

Blockchain-Enabled Drug Supply Chain for Secure Pharmaceutical Tracking

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ABSTRACT

Counterfeit medicines, fragmented record management, limited end-to-end visibility, and dependence on centralized databases create security and traceability challenges in pharmaceutical supply chains. This article presents Pharma-Chain, a blockchain-enabled pharmaceutical supply chain management system developed to record medicine registration, stakeholder interactions, ownership transfer, and authenticity verification on an Ethereum blockchain. The system integrates a React.js frontend with Web3.js, MetaMask wallet authentication, Solidity smart contracts, Truffle deployment tools, and Ganache for local blockchain development and validation. Manufacturers register medicine batches with product and lifecycle information; distributors and retailers verify blockchain records before accepting and transferring ownership; and customers retrieve medicine details and transaction history before purchase. The implementation was tested module by module and as an integrated application in a local Ethereum environment. Testing confirmed successful authentication and role-based access, medicine registration, ownership transfer, transaction validation, blockchain record retrieval, and medicine verification. Each successful supply-chain operation generated a blockchain transaction record, providing an immutable ownership history and improving transparency and auditability. The project demonstrates a practical decentralized approach for secure pharmaceutical tracking while identifying QR-code verification, IoT monitoring, AI-assisted analytics, mobile access, and deployment on public or enterprise blockchain networks as future extensions.

Keywords: Blockchain; Pharmaceutical supply chain; Ethereum; Smart contracts; Drug traceability; Web3; Counterfeit medicine prevention

I. INTRODUCTION

The pharmaceutical supply chain connects manufacturers, distributors, retailers, customers, and regulatory stakeholders, yet conventional centralized record systems can make medicine provenance difficult to verify across organizational boundaries. The project report identifies counterfeit medicines, data tampering, incomplete traceability, manual verification, and limited visibility as principal weaknesses of the traditional approach. Blockchain has been investigated as a distributed mechanism for improving supply-chain transparency, integrity, and auditability in pharmaceutical and broader supply-chain applications [1], [7]-[10].

Pharma-Chain addresses this problem through a decentralized application in which critical medicine and ownership transactions are executed through Solidity smart contracts and stored on the Ethereum blockchain. The system uses React.js for the user interface, Web3.js for communication with deployed contracts, MetaMask for wallet-based authentication and transaction approval, and Ganache with Truffle for local blockchain deployment and testing [11], [14]-[19].

The proposed workflow assigns each medicine batch a blockchain-based record and maintains the sequence of ownership transfers from manufacturer to distributor, retailer, and customer. Authorized stakeholders can retrieve medicine information and transaction history, while customers can verify product details before purchase. The resulting design aims to improve transparency, reduce the opportunity for unauthorized record modification, simplify auditing, and strengthen confidence in pharmaceutical product authenticity.

II. OBJECTIVES

- To design and implement a decentralized pharmaceutical supply chain using blockchain technology.
- To provide complete medicine traceability and support counterfeit medicine prevention through verifiable product history.
- To develop Ethereum smart contracts for secure medicine registration, transaction validation, and ownership transfer.
- To maintain immutable medicine transaction records and transparent interaction among manufacturers, distributors, retailers, and customers.
- To enable blockchain-based medicine verification and reduce manual verification and administrative overhead.

- To support regulatory auditing through permanent transaction history and provide a scalable foundation for future pharmaceutical supply-chain applications.

III. LITERATURE SURVEY

The literature reviewed in the report positions blockchain as a mechanism for addressing trust, traceability, and data-integrity problems in supply-chain systems. Kamble et al. review blockchain use in pharmaceutical supply chains [1], while Casino et al. survey blockchain applications and open issues across domains [2]. Foundational blockchain work emphasizes distributed ledgers, cryptographic linkage, decentralized validation, and tamper resistance [4], [5], [12], [13].

For supply-chain use, the reviewed studies associate blockchain with persistent transaction history, product traceability, reduced fraud exposure, and improved coordination between parties [7]-[10]. The project specifically adopts the concepts of medicine batch identification, end-to-end ownership history, stakeholder verification, and customer-facing authenticity checks described in the report's literature survey. Smart contracts provide the automation layer for enforcing predefined business rules without relying on manual validation [3], [11], [15].

The implementation also follows the Web3 application model described in the report: a browser-based React.js interface communicates with Ethereum contracts through Web3.js, MetaMask provides wallet identity and transaction approval, and Truffle/Ganache support contract deployment and local testing [16]-[19]. IoT integration can extend blockchain-based pharmaceutical logistics by monitoring environmental conditions during transport, although IoT sensing is not implemented in the present system [6].

IV. SYSTEM DESIGN AND METHODOLOGY

System architecture

Pharma-Chain uses a layered architecture consisting of a User Layer, Presentation Layer, Communication Layer, Business Logic Layer, Blockchain Layer, and Storage Layer. Manufacturers, distributors, retailers, and customers interact through the React.js presentation layer. Web3.js forms the communication bridge to Solidity smart contracts, while the Ethereum blockchain provides decentralized transaction storage. Role-based permissions restrict operations to authorized stakeholder functions.

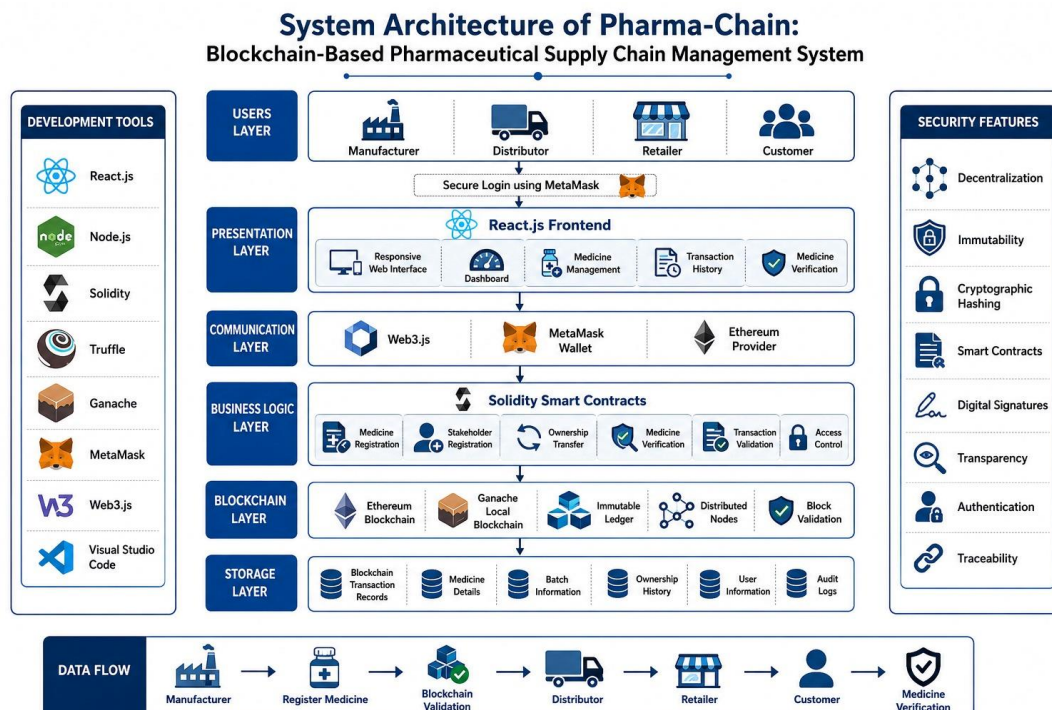


Fig. 1. Layered system architecture of Pharma-Chain.

Supply-chain workflow

Users authenticate through MetaMask, after which the application identifies their role. A manufacturer registers a medicine by submitting medicine name, batch number, manufacturing date, expiry date, quantity, price, and manufacturer information. The smart contract validates the request and records the transaction on Ethereum. Ownership can then be transferred to an authorized distributor, followed by a retailer and ultimately the customer. At each stage, blockchain records are available for verification before ownership is accepted.

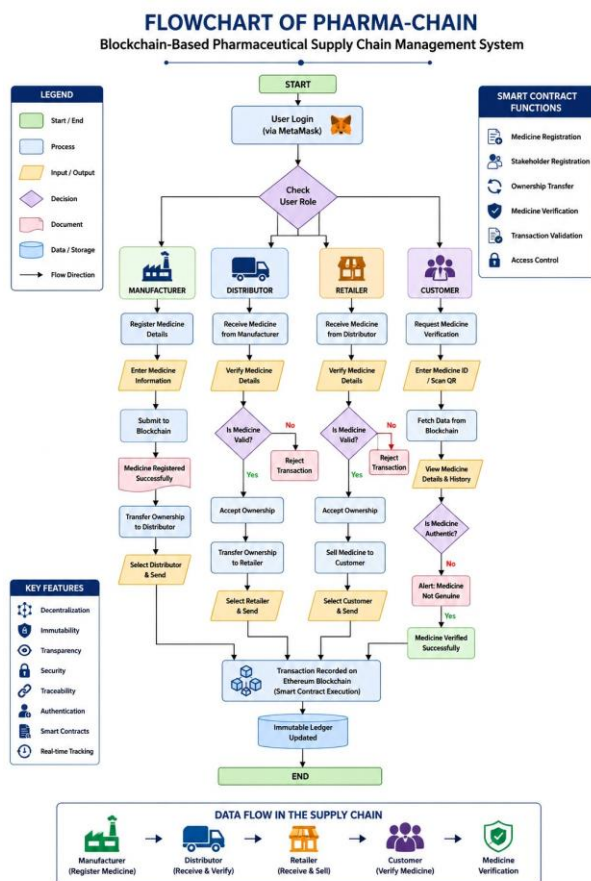


Fig. 2. Operational workflow of Pharma-Chain from authentication to customer verification.

Technology stack

The development stack reported for the system combines web-application and blockchain technologies. Table 1 summarizes the technologies and their roles in the implemented system.

Table 1. Technology stack used for Pharma-Chain

Technology	Purpose
React.js	Frontend User Interface
JavaScript	Application Logic
Node.js	Runtime Environment
Solidity	Smart Contract Development
Ethereum	Blockchain Platform
Ganache	Local Blockchain Testing
MetaMask	Wallet Authentication
Web3.js	Blockchain Communication
Truffle	Smart Contract Deployment
Visual Studio Code	Development Environment
Git & GitHub	Version Control

Implementation and deployment

The business logic was implemented in Solidity smart contracts responsible for stakeholder registration, medicine registration, ownership validation, transaction execution, access control, and medicine verification. React components initiated blockchain requests through Web3.js, while MetaMask was used to connect Ethereum accounts and digitally approve transactions. For development and validation, contracts were compiled and deployed through Truffle to a Ganache local Ethereum blockchain. The React application was configured with the deployed contract addresses and ABI files to complete frontend-blockchain integration [20].

Table 2. Development environment for Pharma-Chain

Software/Tool	Version	Purpose
React.js	Latest	Frontend Development
Node.js	Latest	Runtime Environment
JavaScript	ES6	Application Logic
Solidity	Latest	Smart Contract Development
Ethereum	Blockchain Platform	Decentralized Ledger
Ganache	Latest	Local Blockchain
MetaMask	Latest	Wallet Authentication
Web3.js	Latest	Blockchain Communication
Truffle	Latest	Smart Contract Deployment
Visual Studio Code	Latest	Source Code Editor
GitHub	Latest	Version Control

Testing procedure

Testing was conducted throughout implementation. Individual smart-contract functions and stakeholder modules were validated before complete integration. Functional tests covered MetaMask authentication, role-based access, medicine registration, ownership transfer, blockchain record retrieval, and medicine verification. Invalid or incomplete registration inputs, unauthorized access attempts, and invalid or duplicate transaction conditions were also exercised. Blockchain transaction hashes, execution status, block information, gas consumption, and timestamps were monitored in Ganache as execution evidence; the report does not provide a quantitative benchmark table.

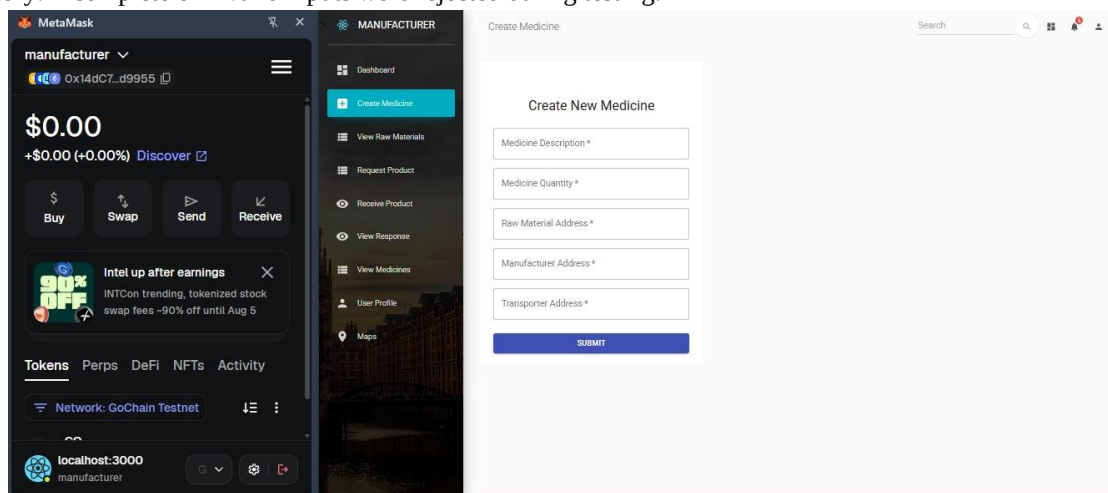
V. RESULTS AND DISCUSSION

Application execution

The integrated application executed successfully in the local Ethereum environment. Ganache provided test accounts and the blockchain network, Truffle deployed the contracts, MetaMask connected stakeholder wallets, and the React.js frontend communicated with the deployed smart contracts through Web3.js. The reported execution followed the intended pharmaceutical workflow from medicine registration through distributor and retailer transfer to customer verification.

Manufacturer and medicine registration results

The manufacturer module allowed authorized manufacturers to enter medicine details, view records, and initiate ownership transfer. Submitted registration data were passed to the smart contract for validation. Successful registration created a blockchain transaction and permanently associated the medicine record with its transaction history. Incomplete or invalid inputs were rejected during testing.


Fig. 3. Manufacturer dashboard for medicine management and ownership operations.

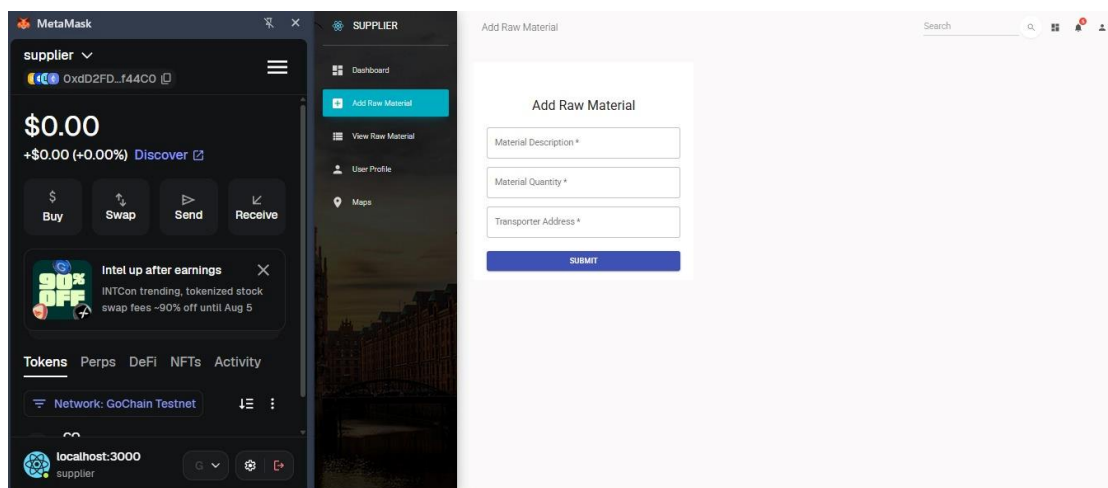


Fig. 4. Medicine registration interface used to submit pharmaceutical batch information.

Distribution and retailer results

The distributor module retrieved manufacturer information, medicine details, ownership history, manufacturing and expiry dates, and transaction information before acceptance and onward transfer. The retailer module similarly retrieved blockchain ownership information before medicines were made available to customers. During testing, ownership changes were validated by the smart contracts and the blockchain maintained the previous transaction history.

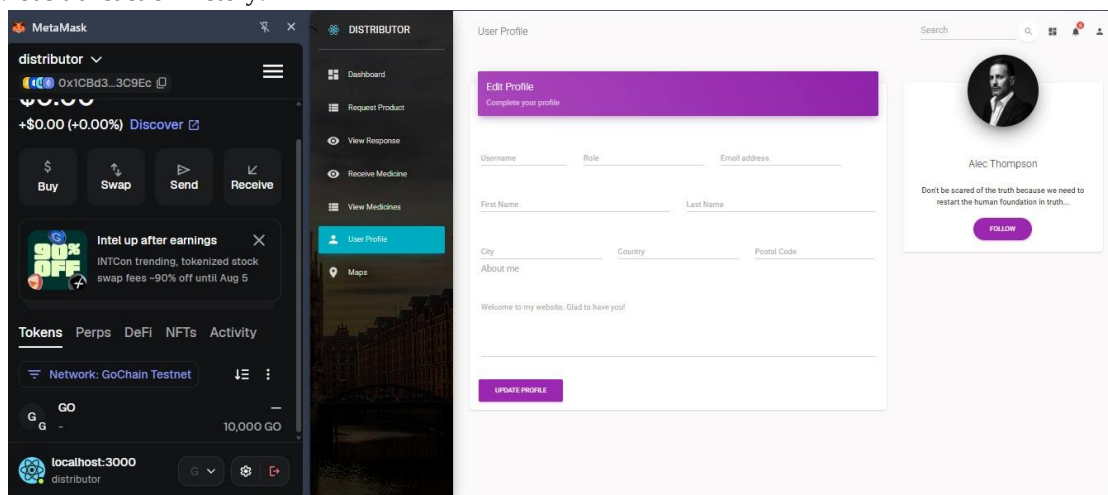


Fig. 5. Distributor dashboard for verification and medicine transfer.

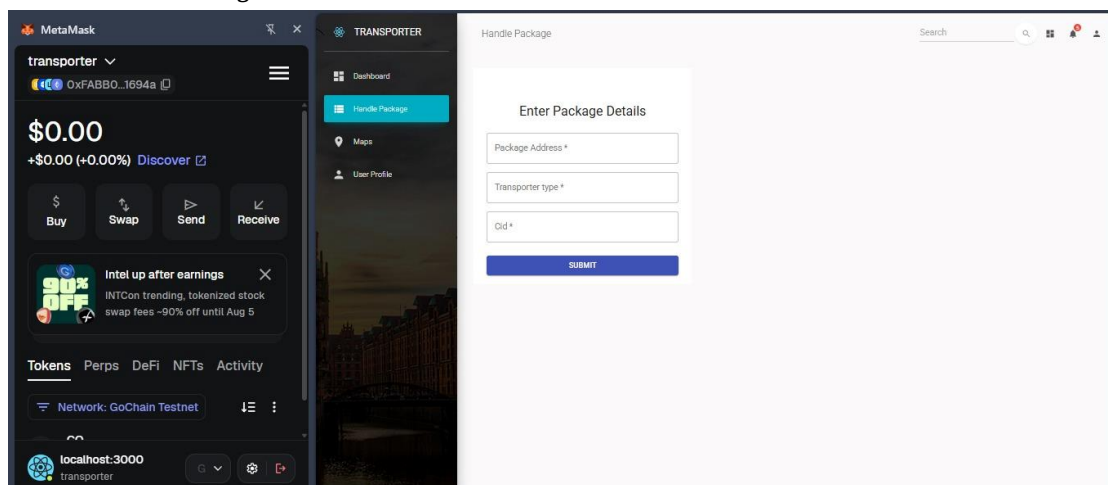


Fig. 6. Retailer dashboard for blockchain-based medicine verification.

Blockchain transaction and verification results

Ganache recorded the blockchain transactions generated by medicine registration and ownership transfer. Transaction hashes, block numbers, gas consumption, execution status, and timestamps were monitored during validation. The customer verification module retrieved manufacturer details, batch number, manufacturing date, expiry date, ownership history, and transaction records for registered medicines. These functions provided the end-to-end traceability required by the project objectives.

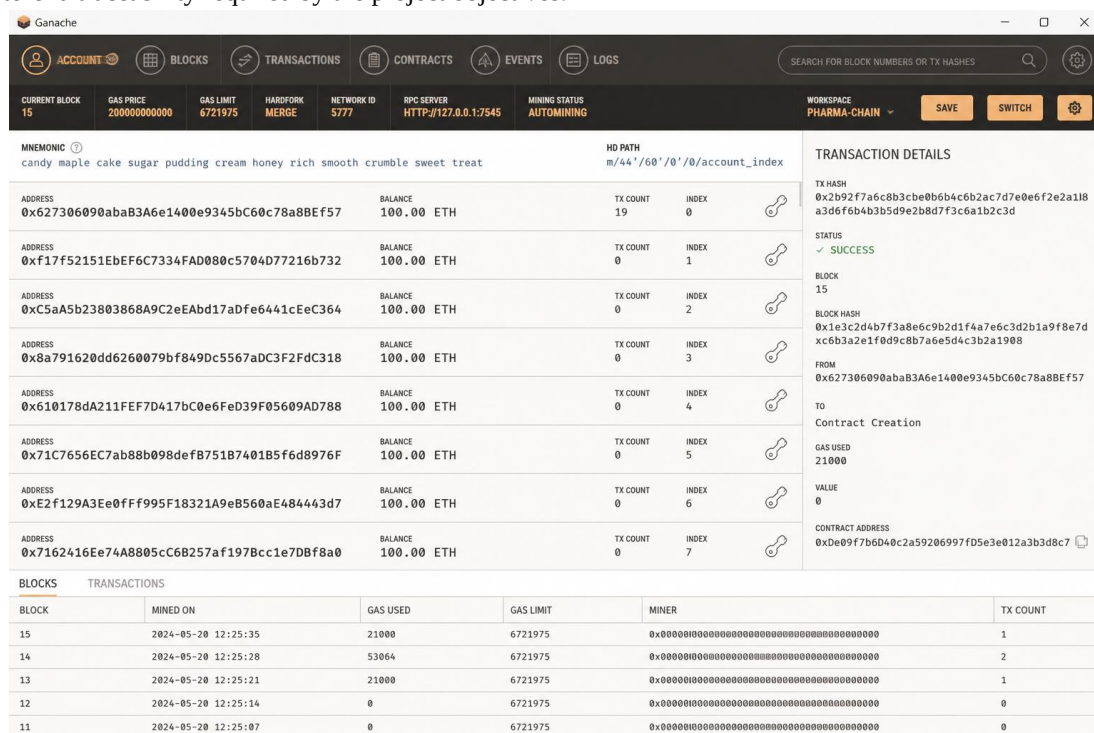


Fig. 7. Ganache dashboard used for local Ethereum deployment and transaction monitoring.

System testing and performance discussion

System testing reported successful wallet authentication for authorized users and restriction of unauthorized operations. Medicine registration validated required fields, ownership transfer updated current ownership while preserving transaction history, and medicine verification retrieved the expected blockchain record. Blockchain communication remained stable and smart contracts executed successfully under the tested operating conditions. No duplicate ownership records or invalid transactions were observed during the reported ownership-transfer tests.

Performance was evaluated qualitatively in terms of security, transparency, reliability, traceability, and usability rather than through a numerical performance benchmark. The principal benefit is that critical supply-chain operations are validated by smart contracts and recorded as immutable blockchain transactions, creating an auditable chain of medicine ownership. Blockchain confirmation introduces additional processing time, but measured latency values were not collected in this implementation. Accordingly, transaction-speed, throughput, gas-cost, and scalability metrics are not claimed.

VI. CONCLUSION

Pharma-Chain was designed and implemented as a decentralized pharmaceutical supply-chain application using React.js, Solidity, Ethereum, Web3.js, MetaMask, Ganache, Node.js, and Truffle. The system supports medicine registration, stakeholder-based ownership transfer, blockchain transaction validation, transaction-history retrieval, and customer-facing authenticity verification. Local deployment and functional testing confirmed successful integration of the stakeholder modules with the Ethereum smart contracts and demonstrated permanent recording of medicine transactions and ownership changes. Within the implemented scope, the system achieves the project objectives of improving transparency, traceability, data integrity, and secure interaction among supply-chain participants while reducing dependence on manually managed centralized records.

Future scope

Future extensions include QR-code verification, IoT-based monitoring of storage conditions, AI and machine-learning support for demand forecasting and anomaly detection, mobile application development, cloud deployment, and migration to public Ethereum or enterprise blockchain platforms as future extensions. These additions remain proposed enhancements and were not part of the reported implementation.

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