Optimizing A Two-Warehouse Inventory System For Deteriorating Items With Ramp-Type Demand And Inflation Using Genetic Algorithm

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Abstract:
This study develops a two-warehouse inventory model for deteriorating items under ramp-type demand and inflation, with partial backlogging. The model considers an owned warehouse (OW) with limited capacity and a rented warehouse (RW) with unlimited capacity, where goods are consumed from RW first. Deterioration is assumed to be time-dependent, and shortages are partially backlogged at an exponential rate. The total average cost includes ordering, holding, deterioration, shortage, and lost sales costs, adjusted for inflation. A Genetic Algorithm (GA) is employed to optimize the order quantity and cycle time. Numerical results demonstrate the model's applicability and provide insights into cost sensitivity with respect to key parameters such as deterioration rate and inflation. The proposed approach offers a practical decision-support tool for managing perishable inventories in dynamic and inflationary environments.

Keywords: Two-Warehouse Inventory System**,** Deteriorating Items**,** Ramp-Type Demand**,** Inflation**,** Partial Backlogging and Genetic Algorithm (GA)

1. INTRODUCTION

Inventory management is a vital aspect of supply chain operations, especially for goods that deteriorate over time, such as food items, pharmaceuticals, chemicals, and certain electronic products. The effective handling of such items becomes increasingly challenging when demand patterns are not static but change over time, and when economic factors like inflation influence overall costs and pricing strategies. In practical business environments, companies often use a combination of owned and rented storage spaces to manage their stock. The owned warehouse usually has a fixed capacity, while the rented warehouse provides additional, often unlimited, storage flexibility. A common practice is to use the rented warehouse first to avoid higher holding costs associated with it, following a two-warehouse inventory policy. This approach is particularly useful for products with seasonal demand, promotional campaigns, or items whose demand increases gradually before reaching a stable level—a trend accurately represented by a ramp-type demand function.

Ramp-type demand reflects a realistic market scenario where demand rises linearly until a specific point and then remains constant. This pattern is frequently observed during new product introductions, seasonal sales, or when a product gradually gains customer acceptance. At the same time, inflation affects various cost components, including holding, shortage, and ordering costs, making it necessary to incorporate inflationary effects into inventory models, especially for planning over extended periods.

This research develops a comprehensive two-warehouse inventory model for deteriorating items under the influence of ramp-type demand and inflation. The model permits shortages, which are partially backlogged at an exponentially decreasing rate. Deterioration is considered to be time-dependent and applies only to the inventory currently in stock. The primary aim is to identify the

optimal replenishment strategy that minimizes the total average cost, encompassing expenses related to ordering, holding, deterioration, shortages, and lost sales.

To address this nonlinear and constrained optimization problem, a Genetic Algorithm is utilized. Genetic Algorithms are powerful, population-based search techniques inspired by the principles of natural selection and genetics. They are well-suited for solving complex optimization problems where traditional derivative-based methods may fail, as they do not require gradient information and can efficiently explore large and irregular search spaces.

The key contributions of this work include the formulation of an integrated two-warehouse inventory model that incorporates ramp-type demand, time-varying deterioration, inflation, and partial backlogging. Analytical expressions are derived for inventory levels in both warehouses and for all relevant cost components. The application of a Genetic Algorithm provides an effective computational tool for determining optimal decision variables, such as order quantity and timing. This study offers a practical decision-support framework for managers and planners dealing with perishable inventory under dynamic demand conditions and inflationary economies.

1. Literature review

Goyal and Giri (2001) offered a comprehensive review of deteriorating inventory models, emphasizing their significance in realistic systems. Further enhancements to these models include the inclusion of time-varying demand, partial backordering, and hybrid storage systems. The concept of a dual-warehouse inventory model, where the own warehouse (OW) has limited capacity and the rented warehouse (RW) has relatively higher holding cost, has proven effective in handling large inventories. Research by Sarma (1987) and later by Bhunia and Maiti (1999) provided analytical insights into two-warehouse inventory scenarios under different conditions, including stock-dependent demand and partial deterioration. While these studies addressed operational limitations, they largely overlooked the growing significance of green investments and promotional efforts. Recent advancements in sustainable inventory management have brought forth new modeling dimensions. Scholars like Sarkar and Moon (2014) introduced inventory systems considering green technology investment, linking it with consumer demand and total emissions. Subsequently, Taleizadeh et al. (2019) and Biswas et al. (2022) developed inventory models incorporating environmental constraints, carbon policies, and demand functions sensitive to green initiatives. Similarly, marketing investment, as a tool to stimulate demand and improve brand visibility, has been included in inventory systems by researchers such as Yan et al. (2018), demonstrating its profitability implications. Despite these developments, the simultaneous consideration of price sensitivity, greening level, and marketing investment within a two-warehouse production-inventory framework remains largely unexplored. This paper bridges this gap by developing a comprehensive model that captures these interdependencies under a deteriorating item setting. The deterioration rate is assumed to be constant and uniform across both warehouses. The demand function is modeled as a decreasing function of selling price and increasing function of both greening level and marketing investment. The greening effort represents the firm's environmental responsibility, while the marketing investment captures strategic promotional expenditure to enhance demand. Moreover, this model contributes to the literature by integrating economic and environmental objectives, incorporating real-world complexities such as limited own-warehouse capacity, fixed production rate, and continuous replenishment. Through analytical derivation and sensitivity analysis, the proposed model evaluates the impact of system parameters—especially greening and marketing investments—on total profit and system sustainability. This integrative approach offers valuable managerial insights for firms seeking to align economic efficiency with environmental stewardship in a competitive marketplace.

ASSUMPTIONS AND NOTATIONS:

In developing the mathematical model of the inventory system the following assumptions are being made:

1. A single item is considered over a prescribed period T units of time.
2. The demand rate D(t) at time t is deterministic and taken as a ramp type function of time i.e.
   $D(t) = Ge^{-Y\{t-(t-P)H(t-P)\}}$, $G > 0, Y > 0$
   where H(t-μ) is the Heaviside's function defined as
   $$H(t-P) = \begin{cases} 0, & t < P \\ 1, & t \geq P \end{cases}$$
3. The replenishment rate is infinite and lead-time is zero.
4. When the demand for goods is more than the supply. Shortages will occur. Customers encountering shortages will either wait for the vender to reorder (backlogging cost involved) or go to other vendors (lost sales cost involved). In this model shortages are allowed and the backlogging rate is exp(-B t), when inventory is in shortage. The backlogging parameter B is a positive constant.
5. The variable rate of deterioration in both warehouse is taken as V(t) = Vt. Where 0< V<< 1 and only applied to on hand inventory.
6. No replacement or repair of deteriorated items is made during a given cycle.
7. The owned warehouse (OW) has a fixed capacity of W units; the rented warehouse (RW) has unlimited capacity.
8. The goods of OW are consumed only after consuming the goods kept in RW.

In addition, the following notations are used throughout this paper:

$S_{MW}(t)$	The inventory level in OW at any time t. Main Warehouse
$S_{LL}(t)$	The inventory level in RW at any time t.
W	The capacity of the own warehouse.
Q	The ordering quantity per cycle.szs
T	Planning horizon.
r	Inflation rate.
α	The holding cost per unit per unit time in OW.
α_1	The holding cost per unit per unit time in RW. where $C_1 < C_2$
C_d	The deterioration cost per unit.
β_1	The shortage cost per unit per unit time.
β_2	The opportunity cost due to lost sales.
C'	The replenishment cost per order.

3 FORMULATION AND SOLUTION OF THE MODEL:

The inventory levels at OW are governed by the following differential equations:

$$\frac{dS_{MW}(t)}{dt} = -V(t)S(t), \qquad 0 \leq t < P \qquad \text{... (1)}$$

$$\frac{dS_{MW}(t)}{dt} + V(t)S(t) = -Ge^{-YP}, \qquad P \leq t \leq t_1 \qquad \text{... (2)}$$

And

$$\frac{dS_{MW}(t)}{dt} = -Ge^{-YP}e^{-Bt}, \qquad t_1 \leq t \leq T \qquad \text{... (3)}$$

with the boundary conditions,

$S_{MW}(0) = N$ and $S(t_1) = 0$ ...(4)

The solutions of equations (1), (2) and (3) are given by

$$S_{MW}(t) = N e^{-V t^2/2}, \qquad 0 \le t < P \qquad \text{... (5)}$$

$$S_{MW}(t) = Ge^{-YP}\left\{(t_1 - t) + V\frac{(t_1^3 - t^3)}{6}\right\}e^{-V t^2/2}, \qquad P \le t \le t_1 \qquad \text{... (6)}$$

And $S_{MW}(t) = \frac{G}{B}e^{-YP}\left\{e^{-Bt} - e^{-Bt_1}\right\}, \qquad t_1 \le t \le T \qquad \text{... (7)}$

respectively.

The inventory level at RW is governed by the following differential equations:

$$\frac{dS_{LL}(t)}{dt} + V(t)S(t) = -Ge^{-Yt}, \qquad 0 \le t < P \qquad \text{... (8)}$$

With the boundary condition $S_{LL}(0) = 0$, the solution of the equation (8) is

$$S_{LL}(t) = G\left\{(P - t) - \frac{Y}{2}\left(P^2 - t^2\right) + \frac{V}{6}(t_1^3 - t^3)\right\}e^{-V t^2/2}, \qquad P \le t \le t_1 \qquad \text{... (9)}$$

Due to continuity of $S_{MW}(t)$ at point t = P, it follows from equations (5) and (6), one has

$$N e^{-VP^2/2} = Ge^{-YP}\left\{(t_1 - P) + V\frac{(t_1^3 - P^3)}{6}\right\}e^{-VP^2/2}$$

$$N = Ge^{-YP}\left\{(t_1 - P) + V\frac{(t_1^3 - P^3)}{6}\right\} \qquad \text{... (10)}$$

The total average cost consists of following elements:

(i) Ordering cost per cycle = α_1 ... (11)

(ii) Holding cost per cycle (C_{HO}) in OW

$$C_{HO} = \alpha\left[\int_0^P S_{MW}(t)e^{-Mt}dt + \int_P^{t_1} S_{MW}(t)e^{-M(P+t)}dt\right]$$

$$C_{HO} = \alpha\left[\begin{array}{l} N\left(P - \frac{MP^2}{2} - \frac{VP^3}{6}\right) + \\ +Ge^{-Y(P+M)}\left\{\begin{array}{l}\left[\frac{t_1^2}{2} - \frac{Mt_1^3}{6} + \frac{Vt_1^4}{12} - \frac{MV}{20}t_1^5 + \right. \\ \frac{MP^2}{6}(3t_1 - 2P) + \\ \frac{MVP^2}{30}\left(5t_1^3 - 3P^3\right) + \\ \frac{VP^3}{24}(4t_1 - 3P)\end{array}\right\}\end{array}\right] \qquad \text{... (12)}$$

(iii) Holding cost per cycle (C_{HR}) in RW

$$C_{HR} = \beta\left[\int_0^P S_{LL}(t)e^{-Mt}dt\right]$$

$$C_{HR} = \beta G\left[\begin{array}{l}\dfrac{P^2}{2} - \dfrac{(3Y+M)}{6}P^3 \\ +\left(\dfrac{V}{12}+\dfrac{YM}{8}\right)P^4 - \left(\dfrac{MV}{20}-\dfrac{YV}{30}\right)P^5\end{array}\right] \quad \text{... (13)}$$

(iv) Cost of deteriorated units per cycle (C_D)

$$= \alpha_d\left[\int_0^P V\,t\,S_{LL}(t)\,e^{-Mt}dt + \int_0^P \theta V t\,S_{MW}(t)\,e^{-Mt}dt + \int_P^{t_1} V\,t\,S_{MW}(t)\,e^{-M(t+P)}dt\right]$$

$$= \alpha_d V\left[\begin{array}{l}\left\{G\left(\begin{array}{l}\dfrac{1}{6}P^3 - \left(\dfrac{Y}{4}+\dfrac{M}{12}\right)P^4 \\ +\left(\dfrac{V}{40}+\dfrac{MY}{15}\right)P^5 \\ -\left(\dfrac{MV}{36}-\dfrac{YV}{24}\right)P^6\end{array}\right)\right\} + \\ \left\{\begin{array}{l}+N\left(\dfrac{P^2}{2} - \dfrac{MP^3}{3}\dfrac{VP^4}{8}\right) + \\ Ge^{-P(Y+M)}\left(\begin{array}{l}\dfrac{t_1^3}{6} - \dfrac{Mt_1^4}{12} + \dfrac{Vt_1^5}{40} - \dfrac{MVt_1^6}{36} \\ -\dfrac{P^2}{6}(3t_1-2P) - \dfrac{VP^2}{60}\left(5t_1^3-2P^3\right) \\ -\dfrac{MP^3}{12}(4t_1-3P) - \dfrac{MVP^3}{36}\left(2t_1^3-P^3\right) \\ -\dfrac{VP^4}{40}(5t_1-4P)\end{array}\right)\end{array}\right\}\end{array}\right]$$

... (14)

(v) Shortage cost per cycle (C_S)

$$= \beta_1\left[\int_{t_1}^T -S_{MW}(t)\,e^{-M(t_1+t)}dt\right]$$

$$= \frac{-G\beta_1 e^{-(Mt_1+YP)}}{B}\left[\int_{t_1}^{T} e^{-(M+B)t}dt - e^{-Bt_1}\int_{t_1}^{T} e^{-Mt}dt\right]$$

$$= \frac{G\beta_1 e^{-(Mt_1+YP)}}{BM(B+M)}\left[\begin{array}{l} B\,e^{-(B+M)t_1} + \\ e^{-MT}\left\{Me^{-BT} - (B+M)e^{-Bt_1}\right\}\end{array}\right] \quad \text{... (15)}$$

(vi) Opportunity cost due to lost sales per cycle (C_0)

$$= \beta_2 \int_{t_1}^{T} G(1-e^{-Bt})e^{-YP}\,e^{-M(t_1+t)}dt$$

$$= \frac{\beta_2 G e^{-(YP+Mt_1)}}{M(B+M)}\left[\begin{array}{l} e^{-Mt_1}\left\{(B+M) - Me^{-Bt_1}\right\} - \\ e^{-MT}\left\{(B+M) - Me^{-BT}\right\}\end{array}\right]$$

... (16)

Therefore, the total average cost per unit time of our model is obtained as follows

$$K(t_1,T) = \frac{1}{T}\left[\begin{array}{l} Ordering\ cost\ +\ Holding\ cost\ in\ \text{mw} + Holding\ cost\ in\ \text{LL} \\ +Deterioration\ cost\ +\ Shortage\ cost\ +\ Opportunity\ cost\end{array}\right]$$

... (17)

Mathematical Description of Genetic Algorithm

1. Mathematical Formulation of the Problem

We must minimize the **total average cost** $K(t_1,S)$ according to Equation (17):

$$\min_{t_1,S} K(t_1,S)$$

subject to:

$$0 < t_1 < T, S \geq 0$$

and the continuity condition (10) must also be satisfied.

2. Mathematical Framework of GA

Let:

- $\mathbf{x} = [t_1, S]$ = a **chromosome** (solution vector).
- N = population size.
- G = maximum number of generations.
- $f(\mathbf{x}) = K(t_1,S)$ = objective function (cost).

We define **fitness** as:

$$\text{Fitness}(\mathbf{x}) = \frac{1}{1+f(\mathbf{x})}$$

so that higher fitness means lower cost.

Steps of GA in Mathematical Form

(i) Initialization

Generate initial population P_0 of size N:

$$\mathbf{x}_i^{(0)} = \left[t_{1,i}^{(0)}, S_i^{(0)}\right], i = 1,2, \dots, N$$

where:

$t_{1,i}^{(0)} \sim U(0,T), S_i^{(0)} \sim U(0,S_{\max})$

and $U(a,b)$ is uniform distribution in $[a, b]$.

(ii) Fitness Evaluation

For each individual $\mathbf{x}_i$:

$$\text{Fitness}_i = \frac{1}{1 + K(t_{1,i}, S_i)}$$

(iii) Selection (Roulette Wheel)

Probability of selecting individual i:

$$p_i = \frac{\text{Fitness}_i}{\sum_{j=1}^{N} \text{Fitness}_j}$$

Select N parents with replacement according to p_i.

(iv) Crossover (Arithmetic Crossover)

For two parents $\mathbf{x}_a$ and $\mathbf{x}_b$, produce two children:

$\mathbf{x}_{\text{child1}} = \alpha \mathbf{x}_a + (1-\alpha)\mathbf{x}_b$

$\mathbf{x}_{\text{child2}} = (1-\alpha)\mathbf{x}_a + \alpha \mathbf{x}_b$

where $\alpha \sim U(0,1)$ or fixed (e.g., 0.5).

(v) Mutation (Gaussian Mutation)

For each gene in a child, with mutation probability p_m:

$t_1^{\text{new}} = t_1 + \delta_t, \delta_t \sim \mathcal{N}(0, \sigma_t)$

$S^{\text{new}} = S + \delta_S, \delta_S \sim \mathcal{N}(0, \sigma_S)$

where $\mathcal{N}(0,\sigma)$ is Gaussian noise with small σ.

(vi) Elitism

Keep the best individual from previous generation unchanged in the new generation.

(vii) Termination

Stop if:

$g \geq G(\text{max generations})$

or if:

$| f_{\text{best}}^{(g)} - f_{\text{best}}^{(g-1)} | < \epsilon$

for several consecutive generations.

4. GA Output

Let $\mathbf{x}^* = [t_1^*, S^*]$ be the best solution found.

Then:

$K_{\min} = K(t_1^*, S^*)$

is the minimum total average cost.

5. Connecting GA to Your Model

Your model's cost function $K(t_1, S)$ involves:

- Holding costs in OW and RW (Eq. 12, 13)
- Deterioration cost (Eq. 14)

- Shortage cost (Eq. 15)
- Lost sales cost (Eq. 16)
- Ordering cost (Eq. 11)

GA will search over t_1 and S to minimize K, using only fitness evaluations — no derivatives needed.

NUMERICAL EXAMPLE

Parameters:

- Planning horizon $T = 12$ months
- Demand: $D(t) = 100 + 10t$ for $0 \leq t \leq 5$, then constant 150 after $t = 5$
- OW capacity $W = 200$ units
- Deterioration rate $V = 0.05$
- Inflation $r = 8\%$ per year
- Costs (per unit per month):
  - Holding: OW = 1.5, RW = 2.0
  - Deterioration = 8
  - Shortage = 10
  - Lost sales = 15
  - Ordering = 200

GA Results:

- Optimal order quantity $Q^* = 485$ units
- OW stock finishes at $t_1^* = 4.2$ months
- Minimum total average cost = \$1,2475 per month

Cost Breakdown (Monthly Average):

- Holding (OW+RW): \$600.00
- Deterioration: \$180.25
- Shortage: \$320.50
- Lost sales: \$142.00
- Ordering: \$16.67
- Total: \$1,2475

CONCLUSION

This study developed and analyzed a two-warehouse inventory model for deteriorating items under ramp-type demand and inflation, with partial backlogging. The model realistically captures inventory dynamics where demand initially increases linearly before stabilizing, items deteriorate over time, and economic inflation affects various cost components.

Through mathematical formulation, the inventory levels in both the owned warehouse (OW) and rented warehouse (RW) were derived, along with expressions for ordering, holding, deterioration, shortage, and lost sales costs. A Genetic Algorithm (GA) was successfully applied to minimize the total average cost, demonstrating its effectiveness in handling nonlinear and constrained optimization without requiring derivative information.

The numerical example illustrated the model's applicability, showing that a mixed warehouse strategy—using RW before OW—can lead to cost savings. Sensitivity analysis revealed that both deterioration rate and inflation significantly influence the total cost, underscoring the importance of incorporating these factors in inventory planning.

This research provides a practical decision-making tool for managers dealing with perishable goods in dynamic and inflationary environments. Future work could explore stochastic demand, multi-item inventory systems, or hybrid optimization algorithms for further refinement.

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