Ætheric Public Distribution System: A Blockchain and AI-Driven Framework for Transparent Food Grain Distribution

Abstract

India's Public Distribution System (PDS) is the largest food security program in the world, serving over 800 million beneficiaries. However, systemic inefficiencies such as leakage, fraud, and stock mismanagement hinder its effectiveness. This paper proposes the Ætheric Public Distribution System (ePDS), an interoperable framework integrating Ethereum-based blockchain, Bharat Stack APIs (Aadhaar, UPI), RRFID / NFC tracking and AI-powered stock forecasting. The proposed solution ensures transparency, tamper-proof grain tracking, and optimized stock management, complementing the One Nation One Ration Card (ONORC) initiative. We present the architecture, simulated implementation, and potential benefits, drawing from related work in blockchain-enabled supply chains and AI-based demand forecasting. The approach promises to reduce fraud, improve resource allocation, and enhance accountability in India's food distribution ecosystem.

1 Introduction

The Public Distribution System (PDS) in India is one of the largest food security programs in the world, covering over two-thirds of the nation's population. Through a network of fair price shops, it provides subsidized food grains to vulnerable communities, thereby contributing significantly to poverty alleviation and nutritional security. However, despite its massive scale and importance, the PDS continues to face structural inefficiencies. Problems such as grain diversion, ghost beneficiaries, ration card duplication, and lack of accountability have hindered its effectiveness. Furthermore, during crises such as the COVID-19 pandemic, weaknesses in centralized data management and manual processes became evident, leading to ration shortages and access delays for millions of beneficiaries.

In response, the Government of India launched the One Nation One Ration Card (ONORC) scheme to improve portability and accessibility across states. While ONORC represents a significant step forward, its reliance on centralized databases introduces vulnerabilities, including susceptibility to fraud, data mismatches, and lack of interoperability across other national digital platforms. These challenges call for innovative technological interventions that can complement existing policies and create a transparent, secure, and scalable ecosystem for food distribution.

Blockchain technology has emerged as a promising solution due to its inherent characteristics of immutability, transparency, and distributed trust. Prior research has demonstrated its potential in ensuring end-to-end traceability in both public distribution and agri-food supply chains. However, most existing blockchain-based frameworks for PDS have been limited to conceptual models or

small-scale implementations, often overlooking critical aspects such as cross-chain interoperability, integration with Aadhaar and UPI, AI-driven decision-making, and IoT-based supply chain monitoring.

This paper introduces the **Ætheric Public Distribution System (ePDS)**, a novel framework that integrates blockchain with **Bharat Stack APIs**, enabling interoperability with Aadhaar for beneficiary authentication and UPI for secure transactions. The proposed solution further incorporates **RFID/NFC for grain tracking**, **AI-based stock forecasting**, and a **mobile/web interface** to enhance accessibility and accountability. By addressing technological, logistical, and governance challenges, the ePDS model aspires to reimagine food distribution in India, ensuring that subsidies and essential commodities reach the intended beneficiaries without leakage or inefficiency.

2 Literature Survey

Blockchain applications in food supply chains and public distribution systems have been extensively studied in recent years, with researchers emphasizing transparency, immutability, and fraud prevention. Several studies specifically focus on the Indian PDS. Valarmathi et al. [1] and Pawade et al. [2] propose blockchain-based PDS frameworks, highlighting the potential for tamper-proof record-keeping but lacking detailed implementation of cross-chain interoperability. Krishna et al. [3] present a blockchain-based design for ration distribution but limit their scope to conceptual models without AI integration. Similarly, Shwetha and Prabodh [14] emphasize accountability through blockchain but overlook scalability challenges.

Joni et al. [4] advance the field by introducing **quantum-resistant blockchain** for ration distribution, integrating hardware security modules. While this adds robustness, it does not address real-world integration with Aadhaar or UPI. Raghunandan et al. [5] propose a scalable blockchain framework for India's Targeted PDS, focusing on scalability but lacking in interoperability and AI-driven demand forecasting. Singh et al. [16] present a conceptual model using consortium blockchain with hybrid on-chain/off-chain data, but implementation details remain scarce. Mishra and Maheshwari [13] discuss enablers and disablers of blockchain in PDS, but their work remains largely at a conceptual level.

Beyond PDS-specific research, blockchain has also been explored in agriculture and food supply chains. Kumar et al. [6] introduce Agro-Ledger, emphasizing transparency and traceability in agri-food chains, while Ukidve et al. [8] extend this toward **Agroecosystems 5.0**. Kansal et al. [9] propose BlockTrackers for food chain monitoring, ensuring accountability but lacking integration with national identity systems. Farooq et al. [15] build a blockchain-based framework for wheat crop supply chains, highlighting reliability but without addressing ration distribution. Gomes et al. [18] propose AgriChain, integrating blockchain for traceability but not for subsidy-linked distribution.

Studies such as Kumar et al. [7] and Del Castillo [10] emphasize the importance of digitization during crises like COVID-19, suggesting blockchain as a trust-restoring mechanism for food security. Babu et al. [17] also argue for blockchain in agricultural product traceability, while Girma [12] explores smart contracts in PDS, stressing transparency.

From this review, several research gaps emerge. While many works acknowledge blockchain's potential, few have explored **integration with Bharat Stack (Aadhaar, UPI)** to ensure nationwide beneficiary verification and financial interoperability. Similarly, **AI-powered stock forecasting**, **IoT-driven grain tracking (RFID/NFC)**, and **mobile-first beneficiary engagement** are underexplored in existing literature. Moreover, sustainability concerns, scalability benchmarks, and socio-economic adoption challenges remain largely absent.

Against this backdrop, the proposed **Ætheric PDS** distinguishes itself by explicitly addressing interoperability, real-time monitoring, AI forecasting, and user accessibility, thereby extending beyond the conceptual limitations of existing research.

3 Proposed Methodology

The ePDS methodology adopts a multi-layered architecture to ensure transparency, security, and efficiency in PDS operations. It combines blockchain for immutable record-keeping, Bharat Stack APIs for identity verification, simulated IoT for physical tracking, AI for predictive analytics, and cross-platform applications for user interaction. The design follows a cross-chain agent paradigm, enabling interoperability between Ethereum-compatible blockchains and India's digital public infrastructure.

Step 1: Grain Movement Recording

• The deposit of each farmer is stored in their Kisan Card or Aadhar Card
• Food bags are tagged (simulated) with RFID/NFC.
• Every movement—warehouse to shop to beneficiary—is recorded on the blockchain.
• Immutable records prevent tampering and fraud.

Step 2: Beneficiary Authentication

• Beneficiary uses Smart Card/ Aadhaar (mocked via Bharat Stack API) at ration shop.
• System verifies identity and eligibility instantly.
• Prevents fake or duplicate ration card usage.

Step 3: AI Forecasting for Stock Management

• AI model predicts demand based on historical and simulated data.
• Helps shopkeepers maintain optimal stock levels.

Step 4: User Access via Mobile App

• Shopkeepers and officials use a Flutter app to track stock and transactions.
• Beneficiaries can check their entitlements and transaction history.
Importance of Ethereum in the Project:
Ethereum blockchain acts as an unbiased third-party that offers transparency and integrity. It enables third parties to easily verify flow of grains and allows to track any malpractice or losses easily. Making Ethereum the core of the solution also increases the government’s accountability.

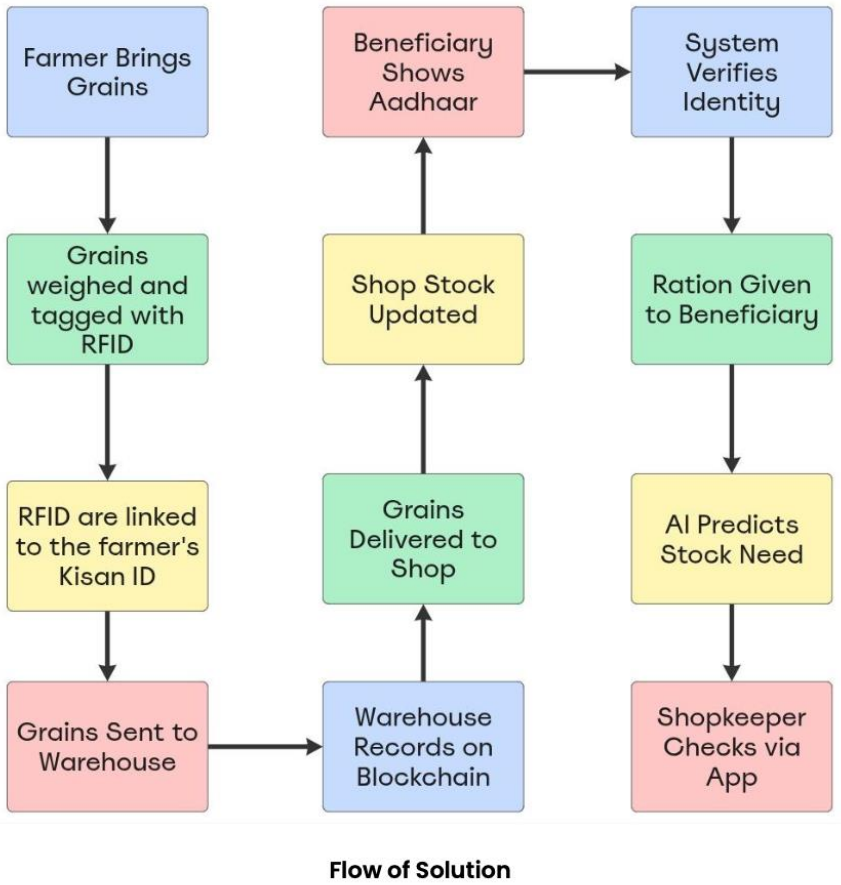

Figure 1: The Flow of the Solution

3.1 System Architecture

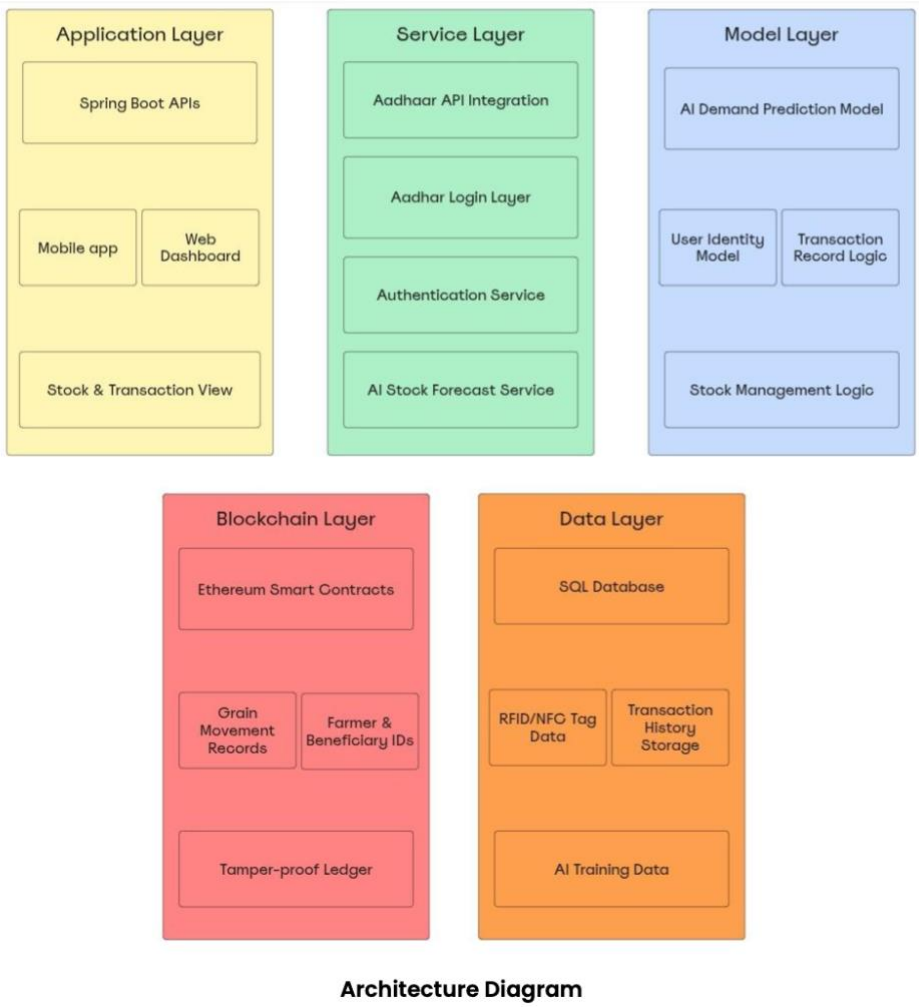

*Figure2 :*The architecture encompasses data flows from grain procurement to beneficiary delivery, with blockchain nodes operated by government agencies, and APIs interfacing with Bharat Stack for authentication.

3.2 Implementation and Simulation

The prototype simulates:

1. RFID-tagged grain tracking from warehouse to shop.
2. Aadhaar verification using mocked Bharat Stack APIs.
3. Blockchain transaction recording using a private Ethereum network.
4. AI forecasting model predicting monthly stock needs.
5. Flutter app for shopkeepers and beneficiaries.

3.3 Evaluation

Our evaluation focuses on:

- Transparency: Immutable records deter fraud.

- Scalability: Private Ethereum chain supports concurrent transactions.
- Accuracy: AI forecasting reduces stock imbalance.
- Interoperability: Seamless integration with Bharat Stack.

4 Discussion and Limitations

The ePDS framework offers several strengths, including enhanced transparency through blockchain's immutability, which directly mitigates PDS leakages as identified in literature [3, 13, 14]. Integration with AI and simulated IoT addresses gaps in complementary technologies [6, 8, 9], enabling proactive stock management. Interoperability with Bharat Stack bridges Web3 and centralized systems, potentially scaling ONORC [5, 16]. However, limitations exist: The MVP relies on simulations, lacking empirical validation in real PDS environments [2, 11, 12]. Privacy concerns with Aadhaar data require advanced techniques like zero-knowledge proofs [4, 15]. Cost implications, such as Ethereum gas fees, and energy consumption for blockchain operations remain unquantified [10, 13]. Adoption barriers, including digital literacy in rural areas, could hinder rollout [7, 13]. Compared to prior works, ePDS advances hybrid models by emphasizing cross-chain agents, offering greater potential for nationwide PDS reform. Future impacts include reduced fraud (potentially 20-30% leakage savings) and improved food security, aligning with Sustainable Development Goals.

5 Conclusion and Future Work

This paper presented the ePDS framework, a blockchain-based solution integrating Bharat Stack, AI, and IoT simulations to overhaul India's PDS. By addressing transparency, interoperability, and efficiency gaps in existing literature, ePDS paves the way for tamper-proof food distribution. While the MVP demonstrates viability, full implementation requires pilot testing and regulatory alignment. Future work includes real-world deployments, advanced privacy enhancements, and cost analyses to realize its transformative potential.

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