and tamper-proof solution to these challenges by enabling immutable record keeping and transparent verification[3][4]. When combined with cryptographic authentication mechanisms, blockchain can ensure that only authorised stakeholders are allowed to update supply chain information. Environmental factors such as temperature and humidity are equally critical, as deviations can significantly affect drug quality.

This project proposes a blockchain-based pharmaceutical supply chain monitoring system that integrates Ethereum smart contracts and ECC-based authentication to ensure secure tracking, role-based access, and temperature validation throughout the entire supply chain lifecycle.

II. RELATED WORK

Blockchain has been effectively used to ensure transparent ownership transfer and counterfeit prevention in supply chains, as demonstrated by Toyoda et al. [1] and further analysed in [3]. Studies across various industries demonstrate that blockchain enables tamper-proof recording of product movement among multiple stakeholders, reducing fraud and improving accountability without reliance on centralised systems.

In the pharmaceutical domain, blockchain-based solutions have been proposed to address counterfeit drug circulation and traceability challenges[2][9]. Existing research focuses on tracking drug batches, ownership transfers, and storage conditions across the supply chain. However, many proposed systems remain conceptual or limited to prototypes and often lack integrated security mechanisms such as strong authentication, role-based access control, and consumer-level verification.

Elliptic Curve Cryptography (ECC) has gained importance in blockchain environments due to its strong security with lower computational overhead compared to traditional cryptographic algorithms[6][7]. Prior studies highlight ECC's effectiveness in digital signatures, secure authentication, and non-repudiation, making it suitable for supply chain applications where identity verification and accountability are essential.

Maintaining proper temperature conditions during pharmaceutical storage and transportation is critical for drug safety. Traditional centralised or manual monitoring systems lack immutability and auditability. Recording temperature data on blockchain provides traceability and tamper resistance, supporting regulatory compliance[8][9].

Despite existing research, there is a lack of practical systems that combine blockchain-based traceability, ECC-based authentication, role-based access control, temperature validation, and consumer verification within a single platform. This project addresses this gap by presenting a complete and implementable blockchain-enabled pharmaceutical supply chain monitoring system.

III. SYSTEM ARCHITECTURE AND WORKFLOW

The proposed pharmaceutical supply chain monitoring system adopts a layered and modular architecture that integrates blockchain technology with cryptographic authentication mechanisms to ensure secure identification, transparent tracking, and reliable verification of pharmaceutical products. The system supports secure interaction among multiple stakeholders while maintaining data integrity, traceability, and consumer trust.

The architecture consists of three integrated layers: the frontend layer, the backend service layer, and the blockchain layer. The frontend, developed using React.js, provides role-based dashboards for manufacturers, distributors, retailers, and consumers. Each role is restricted to relevant operations—manufacturers register products and define storage conditions, distributors and retailers update product movement and environmental data, and consumers verify product authenticity and temperature compliance. This approach enhances usability while preventing unauthorised access.

The backend service layer is implemented using FastAPI and acts as a secure intermediary between the frontend and the blockchain. It processes requests, validates user roles, and verifies Elliptic Curve Cryptography (ECC) signatures. All transactions are digitally signed by users, and only verified requests are forwarded to the blockchain. This layer also manages communication with Ethereum smart contracts, ensuring secure transaction execution.

The blockchain layer uses Ethereum smart contracts written in Solidity [5] to store immutable records of product registration, ownership transfers, and temperature updates. Each product is assigned a unique cryptographic ID that enables tracking throughout its lifecycle. Blockchain storage ensures transparency, tamper resistance, and auditability.

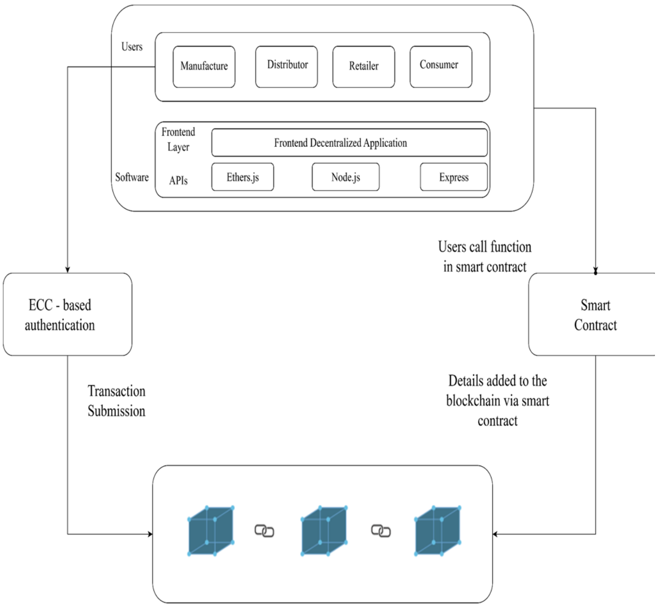


Figure 1: System Architecture Diagram

The workflow begins with manufacturers registering products on the blockchain, recording product IDs, batch details, and acceptable temperature limits. As products move through distributors and retailers, authorised users update status and manually record temperature and humidity data via the dashboard. These readings are permanently stored on the blockchain, creating a verifiable environmental history. Temperature deviations are flagged as non-compliant without interrupting the supply process, emphasising transparency over enforcement.

At the final stage, consumers verify products by entering a product ID or scanning a QR code. They can view the complete blockchain-stored history, including ownership changes, timestamps, and temperature records. If violations are detected, the system clearly marks the product as invalid, enabling informed consumer decisions.

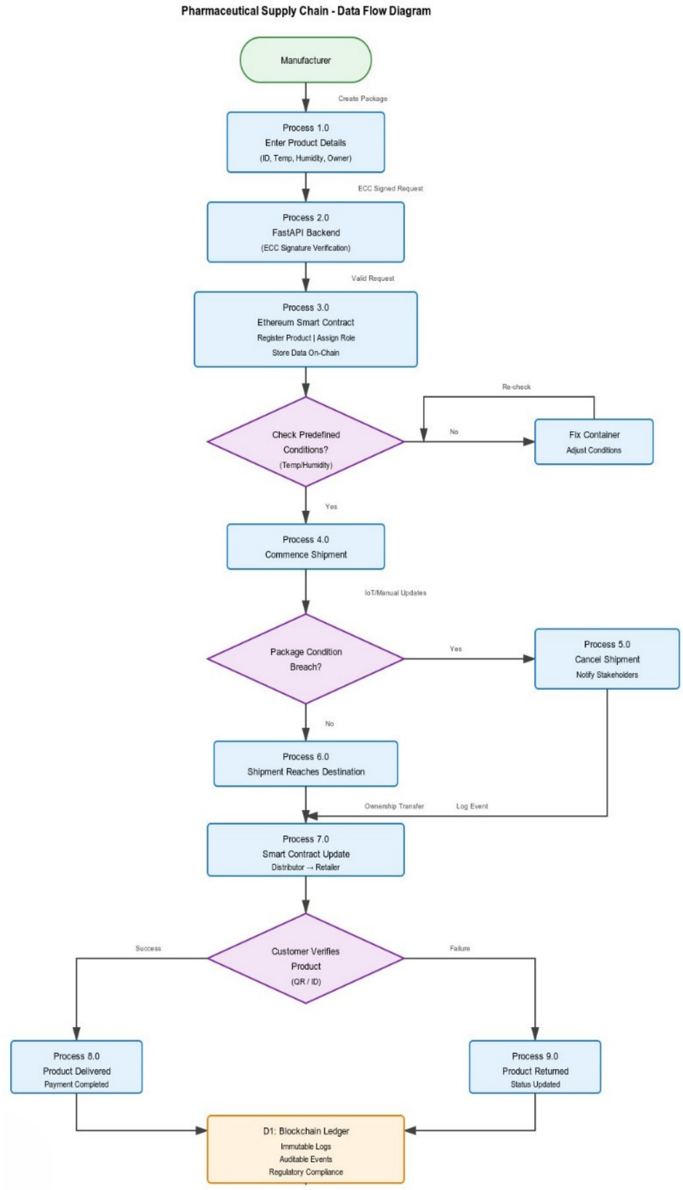


Figure 2: Data Flow Diagram

To further explain system interactions and user responsibilities, a use case diagram is employed. The use case diagram visually represents the roles of manufacturers, distributors, retailers, and consumers and their interactions with system functionalities. It highlights key operations such as product registration, status updates, temperature logging, and product verification. By illustrating how each user interacts with the system, the use case diagram provides a clear understanding of access control and functional boundaries. This representation helps in validating system requirements and ensuring that all stakeholder interactions are securely and logically defined.

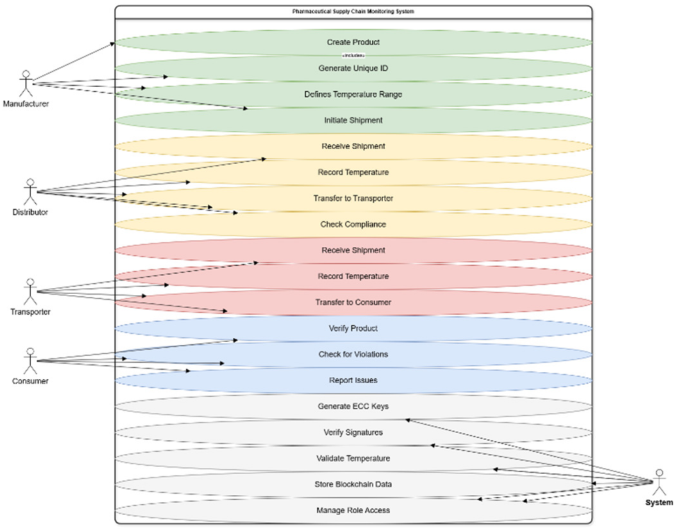


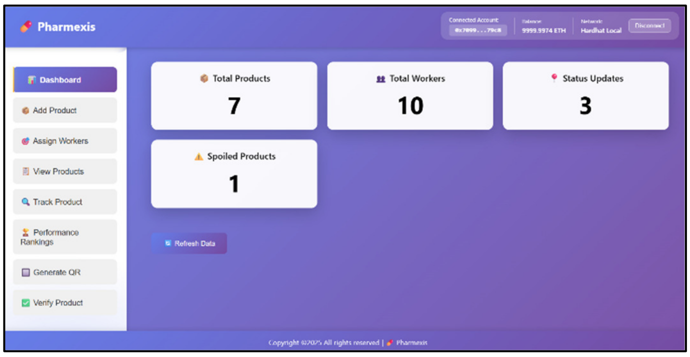
Figure 3: Use Case Diagram

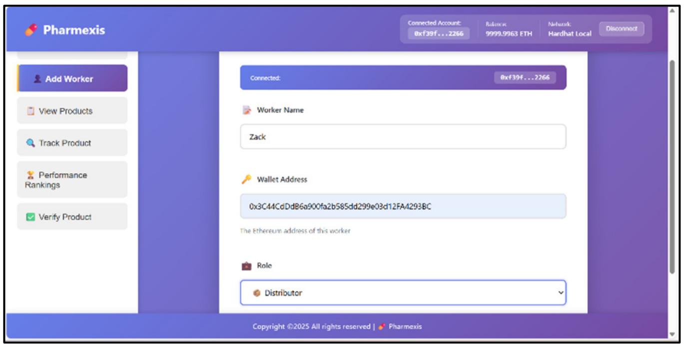
IV. SECURITY MECHANISM

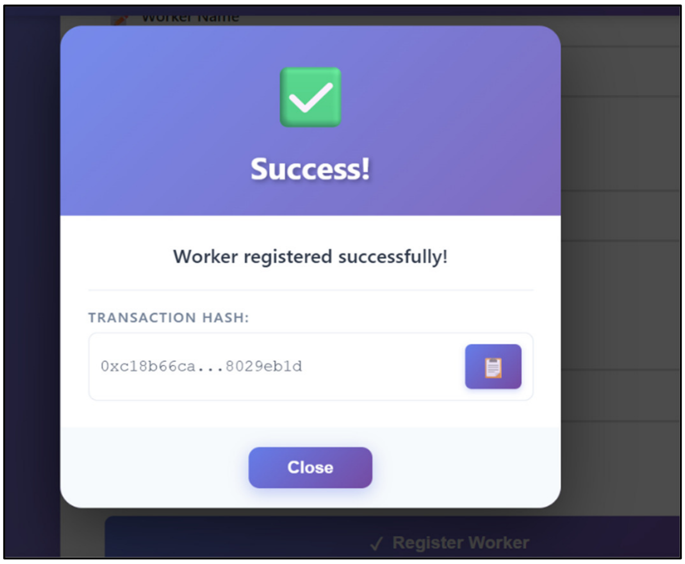
Security in the proposed system is enforced using Elliptic Curve Cryptography and blockchain-based access control[6]. Each user possesses a unique ECC key pair, where the private key is used to digitally sign transactions, and the public key is used for verification. Smart contracts verify signatures and user roles before allowing any operation. This ensures non-repudiation, prevents unauthorised access, and guarantees data integrity throughout the supply chain.

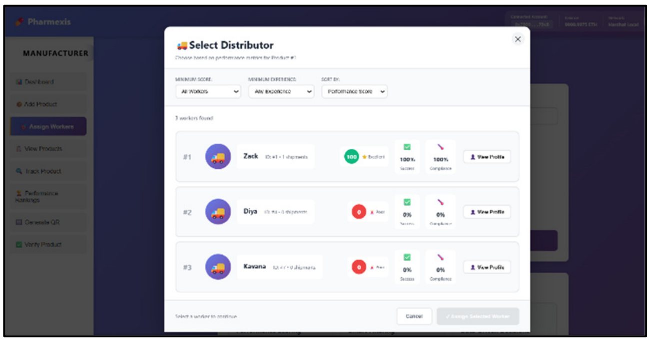
Ownership changes are securely executed through signed blockchain transactions, ensuring authenticity and non-repudiation. All updates are permanently stored on the blockchain, creating an immutable audit trail. Consumers can verify product authenticity by entering the product ID or scanning a QR code to view the complete product history and environmental compliance records.

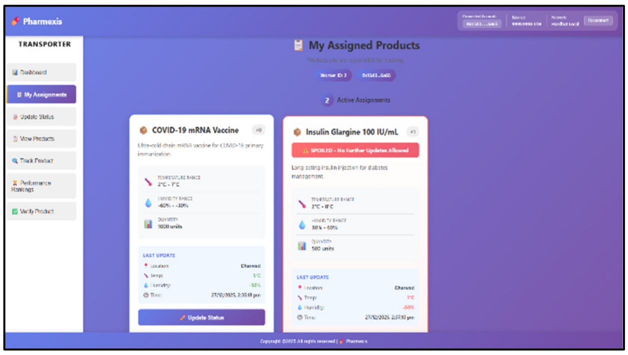
V. RESULTS AND DISCUSSION

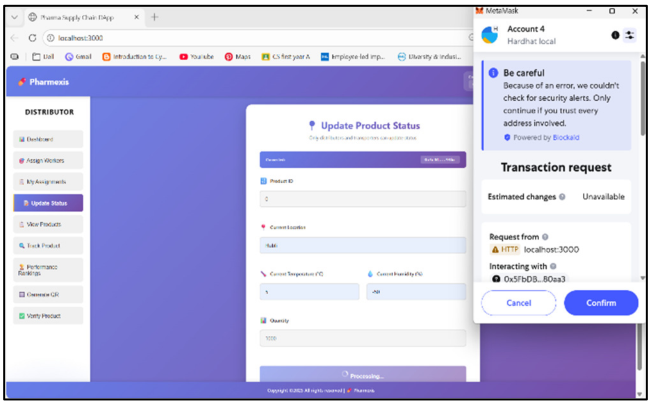


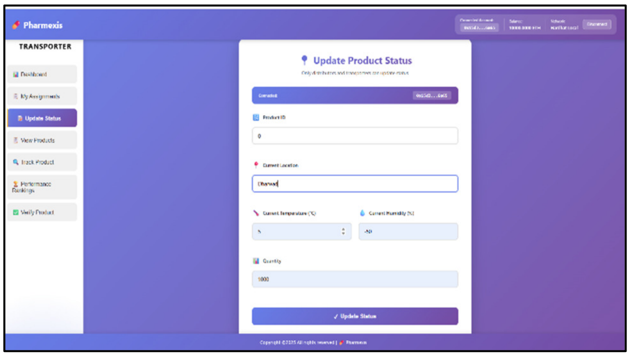


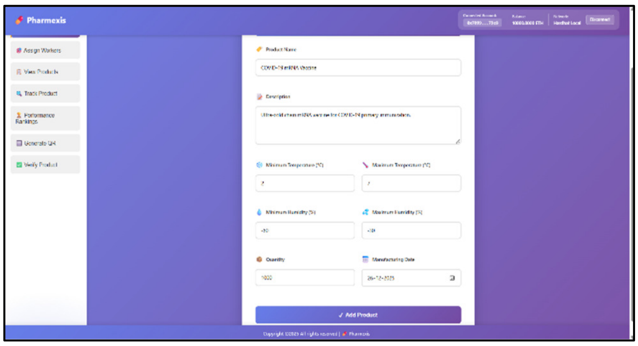



Pharmexis
MANUFACTURER
Select Distributor
Zack
Diya
Kavana


Pharmexis
TRANSPORTER
My Assigned Products
COVID-19 mRNA Vaccine
Insulin Glargine 100 IU/mL


Pharmexis
DISTRIBUTOR
Update Product Status
MetaMask
Account 4
Hardhat local
Be careful
Because of an error, we couldn't check for security alerts. Only continue if you trust every address involved.
Transaction request
Estimated changes
Unavailable
Request from
localhost:3000
Interacting with
0x5FbDB...80aa3
Cancel
Confirm


Pharmexis
TRANSPORTER
Update Product Status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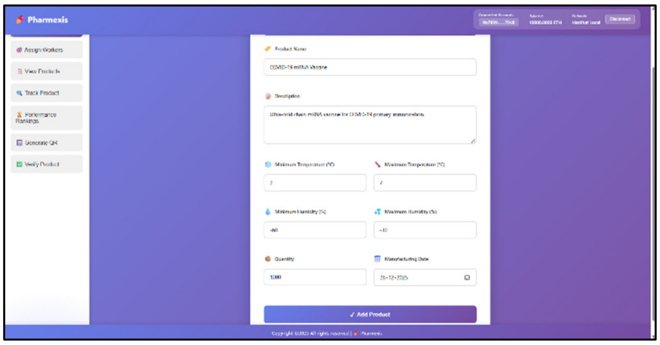
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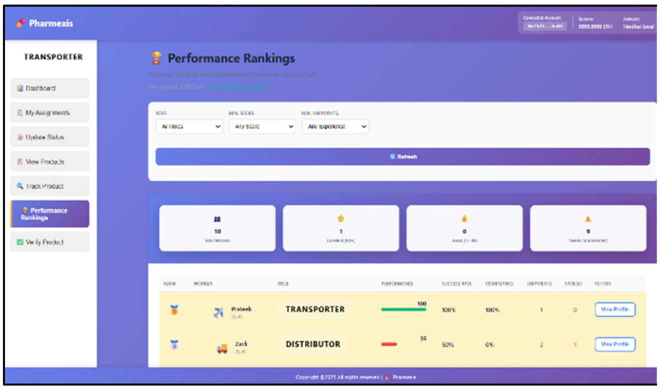
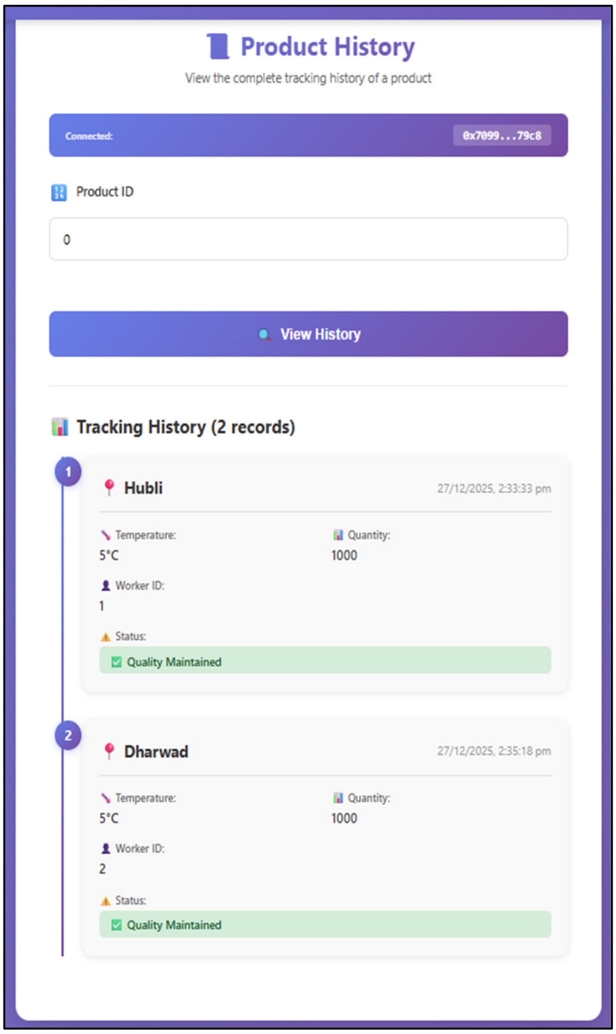

Pharmexis
TRANSPORTER
Performance Rankings
TRANSPORTER
DISTRIBUTOR



VI. CONCLUSIONS

The proposed ECC-Blockchain-Based Pharmaceutical Supply Chain Monitoring System provides a secure, transparent, and tamper-proof solution for tracking pharmaceutical products. By integrating Ethereum smart contracts, ECC-based authentication, role-based access control, and temperature validation, the system effectively addresses counterfeit detection, improper storage conditions, and lack of accountability. The system enhances consumer trust, improves regulatory compliance, and ensures patient safety through end-to-end traceability.

VII. ACKNOWLEDGMENT

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