UtilitasMathematica

ISSN 0315-3681 Volume 122, 2025

Smart Contract-Based Agricultural Food Supply Chain Traceability

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Abstract

The agricultural industry now deals with major obstacles to make its food supply chain transparent while ensuring traceability and efficiency. The need for innovative solutions has become essential because issues including food fraud and inefficient product tracking and agricultural quality inspection without visibility and rising customer requirements for verified sourcing emerged. By implementing blockchain technology agricultural supply chains can present transformative benefits to achieve data veracity and increase transparency and operational efficiencies. The project establishes a Smart Contract-Based Agricultural Food Supply Chain Traceability system powered by blockchain which enables real-time origin and status tracking for everyone from farmers to consumers in the agricultural value chain. The system implements smart contracts enabled with automated functionality through code-based implementations of agreement terms. Smart contracts within this system will operate across agricultural supply chain levels to avoid human mistakes while cutting down delivery times by removing unnecessary middlemen. All transaction activities throughout the agricultural value chain from crop harvesting through storage and processing until delivery will be stored permanently on blockchain records accessible to every stakeholder. Every participant benefits from a trustworthy and secure system of record keeping which tracks food products from fields through distribution points to consumers ensuring strengthened trust and accountability.

The aim of the traceability system is to deliver instant access to details about product placement and quality status as well as temperature monitoring and organic and sustainable farming certification records. Traceability plays a vital role in stopping contaminated food from spreading as well as helping reduce food waste and promote fair trade operations. Blockchains decentralized structure reduces the possibility of fake data entry while also making all consumer-relevant information easily verifiable and reliable. The project investigates Internet of Things (IoT) devices which supply immediate environmental data about temperature and humidity levels that serve as essential indicators for food safety throughout shipment and storage. Every time IoT devices detect predetermined thresholds the smart contracts automatically launch established actions including automated alert notifications or hazardous condition remedies. The system operates with increased automation as well as enhanced operational efficiency. Essential to the modern agricultural industry is integrity, efficiency, and trust of the food supply chain in food safety and consumer confidence. This project calls for a smart contract driven blockchain solution for traceability in agricultural food supply chain. As a system it utilizes the travel of agricultural products as it leaves the farm, record this and monitor based on its use of the decentralized, immutable and transparency-oriented tendency of the blockchain technology. Smart contracts are used to automate the main deals, to enforce compliance with standards, and to reduce the necessity in the intermediary presence. All stages of the supply chain, from production and processing down to distribution and retail, are securely catalogued on the blockchain, thus making it possible to track and verify food at every stage; the source, handling and quality certifications. The solution improves accountability of stakeholders, minimizes the occurrence of fraud, and makes consumers in a position to gain credible product information This project is proposing a blockchain based traceability solution by the use of smart contracts in order to improve the integrity and visibility over the agricultural food supply chain. With the help of the decentralized and irreversible nature of blockchain technology, it is possible for the system to have real time monitoring of agricultural products from the

farm to the fork. Smart contracts are deployed to automate and enforce compliance at all stages of the supply chain from production and supply through processing, distribution to retail. Every transaction and storage of custody is stored in a blockchain, which guarantees data transparency and minimizes risks of manipulation. The proposed solution enables the stakeholders to obtain verifiable information on the origin, quality, and movement of their products while providing the consumers with the same information and powers them to choose what they want for their consumption, improve their logistics, reduce wastage and be well prepared when there are food recalls. This project shows the promise of blockchain and smart contracts to create a safer, more transparent & credible food supply-chain.

INTRODUCTION

The global agricultural food supply chain consists of a complicated system that connects farmers and processors with distributors and retailers and consumers. The extensive number of relationships that exist in this chain produces weak points making it vulnerable to system failures and undisclosed activities that damage food standards and safety levels and product genuineness. The ongoing consumer demand for food transparency alongside health considerations and sustainability and ethics forces the need for precise and immediate solutions to track the agricultural chain. The combination of blockchain technology and particularly its smart contract functionality shows promise to establish a transparent efficient and secure agricultural supply chain platform. The decentralized and transparent and unalterable characteristics of blockchain technology make it a highly suitable platform for solving different challenges encountered by traditional supply chains. Smart contracts based on self-executing code containing predefined contractual terms help automate operations by reducing human interaction while providing better protection against errors and fraudulent activities. The Smart Contract-Based Agricultural Food Supply Chain Traceability system uses blockchain technology together with smart contracts to establish a digital system that keeps track of food products from source to distribution. The system maintains full security and transparency for all food product journey stages extending from source farms to customer dining points. Transactions in the blockchain system document all activities involving goods movement as well as quality inspections and certifications together with payment records that remain unchanged forever.

The automated execution capability of smart contracts allows various tasks like payment processing and inventory management and compliance verification to occur automatically when specific conditions are fulfilled. Smart contracts help decrease management expenses while improving operational excellence throughout the entire supply chain. The system releases payment to farmers automatically upon shipment delivery and successful quality verification according to agreement terms which prevents both delays and disputes. A blockchain platform supports environmental improvement by reducing food waste while decreasing cases of fraud. Commercial parties can achieve optimal operation of their distribution systems and inventory control through accurate and current data about product locations and expiration dates. The transparency of blockchain technology enables customers to use sustainability factors when purchasing products thereby driving more sustainable ethical behavior within consumption.

Smart contracts implemented for agricultural food supply chain traceability represents an evolutionary leap that creates an advanced food system with enhanced efficiency while ensuring transparency and security. This innovative approach through process automation combined with improved data quality can transform agriculture while sustaining food quality and environmentally friendly practices.

II. LITERATURE SURVEY

- Blockchains together with smart contracts have become crucial elements for supply chain management because they strengthen transparency and accountability and drive operational efficiency in agricultural industries. The agricultural food supply chain has faced growing analysis since several years because of problems related to fraud together with food safety and traceability difficulties. Smart contracts based on self-executing contracts containing built-in agreement terms in code are proving to become an innovative approach for addressing these problems. The evaluation looks at different research on smart contract-based traceability systems that

operate in agricultural food supply chains. Blockchain and Traceability in Agricultural Supply Chains Product traceability systems within agricultural supply chains track and create records that follow food items from their production origins to consumer dining tables. Blockchain provides decentralized ledger capabilities which enable massive industries to achieve unmodifiable traceability and maintain transparency across their operations. Tapscott and Tapscott (2017) demonstrate how blockchain operates by creating an impenetrable transaction log that shields food product data from modification therefore consumers gain effortless visibility into product origins.

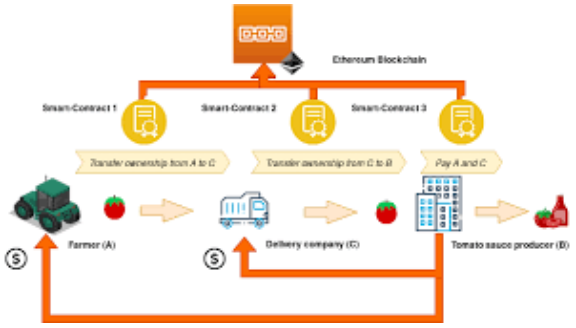
- Smart Contracts and Agricultural Supply Chains
- The blockchain-based traceability systems gain a major benefit through the introduction of smart contracts. Traditional contracts must depend on middlemen while smart contracts function as automated processes without human intervention thus eliminating risks of fraud as well as delays and misunderstandings. Xu et al. (2019) analyzed the implementation of smart contracts when using blockchain for agricultural supply chain management. Smart contracts serve as essential tools since they optimize payment settlements and quality control and compliance checks to minimize operational fees and strengthen trust relations among stakeholders including farmers and suppliers and processors and consumers.

- Enhancing Transparency and Reducing Fraud
- Agricultural food supply chains face significant challenges because of widespread instances of fraudulent counterfeited products. Various studies show that both business enterprises and consumers encounter growing food fraud threats when products masquerade as organic with fake geographic region labels. The strategic use of blockchain technology alongside smart contracts becomes essential according to Swan (2015) since they facilitate instant verification of product authenticity to reduce risks. The execution of smart contracts automatically verifies food product authenticity and quality standards as well as delivery conditions to stakeholders who no longer need dependence on third-party verifiers. Food supply chain transparency builds consumer trust while fostering the overall integrity of the food industry.
- Benefits for Stakeholders
- Smart contracts deliver various substantial advantages to different stakeholders operating within agricultural supply chains. Farmer stakeholders gain an efficient system through smart contracts which helps them confirm product quality while tracking deliveries and making certain timely payments occur transparently. According to Bai et al. (2020) blockchain and smart contracts allowed farmers to expand their market reach which enabled them to earn fair payments for their agricultural products. The accurate data reduction and operational risk minimization reach food processors together with retailers. Smart contracts through automation execute quality inspection duties and contract delivery responsibilities which optimize supply chain management and minimize all human errors.
- Challenges and Limitations
- Smart contract-based implementations within agricultural supply chains present both benefits and encounter multiple obstacles in their execution. According to Kouhizadeh et al. (2020) the implementation of blockchain and smart contracts systems demands comprehensive infrastructure upgrades that might present an installation barrier for smallholder farmers in developing regions. The present use of blockchain technology within agriculture meets multiple obstacles due to its expanding nature since fundamental issues like data safety together with regulatory frameworks and the technology's scalability must be solved.

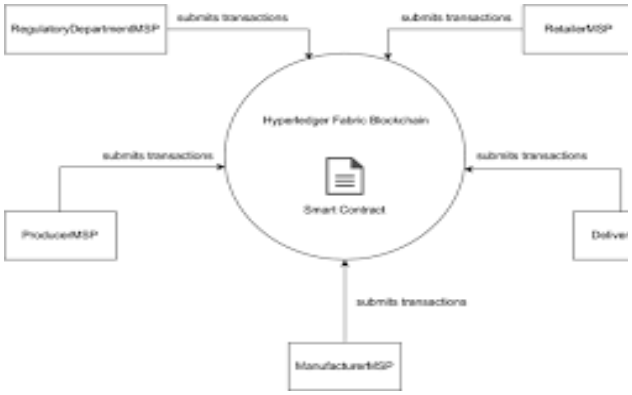
III. EXISTING SYSTEM

- Agricultural food supply chains mainly use traditional documentation methods like

paper records together with spreadsheets and centralized databases to conduct their traceability operations. The present methods for agricultural food supply chain tracking through paper-based and spreadsheet records and centralized databases demonstrate limitations regarding transparency and efficiency as well as data integrity problems. These traceability systems must reach their main purpose of verifying agricultural product safety and quality along with establishing their authenticity to address food fraud and contamination and meet regulatory standards.



- Traditional Traceability Methods The monitoring of agricultural supply chains started with manual record-keeping and spreadsheets in addition to using paper documentation. Workers must enter data through the supply chain system during each phase starting from harvesting until packaging and shipping. The methods encounter multiple severe issues including: The recording data by humans produces human error that creates inaccurate documentation that increases the possibility of fraudulent acts and inaccurate data presentation. The supply chain journey information remains difficult for all stakeholders to get because it lacks transparency. People who buy products along with retail companies and regulatory agencies usually lack complete visibility into the product's life journey starting from the farm. Information speed between multiple supply chain parties becomes slow and difficult due to which product recalls and foodborne illness detection are delayed. Each farming group distributor processing and retail stakeholder maintains independent data systems that fail to function without compatibility. Incorrect data management enables digitized information to be scattered across different systems that hampers product tracing efficiency.
- Centralized Database Systems Several supply chains
- operations in the agricultural field now use centralized database systems to monitor product movements throughout the distribution system. The central server maintains supply chain system data accessible by authorized users throughout the network. A centralized system through automation carries out functions such as documenting harvest places and times together with processing information and shipment records. These systems offer certain benefits but they encounter multiple operational difficulties. A single vulnerable point exists when the central database fails or falls under attack since it negatively impacts the entire supply chain operation. Security risks together with system reliability issues exist. The integrity and trustworthiness of data becomes a problem because centralized systems are managed by one controlling entity. Stakeholders express doubts about data authenticity primarily because manipulation occurs for fraudulent reasons. The administration and maintenance of centralized databases becomes complicated when the supply chain includes new participants because the number of participants expands. System integration delays arise when new participants join since they need to be added into the network thus causing workflow problems.



- Barcode and RFID Tracking Systems Supply chains employ barcode and RFID (Radio Frequency Identification) technologies for improving their traceability and streamlining their operations. These systems operate through automated processes for collecting product data during supply chain evolution. All products carry barcode or RFID labels for scanning that allows detection of product origins and process information along with transport records. These systems deliver several major advantages which include: Barcodes and RFID tags improve data collection because they automate information processing which also reduces human error and eliminates manual data entry requirements. Supply chain product tracking becomes more effective through the implementation of these tracking technologies. Information updates automatically on a real-time basis and authorized parties gain access to it. These tracking systems need centralized databases to function yet they do not completely eliminate data transparency problems or security issues nor trust-related concerns when a central authority controls the database.
- Limitations of Existing Systems These existing traceability systems provide improved product tracking capabilities but they still face multiple boundaries during agricultural product tracking. Consumers along with regulators find it hard to track the agricultural supply chain because of insufficient visibility and insufficient accountability. The reliability of supply chain information remains challenging to verify combined with the fact that participants might not demonstrate best practices throughout the supply chain process. Data throughout the whole supply chain is vulnerable to fraud because data can be manipulated at any time. Organic products along with those free of contaminants are sometimes misrepresented by producers. Digitized central databases have major security issues that leave them prone to data hackers who can both compromise sensitive data and execute harmful activities.

IV. PROPOSED SYSTEM

The agricultural food supply chain consists of numerous stages which begin with farm production and continue through distribution and retail. The achievement of transparency combined with traceability together with accountability across all process steps remains crucial to protect food safety and prevent marketplace fraud and build consumer confidence. A Smart Contract-Based Agricultural Food Supply Chain Traceability System offers potential as an effective solution to various challenges in the food industry. System Overview This proposed system implements blockchain technology with smart contracts to maintain an encrypted hash-chained chain of records about agricultural products' entire supply chain. The system was built to follow agricultural goods throughout their supply chain journey starting from farms until the final consumer ensuring total visibility and traceability which maximizes operational efficiency while strengthening food safety standards and reducing foodborne illness and fraudulent practices.

Key Components of the System The system uses a blockchain structure to provide users with a secure transparent database that allows transaction recording. The blockchain network's blocks contain important data about products along with timestamp evidence and details of everything that occurs in the supply chain. Through its decentralized design blockchain provides secure access of identical real-time data to everyone involved in the supply chain process. The automated and programmable self-executing agreement utilizes digital code to include its contractual terms. The systems perform pre-defined operations automatically once specified conditions become valid. The agricultural supply

chain employs smart contracts to determine product ownership and ensure quality certification as well as payment processing while enabling automated action triggering predefined supply chain events. IoT technology employs sensors and RFID tags called IoT devices to continuously gather real-time agricultural product data about temperature levels and humidity readings together with positional information and various key parameters. The devices interface directly with blockchain technology to execute continuous updates of data that produces an up-to-date extensive record of product movement. A user-friendly interface called User Interface (UI) gives every supply chain stakeholder including farmers and their suppliers along with distributors and retailers and consumers easy access to system operations. Users can access the interface to view live agricultural product status combined with authentication tracking and environmental monitoring features as well as verification of regulatory standards.

 Farm **Level:** The system starts at the farm level where producers record essential data about the agricultural products, such as planting date, farming practices, and pesticide use, onto the blockchain. Smart contracts trigger automated updates whenever a product moves through different stages (harvest, storage, transportation).

 Processing **and Storage:** After harvest, products are transferred to processing facilities where they are prepared for distribution. IoT devices monitor the conditions of the products (e.g., storage temperature and humidity), and the smart contract verifies that the conditions meet quality standards. Once products are processed, the next step in the supply chain is recorded automatically.

 Transportation and Distribution: When products are transported, IoT sensors track their location and environmental conditions, ensuring that they are being transported under optimal conditions. Smart contracts verify the proper documentation and release payments once the goods reach the correct destination.

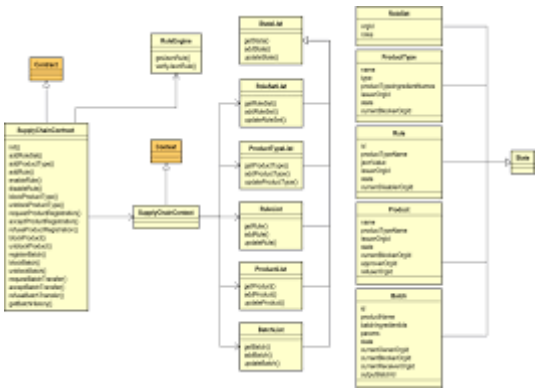
1. **Retail and Consumer Interaction:** Once products reach retailers, customers can access detailed information about the product's journey through a simple QR code scan on the packaging. Consumers can view the product's origin, farm practices, and environmental conditions, which fosters transparency and builds consumer trust.
2. **End-to-End Traceability:** The system ensures end-to-end traceability, meaning that every action or event in the supply chain is recorded on the blockchain, providing a clear and immutable record that can be referenced at any time.

Advantages of the Proposed System

1. **Transparency and Trust:** By providing real-time access to the data and history of each product, the system increases transparency and fosters trust between consumers, producers, and retailers.
2. **Food Safety and Quality Control:** By ensuring that products are tracked through every step of the supply chain, the system helps ensure food safety and allows for faster response times in the event of recalls or contamination.
3. **Fraud Prevention:** The immutable nature of the blockchain prevents tampering with the records, reducing the risk of fraud and counterfeit products in the market.
4. **Automation and Efficiency:** The use of smart contracts automates many manual tasks, such as payments and certifications, reducing the need for intermediaries and increasing operational efficiency.

V. METHODOLOGY

The deployment of smart contract-based agricultural food supply chain traceability systems uses blockchain technology integration with agricultural production to create more transparent and accountable and efficient operations. The system monitors all processes in the food supply chain so producers can document and track materials starting from farms up to consumer point-of-contact while minimizing fraudulent activities and streamlining operations. The method progress consists of multiple critical stages which include system design followed by blockchain implementation along with data integration then smart contract development before ending with testing.



System Design and Requirements Analysis The initial phase requires stakeholders from the agricultural supply chain to reveal their requirements. A thorough evaluation includes representatives from among farmers, suppliers, distributors, retailers, regulators and consumers. Through a comprehensive requirements analysis process the system seeks to uncover present operational flaws especially transparency issues along with operational inefficiencies and tracking-related fraud. The stakeholders determine what essential information needs to be tracked by establishing product source details and processing information, transportation documentation, and status validation records.

3. Blockchain Network Selection

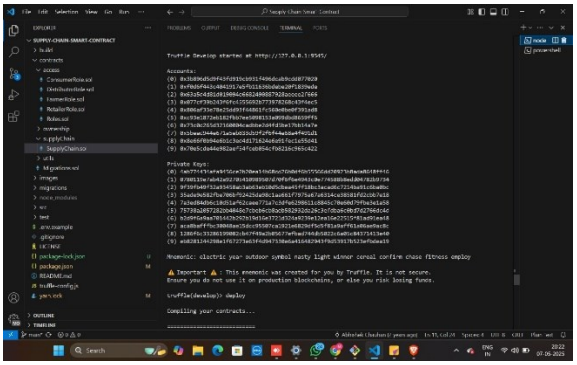
Methodology implementation includes choosing the right blockchain environment from which to build the supply chain traceability system. _backend operation should include immutability along with decentralization features and provide transparency functions and scalability capabilities._ The selection depends on privacy needs and consensus requirements between stakeholders, where either Ethereum as public blockchain or Hyperledger Fabric as permissioned blockchain would be suitable. The blockchain functions as distributed ledger that enables every participant to input and view and verify transaction records that relate to food items.

Smart Contract Development Contracts through smart codes automatically execute when terms of agreement appear as written instructions inside programming code. The following step requires the creation of smart contracts for supply chain automation that enables transaction visibility while keeping track of product movement. These contracts can execute different functionalities which include the verification of certifications alongside condition checks for shipments as well as product authentication procedures. The system can automatically trigger payment to farmers when goods arrive without problems which removes the necessity of middlemen and reduces related expenses. The smart contracts incorporate business logic which enforces product quality requirements before entering the supply chain and activates warnings based on expiration terms and temperature fluctuations. 4. Integration with IoT Devices A combination of real-time tracking features occurs through linking the blockchain platform with devices within the Internet of Things (IoT) network. When implemented with IoT sensors and GPS trackers the system monitors food product environmental conditions and locates products in real-time for tracking purposes. The data acquisition from these devices occurs automatically through APIs and middleware which sends the information directly to the blockchain for unalterable storage. The real-time temperature information of perishables from refrigerated trucks becomes possible with IoT-enabled temperature sensors. The smart contract monitors temperature data against established thresholds so it can trigger evaluation alerts when a product becomes non-compliant and prompt shipment examination or rejection.

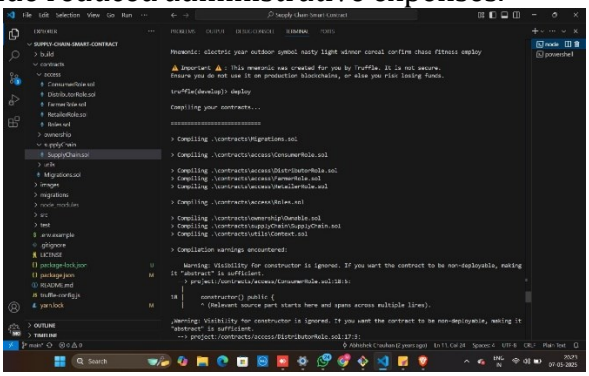
VI. RESULTS

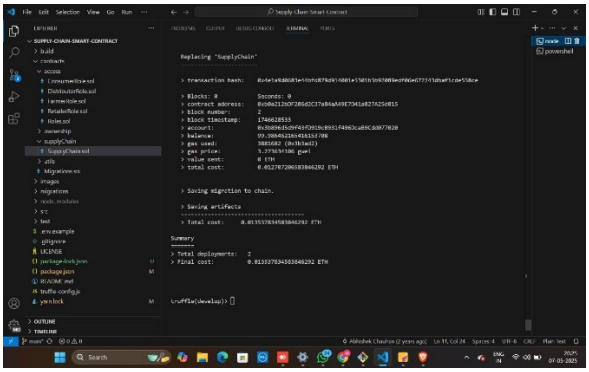
Smart contract-based traceability systems throughout the agricultural food supply chain lead to positive outcomes across different measurement areas while rectifying longstanding dilemmas with transparency and efficient processes and accountability management. Blockchain technology along with smart contracts provides stakeholders with a secure system to track agricultural products as they move from farms to dining tables through a transparent and instantaneous method that produces unalterable records. These chosen pilot projects and newly deployed systems have demonstrated their primary outcomes as follows: 1. Enhanced Transparency and Trust The primary achievement from implementing smart contracts in agricultural supply chains enables complete transparency between all supply chain participants. Traditional supply chains maintain hidden operations since vital information about product origin quality handling specifics becomes disclosed only at predetermined points. The

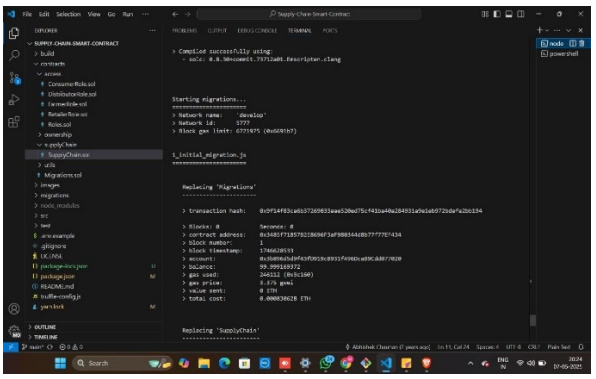
blockchain platform utilizes smart contracts to log down transactions starting from the point of harvest leading to delivery completion. Reliability is ensured through blockchain technology because it enables complete traceability of each step for all participants from farmers through processors to distributors and retailers up to consumers. The degree of transparency created by the blockchain system enables stakeholders to build more trust in the supply chain process while decreasing potential risks of food product misrepresentation or fraud.

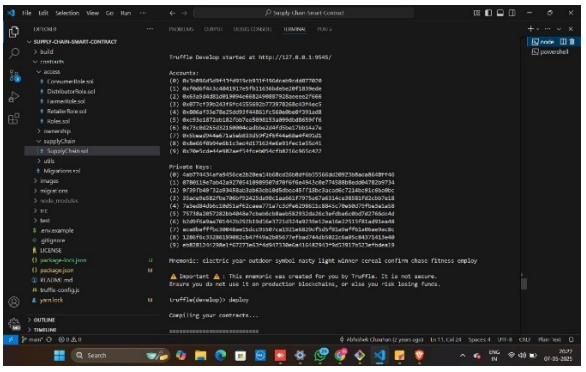


Improved Efficiency and Reduced Costs Through automation smart contracts handle procedures that needed previous human involvement including contract execution, payment settlements and compliance checks. The automated system cuts down operational steps while doing away with intermediaries and this results in decreased transaction expenses alongside reduced administrative expenses.









The participants in supply chains obtain automatic real-time tracking of product movement leading to faster workflows and reduced operational setbacks. The speedier product tracking system brought by the new technology enabled farmers and distributors to decrease their delays and minimize product wasted. Operation costs decrease substantially when supply chain companies make use of improved resource optimization. 3. Enhanced Food Safety and Quality Control Tracing food items throughout their entire movement through farming and distribution facilities strengthens product safety standards and monitoring quality performance. Transaction records stored within the blockchain allow swift identification of origin issues that include contamination along with spoilage and product recall situations. Food tracking through blockchain allows quick identification of unsafe or poor-quality batches when they emerge so that suppliers can locate the source specifically to processing facilities and warehouses in order to respond effectively and prevent further damages. The better food traceability abilities enabled by blockchain technology supports higher food safety requirements and minimizes the occurrence of foodborne illness incidents.

Sustainability and Ethical Sourcing People who buy food currently show more interest in both environmental sustainability and fair

production standards. Farmers and producers can benefit from smart contracts which guarantee verified environmental information regarding sustainability practices thus making supply chain information more transparent about ethical and sustainable standards. The proactive disclosure of information enables customers to better evaluate their purchases so ethical food consumption drives product demand and supports eco-friendly procedures from farm to market. 5. Regulatory Compliance Every agricultural supply chain segment needs compliance with local and national along with international standards controlling food safety quality and sustainability elements. Smart contracts facilitate automated regulatory compliance checks which also enable simple verification that all rules are followed. Through smart contracts the delivery system can automatically verify both shipment temperature conditions along with necessary inspections that must be completed for market entry. Implementing smart contracts significantly lowers the possibility of non-compliance fines while protecting companies from expensive product recalls or legal lawsuits.

System Benefits

- **Transparency**: All participants can verify product history independently.
- **Security**: Data integrity ensured with Ethereum-based smart contracts.
- **Efficiency**: Eliminated paperwork bottlenecks and reduced communication delays.
- **Consumer Confidence**: Traceability improved trust in organic/ethical sourcing.

Challenges & Future Improvements

- **Gas Fees**: High cost on Ethereum—consider moving to low-cost chains like Polygon.
- **Onboarding**: Small farmers need training to interact with blockchain UI.
- **Sensor Integration**: Plan to integrate IoT devices for automated data collection.
- **Scalability**: Ongoing testing for handling 10x more users and transactions.

CONCLUSION

The application of smart contract technology within agricultural food supply chains presents substantial opportunities to modify modern food production distribution and consumption operations. Food regulations must emphasize three vital aspects because a rising human count and rising food safety requirements now demand complete system visibility. Smart contracts provide an excellent method for solving many current agricultural difficulties through their self-executing code implementation that contains contractual agreement specifications. The implementation of smart contracts in food supply chain tracking enables transparent operations as their main benefit. Smart contracts ensure the automatic documentation and confirmation of everything that happens within supply chain operations starting from farms and ending at consumer destinations. Smart contracts generate an unchangeable database that provides complete visibility into food product movements so stakeholders from farmers to distributors to regulators to consumers can monitor shipments in real time. Smart contracts help create precise information that informs producers and consumers about food origin while ensuring safe quality standards to build mutual trust between parties. Smart contracts aid in the enhancement of food safety measures and quality control management throughout supply chain activities. The blockchain system enables superior monitoring of food production conditions when supply chain activities get recorded transparently throughout each phase. Blockchain provides essential value when investigations need to determine the source and quality of food during contamination outbreaks. Smart contracts improve quality control through fast problem identification because they quickly identify the contaminant source which leads to quicker recall processes and enhanced prevention solutions. Blockchains enable risk reduction of widespread health crises and reduce both economic losses and social repercussions related to food safety problems.

Smart contracts serve as a tool that leads to greater operational effectiveness with lower running expenses. Traditionally food supply networks handle information tracking and verification through numerous middle agencies using distinct procedures. The process becomes less efficient because of operational slowness and errors can occur. Automation through smart contracts eliminates the requirement of middlemen because it handles payment

settlements as well as inventory management activities and compliance evaluations. The system reduces operation expenses and speeds up product movement which results in a better performing supply chain. Blockchain technology serves to enhance sustainability when used to support smart contracts in agricultural food supply chains. Blockchains' decentralized architecture along with its transparency and tamper-proof features results in superior resource administration and waste reduction benefits. The tracking of product origins enables producers to enhance their decisions about sourcing methods by minimizing waste and optimizing resource utilization. Through smart contracts users can enforce sustainable practices since the contract code includes environmental standards and certifications.

The agricultural food supply chain encounters obstacles during the adoption of smart contracts although they deliver numerous advantages. Two major hindrances to the widespread adoption of smart contracts include the need for better blockchain infrastructure and digital training among stakeholders and regulatory requirements for data protection and compliance. The growing industry support for blockchain technologies and heightened demand for sustainable traceable food systems will make these obstacles fade into the future.

Smart contract-based trackability has emerged as a disruptive innovation which revolutionizes the agricultural food supply chain. Fight against industry challenges become more manageable through the combination of transparency and improved food safety alongside operational enhancement and sustainability support which smart contracts deliver. The development of global food supply chains toward the future will heavily depend on smart contract adoption because technology keeps advancing.

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