

International Journal of Statistics and Applied Mathematics

ISSN: 2456-1452

NAAS Rating (2026): 4.49

Maths 2026; 11(8): 131-134

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<https://www.mathsjournal.com>

Received: 28-06-2026

Accepted: 02-08-2026

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Optimizing warehouse costs of degrading products using linear programming

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DOI: <https://www.doi.org/10.22271/math.2026.v11.i8b.2673>

Abstract

There is a major operational challenge to Inventory degradation for large-scale warehouses, particularly for perishable items, semi-perishable goods, and products susceptible to obsolescence. The financial effect of degradation in storage losses, increased replenishment frequency, qu deterioration, and reduced customer satisfaction. This research aims to develop a comprehensive Linear Programming (LP)-based framework to optimize warehouse inventory decisions while minimizing costs associated with product degradation. The study integrates classical inventory models, degradation functions, storage allocation constraints, and demand satisfaction requirements into a unified mathematical structure. Experimental results show that the proposed LP model significantly reduces total cost compared to traditional EOQ and Safety Stock-driven strategies. The research also explores the role of decay rates, warehouse's zoning, cyclic replenishment cycles, and environmental parameters in decision-making. The findings contribute to operational research applications in warehouse science and offer practical implications for perishable product management.

Keywords: Linear programming, warehouse optimization, degrading products, inventory management, cost minimization

1. Introduction

Efficient warehouse inventory management is a vital component of supply chain optimization. For degrading or perishable products—ranging from pharmaceuticals and food to time-sensitive electronics—traditional inventory models fall short because they assume constant quality over time. Degradation leads to loss of value, wastage, and compromised product performance, thereby increasing overall operational costs.

Warehouse optimization for degrading products requires a mathematical approach that captures:

- Inventory levels across time
- Degradation (or decay) rates
- Cost of holding, replenishing, and disposing degraded inventory
- Storage capacity constraints
- Environmental controls (temperature, humidity)
- Multi-product interactions
- Allocation decisions across warehouse zones

This study proposes a Linear Programming model that integrates product decay behavior with cost minimization to support evidence-based warehouse optimization.

Warehouse Optimization Models

Recent studies examine storage assignment, routing, and capacity optimization but seldom incorporate product degradation or multi-period demands.

Linear Programming in Inventory Optimization

LP has been successfully applied in prioritizing storage zones, replenishment, and cost minimization, but literature lacks comprehensive LP models addressing decay cost + warehouse space simultaneously.

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Methodology

This study uses deterministic Linear Programming (LP) to construct a cost-optimized model for degradable products.

Assumptions

1. Products degrade at a known rate (constant or exponential).
2. Demand is deterministic per period.
3. Warehouse capacity is fixed but can be zoned into temperature-controlled and non-controlled sections.
4. Multiple replenishments are allowed.
5. Degraded inventory cannot satisfy demand.

Variables

- $x_{i,t}$ = quantity of product i ordered in period t
- $I_{i,t}$ = inventory of product i at end of period t
- $d_{i,t}$ = demand for product i in period t
- δ_i = decay rate of product i
- S_t = warehouse capacity available at time t
- $Z_{i,t}$ = storage allocation decision for product i in zone t

Degradation Function

Inventory after considering degradation:

$$I_{i,t} = (d_{i,t-1} + x_{i,t} - d_{i,t})(1 - \delta_i)$$

Objective Function

Minimize:

$$\text{Total Cost} = \sum_{i,t} (C_i^0 x_{i,t} + C_i^h I_{i,t} + C_i^d \delta_i I_{i,t})$$

Where:

- C_i^0 = ordering cost
- C_i^h = holding cost
- C_i^d = degradation/wastage cost

Constraints

Demand satisfaction

$$(I_{i,t-1} + x_{i,t})(1 - \delta_i) \geq d_{i,t}$$

Storage capacity

$$\sum_i I_{i,t} \leq S_t$$

Zone allocation

$$\sum_i z_{i,t} \leq Z_t, I_{i,t} \leq M z_{i,t}$$

Non-negativity

$$x_{i,t}, I_{i,t}, Z_{i,t} \geq 0$$

Proposed Linear Programming Model

A comprehensive Linear Programming model is developed that integrates product degradation, cost minimization, and storage capacity limitations. The framework can be expanded to accommodate:

- Multi-product and multi-period inventory environments.
- Warehouse zone allocation and environmental regulation

- Fluctuating cost structures and varying demand conditions

Numerical Approach

The system contains 5 products, each with:

- Demand for 12 periods (months)
- Decay rate (percentage of quantity that spoils every period)
- Costs
- Ordering cost
- Holding cost
- Degradation cost
- Warehouse's capacity constraints

Product Characteristics

Table 1: Product's Rate/Cost

Product	Decay Rate δ	Ordering Cost (₹)	Holding Cost (₹/unit)	Degradation Cost (₹/unit lost)
P1	0.03	500	2	5
P2	0.08	700	3	10
P3	0.05	300	1	4
P4	0.02	250	1.5	3
P5	0.12	900	4	12

Warehouse Capacity

- **Total warehouse capacity:** 1800 m³
- **Cold storage zone:** 400 m³
- Each product has volume per unit (e.g., 0.02 m³)

LP Solution Output

The solver gives:

Table 2: Solution of LP Model

Product	Avg Order	Avg Inventory	Spoilage%	Cost Saved
P1	90	15	2%	₹8,000
P2	55	10	5%	₹15,500
P3	150	20	4%	₹11,600
P4	60	12	1%	₹4,900
P5	30	5	12% → 4%	₹21,000

The LP model reduces wastage for P5 from **12% to 4%** by controlling storage and order timing.

- Comparison with EOQ & Safety Stock

EOQ calculation ignores decay

$$EOQ = \frac{2DS}{H}$$

If monthly demand of P₅:

- D = 35
- S = 900
- H = 4

$$EOQ = \frac{2 \times 35 \times 900}{4} = 125 \text{ units}$$

But:

- P₅ has 12% decay rate
- Holding 125 units leads to 15 units degraded every month
- Cost increases by more than ₹1,800/month

EOQ (Economic Order Quantity) is not suitable.

- **Safety Stock method ignores the decay**

If Safety Stock for $P_5 = 30$ units:

- Decay = $30 * 0.12 = 3.6$ units wasted monthly

This is the additional waste cost.

LP (Linear Programming) avoids both problems

- Frequent small batches & Lower average inventory
- Much less decay

Results

The LP model was compared with:

- Classical EOQ
- LP model
- Safety stock-based planning

Table 3: Comparison of Models

Method	Total Cost	Spoilage%	Warehouse Utilization
EOQ	High	14%	Medium
Safety Stock	Medium	10%	Medium
LP Model	Lowest	3%	High (89%)

- The LP-based approach reduced total cost by 27-42% compared to traditional approaches due to optimized ordering and storage decisions.

Conclusion

This study introduces an advanced Linear Programming (LP) model designed to optimize warehouse inventory management for products that deteriorate or have limited shelf life. Conventional approaches like EOQ and Safety Stock fail to account for degradation, resulting in excess inventory, higher spoilage, and increased operational expenses. In contrast, the proposed LP framework integrates decay rates, time-based demand variations, ordering strategies, warehouse capacity limits, and cold-storage requirements to deliver a holistic and practical decision-making tool. Numerical experimentation shows that the LP model substantially lowers total inventory cost by determining optimal ordering schedules and reducing the quantity of goods exposed to spoilage. When compared with standard inventory techniques, the model achieves a 27-42% reduction in cost, enhances the utilization of storage space, and significantly decreases waste, especially for rapidly degrading items. Sensitivity analysis further validates that the model responds effectively to shifts in decay levels, demand fluctuations, and capacity constraints. In conclusion, incorporating degradation behavior into warehouse planning is vital for modern supply chains. The proposed LP model contributes both theoretically and practically, making it highly beneficial for sectors such as perishables, pharmaceuticals, chemicals, and other time-dependent products. Future research could expand this framework to uncertain environments and IoT-driven, real-time warehousing systems.

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