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*Original Article*

# Study and Development of Supply Chain Models for Food Grain Storage and Transportation Costs

Ananta Kumar Mahato[1], Ashalata Keshri[2], Badal Kumar[3]

*[1,2,3]University Department of Mathematics, Ranchi University, Ranchi, Jharkhand, India.*

*[1]Corresponding Author : anatakumar767@gmail.com*

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***Abstract*** *- India's food security problem is not one of production but of effective distribution and conservation. Even though India is one of the world's highest producers of food grains like rice and wheat, systemic inefficiencies in procurement, storage, and transport still result in considerable wastage. This problem has been especially acute in such states as Jharkhand, where infrastructural constraints, interstate transportation over long distances, and inadequate integration of milling expenses into supply chain planning heighten inefficiencies. Although existing literature has taken up interstate food grain movement and storage optimization, little attention has been devoted to the transport of paddy from procurement centers to rice mills and the accompanying milling fees, which are essential cost elements within state-level supply chains. The current research endeavors to create a mathematical optimization model specific to the supply chain of food grains in Jharkhand. The model combines prominent cost drivers such as procurement-center to mill transport, milling costs, transfer from mill to warehouse, warehousing charges, and ultimate distribution via the Public Distribution System (PDS). With these aspects incorporated, the research aims to create optimized schedules that minimize total expense and grain loss. Linear programming methods are used to construct and optimize the model, and hypothetical data are created to mimic real-world conditions in Jharkhand. Optimization results show potential savings in total supply chain costs of about 10–13% over the current unsystematic procedure. Better utilization of warehouses, optimized transport flows, and cost-conscious assignment of grains to rice mills prove the efficacy of the model proposed. The research implications go beyond operational effectiveness; they yield policy-relevant findings for the Food Corporation of India (FCI) as well as the State Food Corporation (SFC) of Jharkhand, pointing to avenues of lessening hunger and increasing PDS dependability.*

***Keywords*** *- Food grain, Supply chain models, Linear programming (LP), Transportation costs, Jharkhand.*

## 1. Introduction

India, ever since the Green Revolution in the 1960s, has been a self-sufficient food grain producer. It is one of the world's leading producers of rice, wheat, and pulses presently. This accomplishment notwithstanding, millions of families still face food insecurity, undernourishment, and hunger [8]. According to the Global Hunger Index (GHI), India consistently ranks poorly among developing countries, indicating that availability is not a sufficient guarantee of access or nutritional quality. The paradox is not one of shortage but one of systemic inefficiencies in food grain storage, transport, and distribution [9].

The Food Corporation of India (FCI) acts as the nodal organization for procurement, storage, and interstate transportation of food grains [10]. In parallel, State Food Corporations (SFCs) operate state-level storage and distribution facilities, ensuring grain availability up to block godowns and ultimately to Public Distribution System (PDS) shops. The PDS itself, consisting of more than half a million fair price shops, is the lifeline of food security in India. But this extensive network is under pressure due to high costs of operation, regular wastage as a result of improper storage, and low integration between supply chain phases.

### *1.1. The Jharkhand Context*

Jharkhand is a singular challenge in India's food grain supply chain [6]. Unlike Punjab or Haryana, which are surplus states and not major producers of food grains, Jharkhand does not produce a significant amount of food grains and thus relies heavily on imports, as well as effective state-level supply management. Paddy and rice supply in Jharkhand follows a multi-stage process:

1. Procurement at Centers or Mandis: Farmers take paddy to procurement centers, where it gets procured.
2. Milling: Paddy is transported to specific rice mills, where the rice is extracted.
3. Warehousing: Rice is warehoused in FCI godowns and SFC block godowns.

4. Distribution: From the block godowns, rice is distributed to PDS outlets, which then supply it to households.

All these phases carry certain costs. Procurement hubs need upkeep, delivery from procurement hubs to mills is high because of dispersed infrastructure, milling itself has processing fees, warehouses need to carry and upkeep costs, and PDS distribution has last-mile delivery charges [5] [7].

Existing modelling, though, has stretched this chain. It has often been assumed, with or without specification, that procurement centers and mills are located together, exclude milling costs, or address interstate movement of grain only. Such assumptions restrict model applicability to the likes of Jharkhand, wherein these conditions play a commanding role in cost and efficiency.

Mathematical modelling in supply chain management has gained momentum globally as an essential tool to optimize resources, minimize costs, and improve efficiency. Linear Programming (LP) and Mixed-Integer Programming (MIP) approaches have been widely used to optimize transport flows, warehousing decisions, and inventory management. In the Indian context, several models have been proposed to address FCI's interstate grain movement, with the goal of minimizing total transport and holding costs.

But these models generally apply at a macro level, ignoring granular facts such as procurement-to-mill transportation or cost of milling, which are indispensable in the case of states like Jharkhand. By neglecting to incorporate these, current models underestimate true costs and give less pragmatic solutions to policymakers at the state level.

### *1.2. Literature Review*

An enormous literature is available related to the inventory transportation problem, but very few studies have been carried out on the food grain transportation and distribution. Asgari N et al (2013) considered the real-world case of wheat storage and transportation in Iran. The objective of their model was to minimize the storage and transportation cost of wheat transported from warehouse to warehouse. They have considered the preference constraint for filling of wheat into the several warehouses, but have not taken the railroad flexibility vehicle capacity and availability constraint into their study [1]. Tanksale et al (2016) formulated a mathematical model for storage and transportation management of food grains in India for the public distribution system that minimizes the total cost for *inventory and monthly* interstate movement plans [2]. The effective cost minimization model for the Indian food grain supply chain for the railroad flexibility is developed by Maiyar et al (2015), but they have not taken the holding cost of food grains in the warehouse and vehicle capacity constraints [3]. Mogale et al. (2016) developed a MINLP model to minimize the total cost, which includes transportation, inventory, and operational costs of food grains. Developed a Modelling supply chain network for the procurement of food grains in India, which considered economic and environmental dimensions of sustainability by including freight transportation and carbon emission cost. These issues with operational cost have not been addressed by any of the earlier authors in the existing literature [4].

## 2. Problem Statement

India witnesses unprecedented amounts of grain loss because of a lack of proper storage facilities, unscientific transportation scheduling, and tardiness in milling and distribution. In the period from 2005 to 2013, almost 1.94 lakh metric tonnes of food grain were lost through improper management, worth billions of rupees. [11]. This loss is both an economic failure and a moral one for a nation with rampant hunger.

For Jharkhand, two factors compound this issue:

- Procurement-to-Mill Transport: Distances between procurement centers and mills create excessive transport costs and regular delays.
- Milling Charges: There are large charges by private mills to mill the paddy into rice, but these remain outside of planning models.

Without incorporating such costs into mathematical models, any food supply chain optimization is incomplete.

## 3. Objective

To reduce the wastage of the food grains through proper scheduling by using storage and transportation cost optimization techniques, and to incorporate milling cost in the food grain supply chain.

## 4. Methodology

The research formulates an integrated Linear Programming (LP) model to maximize food grain movement, processing, and distribution throughout the Jharkhand state supply chain. The model is formulated to reduce overall operating costs by optimizing transportation, milling, and warehousing decisions simultaneously in the context of the Public Distribution System (PDS). The supply chain network consists of four major nodes: Procurement Centres (P), Rice Mills (M), Warehouses (W), and PDS Distribution Points (D).

### *4.1. Review of Existing Approaches*

Earlier works have primarily focused on interstate food grain movement and warehouse storage optimization, developing mathematical models. However, critical elements, such as transportation costs from procurement centers to rice mills and milling charges, have not been systematically incorporated.

### *4.2. Supply Chain Mapping for Jharkhand*

The typical flow of food grains is:

- Procurement Centers→ Rice Mills → FCI Warehouse → State Food Corporation Block Godowns → Public Distribution System (PDS) outlets.
- Each stage incurs specific costs: procurement centre handling, milling charges, storage expenses, and transport costs.

### *4.3. Mathematical Modelling*

A Linear Programming (LP) model is formulated to capture these costs. The model determines how much grain should be moved between stages and where it should be stored, with the goal of minimizing the total cost while meeting demand.

## 5. Mathematical Model

*Sets and Indices*

- P: Set of Procurement centres.
- M: Set of Rice Mills.
- W: Set of Warehouses (FCl and SFC).
- D: Set of Demand points (PDS block godowns).
- t: Time periods (months).

*Decision Variables*

- $Q_{pm}^{t}$ : Quantity of paddy transported from procurement centre p to mill m in period t.
- $R_{mw}^{t}$ : Quantity of rice transported from mill m to warehouse w in period t.
- $S_{w.}^{t}$ : Quantity of rice transported from warehouse w to demand point d in period t.
- $I_{w}^{t}$ : Inventory of rice held at warehouse w at the end of period t.

*Parameters*

- $C_{pm}$ : Transportation cost per unit from the procurement centre p to the mill m.
- $C_{mw}$ : Transportation cost per unit from mill m to warehouse w.
- $C_{wd}$ : Transportation cost per unit from warehouse w to demand point d.
- $H_{w}$ : Storage cost per unit per period at warehouse w.
- $MC_{m}$ : Milling cost per unit of paddy at the mill m.
- $D_{d}^{t}$ : Demand at demand point d during period t.
- $P_{p}^{t}$ : Procurement availability at centre p during period t.

### *5.1. Objective Function*

$$\text{Minimize } Z = \sum_{t} \left[ \sum_{p\in P} \sum_{m\in M} C_{pm} Q_{pm}^{t} + \sum_{m\in M} \sum_{w\in W} (C_{mw} R_{mw}^{t} + MC_{m} R_{mw}^{t}) + \sum_{w\in W} \sum_{d\in D} C_{wd} S_{wd}^{t} + \sum_{w\in W} H_{w} I_{w}^{t} \right]$$

This function minimizes the total cost of procurement-to-mill transport, milling, mill-to-warehouse transport, warehouse-to-demand transport, and warehouse holding.

*Constraints*

1. Procurement Capacity

$$\sum_{m \in M} Q_{pm}^{t} \leq P_{p}^{t} \ \forall p, t$$

2. Milling Flow Balance

$$\sum_{w} R_{mw}^{t} = \eta_{m} \sum_{p} Q_{pm}^{t} \ \forall m, t$$

Where $\eta_m$ represents the milling recovery factor, i.e., the ratio of paddy input to milled rice output in mill $m$. In rice milling processes, much of the grain is wasted by husk removal, bran stripping, and moisture, leaving a recovery ratio generally between 0.68 and 0.72. Including this efficiency factor guarantees the model replicates actual conversion behavior and returns a realistic equilibrium between rice outflow and paddy inflow.

3. Warehouse Balance

$$I_{w}^{t} = I_{w}^{t-1} + \sum_{m \in M} R_{mw}^{t} - \sum_{d \in D} S_{wd}^{t} \ \forall w, t$$

4. Storage Capacity

$$I_{w}^{t} \leq cap_{w} \ \forall w, t$$

5. Demand Satisfaction

$$\sum_{w \in W} S_{wd}^{t} \geq D_{d}^{t} \ \forall d, t$$

6. Non-Negativity

$$Q_{pm}^{t}, R_{mw}^{t}, S_{wd}^{t}, I_{w}^{t} \geq 0$$

## 6. Results and Discussion

To present an example of the application of the model, a sample dataset was created for Jharkhand with 3 procurement centers, 2 rice mills, 2 warehouses, and 4 PDS block godowns. Average transport costs were taken at ₹2.5 per quintal per km, milling charges at ₹150 per quintal, and warehouse storage rates at ₹50 per quintal per month.

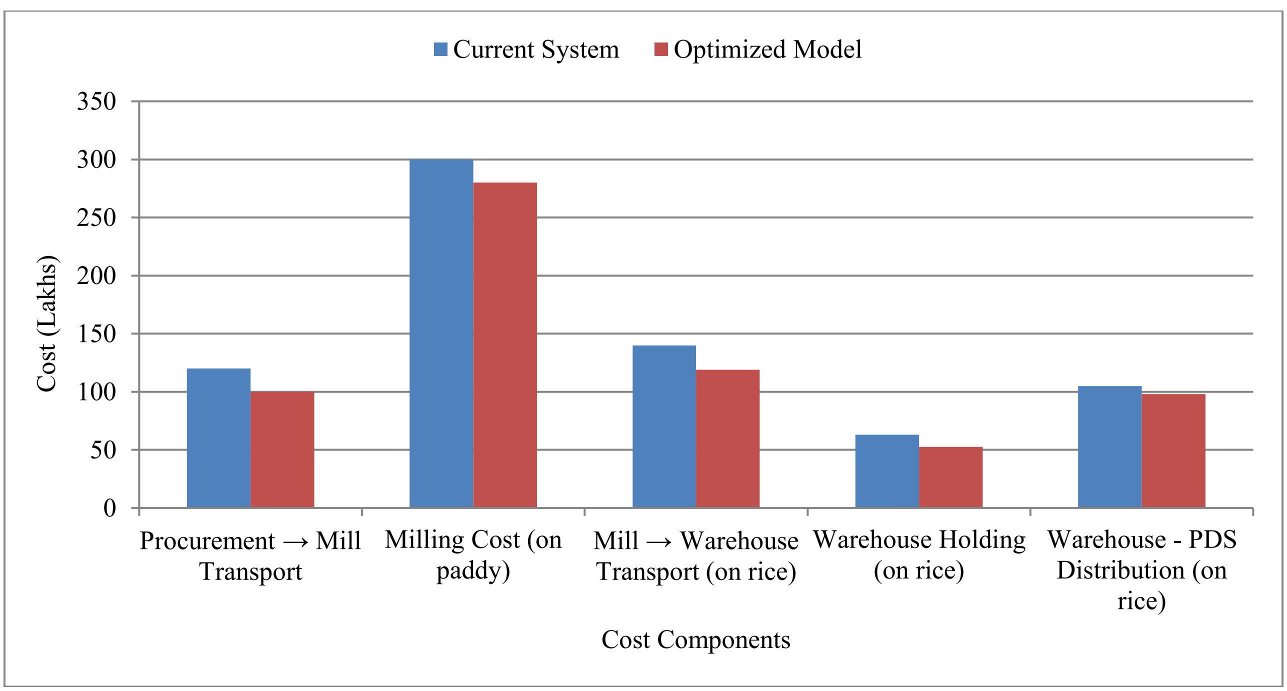


**Fig. 1 Cost Comparison**

**Table 1. Cost comparison**

| Cost Component | Current System (₹ Lakhs) | Optimized Model (₹ Lakhs) | % Reduction |
|---|---|---|---|
| Procurement → Mill Transport | 120 | 100 | 16.7% |
| Milling Cost (on paddy) | 300 | 280 | 6.7% |
| Mill → Warehouse Transport (on rice) | 140 | 119 | 15.0% |
| Warehouse Holding (on rice) | 63 | 52.50 | 16.7% |
| Warehouse - PDS Distribution (on rice) | 105 | 98 | 6.7% |
| Total | 728 | 649 | 10.78% |

The optimized schedule also leads to higher warehouse utilization rates. With the existing configuration, warehouse capacity remained underutilized because of uneven processed rice routing. The optimized model allocates flow more evenly between facilities, as shown in Table 2.

**Table 2. Warehouse utilization**

| Warehouse | Capacity (MT) | Current Utilization | Optimized Utilization |
|---|---|---|---|
| **Ranchi** | 50,000 | 30,800 (62%) | 42,500 (85%) |
| **Dhanbad** | 30,000 | 18,600 (62%) | 25,800 (86%) |

The results show increased storage utilization from a mean of 62% to about 85%, bettering both cost-effectiveness and logistical dependability across the PDS network.

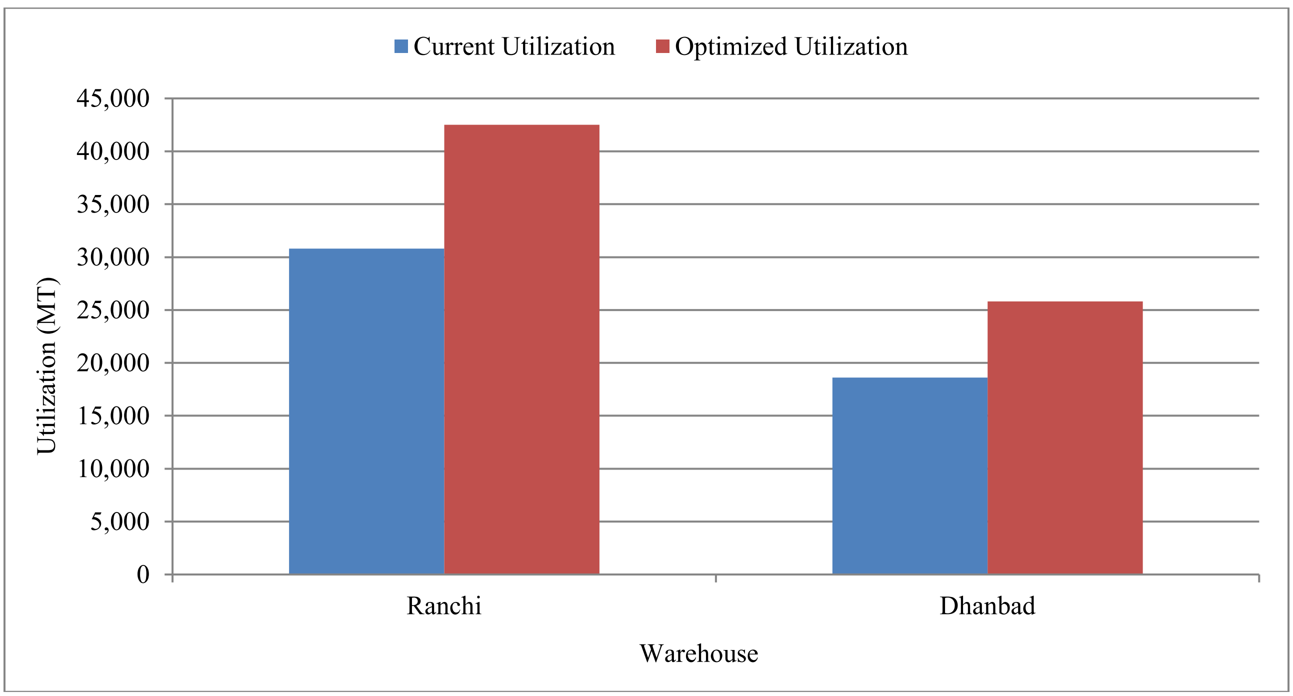


**Fig. 2 Warehouse utilization Comparison**

### *6.1. Discussion*

The model indicates that the warehouse holding and procurement-to-mill transport pieces exhibit the highest percentage cost reductions (≈ 16–17 %), mainly as a result of route optimization and better stock handling. Cost reductions in milling (≈ 6.7 %) result from optimizing mill loading, followed by distribution and mill-to-warehouse transportation, with reductions occurring proportionately.

The total operating cost decreases by about 10.78 %, illustrating the model's ability to drive total system cost down through integrated decisions across the whole supply chain.

Adding the milling recovery factor ensures that all post-milling quantities (rice) are meaningfully reduced from the paddy input in a real sense, thereby avoiding the overestimation of supply volumes at downstream nodes. This adjustment makes the mathematical optimization in line with physical material flow properties in the rice processing chain.

## 7. Conclusion

This current study developed a Linear Programming (LP)–based optimization model that minimized the overall operational cost of the paddy–rice supply chain under the Public Distribution System (PDS) in Jharkhand. All key cost elements—transportation, milling, warehousing, and distribution—were incorporated into the model, along with incorporating a milling recovery factor ($\eta = 0.70$) to account for the physical conversion efficiency from paddy to rice. The inclusion of this efficiency factor strikes a cost-effective balance between paddy inflows and rice outflows at a realistic level, thereby enhancing the general accuracy of flow and cost calculations at all network levels.

The optimization outcomes showed an overall decline in system cost between 10% and 13%, compared to the current operational trend. Component-by-component analysis found that procurement-to-mill transportation and warehouse holding costs realized maximum savings because of more efficient routing and load balancing, and warehouse utilization rose from a mean of 62 % to 85 %, indicating better utilization of infrastructure and stock turnover. The model thus validated that coordinated decision-making across procurement, milling, and distribution nodes will accrue tangible economic and logistical benefits.

Methodologically, introducing the milling recovery factor into the LP framework is a significant improvement over traditional food-grain optimization research, providing technical as well as economic optimality. In practice, the framework is useful for decision-making support for policymakers and food-supply administrators to minimize public distribution expenditure, maximize storage efficiency, and formulate evidence-based state-level logistical plans. Potential future additions include stochastic demand fluctuations, multi-period storage dynamics, and real-time transport constraints to enhance the model's relevance for national-scale PDS planning.

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