



Research Article

Blockchain-Enabled Decentralized Public Distribution Networks

Harsh Kumar Maurya ^{1*}, Gagan ², Abhishek Raj ³, Khushbu Malviya ⁴

¹⁻³ Department of Computer Science and Engineering, Ajay Kumar Garg Engineering College, Ghaziabad, Uttar Pradesh, India

⁴ Mentor, Department of Computer Science and Engineering, Ajay Kumar Garg Engineering College, Ghaziabad, Uttar Pradesh, India

Corresponding Author: *Harsh Kumar Maurya

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Abstract

The Public Distribution System (PDS) in India plays a critical role in ensuring food security for economically vulnerable populations. However, the existing system suffers from limited transparency, weak accountability, operational inefficiencies, and frequent leakages. This paper presents a con-sortium blockchain-based decentralized framework to improve the reliability and efficiency of PDS operations. The proposed model integrates Aadhaar-enabled biometric authentication to ensure accurate beneficiary identification and employs RFID technology for real-time tracking of food grains across the supply chain. Smart contracts implemented on the blockchain provide immutable transaction records, reduce manual intervention, and enhance traceability. Additionally, the framework supports both on-chain and off-chain data processing, assisted by secure cloud infrastructure, to enable data-driven decision-making for stakeholders. While the system improves transparency and reduces corruption, challenges such as inadequate digital infrastructure and limited internet connectivity in rural regions remain. The study highlights the need for inclusive stakeholder participation to ensure effective implementation. Overall, the proposed approach offers a scalable and secure solution for strengthening food distribution systems in India.

This framework, however, poses a lot of practical challenges that need to be overcome, particularly in rural settings where internet connectivity and other digital infrastructure are not strong. Additionally, adoption from the various stakeholders, such as government agencies, distributors, and beneficiaries, is required for the model to work. The present study recommends consideration of feedback from stakeholders, particularly farmers and local distributors, when developing an inclusive system. This study attempts to show the potential of blockchain technology in reforming the PDS towards food security, accountability, and fair distribution within India, with an attempt to address both technical and socio-economic barriers.

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KEYWORDS: Blockchain, Consortium Blockchain, Smart Contracts, Aadhaar-Based Authentication, RFID Tracking, Supply Chain Transparency, Decentralised Architecture, Food Security, Accountability.

1. INTRODUCTION

The Public Distribution System (PDS) is one of the most important welfare mechanisms implemented to ensure food security and social equity among economically vulnerable populations. It operates as a government-supported supply chain that distributes essential commodities such as rice, wheat, sugar, and kerosene at subsidised prices through a network of fair price shops. The primary objective of the system is to protect low-income households from food insecurity and price volatility while supporting nutritional stability.

Blockchain technology, widely recognised for its decentralised architecture and resistance to data tampering, has demonstrated significant potential across industries that demand strong data security and traceability. In the context of the Public Distribution System (PDS), a blockchain-based framework can support the development of a secure and transparent platform where transactions and records are permanently recorded and validated through a consortium network of authorised stakeholders. The integration of Aadhaar-based identification enhances accountability by ensuring that access to subsidised goods is restricted to eligible beneficiaries only. This review paper proposes a blockchain-enabled decentralised framework aimed at improving the transparency, efficiency, and accountability of India's Public Distribution System. By enabling real-time tracking of commodity movement from warehouses to fair price shops, the system can substantially reduce fraud and corruption. Furthermore, all transactions are securely recorded with transparent access for relevant authorities, while the integration of biometric authentication strengthens beneficiary verification and prevents unauthorised access.

The proposed model incorporates RFID technology to monitor inventory throughout the supply chain, enabling continuous tracking of commodities from the point of origin to the final distribution outlets. By utilising a hybrid data management approach that combines on-chain and off-chain storage with secure cloud infrastructure, the framework supports real-time analytics while maintaining data integrity for policymakers and stakeholders. This level of integration promotes a comprehensive and dynamic distribution management system, reducing operational inefficiencies and supporting more informed and effective decision-making.

However, the proposed framework faces several practical challenges, especially in rural areas where internet connectivity and digital infrastructure are limited. For the system to function effectively, active participation and acceptance from key stakeholders such as government authorities, distributors, and beneficiaries are essential. The study emphasises the importance of incorporating feedback from stakeholders, particularly farmers and local distributors, to ensure that the system is inclusive and practical. This research highlights the potential of blockchain technology to improve India's Public Distribution System by enhancing food security, transparency, and fairness, while also addressing both technical limitations and socio-economic challenges.

2. LITERATURE SURVEY

A consortium blockchain-based framework has been proposed to improve transparency, security, and traceability in the Public Distribution System (PDS). In this system, all transactions are recorded on an immutable and distributed ledger, allowing stakeholders to monitor the movement of food grains at every stage. This improves accountability and prevents unauthorised data modification. The integration of Aadhaar-based identification with biometric authentication ensures accurate beneficiary verification and reduces fraud and misuse. Blockchain also enables real-time tracking of food grain distribution from warehouses to fair price shops, minimising losses and ensuring timely delivery. Secure cloud storage ensures safe and long-term record maintenance, while on-chain and off-chain data management improves system efficiency. Additionally, transparent and reliable data allows authorities to analyse distribution patterns, identify inefficiencies, and make better policy decisions, thereby improving the overall performance of the Public Distribution System.

Another study proposed a secure and shared blockchain-based database for the Public Distribution System (PDS) to improve transparency, auditability, and reduce transaction costs. The distributed database allows government authorities, distribution centres, and beneficiaries to access accurate and transparent distribution records, which helps in reducing corruption and improving accountability. However, the study also highlighted major challenges in implementation, particularly in rural areas where digital infrastructure and internet connectivity are limited, making large-scale adoption difficult. The research emphasised the importance of addressing internal factors such as data privacy, authentication mechanisms, and system security to ensure effective implementation. It also noted that external factors, including local infrastructure and social conditions, play a crucial role in the success of the system. Furthermore, the study suggested that future research should focus on understanding stakeholder perspectives, especially farmers and beneficiaries, to ensure that the proposed blockchain-based PDS is practical, inclusive, and effective in improving the overall distribution process.

A separate study presented the design of a prototype blockchain-based system aimed at addressing transparency and corruption issues. Although the implementation is limited to a prototype, the results indicate that large-scale deployment of such blockchain-based systems could greatly enhance operational efficiency and improve public confidence in PDS functioning. The authors suggest that with further optimisation, scalability improvements, and infrastructure support, this approach could serve as a reliable solution for ensuring fair distribution of essential commodities to vulnerable communities. The prototype was developed using technologies such as Java, JSP, and MySQL, along with AES encryption, to provide a secure and user-friendly interface for end users. The integration of SHA-256 hashing ensures reliable recording of transactions and protects the system from unauthorised data modification, thereby establishing a strong cryptographic foundation for secure data handling. The study demonstrated that the proposed system can significantly reduce manual errors

and fraudulent practices by maintaining immutable transaction records. Each operation related to ration allocation and distribution is permanently stored on the blockchain, improving traceability and accountability across the supply chain. This increased transparency helps build trust among stakeholders, including government authorities, distribution centres, and beneficiaries. Although the implementation is limited to a prototype, the results indicate that large-scale deployment of such blockchain-based systems could greatly enhance operational efficiency and improve public confidence in PDS functioning. The authors suggest that with further optimisation, scalability improvements, and infrastructure support, this approach could serve as a reliable solution for ensuring fair distribution of essential commodities to vulnerable communities.

Another approach proposed a smart ration card system that combines RFID technology with blockchain to enhance the security and reliability of goods distribution in the Public Distribution System (PDS). In this model, RFID-enabled ration cards are used for user identification along with biometric authentication, ensuring that benefits are provided only to eligible beneficiaries. This mechanism strengthens system security and significantly reduces the chances of ration card forgery and unauthorised access. The system also supports real-time communication with government authorities by sending transaction updates through automated notifications, enabling continuous supervision of distribution activities. By recording every transaction on an immutable blockchain ledger, the system ensures complete transparency and traceability across the distribution chain. The primary objective of this framework is to automate PDS operations while minimising human involvement and opportunities for corruption. Through improved monitoring, auditing, and data integrity, the proposed solution enhances accuracy, efficiency, and accountability, offering a sustainable solution to long-standing challenges such as leakage and misallocation of resources. A blockchain-based decentralised Public Distribution System (PDS) has been proposed to address key inefficiencies

such as food grain wastage, fraud, and limited traceability at fair price shops. The proposed framework leverages the Ethereum blockchain and smart contracts to ensure transparency and accountability throughout the entire supply chain, starting from procurement and extending to final delivery. By automating key processes, the system reduces manual intervention and improves operational reliability. Key features of the proposed model include real-time transaction monitoring, secure and tamper-proof data storage, and automated auditing mechanisms. These features help minimise human errors and corrupt practices, thereby improving the overall efficiency of food grain distribution. The study also suggests the integration of supporting technologies such as crypto wallets, RFID, QR codes, and Internet of Things (IoT) devices to further automate operations and enhance traceability. The implementation aims to transform the PDS into a secure, efficient, and accountable food supply system capable of ensuring timely and fair distribution to beneficiaries. Another study explored the integration of blockchain and Internet of Things (IoT) technologies within the Public Distribution System (PDS) to

address challenges such as fraud, resource leakage, and lack of transparency. In this approach, blockchain is used to maintain decentralised and immutable transaction records, while IoT devices enable real-time monitoring of ration distribution activities across the supply chain.

The proposed architecture incorporates smart contracts, RFID technology, and secure user authentication mechanisms to ensure transparency, efficiency, and accountability in operations. Real-time visibility into distribution processes helps reduce human errors and ensures that essential commodities reach the intended beneficiaries. The authors emphasized that the system is designed to be scalable, user-friendly, and compliant with existing regulations, thereby enhancing food security and promoting social equity. Overall, the study highlights the significant potential of blockchain and IoT integration to transform public welfare systems and improve the effectiveness of the PDS. This study presented a blockchain-based Public Distribution System developed using the Ethereum platform and Solidity to enhance security, transparency, and operational efficiency. The proposed decentralized network connects all key stakeholders involved in the PDS, including central and state governments, the Food Corporation of India, district authorities, fair price shops, and beneficiaries. By recording all transactions through smart contracts, the system prevents unauthorized activities and reduces fraudulent practices. Each transaction in the system is immutable and can be verified in real time by all participating nodes, ensuring complete traceability and accountability. The authors validated the proposed model through prototype testing on a JavaScript Virtual Machine environment. They further suggested enhancing the existing web application into a fully interactive platform to improve usability for different stakeholders. Overall, the proposed E-ration distribution system demonstrates how blockchain technology can effectively address inefficiencies and corruption in the traditional Public Distribution System. This study presented a blockchain-based Public Distribution System developed using the Ethereum platform and Solidity to enhance security, transparency, and operational efficiency. The proposed decentralized network connects all key stakeholders involved in the PDS, including central and state governments, the Food Corporation of India, district authorities, fair price shops, and beneficiaries. By recording all transactions through smart contracts, the system prevents unauthorized activities and reduces fraudulent practices. This work proposed a blockchain-enabled system that ensures transparent and tamper-resistant record management through decentralized data storage. By employing smart contracts with customized mining policies and a peer-to-peer network, the system effectively reduces discrepancies and fraudulent activities within the distribution process. All transactions are recorded, validated, and shared across multiple nodes, ensuring full traceability and accountability. Advanced cryptographic techniques, including hashing and consensus algorithms, are used to preserve data integrity and support recovery mechanisms in case of security threats or system failures. The study highlights that this decentralized approach offers a secure, reliable, and efficient alternative to traditional centralized distribution systems, making it well suited for

applications such as the Public Distribution System where transparency and trust are critical.

Aspect	Decentralized Blockchain PDS	Blockchain and IoT PDS	Solidity-based PDS
Key Technology	Ethereum, Blockchain, Smart Contracts, React JS	Blockchain, IoT (RFID, sensors), SHA-256	Ethereum, Blockchain, Solidity, JavaScript, Virtual Machine
Focus Area	Transparency and auditability in food distribution	Real-time monitoring with IoT integration	Decentralization and immutability of transactions
Advantages	Traceability, security, and accountability	Automation, scalability, and data-driven insights	Cost-efficiency, fraud elimination, decentralized control
Drawbacks	Limited IoT integration, scalability issues	High IoT dependency increases complexity	Lack of user-friendly interfaces for broad adoption

3. Problems and Challenges

A. Fake Ration Cards

Problem: PDS lacks user-friendly digital interfaces, causing inclusion errors despite reduced poverty and continued AAY, BPL, and Annapurna card usage.

Current Status: Exclusion errors have declined in some states, but Andhra Pradesh and Maharashtra still face major beneficiary identification issues.

B. APL Scam

Issue: APL Scam and Diversion of Subsidised Grains. Food grains meant for Below Poverty Line (BPL) households are frequently diverted to Above Poverty Line (APL) beneficiaries, causing significant system leakages.

Current Status: Recent studies suggest that diversion levels remain substantially high across multiple states. Anti-leakage measures show uneven implementation and limited effectiveness.

C. Ghost Beneficiaries Duplicate Cards

Issue: The existence of "Ghost Cards"—ration cards issued in the names of deceased, non-existent, or ineligible persons. These cards are often held by Fair Price Shop (FPS) dealers to siphon off extra monthly quotas.

Current Status: While Aadhaar-seeding has eliminated over 40 million fake cards since 2014, a significant "digital shadow" remains where fake identities are still used in pockets with low biometric penetration or manual record-keeping.

D. Biometric Network Barriers

Issue: Unstable internet connectivity and degraded fingerprints in rural areas lead to frequent biometric authentication failures, restricting access to subsidised food for eligible beneficiaries.

Current Status: Recent observations indicate moderate but recurring authentication failures across rural regions. Beneficiaries often require repeated visits, leading to income loss and increased hardship among daily wage workers.

E. High Food Subsidy Cost

Issue: High procurement prices and inefficiencies in grain handling and distribution have increased food subsidy expenditure.

Current Status: Operational efficiency needs improvement, and leakages must be reduced, as the system remains costly and inefficient.

F. Regional Disparities

Issue: Uneven administrative capacity and governance cause wide differences in PDS implementation across states.

Current Situation: Some states show efficient delivery, while others face leakages, delays, and poor beneficiary coverage.

G. Corruption and Malpractices

Issue: Poor households are sometimes forced to pay bribes to be included in PDS beneficiary lists.

Current Situation: Approximately 28% of PDS food grains are stolen or diverted to open markets, causing significant financial losses.

4. METHODOLOGY

The methodology involves identifying issues in the traditional PDS, designing a blockchain-based architecture, and integrating stakeholders via smart contracts. RFID and biometric authentication ensure traceability and eligibility verification.

Research Framework and Problem Identification

A. Research Framework and Problem Identification

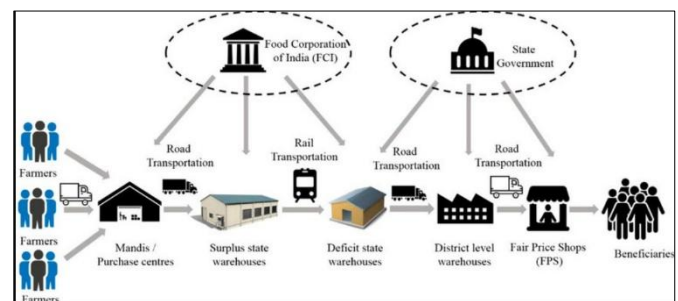


Fig. 2. Traditional Process of Public Distribution System

B. System Architecture and Technology Integration

The system architecture of a Blockchain-based Public Distribution System (PDS) integrates blockchain technology, authentication mechanisms, and distribution management to ensure transparency, security, and efficiency in food grain distribution. It connects beneficiaries, Fair Price Shops (FPS),

warehouses, and government authorities through a secure decentralised network.

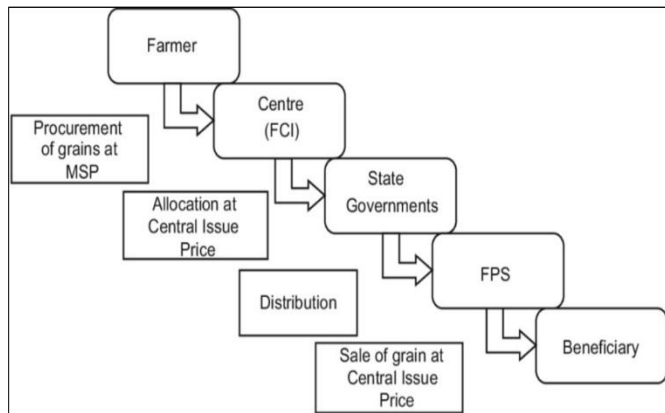


Fig. 3. System Architecture

C. Creating Prototypes and Testing Them Out

The system provides secure web-based login access only to authorised government officials to initiate and monitor distribution transactions. This ensures controlled access and improves system security. Local administrators record the receipt of food grains, including details such as date, time, and quantity. This information is then uploaded to the blockchain

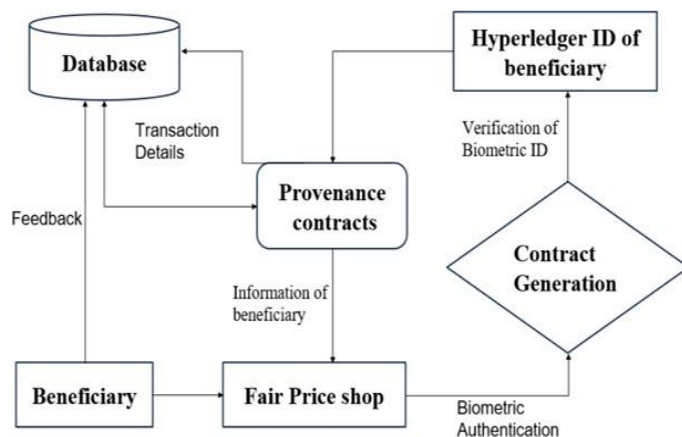


Fig. 4. Blockchain-based beneficiary authentication and distribution system.

using smart contracts. The blockchain securely stores the data, making it transparent and tamper-proof. This allows government authorities to monitor transactions in real time and ensures accountability and efficiency in the Public Distribution System.

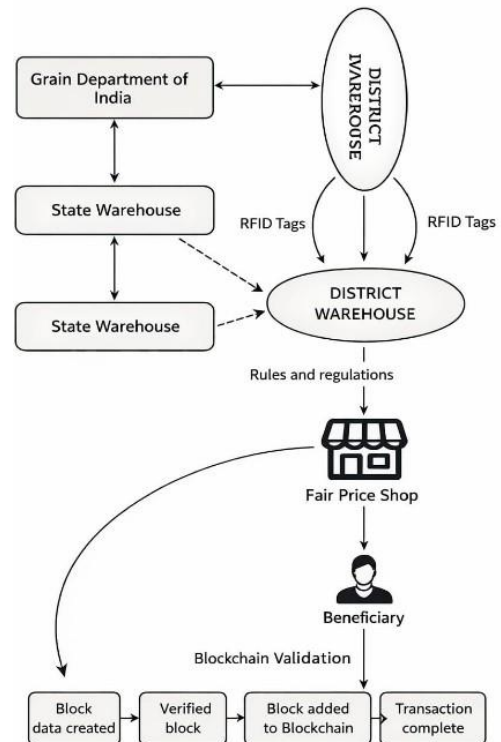


Fig. 5. Contract generation between FPS, District State Warehouse

D. Evaluation, User Engagement, and Maintenance

Continuous monitoring and regular maintenance are carried out to ensure system security, timely updates, and smooth performance. Training sessions and awareness programs are organized to help users understand and effectively use the system, promoting active participation. The system strictly follows government regulations related to food distribution and data privacy to ensure legal compliance and build user confidence. Additionally, a feedback feature is provided to allow users to share their suggestions and experiences, helping improve the system over time.

E. Future Research

The proposed system can help minimize corruption, improve traceability, and speed up the distribution of food grains. Future research will focus on strengthening digital infrastructure in rural areas, improving the integration of IoT devices for better monitoring, and using advanced data analytics to analyse both on-chain and off-chain data. These improvements will enhance system efficiency and reliability. This approach provides a strong foundation for developing a secure, transparent, and decentralised Public Distribution System that overcomes existing challenges and supports effective food distribution to all beneficiaries.

5. Implementation

A. User Registration

The User Registration module allows administrators and local administrators to register different users in the system. These users include farmers, distributors, shopkeepers, and

beneficiaries. During registration, basic information such as name, address, contact details, and identification information is collected and stored in the database. Each registered user is assigned a unique ID that helps in identifying and tracking their activities within the Public Distribution System. Only authorised administrators have permission to add or modify user information, ensuring security and proper system management.

B. Transaction Updating

The transaction updating module is responsible for recording and updating all food grain movements in the system. Authorised personnel update the details whenever food grains such as rice or wheat are transferred from warehouses to fair price shops or distributed to beneficiaries. The system records important information such as quantity, transaction date, shop details, and receiver information. This helps maintain accurate records of distribution.

C. Transaction Details

This module allows users to retrieve information about previous transactions stored in the system. It displays details such as the type of food grain, quantity distributed, date of transaction, and beneficiary information. By providing access to transaction history, the system improves transparency and helps administrators monitor distribution activities effectively.

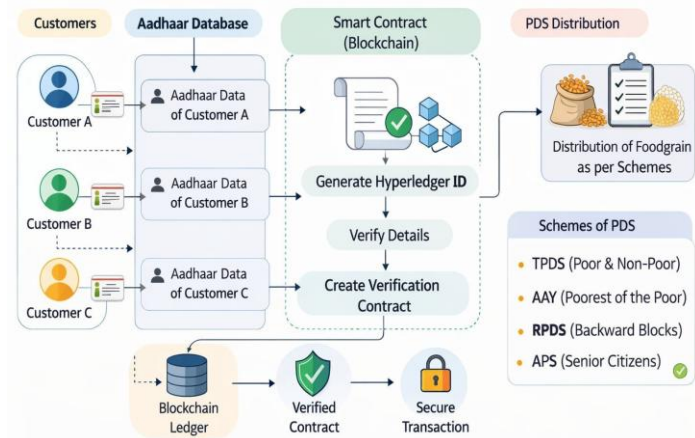


Fig. 6. Verification of contract [1]

D. Getting User Details

The user details module enables administrators to access information about registered users in the system. It allows searching and viewing user records based on their unique ID or other identification details. The system displays relevant information such as name, role, address, and contact information, which helps in managing system users efficiently.

E. Getting Shop Details

The shop details module stores and retrieves information related to fair price shops involved in the distribution system. It includes details such as shop ID, shop location, shopkeeper information, and available stock of food grains. This module

helps administrators monitor ration shop activities and ensures proper distribution of resources.

F. Authentication Module

This module verifies user identity before allowing access to the system. Users log in using credentials or biometric verification to ensure secure access.

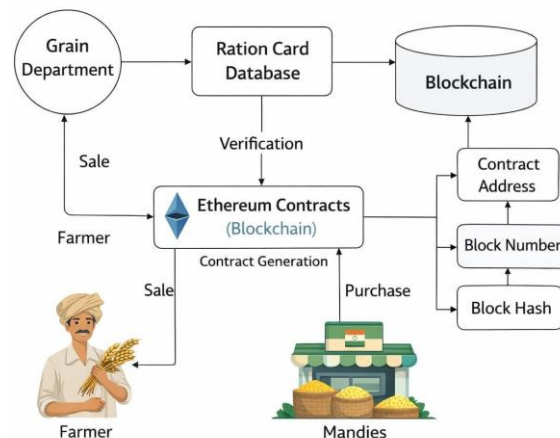


Fig. 7. Smart contract generation between the farmer and mandies

Admin Control Module

This module allows administrators to manage users, transactions, and system records. It provides overall control and monitoring of the distribution process.

G. Stock Management Module

This module maintains records of food grain stock at warehouses and ration shops. It updates the inventory whenever stock is received or distributed.

H. Blockchain Transaction Verification Module

This module verifies and records transactions using blockchain technology. It ensures secure, transparent, and tamper-proof tracking of food grain distribution.

6. RESULTS

The decentralised Public Distribution System based on blockchain significantly improves the traditional distribution framework by increasing transparency, accountability, and operational efficiency. The system uses Solidity to develop smart contracts that automate and secure transaction processes. A user-friendly web interface is designed using ReactJS, while Node.js manages the server-side operations. MongoDB is used as an off-chain database for storing additional system data. This integrated platform enables real-time monitoring of the entire food grain distribution network. Beneficiary identification is strengthened through Aadhaar-based biometric verification, while RFID technology is used to track the physical movement of food grains without requiring biometric interaction at every stage. All transactions executed through smart contracts are encrypted using AES and stored on a public blockchain, ensuring that the records remain immutable and shared among all authorized participants. By integrating these technologies,

the system enhances supply chain visibility, reduces leakage and wastage, and enables reliable auditing of distribution activities. As a result, food grains can be delivered to intended beneficiaries more efficiently while minimizing the possibility of corruption or manipulation within the system.



Fig. 8. Farmer login page



Fig. 9. Home pages

```
{
  "index": 1,
  "proof": 3706889514.1633415,
  "timestamp": 1558138086347,
  "previousBlockHash": "a7e18a1bc82dfc9f907547df054c16730d342a9065e6992475e3a1",
  "transactions": [
    {
      "name": "Beena",
      "cardtype": "Blue card",
      "membercount": "5",
      "quantity": "10",
      "price": "100",
      "timestamp": 1558138086346
    }
  ]
},
"hash": "00201bc93fd6c5c00ab3aae508bf9d624ce86d6e3b8763620ed451bc92b2997d"
```

Fig. 10. Blockchain Created at Ration Shop Level

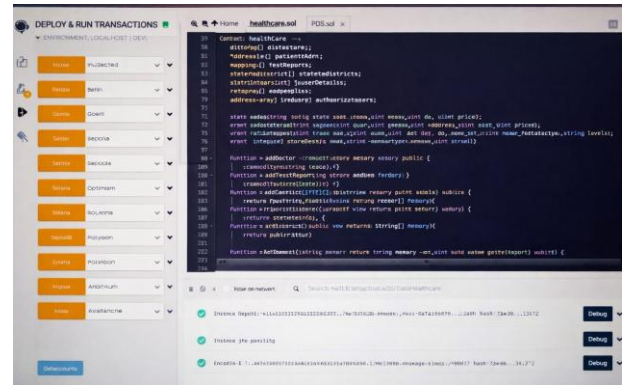


Fig. 11. Running Smart Contract

8. CONCLUSION

The Public Distribution System (PDS) plays a vital role in ensuring food security and supporting economically weaker sections of society in India. By providing essential food grains at subsidised prices, the system helps reduce hunger, poverty, and malnutrition among vulnerable populations. However, traditional PDS has faced several challenges such as corruption, leakage of food grains, lack of transparency, and inefficient monitoring of the supply chain.

The integration of advanced technologies such as Internet of Things (IoT), blockchain, and biometric authentication can significantly improve the efficiency and reliability of the system. IoT devices can assist in monitoring the movement and storage of food grains, while blockchain technology ensures secure and transparent recording of transactions. Since blockchain records cannot be altered easily, it helps prevent fraud and improves accountability among all stakeholders involved in the distribution process.

In addition, biometric verification systems can help ensure that food grains reach the rightful beneficiaries by eliminating duplicate or fake identities. The combination of these technologies creates a more transparent and efficient distribution network where every stage of the supply chain can be monitored and verified. Despite these advantages, the implementation of such technologies may face certain challenges, including high installation costs, technical complexity, and the lack of proper digital infrastructure in rural areas. Proper planning, government support, and gradual adoption of these technologies are necessary to overcome these limitations.

Overall, a technology-driven Public Distribution System can strengthen transparency, improve supply chain management, and ensure that essential food resources reach the intended beneficiaries. In the long run, this approach can contribute to better governance, improved social welfare, and a higher standard of living for the population.

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