TRACK AND TRACE SUPPLY CHAIN MANAGEMENT SYSTEM

A PROJECT REPORT

Submitted by,

ADITYA KUMAR JHA	**20211CSE0878**
ABHINAV KUMAR SINGH	**20211CSE0849**
AADITYA KUMAR	**20211CSE0830**
SOUROV BHOWMICK	**20211CSE0862**

Under the guidance of,

Dr. Abdul Khadar A
Associate Professor, Presidency University, Bengaluru.

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PRESIDENCY UNIVERSITY

SCHOOL OF COMPUTER SCIENCE ENGINEERING

CERTIFICATE

This is to certify that the Project report **"TRACK AND TRACE SUPPLY CHAIN MANAGEMENT SYSTEM"** being submitted by **"ADITYA KUMAR JHA, ABHINAV KUMAR SINGH, AADITYA KUMAR, SOURAV BHOWMICK"** bearing roll number(s) "**20211CSE0878**, **20211CSE0849**, **20211CSE0830, 20211CSE0862"** in partial fulfilment of requirement for the award of degree of Bachelor of Technology in Computer Science and Engineering is a bonafede work carried out under my supervision.

Dr. Abdul Khadar A
Associate Professor
School of CSE
Presidency University

Dr.Asif Mohammad H B
Associate Professor & HoD
School of CSE
Presidency University

Dr. L. SHAKKEERA
Associate Dean
School of CSE
Presidency University

Dr. MYDHILI K NAIR
Associate Dean
School of CSE
Presidency University

Dr. SAMEERUDDIN KHAN
Pro-VC School of Engineering
Dean -School of CSE&IS
Presidency University

PRESIDENCY UNIVERSITY

SCHOOL OF COMPUTER SCIENCE ENGINEERING

DECLARATION

We hereby declare that the work, which is being presented in the project report entitled **TRACK AND TRACE SUPPLY CHAIN MANAGEMENT SYSTEM** in partial fulfillment for the award of Degree of **Bachelor of Technology** in **Computer Science and Engineering**, is a record of our own investigations carried under the guidance of **Dr. ABDUL KHADAR A, Associate Professor, School of Computer Science Engineering, Presidency University, Bengaluru.**

We have not submitted the matter presented in this report anywhere for the award of any other Degree.

Aditya Kumar Jha	20211CSE0878
Abhinav Kumar Singh	20211CSE0849
Aaditya Kumar	20211CSE0830
Sourav Bhowmick	20211CSE0862

ABSTRACT

The **Track and Trace Supply Chain Management** Project will create a transformational form of traditional supply chain management systems using blockchain to provide greater transparency, security, and efficiency to it. The project seeks to address issues such as counterfeit products, data tampering, operational inefficiencies, and lack of real-time visibility using the latest available technologies, namely the Ethereum blockchain, IoT devices, and smartcontracts.

The proposed solution integrates decentralized systems with IoT for real-time data capturing and transparency, enabling beneficiaries to access immutable records of product movements and conditions. Smart contracts automate workflows, eliminate manual errors, and improve decision-making capabilities, while decentralized storage solutions like IPFS ensure that data is stored securely and cheaply.Layer-2 scalability further optimizes performance to enable the support of high transaction loads for supply chains across the world.

The project will also bring web and mobile applications that will provide a QR code to the end customer to verify the authenticity of a product and trace its origin. The system is designed to incorporate sustainability aspects by allowing enterprises to monitor eco-friendly practices in their supply chains while meeting regulatory compliance requirement

The project, by closing the operational bottlenecks, enhancing customer trust, and encouraging sustainability, will set a benchmark for modern supply chain management. It demonstrates the disruptive capacity of blockchain technology for supply chains with potential to build a new transparent, efficient, and secure global trade ecosystem.

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Aditya Kumar Jha

Abhinav Kumar Singh

Aaditya Kumar

Sourav Bhowmick

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INTRODUCTION

1.1 Overview of Supply Chain Management

1.1.1 Importance of Tracking and Tracing in Supply Chains

Supply chain management serves as the hub of every operation of distribution and ensures the smooth flow of goods, information, and finances all the way from the sender to the receiver. The major obstacle the modern supply chain faces is transparency and traceability of the products, which leads to various inefficiencies, fraud, and counterfeiting. Use of tracking and tracing solutions gives an end-to-end surveillance of the whole process, using advanced technologies, which could allow for all stakeholders to monitor and verify the authenticity of a product at each stage.

The coming of the blockchain based technologies such as Ethereum provides disruptive possibilities in reinventing the supply chain. Blockchains improve trust and accountability to be seamless over global supply networks through their characteristics of immutability, decentralization, and real-time availability of information. The use of these technologies also helps in solving counterfeited goods, shipment delays, and imperfect inventory control which have been plaguing traditional systems.

1.2 Blockchain Technology in Supply Chains

Blockchain technology is one of the attractions of contemporary tracking and tracing systems. While centralized systems are prone to manipulation and cyber threats, a blockchain is a distributed ledger that enables secure and reliable recording of all transactions.

Key characteristics of blockchain that benefit supply chains include:

- **Transparency:** All participants share access to an immutable shared record of transactions, thus forming trust.
- **Security:** Data integrity is maintained and data is further protected from unauthorized modifications by cryptographic mechanisms.

- **Automation:** Smart contracts on the Ethereum platform make workflows simpler and lessen manual interventions.

Blockchain technology finds solution applicability in pharmaceutical and food production, ensuring that goods meet acceptable safety standards and can be traced back to their origins. Consumer confidence is thus bolstered.

1.3 Integration of IoT with Blockchain

The Internet of Things will complement blockchain in improving supply chain systems. IoT devices-such as RFID tags and GPS sensors-make real-time data about the condition, location, and status of products. This information is sent to the blockchain in a secured manner, and thus, the stakeholders are able to see real-time information and can make decisions proactively. For example:

- IoT-enabled temperature sensors can monitor perishable goods, ensuring they remain within safe storage conditions during transit.
- RFID tags allow precise tracking of shipments, reducing losses and misplacements.

The integration of IoT and blockchain not only improves operational efficiency but also ensures compliance with regulations and standards, addressing key challenges faced by traditional systems.

1.4 Objectives of the Project

This project aims to design and implement a blockchain-based tracking and tracing solution tailored for supply chain management. The specific objectives include:

- Developing a transparent and tamper-proof system for product traceability.
- Leveraging Ethereum smart contracts for automating supply chain processes.
- Integrating IoT devices to capture and record real-time data for enhanced tracking.
- Providing user-friendly interfaces for stakeholders, including QR-based product authentication for consumers.

With these objectives, the project seeks to address inefficiencies, enhance trust among stakeholders, and promote sustainability in supply chain operations.

CHAPTER-2
LITERATURE SURVEY

2.1 GENERAL

The literature review discusses the current state of supply chain management technological development, with a focus on blockchain and Internet-of-Things. Over the years, traditional systems have been unable to meet the growing need for transparency, efficiency, and security in the supply chain processes. Increasing attention has turned toward technology-driven solutions due to concerns arising from fraud, counterfeiting, inefficiency, and the inability to track goods in real-time.

This decentralized ledger of blockchain provides a solution to securing traceability as well as trust between the different stakeholders involved. Many studies indicate its success in industries such as food safety, pharmaceuticals, and logistics. Nonetheless, scalability, high-energy consumption, and the issue of integration are some of the foremost challenges. IoT enhances these systems by ensuring real-time tracking of goods and environmental conditions and helping bridge the gap between physical and digital supply chains.

Key takeaways from existing research include:

- The requirement to ensure interoperability between the different blockchain and the conventional enterprise software solutions.
- With increased emphasis on data privacy now and to comply with regulations such as GDPR.
- Challenges with ensuring security for IoT devices and their smooth connectivity with blockchain networks.

2.2 EXISTING METHODS IN SUPPLY CHAIN MANAGEMENT

2.2.1 Traditional Systems

Transparency issues: It is difficult for stakeholders to have access to real-time data on the product movement thus making it hard to verify the authenticity of products or detect anomalies.

- **Transparency issues:** It is difficult for stakeholders to have access to real-time data on the product movement thus making it hard to verify the authenticity of products or detect anomalies.
- **High operational costs**: Manual processes add excessive administrative costs and extended processing times.
- **Tampering:** Centralized systems remain very vulnerable to hacking, unauthorized access, and record manipulation**.**

Although they seem versatile, these systems are incapable of properly communicating the global needs of various sectors concerning modern supply chains, such as agri-foods, healthcare, and retail.

2.2.2 Blockchain-Based Solutions

Blockchain technology, complete and unwavering accountability of transaction records in supply chain management has been supported by safety transparent transactions. The pertinent advantages attendant to blockchain-based systems include crystallizing the following:

- **Enhanced Traceability:** Every transaction is recorded on an immutable ledger, allowing stakeholders to track products from origin to destination.
- **Smart Contracts:** Automated workflows eliminate intermediaries, reduce human error, and streamline processes like payments and inventory updates.
- **Decentralized Architecture:** Eliminates the risk of a single point of failure, enhancing data security.

Despite these advantages, existing blockchain-based systems face several challenges:

- **Scalability Issues:** Public blockchain, like Ethereum, experience slower transaction speeds and higher costs during peak usage.
- **High Energy Consumption:** Proof-of-work consensus mechanisms consume significant energy, raising concerns about sustainability.
- **Interoperability Gaps:** Integration with traditional systems and IoT devices remains a challenge.
- **Limited Adoption:** High initial setup costs and technical complexity deter smaller businesses from adopting blockchain solutions.

Examples of successful implementations include:

- **IBM Food Trust:** Tracks food supply chains, ensuring quality and compliance.
- **TradeLens (by Maersk):** Focuses on improving efficiency and reducing delays in global shipping.

2.2.3 IoT Integration

The Internet of Things (IoT) complements blockchain by providing real-time data on product conditions and location, making it indispensable in tracking and tracing. Key features include:

- **Real-Time Monitoring:** Sensors collect data on temperature, humidity, and location, ensuring goods are transported under optimal conditions.
- **Predictive Maintenance:** IoT devices identify potential risks, such as equipment failures, before they escalate into larger issues.
- **Automated Updates:** IoT devices push updates to the blockchain, ensuring accurate and timely recording of events.

Challenges in IoT integration include:

- **Device Security:** IoT devices are vulnerable to hacking, which could compromise the integrity of supply chain data.
- **Interoperability:** Legacy systems often struggle to integrate with IoT, requiring significant upgrades and investment.
- **Data Overload:** Managing and processing the vast amount of data generated by IoT devices can be complex and resource-intensive.

Studies highlight the potential for combining IoT and blockchain to create robust and efficient supply chain systems. For instance:

- IoT sensors are used in the pharmaceutical industry to monitor the temperature of vaccines during transportation.
- RFID tags in the retail sector improve inventory management and reduce losses.

CHAPTER-3

RESEARCH GAPS OF EXISTING METHODS

3.1 Scalability:

- Public blockchain face constraints like high transaction fees and slow processing speeds during peak usage, limiting their effectiveness for large-scale supply chains. This is particularly problematic for industries dealing with high transaction volumes, such as retail and logistics.
- Current systems lack the flexibility to scale operations across global supply chains with varying regulatory and operational requirements.

3.2 Data Privacy:

- Supply chain data often includes sensitive information, such as proprietary processes and trade secrets. Ensuring privacy while maintaining transparency and traceability is a critical challenge. Current solutions struggle to balance these requirements effectively.
- Encryption methods and access control mechanisms need to be refined to protect sensitive data without impeding accessibility.

3.3 Integration Challenges:

- Existing solutions struggle with integrating blockchain and IoT with traditional supply chain systems, creating barriers for adoption. Many businesses face significant costs and technical difficulties when attempting to modernize their systems.
- Cross-platform compatibility and the lack of standardization in IoT device communication hinder seamless integration.

3.4 Customer Engagement:

- Current systems do not adequately focus on creating user-friendly interfaces, leaving end customers unable to verify product authenticity

- conveniently. This lack of accessibility diminishes the potential impact of blockchain solutions on consumer trust.
- Limited awareness and education about blockchain technologies among customers further reduce their engagement with the system.

CHAPTER-4
PROPOSED MOTHODOLOGY

4.1 Blockchain Technology

- **Ethereum Blockchain**
  Use Ether as the main blockchain platform, given its advanced smart contracts and popularity. This means that workflows will be auto executed and supply chain data can be trusted to be preserved and authenticated..
- **Layer-2 Solutions**
  Layer-2 technologies such as Polygon integrate into blockchains with scalability issues to solve scalability problems and bring down transactional costs. This affords processing that is high-throughput and cost-efficient, gearing the system suitable for sectors dealing with large volumes of transactional loads.
- **Private Blockchain Networks**
  Private blockchain networks are utilized for dealing with sensitive data, including proprietary processes or trade secrets, by guaranteeing privacy whilst maintaining overall transparency all the same.

4.2 Smart Contracts

- **Development and Design**
  Develop smart contracts in Solidity - the native language of Ethereum-for discrete supply chain control activities, such as product registration, ownership transfer, and event logging.
- **Security and Auditing**
  Assess all smart contracts to find and correct any weaknesses before deployment, to ensure system integrity.
- **Advanced Features**:
  - Embed complex business logic to automate repetitive tasks, eliminate manual errors, and ensure consistency.

- Incorporate dispute resolution mechanisms in smart contracts to resolve disagreements with respect to supply chain events (missing shipments, damaged goods).

4.3 Decentralized Storage

- **IPFS (InterPlanetary File System)**
  These include storing product certifications, environmental data, and other types of data in a decentralized manner through the interplanetary file system (IPFS). The information is to be stored only as a cryptographic hash on the blockchain to guarantee data integrity and avoid excessive storage costs.
- **Redundancy and Fault Tolerance**
  Set up some redundancy on the IPFS setup so that one can maintain high availability for the stored data and mitigate data loss during hardware failures or network problems.

4.4 IoT Integration

- **Real-Time Data Collection**
  Make sure to deploy IoT devices to capture product-related data in real-time, like temperature, humidity, and location, to accurately track and monitor across the supply chain.
- **Secure Data Transmission**
  Use encrypted communication protocols to make sure that the data captured by the IoT devices are transmitted securely and are tamper-proof before reaching the blockchain.
- **Tamper-Proof Devices**
  Use IoT devices with tamper-resistant features that prevent any unauthorized manipulation of data or device settings.

4.5 Customer Interface

- **Web and Mobile Applications.**
  Develop web and mobile-accessible intuitive user interfaces that enable seamless interaction with the system among stakeholders (manufacturer, supplier, and customer).
- **Metamask Integration.**
  Connect the Metamask wallet for secure access to blockchain data so that stakeholders can view verified supply chain data from their own account.
- **QR Code Functionality.**
  Embed QR code-based verification for end customers, which enables them to simply scan codes to validate the authenticity and traceability of products.
- **Educational Features.**
  Deliver an in-app tutorial, FAQs, and interactive guides about the advantages of blockchain and supply chain visibility, thus improving adoption rates of the systems among users.

CHAPTER-5
OBJECTIVES

5.1 Enhance Transparency

5.1.1 Real-Time Visibility

Develop a system that provides real-time visibility into all processes across the supply chain, empowering stakeholders to follow and evaluate accurate and real-time data across every stage of the supply chain.

5.1.2 Immutable Data Records

Generate immutable records of every transaction and update, using the phenomenal application of blockchain technology to safeguard against fraud, and misinformation.

5.1.3 Sustainability Traceability

Implement mechanisms for tracing environmental sustainability initiatives, enabling businesses to comply with environmental regulations while meeting consumer demands for sustainable practices.

5.2 Improve Security

5.2.1 Blockchain Security

Leverage blockchain's decentralized and cryptographic nature to safeguard the integrity of supply chain data, eliminating risks of unauthorized access or manipulation.

5.2.2 Data Encryption

Ensure all data transmitted and stored within the system is encrypted and tamper-proof, protecting sensitive business information, including trade secrets and proprietary processes.

5.3 Optimize Efficiency

5.3.1 Automation Through Smart Contracts

Utilize smart contracts to automate repetitive and manual tasks, minimizing human errors, streamlining workflows, and reducing operational delays.

5.3.2 Reducing Intermediaries

Eliminate the need for intermediaries by enabling direct and automated processes, resulting in significant cost savings and reduced administrative overhead.

5.3.3 Real-Time Analytics

Provide real-time analytics tools to supply chain stakeholders, improving decision-making and enabling quicker responses to disruptions or demand fluctuations.

5.4 Foster Trust among Stakeholders

5.4.1 Customer Verification Tools.

Equip customers with user-friendly tools, such as QR code scanning, to verify product authenticity and traceability, building trust and enhancing brand loyalty.

5.4.2 Accountability and Ethical Practices.

Promote accountability by ensuring transparency across the supply chain and demonstrating a commitment to ethical practices.

5.4.3 Stakeholder Education.

Educate businesses and end users on the benefits of blockchain-based systems to improve understanding, increase adoption, and foster confidence in the platform.

5.5 Address Scalability and Integration Challenges

5.5.1 Scalability Solutions

Integrate layer-2 blockchain technologies, such as Polygon, to handle high transaction volumes efficiently, ensuring smooth operations even during peak demand.

5.5.2 Legacy System Integration

Ensure compatibility with existing supply chain systems to reduce costs and technical difficulties for businesses adopting the platform.

5.5.3 Standardization and Interoperability

Establish standardized communication protocols for IoT devices and blockchain systems, enabling seamless operations across diverse industries and global supply chains.

5.6 Promote Sustainability

5.6.1 Environmental Practice Traceability.

Provide tools to trace and verify sustainable practices, such as eco-friendly sourcing and production, fostering consumer trust and brand reputation.

5.6.2 Regulatory Compliance.

Help businesses comply with environmental regulations by providing transparent records, reducing the risk of fines, and enhancing credibility.

5.6.3 Encouraging Eco-Conscious Practices.

Motivate businesses to adopt sustainable practices by offering operational transparency, aligning with global trends in environmental responsibility.

CHAPTER-6

SYSTEM DESIGN & IMPLEMENTATION

6.1 System Design

1. **Modular Architecture**:
   - The system follows a modular design to ensure flexibility, scalability, and easy integration of its core components: blockchain, IoT devices, and decentralized storage.
   - Each module operates independently but communicates seamlessly with others, allowing for future enhancements or component replacements without overhauling the entire system.
2. **Blockchain Layer**:
   - **Ethereum**: Ethereum is chosen for its smart contract capabilities, which provide automated and transparent execution of supply chain workflows, such as product registration, ownership transfers, and event logging.
   - **Layer-2 Solution (Polygon)**: To address Ethereum's high transaction fees and latency during peak usage, Polygon is integrated. This ensures faster and cost-effective transactions while maintaining security.
   - **Private Blockchain**: Sensitive data, such as proprietary business information, is stored on private blockchain networks to maintain a balance between transparency and privacy. These networks limit access to authorized stakeholders only.
3. **IoT Integration**:
   - IoT devices are deployed at various supply chain touchpoints to capture real-time data such as product location, temperature, humidity, and handling conditions.
   - **Secure APIs**: Data from IoT devices is transmitted to the blockchain using secure APIs, ensuring accuracy and protection against data tampering.

- **Tamper-Proof Devices**: IoT devices are equipped with tamper-proof mechanisms and encryption technologies to prevent unauthorized manipulation of data during collection or transmission.

4. **Decentralized Storage**:
   - **IPFS**: Large volumes of product metadata, certifications, environmental compliance records, and other non-transactional data are stored off-chain using IPFS (InterPlanetary File System).
   - **Cryptographic Hashes**: Instead of storing entire data sets on the blockchain, only the cryptographic hashes of the stored data are recorded on-chain. This approach ensures data integrity while reducing blockchain storage costs.
   - **Redundancy Measures**: The system incorporates redundancy mechanisms within decentralized storage to prevent data loss and ensure high availability.
5. **User Application Layer**:
   - **Web and Mobile Applications**: User interfaces are designed with simplicity and accessibility in mind, catering to all stakeholders, including manufacturers, distributors, and end customers.
   - **Metamask Integration**: The integration of Metamask ensures secure login and access to blockchain data for all stakeholders.
   - **QR Code Functionality**: Products are assigned QR codes that customers can scan to verify authenticity, trace their origin, and view detailed supply chain data, enhancing trust and transparency.
6. **Security Mechanisms**:
   - **Cryptographic Hashing**: All blockchain data is hashed, ensuring that records cannot be altered without detection. This creates an immutable audit trail.
   - **Access Control**: Role-based access ensures stakeholders only view data relevant to their responsibilities, maintaining confidentiality.
   - **Dispute Resolution**: Smart contracts include programmable dispute resolution mechanisms to automatically address inconsistencies or errors in supply chain data.
7. **Workflow Design**:
   - The system tracks products throughout their lifecycle, from manufacturing to the end customer.

- IoT devices continuously record key events, such as temperature changes during transportation or delays in shipment, and log these events on the blockchain.
- Dashboards provide stakeholders with real-time monitoring capabilities, enabling better decision-making and quicker responses to disruptions.

6.2 Implementation

1. **Development**:

    - **Smart Contracts**: Smart contracts are built using Solidity to automate workflows, such as product registration, ownership transfer executions, and event tracking. Such contracts are audited thoroughly to remove any kinds of vulnerabilities and ensure proper functionality.
    - **Application Program Interface:** Custom APIs will be developed to facilitate IoT devices' interaction with the blockchain ecosystem, guaranteeing seamless data transfer.
    - **Off-Chain Data Networking:** IPFS nodes are set for off-chain data storage, with the corresponding cryptographic hashes recorded on the blockchain system for verification.
    - **User Interfaces**: The design for web and mobile applications is achieved using React.js and Flutter, providing intuitive navigation and interaction for all stakeholders and trial groups

2. **Testing**:
    - **Unit Testing:** Individual components check whether smart contracts, APIs, and IoT device integrations manage tasks effectively.
    - **Integration Testing:** All system components are tested as a whole to prove smooth communication and adequacy between IoT devices, blockchain, and decentralized storage.
    - **Performance Testing:** Simulations designed to reach the upper limits of transaction volumes are run in order to check for each ability to properly scale and to work in order, especially under the conditions of heavy transactions.

- **Security Testing:** The penetration tests and vulnerability assessments are performed to ascertain whether the system repels unauthorized access and data breaches.
- **Test Networks:** Test networks, such as Rinkeby and Goerli among others, will be used for testing before full-deployment so that problems can be identified and solved while-the-riskiest-data-live.

3. **Deployment**:
   - After the tests are complete, the system will be deployed on the Ethereum mainnet.
   - **Monitoring Tools**: Tools are established for the monitoring of the system's performance, usage, and security after deployment. Logs and analytics help identify areas where improvement is required.
4. **Training and Support**:
   - Organizing training sessions draw stakeholders in to familiarize themselves with features of the system, which include Metamask integration, QR code scanning and real-time dashboards.
   - Dedicated support is made available during the rollout phase to address tech issues, but more than that, allow users confidence.
5. **Feedback and Improvement**:
   - User feedback is collected through surveys and direct interactions to identify pain points and areas requiring an enhancement.
   - System updates and refinements are implemented iteratively to advance function, usability, and performance.

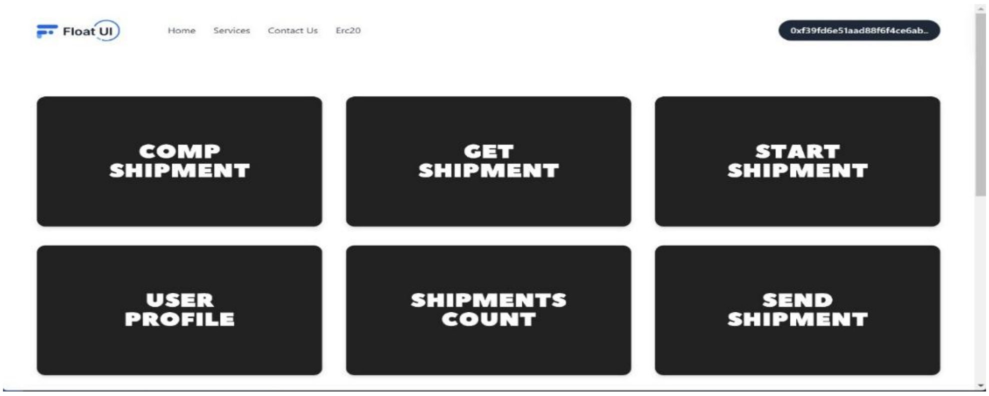

Fig 1 Dashboard

CHAPTER-7

TIMELINE FOR EXECUTION OF PROJECT

(GANTT CHART)

Project Timeline for November, December, and January:

1. **November - Planning and Design**
    - Analyze requirements and define system architecture.
    - Choose the technology stack and finalize project schedules.
2. **December - Development**
    - Develop and test smart contracts in Solidity.
    - Set up decentralized storage and integrate IoT devices.
    - Begin user interface development for web and mobile platforms.
3. **January - Testing and Deployment**
    - Conduct system testing and resolve issues.
    - Finalize the user interface and connect backend systems.
    - Prepare for Ethereum mainnet deployment and user training.

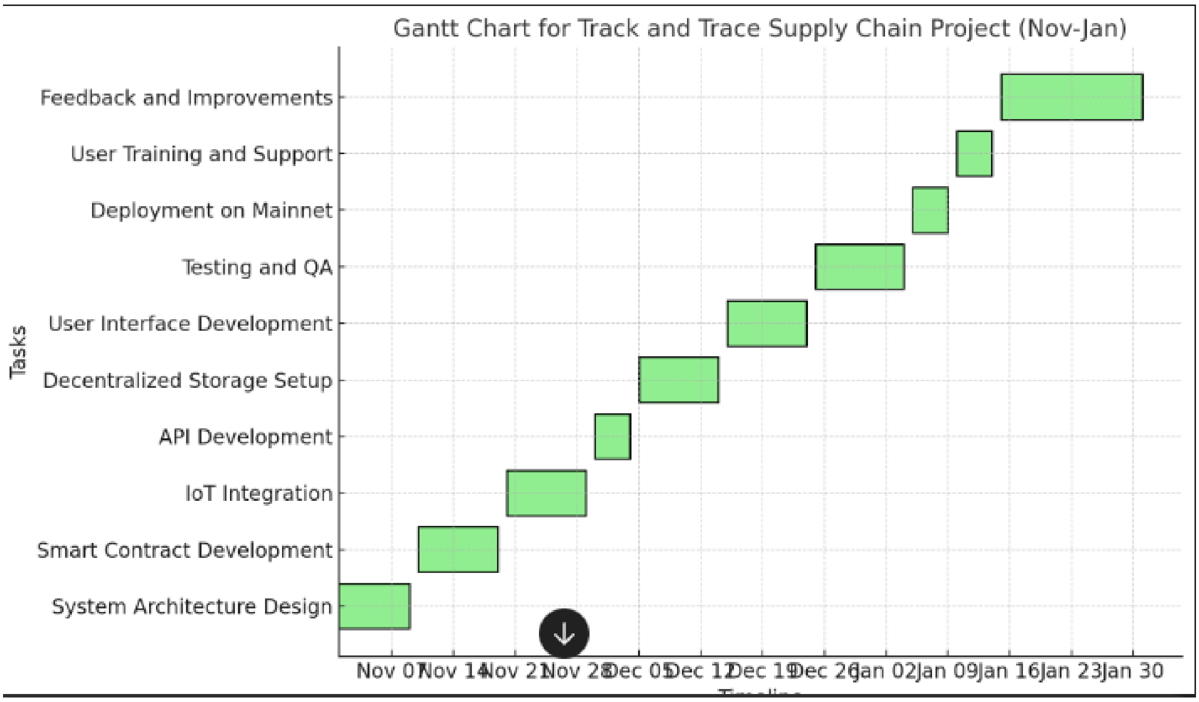

Fig 2 Gantt Chart

CHAPTER-8
OUTCOMES

8.1 Enhanced Transparency and Traceability

- Creation of a real-time, tamper-proof record of all supply chain activities accessible to all stakeholders.
- Improved traceability of products from origin to consumer, reducing fraud and counterfeit goods.
- Availability of product history to ensure regulatory compliance and sustainability practices.

8.2 Improved Security

- Strengthened data integrity with blockchain's immutable ledger, preventing unauthorized data manipulation.
- Enhanced IoT data security through encryption and secure APIs, ensuring reliable transmission and storage of real-time data.
- Reduction in risks related to data breaches and cyberattacks by eliminating single points of failure.

8.3 Operational Efficiency

- Automation of workflows with smart contracts, reducing manual errors and delays.
- Streamlined processes with IoT integration, ensuring accurate real-time tracking of products.
- Cost reduction by eliminating intermediaries and paper-based documentation.

8.4 Scalability and Interoperability

- Use of layer-2 solutions and modular architecture to scale operations across global supply chains effectively.
- Seamless integration with legacy systems and support for cross-platform interoperability.

8.5 Improved Customer Experience

- User-friendly applications and QR code functionality for customers to verify product authenticity and track sustainability practices.
- Increased trust in brands due to transparent supply chains and eco-friendly initiatives.

8.6 Regulatory Compliance and Sustainability

- Enhanced ability to meet environmental and regulatory standards by tracking eco-friendly practices.
- Positive contribution to the company's reputation and alignment with consumer demand for sustainable products.

8.7 Increased Stakeholder Trust

- Establishment of a single source of truth for all parties involved in the supply chain, fostering accountability and collaboration.
- Improved relationships between manufacturers, suppliers, retailers, and consumers through reliable and transparent data sharing.

8.8 Foundation for Future Innovations

- A robust blockchain-based infrastructure that can support additional features like predictive analytics, AI, and machine learning.
- The ability to expand the system to other industries or regions with minimal modifications.

CHAPTER-9
RESULTS AND DISCUSSIONS

9.1 RESULTS

9.1.1 Transparency

- The blockchain system facilitates real-time visibility of supply chain processes for the stakeholders to keep track of the objects in motion.
- Immutable blockchain records allow admitting any logged data never to be altered or deleted, thus greatly reducing fraudulent activity and enhancing accountability.
- Stakeholders were assured with the system allowing authentic verification of the quality of the product and conformity with sustainability standards.

9.1.2 Security

- System aligns the cryptographic security features of blockchain to ward off unauthorized access and tampering of data.
- Decentralized data storage removed a single point of failure common to centralized data systems, thus preventing worldwide large-scale data breaches.
- Secured API and encryption protocols were used in IoT for the integrity protection of real-time data transmitted to the blockchain.

9.1.3 Efficiency

- Automated processes through smart contracts take away manual and paper-based workflows, chopping off delays and mistaken human actions.
- Real-time tracking through IoT integration improved coordination in logistics and ensured that stakeholders could access critical information regarding product conditions, such as temperature and humidity, instantly.
- Operational efficiency ultimately brought cost savings through minimized administrative overhead costs and eliminated middlemen.

9.1.4 Scalability

- Modular design of the system made it very easy to scale solutions for different industries or geographical locations, meeting various regulatory and operational requirements.
- Seamless integration with legacy systems was enabled by the architecture, allowing organizations to embrace the platform without the need for radical changes to their existing infrastructure.

9.2 DISCUSSION

9.2.1 Analysis of Transparency

- The transparency supply chain project saw great improvements, with real-time data sharing between different stakeholders.
- A transparent and tamper-proof record brought down the probability of counterfeit goods and unauthorized activities. The end customers could verify the source and tracing of their purchased items and trust them.
- Transparency aided compliance, especially for industries such as food and pharmaceuticals where traceability of products is mandated.

9.2.2 Evaluation of Security

- The decentralization of blockchain ensured that data was spread across many nodes and all of them were at the same time unlikely to incur cyberattacks and system failures.
- More specifically, the encryption of sensitive supply chain data joined with access control mechanisms, ensuring not only protection of proprietary information but also access by authorized stakeholders to worthy information.
- IoT integration opened new challenges, which included ensuring secure device firmware; nevertheless, these were circumvented through the introduction of tamper-proof IoT devices and trusted communication protocols.

9.2.3 Operational Challenges

- However, smart contracts made it possible to automate even the most complex workflows, since extensive testing was required to locate and take care of any vulnerabilities. Therefore, errors in the actual design of the contract caused no significant delays in the deployment phase.
- The issues surrounding the integration of IoT devices with legacy systems included compatibility with present methods, which were addressed through the use of middleware solutions and tailored APIs.
- Training stakeholders on how to use the system and utilize its features took up a bit of extra time and human resources, pointing to the significance of change management in technology adoption.

9.2.4 Scalability and Adoption Barriers

- Layer-2 scaling solutions regulated uninterrupted performance under high transaction volumes, whereas standardization of blockchain protocols and IoT device communication remained prerequisites for large-scale, global market adoption.
- Resistance to change was mounting among traditional supply chain operators, which constituted a major hurdle, particularly for businesses that neither had technical know-how or adequate resources for blockchain implementation.
- Educating end customers about the potential benefits of product traceability for which they had a stake in verifying about the authenticity of the products became a critical factor in ensuring their engagement.

CHAPTER-10

CONCLUSION

The Track and Trace Supply Chain Management Project tackled major challenges that traditional supply chains face, such as providing transparency, inefficiency, and security liabilities. The system incorporated blockchain, IoT, and smart contract technologies, thereby granting real-time accessibility to information, enhanced security, and operational efficiency. The immutable records created transparency and trust among stakeholders, and the decentralized storage and ensurencryption secured sensitive records.

It resulted in supply chain workflow improvements through automated processes that lowered manual errors and increased the accuracy of product traceability. This should benefit pharma, food, and manufacturing industries where authenticity and regulatory compliance are core boardroom issues. Scalability was achieved through the implementation of layer-2 solutions, allowing the system to handle high volumes of transactions without compromising system performance.

Unfortunately, despite some early issues, including challenges in integrating IoT with legacy systems, debugging smart contracts, and ensuring users received adequate training, the project proved that careful planning and solid and well-articulated designs were important. Training of stakeholders and a good interface proved to enhance its usability and acceptance.

Beyond streamlining supply chain processes, the project enhanced sustainability through the traceability it created in supporting truly green practices and compliance to environmental standards. Increased transparency allowed consumers greater trust in the brands they support by validating product authenticity.

The success of this project clearly shows the role blockchain and IoT technologies can serve to bring about the gestation of a highly transparent, secure, and efficient supply chain. This will alleviate operational bottlenecks and sanction transparency, which in turn will contribute to the long-term value creation for businesses, consumers, and the economy.

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APPENDIX-A

PSUEDOCODE

Define Smart Contract in Solidity

```
contract SupplyChain {
    struct Product {
        uint id;
        string name;
        string status; // e.g., "Manufactured", "In Transit", "Delivered"
        address owner;
        uint timestamp;
    }

    mapping(uint => Product) public products;
    uint public productCount;

    event ProductCreated(uint id, string name, address owner);
    event ProductStatusUpdated(uint id, string status);

    function createProduct(string memory _name) public {
        productCount++;
        products[productCount] = Product(productCount, _name, "Manufactured", msg.sender,
block.timestamp);
        emit ProductCreated(productCount, _name, msg.sender);
    }

    function updateProductStatus(uint _id, string memory _status) public {
        require(products[_id].owner == msg.sender, "Only owner can update status");
        products[_id].status = _status;
        products[_id].timestamp = block.timestamp;
        emit ProductStatusUpdated(_id, _status);
    }
```

```
 function getProduct(uint _id) public view returns (Product memory) {

 return products[_id];
    }
}

// Frontend JavaScript Code
async function init() {
    // Initialize web3 and contract instance
    const web3 = new Web3(Web3.givenProvider || "http://localhost:8545");
    const contract = new web3.eth.Contract(SupplyChainABI, SupplyChainAddress);

    // Load products from blockchain
    await loadProducts(contract);
}

async function loadProducts(contract) {
    const productCount = await contract.methods.productCount().call();
    for (let i = 1; i <= productCount; i++) {
        const product = await contract.methods.getProduct(i).call();
        displayProduct(product);
    }
}

function displayProduct(product) {
    // Create HTML elements to display product information
    const productDiv = document.createElement('div');
    productDiv.innerHTML = `
        <h3>${product.name}</h3>
        <p>Status: ${product.status}</p>
        <p>Owner: ${product.owner}</p>
        <p>Timestamp: ${new Date(product.timestamp * 1000).toLocaleString()}</p>
```

```
  `;
  document.getElementById('productList').appendChild(productDiv);
}

async function createProduct() {
  const productName = document.getElementById('productName').value;
  const accounts = await web3.eth.getAccounts();
  await contract.methods.createProduct(productName).send({ from: accounts[0] });
  loadProducts(contract); // Refresh product list
}

async function updateProductStatus(productId, newStatus) {
  const accounts = await web3.eth.getAccounts();
  await contract.methods.updateProductStatus(productId, newStatus).send({ from:
accounts[0] });
  loadProducts(contract); // Refresh product list
}

// CSS for styling the frontend
/* Add styles for product display */
#productList {
  display: flex;
  flex-direction: column;
  gap: 10px;
}

.product {
  border: 1px solid #ccc;
  padding: 10px;
  border-radius: 5px;
}

// HTML Structure
```

```html
<!DOCTYPE html>
<html lang="en">
<head>
   <meta charset="UTF-8">
   <meta name="viewport" content="width=device-width, initial-scale=1.0">
   <link rel="stylesheet" href="styles.css">
   <title>Track and Trace Supply Chain</title>
</head>
<body>
   <h1>Track and Trace Supply Chain Management System</h1>
   <div id="productList"></div>
   <input type="text" id="productName" placeholder="Enter product name">
   <button onclick="createProduct()">Create Product</button>
   <script src="web3.min.js"></script>
   <script src="app.js"></script>
</body>
</html>
```

APPENDIX-B

SCREENSHOTS

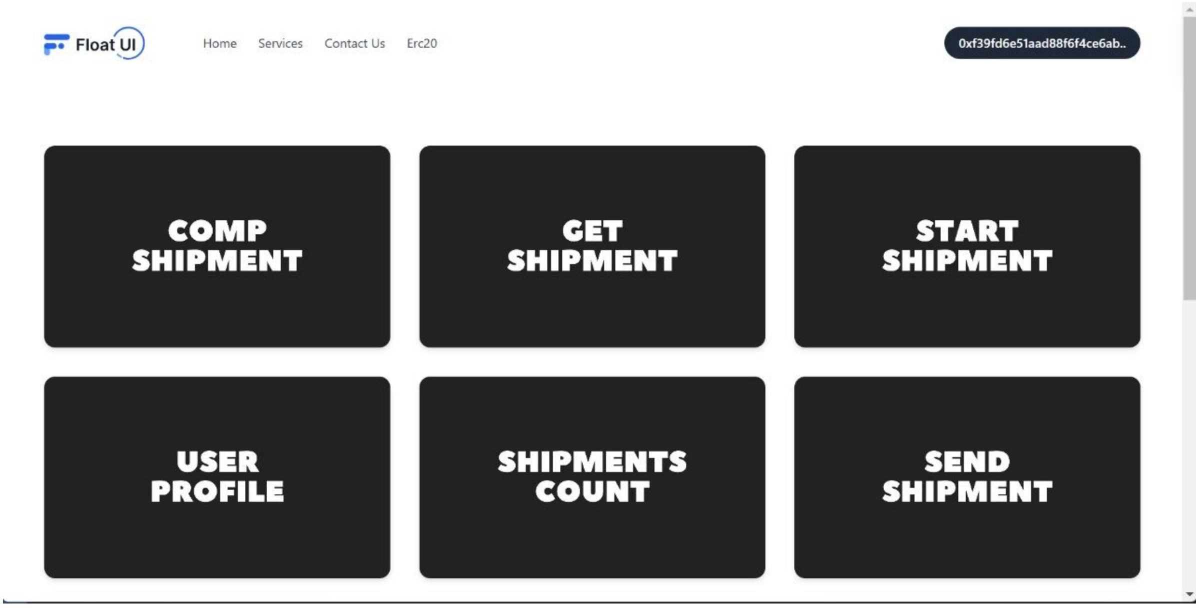

Fig 3 Dashboard

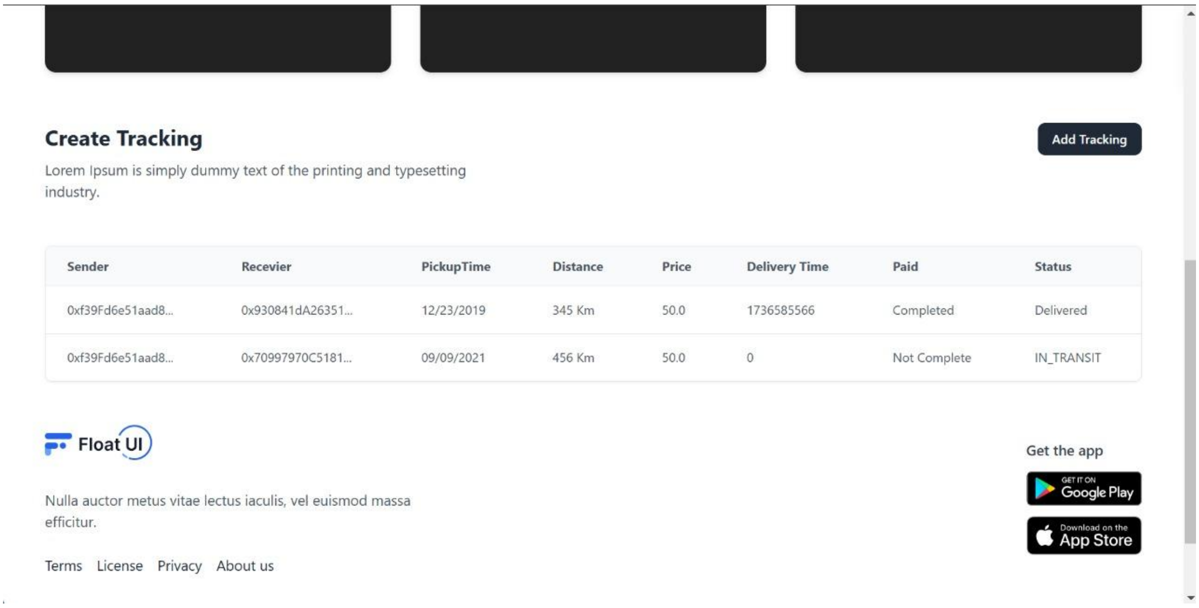

Fig 4 Tracking

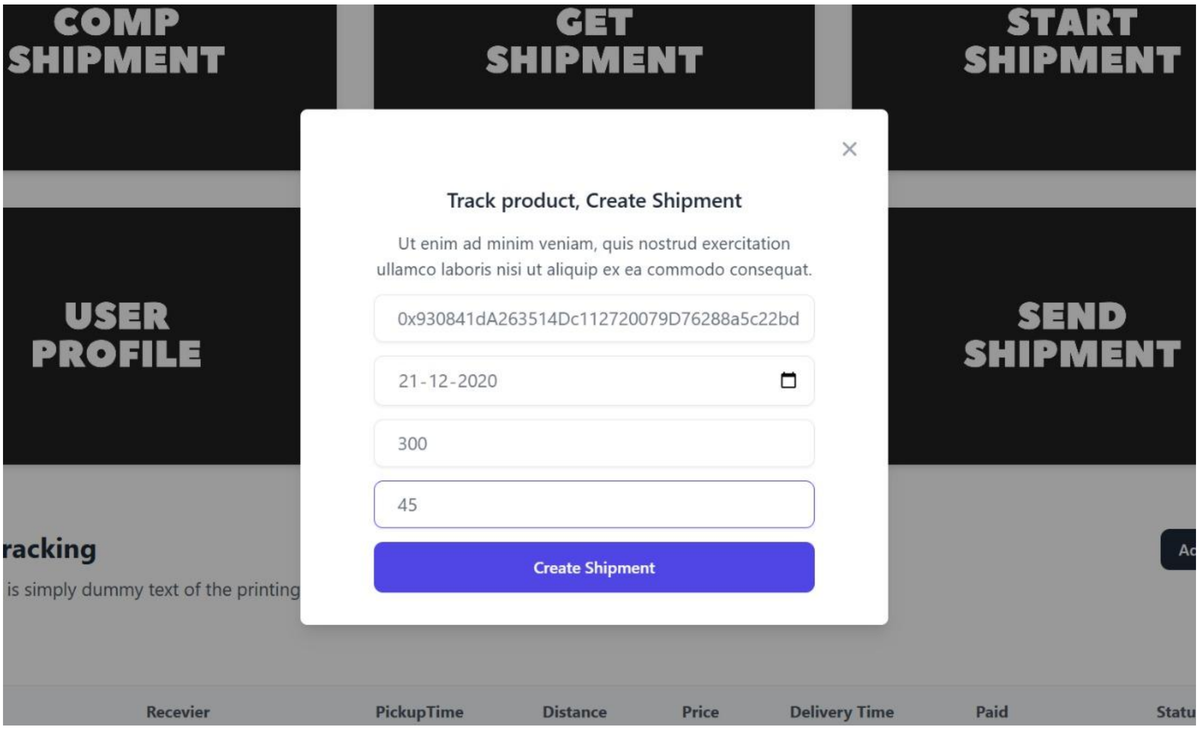

Fig 5 Create Shipment

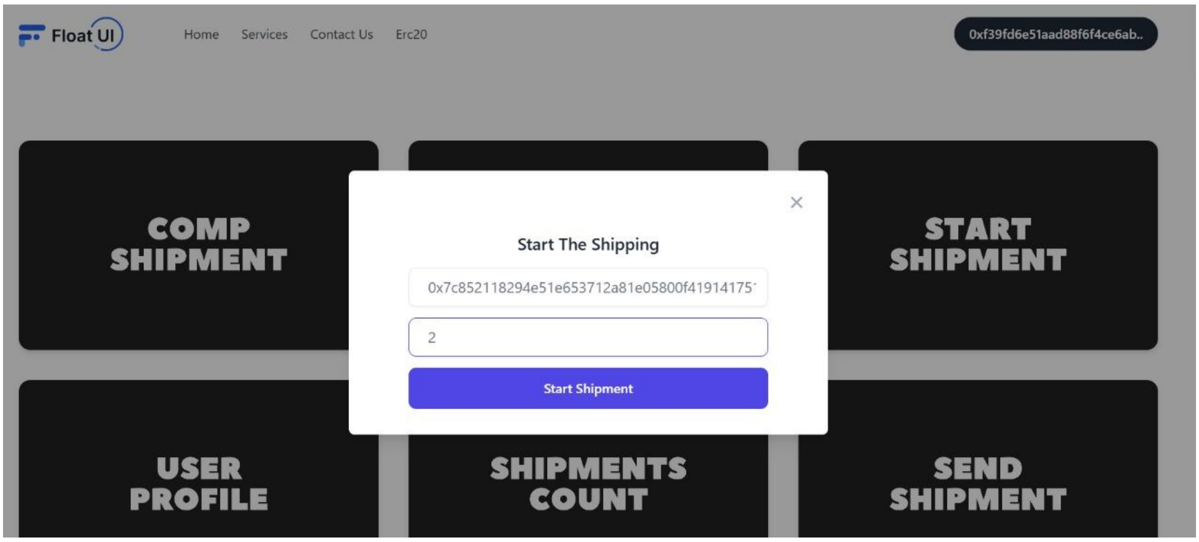

Fig 6 Start Shipment

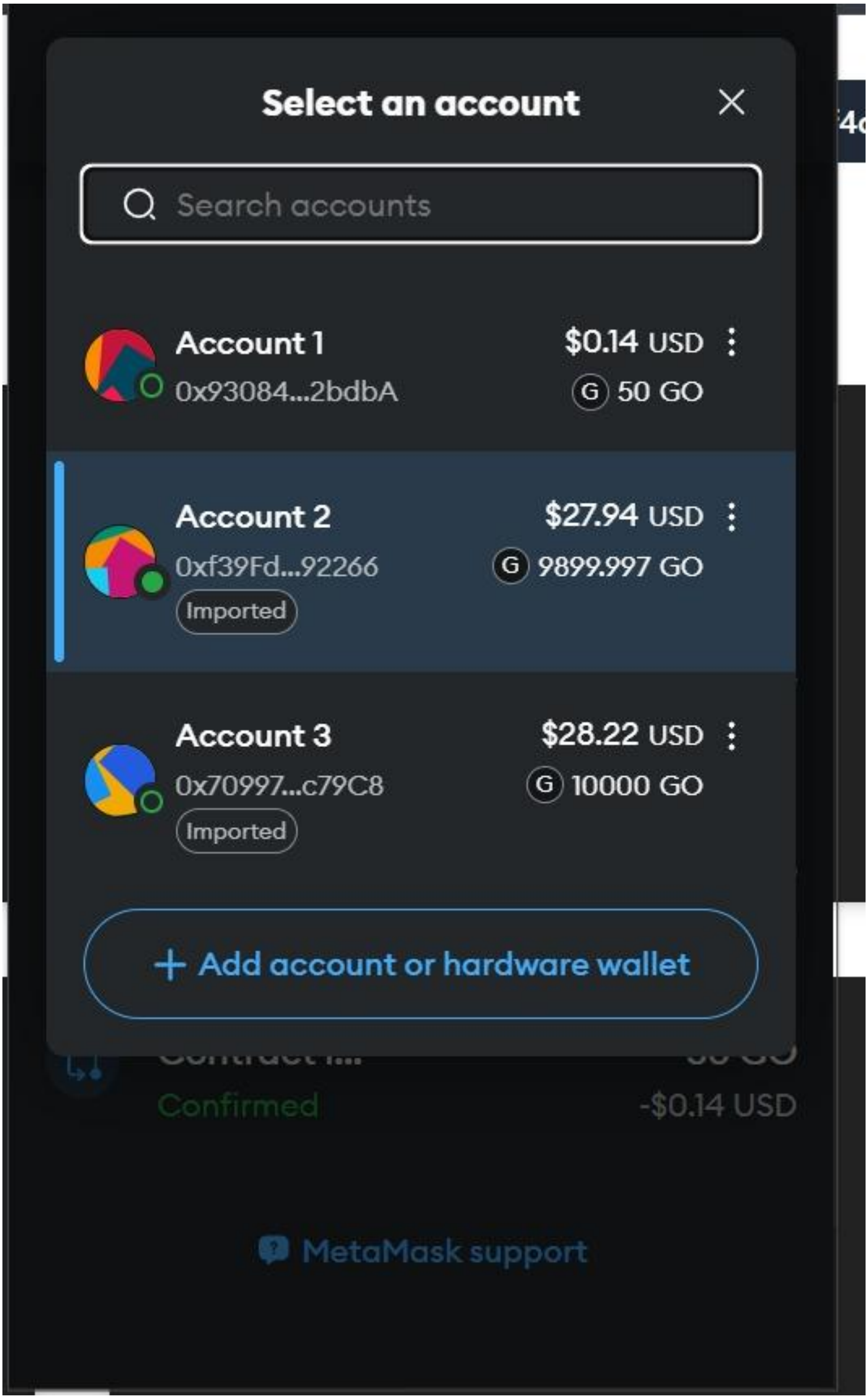

Fig 7 MetaMask Accounts

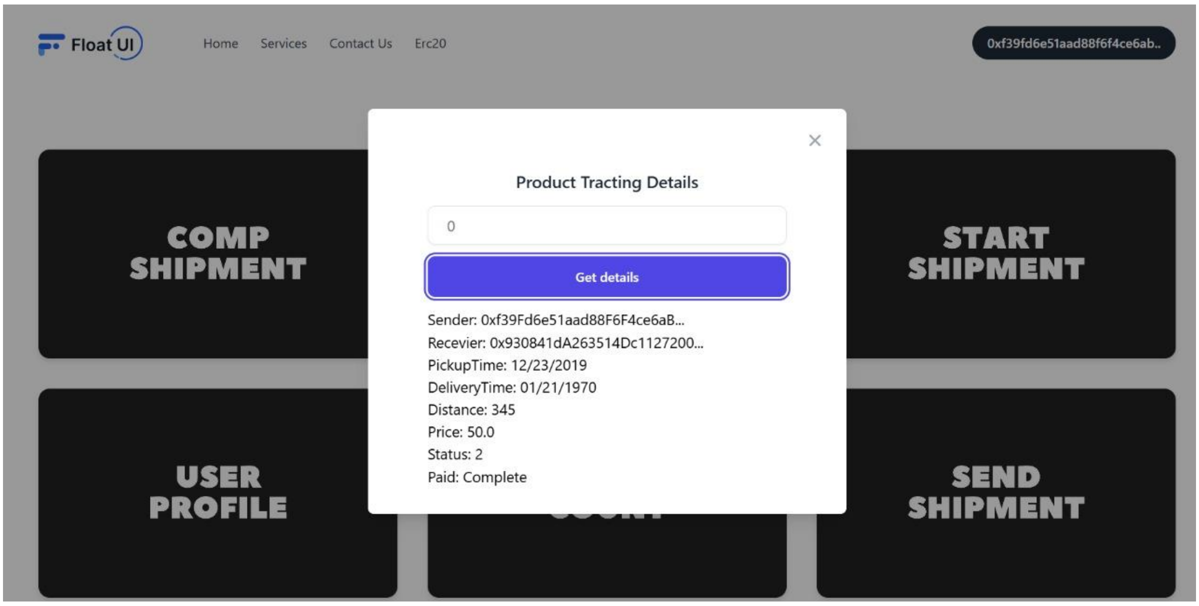

Fig 8 Get Shipment Details

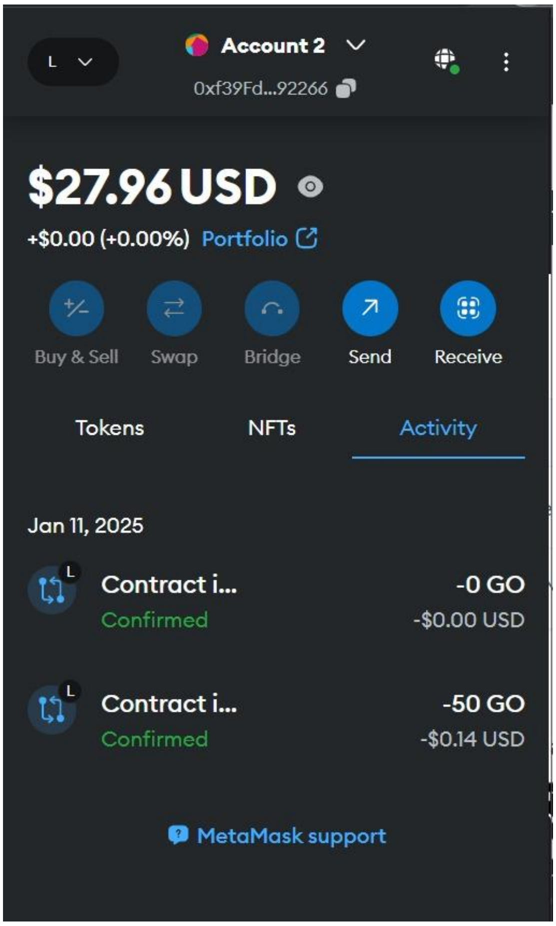

Fig 9 Metamask Account Balance

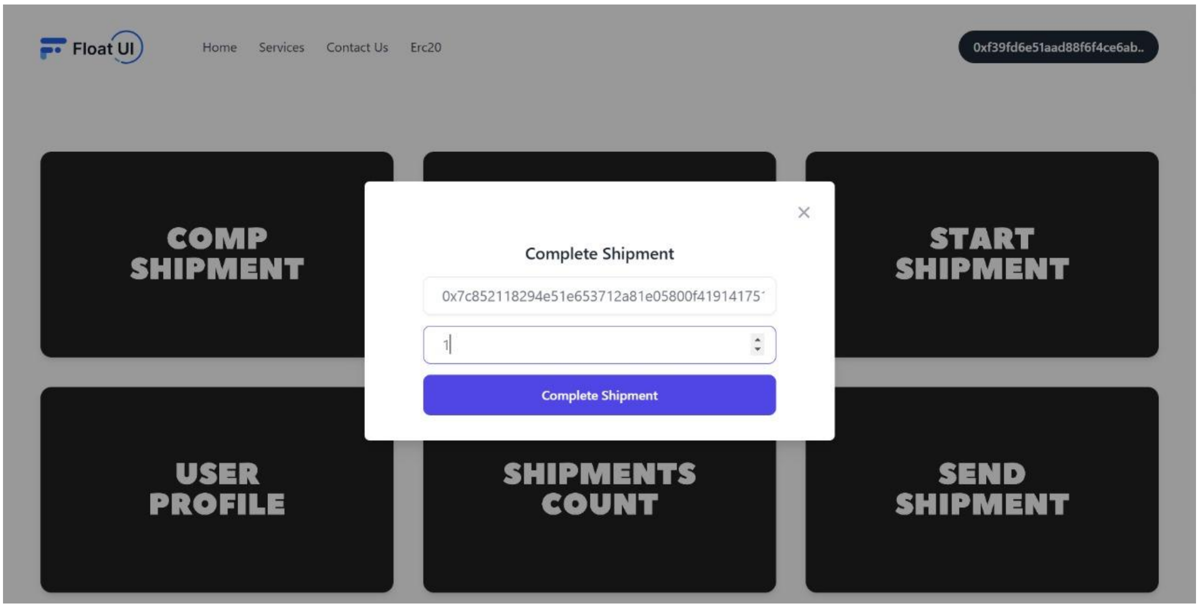

Fig 10 Shipment Completion

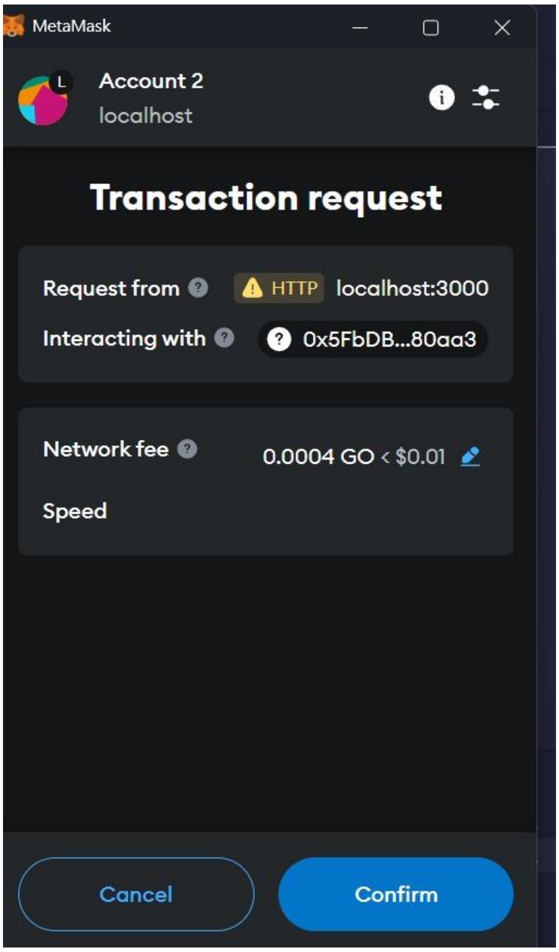

Fig 11 Transaction Details


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RESPONSIBLE
CONSUMPTION
AND PRODUCTION