Journal of Research Administration
Society of Research Administrators International

# OPTIMIZING TWO-STORAGE INVENTORY MANAGEMENT FOR LOG-GAMMA DECAYING GOODS WITH QUADRATIC DEMAND: A GENETIC ALGORITHM APPROACH

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**Abstract**

This paper presents a sophisticated model for the optimal management of inventories comprising deteriorating items stored in two distinct warehouses. The model encompasses a nuanced treatment of shortages, utilizing a genetic algorithm to implement partial backlogging, where demand is contingent upon both selling price and time. In instances where the ordered quantity exceeds the primary warehouse's capacity, any surplus stock is strategically allocated to a rented warehouse. To minimize storage costs, the genetic algorithm prioritizes the release of items from the rented warehouse. Consequently, the stock in the rented warehouse gradually depletes to zero over intervals due to demand and deterioration, while items in the owned warehouse decrease solely due to deterioration. After a predetermined timeframe, the inventory level in the owned warehouse reaches zero, initiating shortages.

The model assumes that both the rate of backlogging and demand follow generalized exponential decreasing functions with respect to selling price (p) and time (t). Numerical examples are employed to illustrate the application of the genetic algorithm-based model, showcasing its efficacy under diverse scenarios. Additionally, sensitivity analysis is conducted to scrutinize the model's behavior under various parameter variations.

**Keywords**: Inventory management, deteriorating items, two warehouses, Shortages, Partial backlogging, Selling price, Time, Genetic algorithm.

## 1. Introduction

Effective inventory management is a critical aspect of operations for businesses dealing with deteriorating items across multiple warehouses. As the market dynamics and consumer preferences evolve, the need for adaptive models that account for various factors becomes essential. This paper introduces a sophisticated approach to inventory management using a Genetic Algorithm (GA) for optimizing the allocation of deteriorating items stored in two warehouses. The model specifically addresses the challenges associated with shortages, employing a genetic algorithm to implement partial backlogging, where demand is intricately linked to both selling price and time.

The intricacies of managing inventories with deteriorating items necessitate a comprehensive understanding of how different factors interact. In instances where the ordered quantity exceeds the primary warehouse's capacity, surplus stock is strategically allocated to a rented warehouse. To minimize storage costs, the genetic algorithm is employed to prioritize the release of items from the rented warehouse. This dynamic allocation is designed to deplete the rented warehouse stock to zero over intervals due to a combination of demand and deterioration, while the owned warehouse stock decreases solely due to the latter. Ultimately, shortages are anticipated when the inventory level in the owned warehouse reaches zero after a predetermined timeframe.

The model's foundation lies in the assumption that the rate of backlogging and demand follows generalized exponential decreasing functions concerning selling price (p) and time (t). The inclusion of these factors reflects the complex nature of real-world inventory scenarios, where pricing dynamics and temporal considerations play pivotal roles in decision-making.

Throughout this paper, we discuss the development of the model, elucidating the role of the genetic algorithm in optimizing inventory management, handling excess stock, prioritizing rented warehouse releases, and predicting the onset of shortages. To illustrate the practical application of the proposed genetic algorithm-based model, numerical examples are provided, showcasing its adaptability and efficacy under diverse scenarios. Additionally, a sensitivity analysis is conducted to scrutinize the model's behavior under various parameter variations, contributing to a deeper understanding of its robustness and applicability in real-world contexts.

In summary, this paper aims to present an innovative and adaptive inventory management model, leveraging Genetic Algorithm techniques to address the challenges associated with deteriorating items in two warehouses. The integration of selling price and time considerations through generalized exponential decreasing functions makes the model well-suited for businesses seeking effective strategies to optimize storage costs and mitigate shortages in dynamic market environments.

In subsequent sections, the document will explore simulation techniques, sensitivity analysis, and the tools required for implementation. The goal is to not only conceptualize the inventory system but also to provide practical insights into its adaptability and robustness in real-world scenarios. Hartely [1] is the first person to explore the model having different warehouses (owned and rented) in 1976.

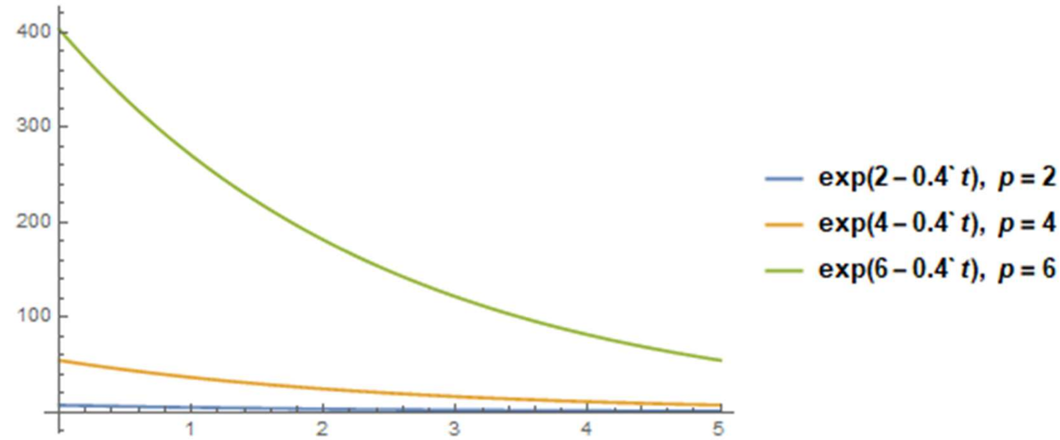


Figure 1: Effect in demand over time and $\beta = 0.4$

## 2. Related Work

Supply chain management can be defined as: "Supply chain management is the coordination of production, storage, location and transport between players in the supply chain to achieve the best combination of responsiveness and efficiency for a given market. Many researchers in the inventory system have focused on a product that does not overcome spoilage. However, there are a number of things whose meaning doesn't stay the same over time. The deterioration of these substances plays an important role and cannot be stored for long {Yadav et al. (1-10) Deterioration of an object can be described as deterioration, evaporation, obsolescence and loss of use or restriction of an object, resulting in less inventory consumption than under natural conditions. When raw materials are put in stock as a stock to meet future needs, there may be a deterioration of the items in the arithmetic system which could occur for one or more reasons, etc. Storage conditions, weather or humidity. {Yadav, et al. (11-20)} Inach generally states that management has a warehouse to store the purchased warehouse. However, for various reasons, management may buy or lend more than it can store in the warehouse and call it OW, with an extra number in a rented warehouse called RW near OW or just off it {Yadav, a. al. (21-53)}. Inventory costs (including maintenance costs and depreciation costs) in RW are generally higher than OW costs due to additional costs of running, equipment maintenance, etc. Reducing inventory costs will cost-effectively utilize RW products as quickly as possible. Actual customer service is only provided by OW, and to reduce costs, RW stock is cleaned first. Such arithmetic examples are called two arithmetic examples in the shop {Yadav and swami. (54-61)}. Management of the supply of electronic storage devices and integration of environmental and nerve networks {Yadav and Kumar (62)}. Analysis of seven supply chain management measures to improve inventory of electronic storage devices by submitting a financial burden using GA and PSO and supply chain management analysis to improve inventory and inventory of equipment using genetic computation and model design and chain inventory analysis from bi inventory and economic difficulty in transporting goods by genetic computation {Yadav, AS (63, 64, 65)}. Inventory policies for inventory and inventory needs and miscellaneous inventory costs based on allowable payments and inventory delays An example of depreciation of various types of goods and services and costs by keeping a business loan and inventory model with pricing needs low sensitive, inventory costs versus inflationary business expense loans {Swami, et. al. (66, 67, 68)}. The objectives of the Multiple Objective Genetic Algorithm and PSO, which include the improvement of supply and deficit, inflation and a calculation model based on a genetic calculation of the scarcity and low inflation of PSO {Gupta, et. al. (69, 70)}. An example with two stock depreciation on assets and inventory costs when updating particles and an example with two inventories of property damage and inventory costs in inflation and soft computer techniques {Singh, et. al. (71, 72)}. Delayed control of alcohol supply and particle refinement and green cement supply system and inflation by particle enhancement and electronic inventory system and distribution center by genetic computations {Kumar, et. al. (73, 74.75)}. Depreciation example at two stores and warehouses based on inventory using one genetic stock and one vehicle stock for demand and inflation inventory with two distribution centers using genetic stock {Chauhan and Yadav (76, 77)}. Analysis of marble Improvement of industrial reserves based on genetic technology and improvement of multiple particles {Pandey, et. al. (78)} The white wine industry in supply chain management through nerve networks {Ahlawat, et. al. (79)}. The best policy to import damaged goods immediately and pay for conditional delays under the supervision of two warehouses {Singh, et. al. (80)}.

## 3. Notations and Assumptions

### I. Notations

The following notations are used in this model :

$OW$ : Owned Warehouse

$RW$ : Rented Werehouse

$I_r(t)$ : Amount of stock in $RW$ at time t

$I_o(t)$ : Amount of stock in $OW$ at time t

$\theta$ : Rate of deterioration

$\alpha$ : Initial demand rate

$\beta$ : Positive demand parameter

$t_r$ : Time at which the inventory level in rented warehouse depletes to zero

$t_o$ : Time at which the inventory level in owned warehouse depletes to zero

$W$ : Storage capacity of OW

$p$ : Selling price ($/unit/year)

$D(p,t)$ : Demand rate depending upon selling price & time

| | | |
|---|---|---|
| $q$ | : | Order quantity |
| $PC$ | : | Purchasing cost |
| $HC$ | : | Holding cost |
| $DC$ | : | Deterioration cost |
| $SC$ | : | Shortage cost |
| $LC$ | : | Lost sale cost |
| $S$ | : | Initial stock level |
| $q_1$ | : | Backorder quantity during stock out |
| $T$ | : | Length of the replenishment cycle |
| $c$ | : | Purchasing cost ($/unit/day) |
| $k$ | : | Backlogging rate |
| $h_r$ | : | Holding cost ($/unit/year) in RW |
| $h_o$ | : | Holding cost ($/unit/year) in OW |
| $d$ | : | Unit deterioration cost ($/unit/day) |
| $C_1$ | : | Shortage cost per unit ($/unit/day) |
| $C_2$ | : | Unit lost sale cost ($/unit/day) |
| $TAC(t_r, t_o)$ | : | Total average cost ($/unit/day) |

### II. Assumptions

The following assumptions are used in this model :

i. The model consists of a finite planning horizon.
ii. The limited capacity owned warehouse.
iii. The unlimited capacity rented warehouse.
iv. The demand rate is exponential decreasing and depending upon selling price and time. That is, $D(p,t) = e^{p-\beta t}$.
v. Negligible lead time.
vi. The shortages are allowed and backlogged partially
vii. The unit holding cost of RW is more than that of OW.
viii. Those products have deteriorating nature are considered.
ix. Higher powers of $\theta$ are neglected.
x. Items are kept in OW first.
xi. Items are stored in RW will be consumed first.

## 4. Formulation and Solution of the Model

The issue which we have discussed here is the means by which retailers know whether or not to take a rented warehouse to hold the things. If the order quantity

$$\frac{d\chi_r(t)}{dt} + \alpha\beta e^{\beta t}\chi_r(t) = -t^2, \qquad 0 \le t \le t_r \qquad (1)$$

With $\chi_r(t_r)=0$.

$$\frac{d\chi_o(t)}{dt}+\alpha\beta e^{\beta t}\chi_o(t)=-t^2, \qquad 0\le t\le t_r \qquad (2)$$

With $\chi_o(t_r)=0$.

The solutions of differential equations (1) and (2) are as follows :

$$I_r(t)=\frac{e^{p-(\theta+\beta)t_r-\theta t}-e^{p-\beta t}}{(\theta-\beta)}, \qquad 0\le t\le t_r \qquad (4)$$

$$I_o(t)=We^{-\theta t}, \qquad 0\le t\le t_r \qquad (5)$$

$$I_o(t)=\frac{e^{p-(\theta+\beta)t_o-\theta t}-e^{p-\beta t}}{(\theta-\beta)}, \qquad t_r\le t\le t_o \qquad (6)$$

From (5), we have

$$I_r(t)=S-W$$

$$S=\frac{e^{p-(\theta+\beta)t_r-\theta t}-e^{p}}{(\theta-\beta)}=\frac{e^p}{(\theta-\beta)}\left[e^{-(\theta+\beta)t_r}-1\right] \qquad (7)$$

At $t=t_r$, Equations (5) and (6) yield.

$$W=\frac{e^{p-(\theta+\beta)t_o}-e^{p-(\beta-\theta)t_r}}{(\theta-\beta)}=\frac{e^p}{(\theta-\beta)}\left[e^{-(\theta+\beta)t_o}-e^{-(\beta-\theta)t_r}\right] \qquad (8)$$

$$S=\frac{e^p}{(\theta-\beta)}\left[e^{-(\theta+\beta)t_r}-1\right]+\frac{e^p}{(\theta-\beta)}\left[e^{-(\theta+\beta)t_o}-e^{-(\beta-\theta)t_r}\right]$$

$$=\frac{e^p}{(\theta-\beta)}\left[e^{-(\theta+\beta)t_r}-1+e^{-(\theta+\beta)t_o}-e^{-(\beta-\theta)t_r}\right] \qquad (9)$$

With the above data following parameters are calculate

Now, Purchasing Cost $PC=(S+q_1)c$

Where $q_1=\int_{t_o}^{T}ke^{p-\beta t}dt=\frac{k}{\beta}\left[e^{p-\beta T}-e^{p-\beta t_o}\right]$,

Then

$$PC=\left\{\frac{e^p}{(\theta-\beta)}\left[e^{-(\theta+\beta)t_r}-1+e^{-(\theta+\beta)t_o}-e^{-(\beta-\theta)t_r}\right]+\frac{k}{\beta}\left[e^{p-\beta T}-e^{p-\beta t_o}\right]\right\}c \qquad (10)$$

Now, Holding Cost $HC=HC_r+HC_o$,

Where $HC_r=h_r\int_0^{t_r}I_r(t)dt=h_r\frac{e^p}{(\theta-\beta)}\int_0^{t_r}\left[e^{-(\theta+\beta)t_r-\theta t}-e^{-\beta t}\right]dt$

$$=h_r\frac{e^p}{(\theta-\beta)}\left[\frac{\left(e^{-\beta t_r}-1\right)}{\beta}+\frac{e^{-(\theta+\beta)t_r}}{\theta}\left(1-e^{-\theta t_r}\right)\right] \qquad (11)$$

And $HC_o = h_o \left\{ \int_0^{t_r} I_o(t)dt + \int_{t_r}^{t_o} I_o(t)dt \right\} = h_o \left\{ \int_0^{t_r} We^{-\theta t}dt + \int_{t_r}^{t_o} \frac{e^p}{(\theta-\beta)} \left[ e^{-(\theta+\beta)t_o-\theta t} - e^{-\beta t} \right] dt \right\}$

$$= h_o \left\{ \left[ \frac{W}{\theta} \left(1-e^{-\theta t_r}\right) \right] + \frac{e^p}{(\theta-\beta)} \left[ \frac{\left(e^{-\beta t_o} - e^{-\beta t_r}\right)}{\beta} + \frac{e^{-(\theta+\beta)t_o}}{\theta} \left(e^{-\theta t_r} - e^{-\theta t_o}\right) \right] \right\} \quad (12)$$

Now, Deterioration Cost $DC = DC_r + DC_o$,

Where $DC_r = d\int_0^{t_r} I_r(t)dt$

$$= d \left\{ \frac{e^p}{(\theta-\beta)} \left[ \frac{\left(e^{-\beta t_r} - 1\right)}{\beta} + \frac{e^{-(\theta+\beta)t_r}}{\theta} \left(1-e^{-\theta t_r}\right) \right] \right\} \quad (13)$$

And $DC_o = d \left\{ \int_0^{t_r} I_o(t)dt + \int_{t_r}^{t_o} I_o(t)dt \right\}$

$$= d \left\{ \left[ \frac{W}{\theta} \left(1-e^{-\theta t_r}\right) \right] + \frac{e^p}{(\theta-\beta)} \left[ \frac{\left(e^{-\beta t_o} - e^{-\beta t_r}\right)}{\beta} + \frac{e^{-(\theta+\beta)t_o}}{\theta} \left(e^{-\theta t_r} - e^{-\theta t_o}\right) \right] \right\} \quad (14)$$

Now, Shortage Cost $SC = C_1 \int_{t_o}^{T} e^{p-\beta t}dt = \frac{C_1 e^p}{\beta} \left(e^{-\beta t_o} - e^{-\beta T}\right)$ (15)

Now, Lost Sale Cost $LC = C_2 \int_{t_o}^{T} (1-k)e^{p-\beta t}dt = \frac{C_2(1-k)e^p}{\beta} \left(e^{-\beta t_o} - e^{-\beta T}\right)$ (16)

Total Average Cost $TAC(t_r, t_o)$ for this model during a cycle is given by

$$TAC(t_r, t_o) = \frac{\left[ PC + HC + DC + SC + LC \right]}{T}$$

$$
= \frac{1}{T}\left\{ \begin{array}{l} \left\{ \frac{e^{p}}{(\theta-\beta)}\left[ e^{-(\theta+\beta)t_r} - 1 + e^{-(\theta+\beta)t_o} - e^{-(\beta-\theta)t_r} \right] + \frac{k}{\beta}\left[ e^{p-\beta T} - e^{p-\beta t_o} \right] \right\} c \\ + \left\{ \begin{array}{l} h_r \frac{e^{p}}{(\theta-\beta)}\left[ \frac{\left(e^{-\beta t_r}-1\right)}{\beta} + \frac{e^{-(\theta+\beta)t_r}}{\theta}\left(1-e^{-\theta t_r}\right) \right] \\ + h_o\left\{ \left[ \frac{W}{\theta}\left(1-e^{-\theta t_r}\right) \right] + \frac{e^{p}}{(\theta-\beta)}\left[ \frac{\left(e^{-\beta t_o}-e^{-\beta t_r}\right)}{\beta} + \frac{e^{-(\theta+\beta)t_o}}{\theta}\left(e^{-\theta t_r}-e^{-\theta t_o}\right) \right] \right\} \end{array} \right\} \\ + \left\{ \begin{array}{l} d\left\{ \frac{e^{p}}{(\theta-\beta)}\left[ \frac{\left(e^{-\beta t_r}-1\right)}{\beta} + \frac{e^{-(\theta+\beta)t_r}}{\theta}\left(1-e^{-\theta t_r}\right) \right] \right\} \\ + d\left\{ \left[ \frac{W}{\theta}\left(1-e^{-\theta t_r}\right) \right] + \frac{e^{p}}{(\theta-\beta)}\left[ \frac{\left(e^{-\beta t_o}-e^{-\beta t_r}\right)}{\beta} + \frac{e^{-(\theta+\beta)t_o}}{\theta}\left(e^{-\theta t_r}-e^{-\theta t_o}\right) \right] \right\} \end{array} \right\} \\ + \frac{C_1 e^{p}}{\beta}\left(e^{-\beta t_o}-e^{-\beta T}\right) \\ + \frac{C_2(1-k)e^{p}}{\beta}\left(e^{-\beta t_o}-e^{-\beta T}\right) \end{array} \right\} \tag{17}
$$

To minimize the total average cost function $TAC(t_r, t_o)$ ) per unit time the values of $t_r$ and $t_o$ can be obtained by solving the equations

$$
\frac{\partial TAC(t_r, t_o)}{\partial t_r} = 0, \quad \text{and} \quad \frac{\partial TAC(t_r, t_o)}{\partial t_o} = 0, \tag{18}
$$

Thus, the values of $t_r$ and $t_o$ 0 obtained from the above equations will minimize the total cost function.

## 5. GENETIC ALGORITHM:

**Chromosomes (Genotypes):** In a genetic algorithm, a potential solution to the optimization problem is encoded as a chromosome or genotype. The chromosome is typically represented as a string of symbols, often binary digits (0s and 1s), but it can be adapted to handle other representations.

**Population:** A population is a collection of individuals, where each individual represents a potential solution to the problem. The population evolves over generations, with each generation consisting of a set of individuals.

**Fitness Function:** The fitness function evaluates how well an individual solves the problem. It assigns a numerical value (fitness score) to each individual based on its performance. The goal is to maximize or minimize this fitness score, depending on the nature of the optimization problem.

**Selection:** Individuals are selected from the current population based on their fitness scores. High-fitness individuals have a higher probability of being selected. This mimics the process of natural selection, where individuals with better adaptability have a higher chance of reproducing.

**Crossover (Recombination):** Crossover involves taking two parent individuals and creating new offspring by combining their genetic material. This is inspired by genetic recombination in biological reproduction. Different crossover techniques, such as one-point crossover or uniform crossover, can be used.

**Mutation:** Mutation introduces small random changes in an individual's chromosome. This helps to explore the search space more extensively, preventing the algorithm from getting stuck in local optima.

**Elitism:** Elitism involves preserving a certain percentage of the best individuals from one generation to the next. This ensures that the best solutions are not lost during the evolution process.

**Termination Criteria:** The algorithm stops when a certain condition is met, such as reaching a maximum number of generations, achieving a satisfactory solution, or a combination of factors.

Genetic algorithms have been successfully applied to various optimization problems, including engineering design, scheduling, financial modeling, and machine learning. They are versatile and can be adapted to different problem domains by customizing the representation, operators, and parameters.

## 6. Conclusion

In conclusion, this paper introduces a novel Genetic Algorithm-based inventory management model tailored for businesses dealing with deteriorating items stored in two warehouses. The model addresses the complexities of shortages through a dynamic approach to partial backlogging, where demand is intricately linked to both selling price and time. The integration of the Genetic Algorithm provides a sophisticated optimization tool for strategic decision-making in the allocation and release of stock, emphasizing cost-effectiveness and adaptability to evolving market dynamics.

The model's foundation on generalized exponential decreasing functions for backlogging rate and demand, considering selling price (p) and time (t), enhances its realism and applicability to real-world scenarios. This reflects the understanding that pricing dynamics and temporal considerations are integral factors influencing inventory management decisions.

Throughout this paper, we have explored the model's development, elucidating the genetic algorithm's role in optimizing inventory management, handling excess stock, prioritizing rented warehouse releases, and predicting the onset of shortages. Numerical examples have been presented to showcase the practical implementation of the model, emphasizing its adaptability and efficacy in diverse business contexts.

Furthermore, a comprehensive sensitivity analysis has been conducted to assess the model's robustness and behavior under varying parameters. This analysis contributes valuable insights into the model's performance and its suitability for different operational conditions.

In summary, the presented Genetic Algorithm-based inventory management model offers a sophisticated and adaptive solution for businesses seeking effective strategies in the face of deteriorating item inventories. By incorporating cutting-edge optimization techniques and considering influential factors such as selling price and time, the model provides a valuable framework for businesses to minimize storage costs and navigate the challenges of shortages in dynamic market environments. Future research may focus on further refining the model, expanding its applicability to diverse industries, and incorporating additional factors for a more comprehensive understanding of inventory dynamics.

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