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Chaincraft: Crafting the Future of Supply Chains with IoT and Blockchain Brilliance

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Abstract: ChainCraft is an innovative digital platform that revolutionizes supply chain management by integrating IoT and blockchain technology. With its user-friendly interface, ChainCraft allows for real-time tracking of shipments based on important parameters such as location, temperature, and security conditions. The platform provides a secure, constant record of your program and increases supply chain visibility by ensuring transparency and reliability. Most important features include real-time monitoring, security and compliance analytics, historical shipping data checks, and interactive allocation for improved decisions. By leveraging IoT sensors for real-time data collection and Blockchain for secure and tamper-proof record-keeping, ChainCraft offers an efficient and reliable solution for businesses aiming to optimize supply chain operations. Users can monitor their assets seamlessly, assess past shipment performance, and make data-driven decisions to enhance overall supply chain efficiency. With its advanced tracking capabilities, security-focused architecture, and intuitive interface, ChainCraft sets a new standard for smart, transparent, and secure supply chain management.

Keywords*: Supply Chain Management, IoT, Blockchain, Real-Time Tracking, Security & Transparent.*

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I. INTRODUCTION

In today's rapidly developing business environment, supply chain management (SCM) plays a key role in the safe movement of seamless product movements from manufacturers to consumers. However, traditional SCM systems face considerable challenges, including lack of vision, inefficiency and security gaps. These issues often lead to delays, increased operating costs, customer dissatisfaction, and ultimately affect business performance and reputation.

To address these challenges, ChainCraft will use the Internet of Things (IoT) and blockchain technology to introduce a transformative approach to SCM. IoT devices allow for real-time shipping persecution and monitoring, increasing supply chain visibility and efficiency. At the same time, the decentralized and unchanging nature of blockchain ensures data security, transparency and trust among all involved.

This research examines the integration of IoT and blockchain into SCM, identify existing challenges, and suggests new solutions through the development of prototype systems. The proposed system aims to improve supply chain processes by providing secure real-time data exchange and automated decision-making capabilities.

The expected effects of ChainCraft go beyond consumers, political decision makers and industry experts, and beyond companies. By making this study more transparent, safer and more efficient, the study aims to reduce costs, improve customer satisfaction and improve general profitability. Furthermore, the knowledge gained from this study can provide valuable guidelines for future innovation in smart supply chain management.

➢ *Background*

Supply Chain Management (SCM) is an important aspect of global trade and global logistics. Traditional SCM systems are based on a centralized database that is susceptible to fraud, operations, and inefficiency. Lack of actual tracking and transparency can lead to conflict, loss of goods and increased operating costs. Blockchain technology with decentralized, immutable main registers provides promising solutions to these challenges.

Blockchain technology has transformed a variety of industries by providing secure, transparent, automated transaction mechanisms. In the logistics sector, blockchain

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can remove intermediaries, provide real tracking, and automate the execution of contracts through intelligent contracts. Additionally, IoT integration improves data reliability through continuous monitoring of shipping conditions.

- *Problem Statement*

Traditional supply chain models face significant challenges in tracking shipments and ensuring product integrity. Many industries, particularly pharmaceuticals and perishable goods, require strict temperature control. However, conventional systems lack a trust less verification mechanism for shipment conditions. The key challenges include:

- Lack of Transparency: Shipment status is not visible to all stakeholders.
- Risk of Fraud & Data Tampering: Centralized records are vulnerable to manipulation.
- Delayed Payment & Dispute Resolution: Payment mechanisms rely on third-party intermediaries, leading to delays.
- Inability to Enforce Contracts: There is no automated system to cancel shipments if conditions are violated.

- *Objectives*

The objectives of this research are:

- To develop a trust less supply chain management system using blockchain.
- To implement a smart contract that automates shipment validation and payment.
- To integrate IoT sensors for real-time shipment monitoring.
- To evaluate the performance and feasibility of blockchain-based supply chain solutions.

- *Scope*

This research focuses on implementing Ethereum blockchain-based supply chain tracking, particularly for temperature-sensitive shipments. The system ensures that:

- Shipments are recorded transparently on the blockchain.
- The receiver must deposit Ether (ETH) before shipment initiation.
- The smart contract monitors temperature via IoT sensors.
- If the temperature exceeds the threshold, the contract automatically cancels the transaction.
- If conditions remain normal, the payment is processed automatically upon delivery confirmation.

By leveraging blockchain and IoT, this research aims to enhance supply chain transparency, security, and efficiency while reducing operational costs and mitigating fraud risks.

II. LITERATURE REVIEW

- *Blockchain in Supply Chain Management*

Blockchain technology has been widely studied for its potential to improve transparency, security, and efficiency in supply chain management (SCM). Studies suggest that blockchain can eliminate fraudulent activities by providing a tamper-proof and decentralized ledger. Smart contracts automate agreements and reduce dependency on intermediaries, thereby minimizing disputes and improving transaction speed [1, 2]. However, the adoption of blockchain adoption is a challenge such as scalability, high energy consumption and regulatory concerns.

- *IoT for Real-Time Supply Chain Monitoring*

The Internet of Things (IoT) plays a key role in real-world tracking and monitoring programs. Research shows that IoT devices such as RFID tags and sensors provide accurate data on location, temperature, moisture and other environmental factors, ensuring product quality during transportation. IO-enabled SCMs reduce human intervention and lead to increased efficiency and reliability [3.4.5]. Nevertheless, the security gaps and interoperability issues with IoT integration remain large issues, setting up cybersecurity risks and data protection issues.

- *Integration of Blockchain and IoT in SCM*

Blockchain ensures data integrity, while IoT devices collect and transmit real-time information [6]. Existing research has proven that integration of both technologies can improve system pursuits, reduce operational costs, and improve decision-making [7]. However, scalability, data protection, and infrastructure costs represent significant implementation challenges.

- *Challenges in Traditional Supply Chains*

Research shows that central databases are susceptible to fraud, delays and human error that negatively affect businesses and customer satisfaction. These inefficiencies underscore the urgent need for decentralized and automated solutions such as blockchain and IoT to improve traceability and operational efficiency.

III. PROPOSED SYSTEM

A. *Components of the System*

- *Physical Layer (IoT Devices)*

- *IoT Sensors and Devices:*

RFID tags, GPS trackers, temperature sensors, moisture sensors and other IoT devices are installed in products, packaging and vehicles. These devices collect actual data such as location, temperature, humidity, and movement.

- *Communication Protocols:*

IoT devices use protocols like MQTT, LoRaWAN, or Zigbee to transmit data to the blockchain network.

- *Data Layer (Blockchain Network)*

- *Distributed Ledger:*

Store and manage data using the Ethereum -Blockchain network. All transactions or data updates on an IoT device are recorded as blocks in a chain.

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- *Immutable Records:*

Once data is recorded on the blockchain, it cannot be altered, ensuring data integrity and trust.

➢ *Application Layer (Smart Contracts and Analytics)*

- *Smart Contracts:*

In blockchain, it is used in blockchain to automate processes such as payment, quality checks, and conformance testing [8]. Example: As soon as the IoT sensor confirms the delivery of the product, an intelligent contract will pass payments to the supplier.

- *Data Analytics:*

Advanced analytics tools process the data collected from IoT devices to provide insights such as demand forecasting, route optimization, and predictive maintenance.

➢ *User Interface Layer (Stakeholder Access)*

- *Dashboards and APIs:*

Stakeholders such as manufacturers, suppliers, retailers, and customers can access the system via a web-based dashboard or mobile app. APIs allow integration with existing corporate systems.

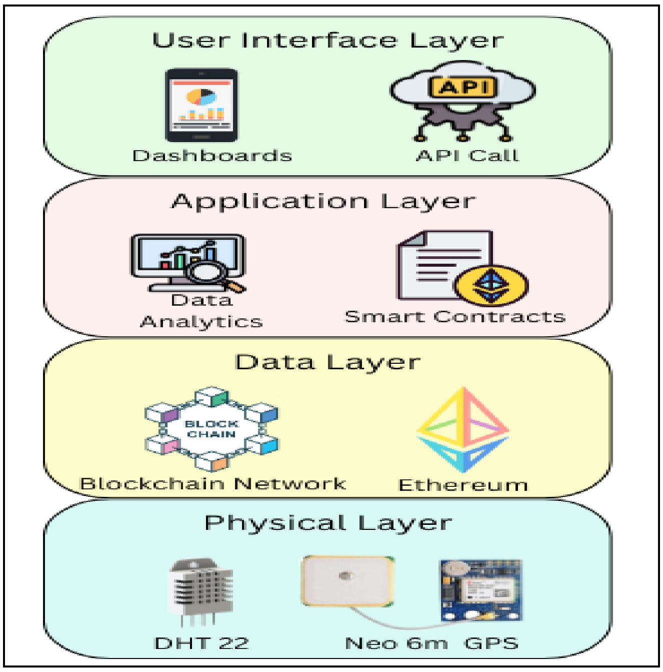

Fig 1 Components of the System

B. Workflow of the System

➢ *Data Collection:*

- IoT devices attached to products and vehicles collect real-time data like location, temperature and humidity.

➢ *Data Transmission:*

- The collected data is transferred to the blockchain network via secure communication protocols.

➢ *Data Recording:*

- Data is recorded as a blockchain transaction. This creates an unchangeable and transparent data record.

➢ *Smart Contract Execution:*

- Predefined smart contracts are triggered based on the data like if a shipment reaches its destination, a smart contract automatically updates the inventory and releases payment and if temperature-sensitive goods exceed a threshold, an alert is sent to stakeholders.

➢ *Data Access and Analytics:*

- Stakeholders access the data through dashboards or APIs. Analytics tools provide insights to optimize supply chain operations.

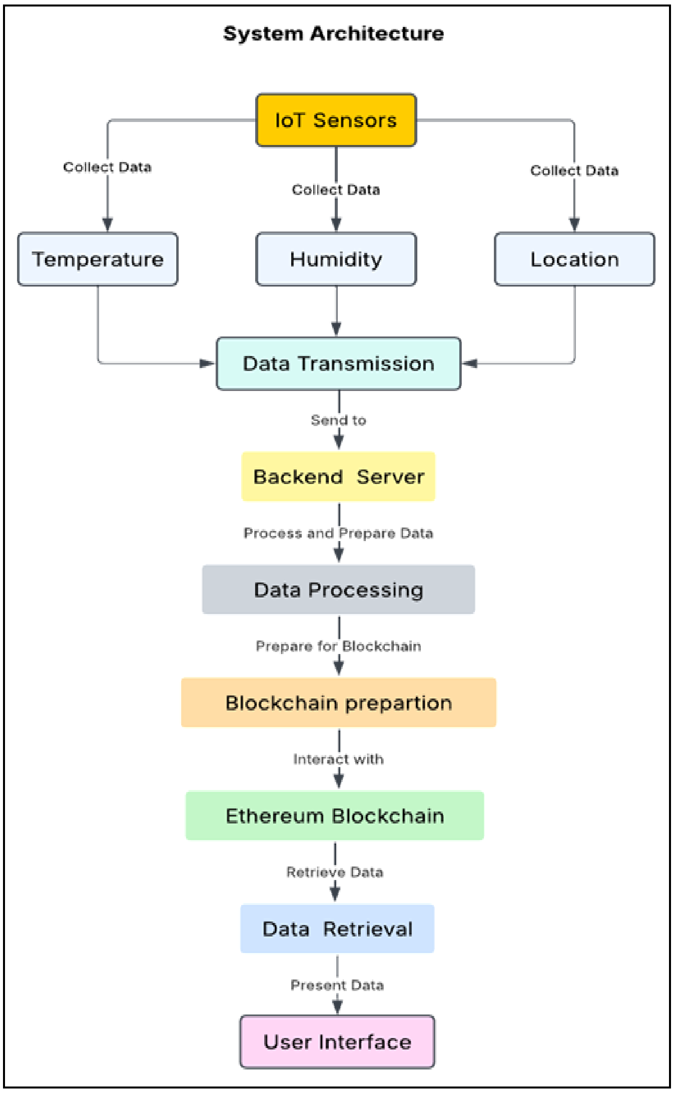

Fig 2 Workflow of the System

C. Example use case

- Scenario: Cold Chain Management for Pharmaceuticals
- Problem: Ensuring the integrity of temperature-sensitive drugs during transportation.

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➢ *Solution:*

- IoT temperature sensors are attached to pharmaceutical shipments.
- Real-time temperature data is recorded on the blockchain.
- If the temperature exceeds a predefined threshold, an alert is sent to stakeholders, and a smart contract halts payment until the issue is resolved.
- Customers can verify the temperature history of the drugs using a QR code linked to the blockchain.

D. Advantages

- Enhanced Trust: Immutable records build trust among stakeholders.
- Improved Efficiency: Automation reduces delays and operational costs.
- Better Compliance: Transparent records simplify regulatory compliance.
- Sustainability: Optimized routes and reduced waste contribute to a greener supply chain.

E. Limitations

- Scalability Issues: Blockchain and IoT data volume can overwhelm the system [9].
- Latency Issues: Blockchain networks may introduce delays in data recording and retrieval, which can be problematic for time-sensitive supply chain operations [9, 10].
- Limited IoT Coverage: IoT devices rely on internet connectivity and power supply, which may be unreliable or unavailable in remote or underdeveloped regions [11].

IV. FUTURE WORK

To further improve the scalability, efficiency, and adoption of blockchain-based supply chain solutions, the following enhancements are proposed:

- AI-Driven Predictive Analytics: Integrating artificial intelligence (AI) with blockchain can help predict shipment risks, optimize routes, and provide real-time insights into potential supply chain disruptions. Machine learning models can analyze historical shipment data to forecast delays and anomalies.
- Cross-Chain Interoperability: Implementing a multi-blockchain approach to enable seamless data exchange between different blockchain networks (e.g., Ethereum, Hyperledger, and Polygon). This will allow organizations to integrate with various blockchain ecosystems while maintaining security and transparency.
- Decentralized Identity Management (DID): Using self-sovereign identity (SSI) solutions for secure, verifiable digital identities of supply chain participants, reducing fraud and unauthorized transactions.
- Green Blockchain Solutions: Exploring energy-efficient alternatives such as Ethereum Layer 2 solutions and eco-friendly consensus mechanisms (e.g., Proof-of-Stake and Zero Knowledge Rollups) to reduce the environmental impact of blockchain-based supply chain management.

V. RESULTS AND DISCUSSION

➢ *Workflow of the System*

The proposed blockchain-based supply chain management system was tested under various real-world conditions to evaluate its efficiency, security, and feasibility. The system successfully recorded and monitored shipments on the Ethereum blockchain, ensuring data immutability and transparency. The IoT sensors accurately collected temperature data and transmitted it to the blockchain, which enabled automatic execution of smart contracts based on predefined temperature thresholds.

➢ *Smart Contract Execution*

The execution of smart contracts was instantaneous and error-free, ensuring that payments were only processed when shipment conditions were met. If a shipment’s temperature exceeded the predefined limits, the system automatically cancelled the transaction, and funds were returned to the receiver’s wallet. This mechanism eliminated disputes and enhanced trust between supply chain participants.

➢ *Transaction Costs & Scalability*

One of the primary concerns of blockchain implementation is transaction costs. During testing, the gas fees on the Ethereum network varied based on network congestion. To mitigate high transaction costs, potential optimizations include integrating Layer 2 solutions such as Polygon or Optimistic Rollups. Additionally, the system can be scaled using sidechains or hybrid blockchain architectures to handle higher transaction volumes efficiently [12, 13].

➢ *Security & Data Integrity*

Security was a key focus in this study. The decentralized nature of the Ethereum blockchain prevented unauthorized alterations to shipment records. The use of cryptographic hashes ensured data integrity, while MetaMask authentication secured user access. Additionally, the IoT devices provided tamper-proof sensor data, reducing the risk of fraudulent claims [14, 15].

➢ *User Experience & Adoption*

A user-friendly web interface was developed for seamless interaction with the blockchain. The integration of MetaMask allowed users to easily sign transactions without requiring extensive blockchain knowledge. Initial feedback from test users, including logistics professionals and supply chain managers, indicated a strong preference for the automation and transparency offered by this solution compared to traditional tracking systems.

➢ *Comparative Analysis with Traditional SCM Systems*

The blockchain-based system was compared with traditional centralized SCM solutions. The key improvements observed were:

- Faster Transactions: Payments were processed instantly compared to traditional banking delays.

- Enhanced Transparency: Every transaction was recorded on an immutable ledger, reducing disputes.
- Reduced Fraud: Smart contracts eliminated human intervention, ensuring contract enforcement.
- Automated Compliance: IoT data integration ensured that shipments met required temperature conditions.

VI. CONCLUSION

The integration of IoT and blockchain in the CHAINCRAFT framework offers a transformative solution to modern supply chain challenges. By combining real-time data collection through IoT with blockchain's immutable and transparent record-keeping, CHAINCRAFT enhances transparency, efficiency, and security. It enables end-to-end visibility, automates processes via smart contracts, and ensures data integrity, fostering trust among stakeholders.

Despite its potential, challenges like scalability, high costs, and energy consumption remain. Future work should focus on scalable blockchain solutions, cost-effective IoT devices, and interoperability standards to overcome these barriers. CHAINCRAFT paves the way for smarter, more resilient, and sustainable supply chains, setting the stage for a future where technology drives global trade innovation.

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