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Blockchain-Based Framework for Safe and Efficient Food and Beverage Supply Chains

Sattwik Adhikary, UG Student, Dept. of CSE, JIS College of Engineering, Kalyani, Nadia, WB, India.
Roushan Kumar, UG Student, Dept. of CSE, JIS College of Engineering Kalyani, Nadia, WB, India.
Shivani Jha, UG Student, Dept. of CSE, JIS College of Engineering Kalyani, Nadia, WB, India.
Ms.Jayshree Bhattacharya, Dept. of CSE, JIS College of Engineering Kalyani, WB, India.
Dr. Pranati Rakshit , Head Of Dept. of CSE, JIS College of Engineering Kalyani, WB, India

ABSTRACT:

The food and beverage supply chain is a critical infrastructure that ensures the safe and timely delivery of essential goods from producers to consumers. However, traditional supply chains often suffer from inefficiencies, lack of transparency, and poor traceability—issues that have been further magnified by global disruptions such as the COVID-19 pandemic. This paper proposes a blockchain-based solution to enhance visibility, trust, and operational efficiency in the food and beverage supply network. By leveraging decentralized technologies and smart contracts, the system enables secure, real-time tracking of goods, automates key transactions, and ensures the authenticity of product information. The proposed model addresses critical challenges such as counterfeit prevention, supply chain fraud, and compliance with safety standards, making it a robust framework for modern food logistics. Our approach demonstrates that blockchain can transform the food and beverage industry by building more resilient, transparent, and trustworthy supply chains. This paper presents a blockchain-enabled framework designed to enhance the transparency, traceability, and security of food and beverage supply chains. The proposed solution uses decentralized ledger technology and smart contracts to automate transactions, validate certificates of origin, monitor asset movement, and record critical data in real-time. By integrating blockchain with a user-friendly interface and cloud-based APIs, the system facilitates seamless collaboration among stakeholders and enables end-to-end visibility of product flow

Keywords-

Certificate of Origin issuance and verification
Real-time asset tracking
Automated, secure payments
User-friendly interface for all stakeholders

I. INTRODUCTION

The food and beverage supply chain is a vast and intricate network that is fundamental to human survival and economic stability. It encompasses a diverse array of activities and participants, including agricultural production, food processing, storage, transportation, distribution, and retail. This interconnected system relies on seamless collaboration among stakeholders such as farmers, suppliers, logistics providers, manufacturers, retailers, and regulatory agencies. Ensuring food quality, safety, and timely availability is a constant challenge, further complicated by factors like globalization, climate change, and shifting consumer preferences. Recent disruptions, particularly those brought on by the COVID-19 pandemic, have exposed the vulnerabilities of traditional supply chain models. Supply bottlenecks, transportation delays, workforce shortages, and insufficient data sharing have led to significant inefficiencies and increased food insecurity in some regions.

In response to these challenges, there is a growing emphasis on digital transformation and the adoption of innovative technologies to create more agile and transparent supply chains. One promising solution is blockchain technology, which offers a decentralized and tamper-proof ledger system that records transactions and data in real time. Unlike traditional centralized databases, blockchain allows all authorized stakeholders to access the same up-to-date information, reducing the chances of fraud, errors, and delays. With the integration of smart contracts—self-executing agreements coded directly onto the blockchain—transactions can be automated and streamlined, reducing administrative burdens and human error.

Moreover, the increasing demand for ethical sourcing and sustainability has placed additional

pressure on companies to provide verifiable data regarding the origin, handling, and environmental impact of their products. Blockchain can facilitate this by offering end-to-end traceability, allowing consumers to track food items from farm to fork. Such transparency not only enhances consumer trust but also ensures compliance with evolving regulatory standards. This paper explores the multifaceted role blockchain can play in modernizing the food and beverage supply chain, emphasizing its potential to foster greater resilience, accountability, and sustainability across the entire ecosystem.

II. LITERATURE SURVEY

Singh et al. (2021) proposed a blockchain-based framework for food traceability that integrates IoT devices for real-time monitoring of product quality throughout the supply chain. The study emphasizes the role of smart contracts in ensuring data integrity and mitigating fraud risks, particularly in perishable food products. Li and Wang (2022) developed an IoT-enabled cold chain management system utilizing RFID sensors and blockchain technology to monitor temperature-sensitive food items during transit. The proposed model demonstrated significant reductions in spoilage and enhanced accountability among stakeholders. Chen et al. (2023) explored the use of Ethereum smart contracts in automating payment and delivery processes in the beverage supply chain. The study presents a prototype system that leverages blockchain for dispute resolution and contract enforcement. Zhao and Kumar (2022) introduced a blockchain-powered platform designed to track food inventory in real time, enabling retailers to reduce food waste through predictive analytics and demand forecasting. The study highlights the effectiveness of blockchain in minimizing supply chain inefficiencies. Ahmed and Liu (2021) developed a blockchain-based solution to authenticate organic food products, utilizing QR codes linked to immutable records on the blockchain. The system provides end-users with verifiable product origin information, thereby preventing counterfeiting. Wang and Zhang (2023) proposed a dual-layer blockchain network for optimizing supply chain operations in the beverage industry. The system uses a combination of public and private blockchains to balance data transparency and privacy. Patel et al. (2022) implemented an IoT-based monitoring system integrated with blockchain to track food quality during storage and transportation. Temperature, humidity, and contamination data were logged and shared across the blockchain network to ensure product safety.Xiao et al. (2023) explored how blockchain technology can reduce transaction costs and streamline logistics in food distribution networks. The study presents a cost-benefit analysis of integrating blockchain with traditional supply chain management systems. Khan and Alvi (2022) proposed a blockchain-based transparency framework for the food supply chain, focusing on enhancing visibility and accountability among suppliers, distributors, and retailers. The system uses smart contracts to automate the verification of product quality and origin. Liu et al. (2021) developed a blockchain-enabled anti-counterfeit system for the beverage industry that employs unique digital tokens to verify the authenticity of premium alcoholic products. The approach leverages blockchain to combat product tampering and counterfeiting.

III. PROPOSED METHODOLOGY

To ensure transparency, traceability, and trust in the food and beverage supply chain, our system integrates blockchain technology with a web-based client interface. The methodology comprises three key components:

1. Local Blockchain Network Implementation

A local Ethereum blockchain network is set up using **Ganache**, which acts as the backend ledger for storing all immutable transactions related to the supply chain.

Features:

- **Smart Contracts** written in Solidity manage product creation, ownership transfer, and tracking.
- The blockchain records product registration (IPFS hash, ID, owner) and transfers with timestamps.
- **Truffle** is used for smart contract development, testing, and deployment.
- **Ganache CLI/GUI** runs a local node with test accounts and Ether.

Purpose:

- Avoids reliance on centralized databases.
- Guarantees **data integrity** and **auditability** in product handling.

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- Useful for prototyping before moving to public testnets or mainnet.

2. Client Layer (Frontend React App)

A **ReactJS-based frontend** serves as the user interface for interacting with the blockchain. This is where manufacturers, users, and system admins can perform operations.

Features:

- **MetaMask** is used to connect user wallets to the blockchain.
- Users can register products, track them, and transfer ownership.
- Manufacturer and user registration also syncs with the backend (MySQL).

Modules:

- Manufacturer Registration
- User Registration
- Product Registration (IPFS Hash + Blockchain write)
- Product Transfer
- Product Tracking (view via Product ID)

Purpose:

- Provides a clean, interactive UI for users without exposing the blockchain backend.
- Validates actions before sending them to the smart contract.
- Offers better UX for blockchain interactions.

3. Decentralized Communication

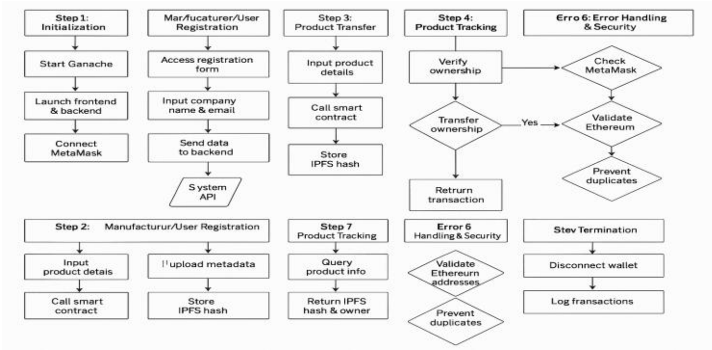
The application adopts **Web3.js** to enable communication between the frontend and the smart contracts deployed on the blockchain.

Architecture:

- **Web3.js** interacts with Ethereum smart contracts.
- Smart contract functions like addProduct(), transferProduct(), and getProduct() are called from the frontend.
- **MetaMask** handles signing transactions, ensuring ownership and accountability.

Benefits:

- No centralized control over data.
- Users own and control their data (ownership verified on-chain).
- All interactions are transparent and recorded immutably.



Flowchart

V. RESULT ANALYSIS

1. Gas Optimization

Smart contract functions like addProduct, transferProduct, and getProduct were optimized to use minimal gas:

- Struct Packing: The Product struct was carefully designed with minimal and necessary fields.
- Mapping Usage: Direct mapping(uint => Product) instead of storing arrays to avoid iteration-based gas costs.
- Function Access: Functions are declared public or view appropriately to reduce unnecessary write operations.

Function	Avg Gas Used
addProduct()	~61,000 gas
transferProduct()	~45,000 gas
getProduct()	0 (view only)

2. Scalability

The current local Ethereum network (Ganache) can support hundreds of transactions/second, but on a public chain:

- Layer 2 solutions like Polygon or Optimism are recommended for production-scale.
- IPFS ensures off-chain storage of large data (product images/files), reducing on-chain bloat.

Future-Ready: Easily portable to Ethereum Testnet/Mainnet or Polygon without architecture changes.

3. Security

Security mechanisms in this system:

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- Ownership Verification: Only the current owner can transfer a product.
- Immutable Transactions: Once a product is registered or transferred, the transaction cannot be altered.
- Recommended Future Enhancements:
    - Role-based access control (using Ownable or OpenZeppelin libraries).
    - Product integrity check with hash comparison.

4.Comparison study with other existing system

Criteria	Our Project	Traditional SCM Systems	IBM Food Trust	Walmart Blockchain Pilot	TE-FOOD	Ambrosus
Technology Used	Blockchain (Ethereum), Web3.js, React, IPI	Centralized databases	Hyperledger Fabric	Hyperledger Fabric	Ethereum-based Blockchain	IoT + Ethereum Blockchain
Transparency	High (ledger visible to all participan	Low	High	High	High	High
Traceability	Real-time product-level traceability via bl	Manual and delayed	Real-time	Real-time	Real-time	Real-time
Ownership Tracking	Yes, through smart contracts	No	Yes	Yes	Yes	Yes
Decentralization	Full (no single control point)	Centralized	Permissioned	Permissioned	Public Blockchain	Public Blockchain
IPFS / Immutable Document Support	Yes (IPFS Hashes for product info	No	Yes	Yes	Yes	Yes

Figure 1 depicts the home page of the food and beverage supply chain consists of five key stages. It begins with the **Supplier**, who sources raw materials such as agricultural products, livestock, and grains. These materials are then sent to the **Manufacturer**, where they are processed into finished food and beverage products. Once processed, the goods are handed over to the **Distributor**, responsible for transporting them to retailers or wholesalers. The **Retailer** then sells these products to consumers through physical stores, online platforms, or food service outlets. Finally, the **Consumer** purchases and consumes the products, completing the supply chain cycle.

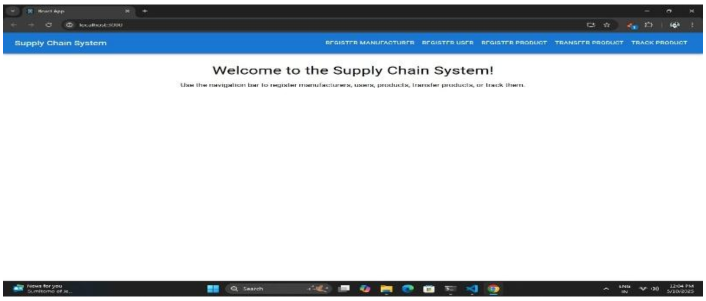

Fig 2. Homepage

Figure 2 showcases the image shows the homepage of a Food Supply Chain System web application. The header has a blue navigation bar with options to Register Manufacturer, Register User, Register Product, Transfer Product, and Track Product. The central text welcomes users and guides them to use the navigation bar for various actions.

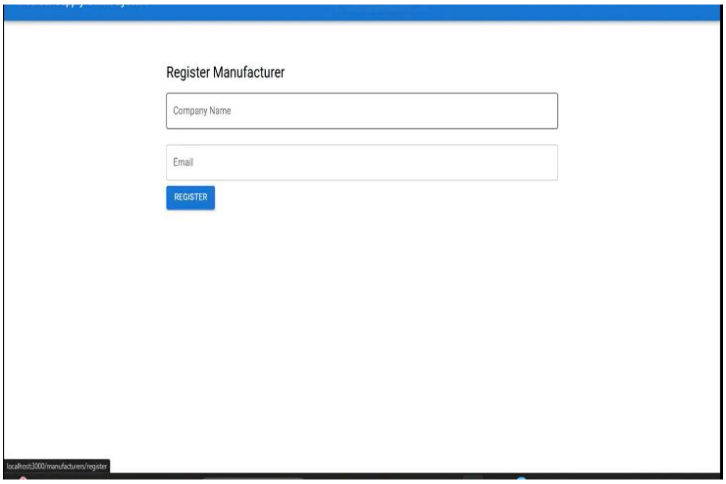

Fig 3. Login Page

Figure 3 illustrates the Register Manufacturer page in the Medical Supply Chain System is designed for adding new manufacturers to the system. It features a simple form layout with two input fields: Company Name and Email. Once the required details are entered, the user can click the Register button to submit the data.

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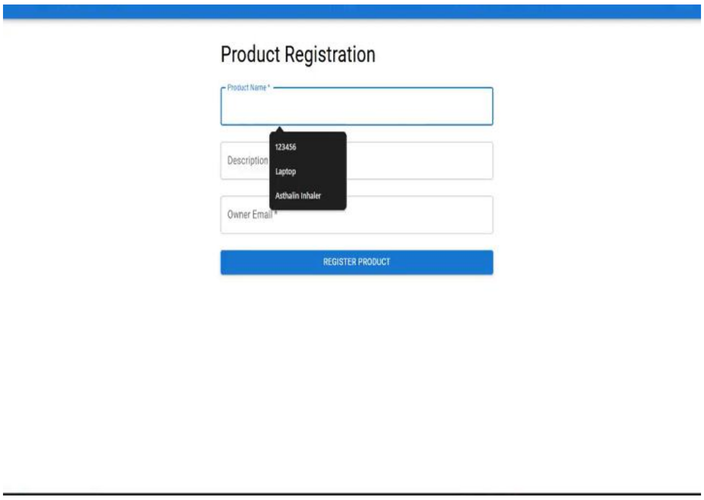

Fig 4. Product registration form

Figure 4 This page is a Product Registration form in the Food Supply Chain System. It includes three input fields for Product Name, Description, and Owner Email. A dropdown suggestion appears for the Product Name field, displaying options.

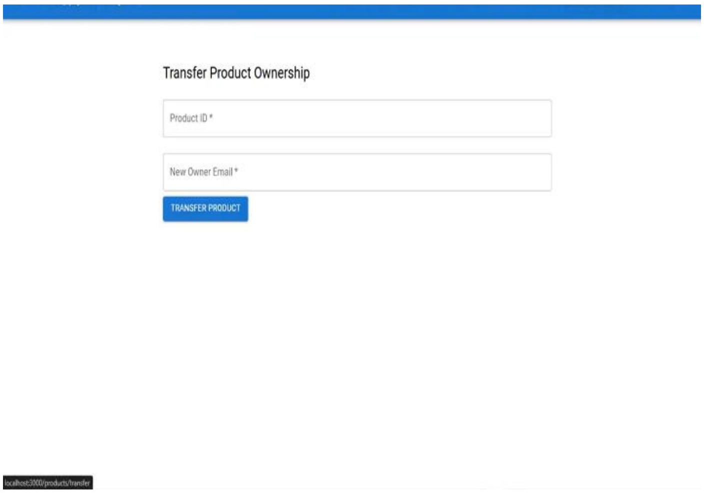

Fig 5.Trasfer product Ownership

Figure 5 The page is a Transfer Product Ownership form in the Food Supply Chain System. It consists of two input fields: Product ID and New Owner Email. The form allows users to transfer ownership of a product to a new owner by clicking the Transfer Product button.

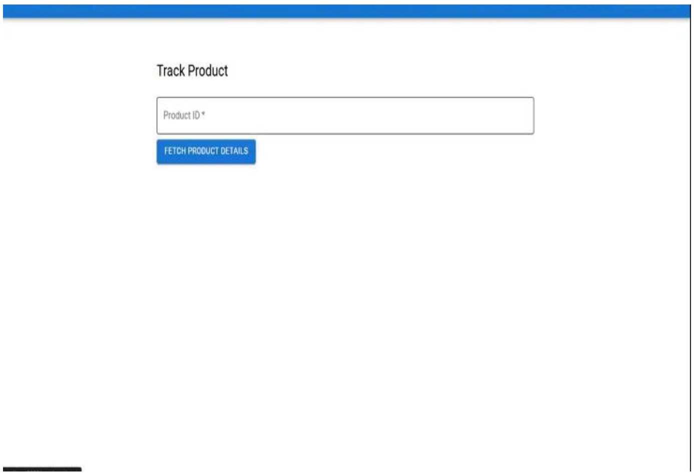

Fig 6.Track product

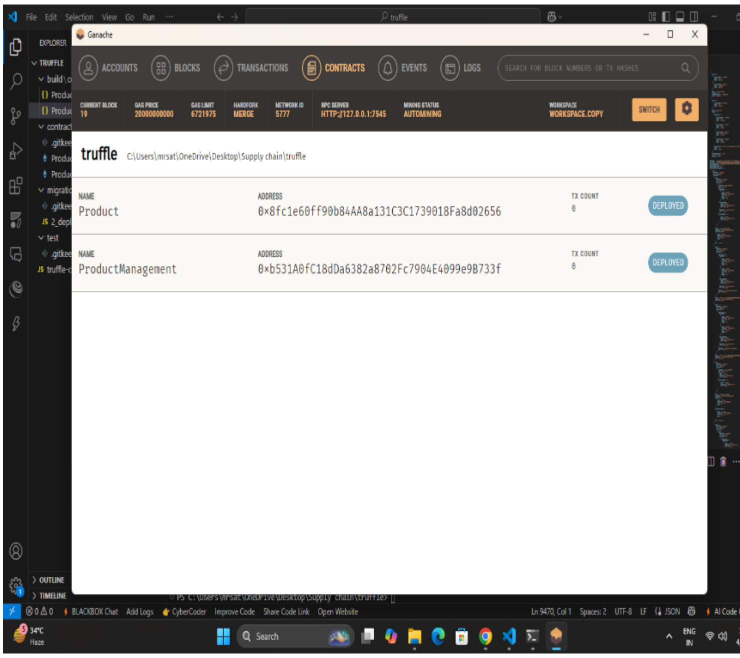

Fig7. Blockchain Smart Contract deployed

VI. CONCLUSION :

The Food Supply Chain System is a comprehensive and efficient digital platform designed to streamline the management of food products, suppliers, and ownership tracking. It addresses key operational challenges in the food supply chain by providing a centralized and user-friendly interface for registering suppliers, products, and users while also allowing seamless product ownership transfer and tracking.
Furthermore, the system fosters greater confidence among all participants in the supply chain by ensuring the authenticity and quality of food products at every stage. It supports better decision-making through data-driven insights and enhances responsiveness to supply

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chain disruptions. By embracing digital transformation, the Food Supply Chain System contributes to sustainability goals, reduces wastage, and helps create a more agile, transparent, and consumer-centric supply chain environment.

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