OPTIMIZING TWO-WAREHOUSE INVENTORY MODEL FOR DETERIORATING ITEMS WITH GENERALIZED EXPONENTIAL DEMAND, PARTIAL BACKLOGGING, AND INFLATION USING BACTERIAL FORAGING OPTIMIZATION

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Abstract

This paper presents a novel two-warehouse inventory model for degrading products, where the demand rate is governed over time by a generalized exponential function. Two real-world supply chain challenges that are taken into account in the model are the economic effects of inflation and partial backlog. By reducing the whole cost, which includes holding, shortage, and degradation charges, the Bacterial Foraging Optimization (BFO) method maximizes inventory management. The effectiveness of the model is validated through a comprehensive numerical example, and graphical representations demonstrate the impact of key factors on system performance. The results demonstrate how BFO may be used to complex inventory problems, giving supply chain managers crucial data as they try to balance cost-effectiveness and demand fluctuations in an inflationary environment. This approach highlights the need of advanced optimization techniques in improving decision-making processes for degrading products in a two-warehouse scenario.

Keywords: Bacterial Foraging Optimization, Two-Warehouse, Inventory Model, Exponential Demand, Partial Backlogging and inflation.

1. Introduction and related work

Effective inventory management is a critical facet of supply chain optimization, particularly in industries dealing with perishable or deteriorating items. The complexities of handling two warehouses, a dynamic demand pattern characterized by a generalized exponential increase, partial backlogging, and the impact of inflation demand advanced models for optimal decision-making. In this context, the Two-Warehouse Inventory Model emerges as a strategic tool, aiming to strike a balance between meeting customer demands, minimizing costs, and adapting to the challenges posed by deteriorating items. Deterioration poses a significant challenge in inventory systems, necessitating vigilant control mechanisms to mitigate losses associated with time-dependent decay. Moreover, the demand for products is rarely static; the generalized exponential increase introduces a nuanced dimension to forecasting and stock replenishment strategies. The concept of partial backlogging acknowledges the practical reality that, at times, not all customer demands can be immediately fulfilled, and a systematic approach to manage backlogs is indispensable. The economic landscape, influenced by inflationary pressures, adds another layer of complexity. Inflation impacts various cost components within the inventory management framework, from holding costs to ordering costs. Therefore, an inclusive model that considers inflationary effects becomes crucial for businesses navigating these challenges. To optimize the intricate parameters of the Two-Warehouse Inventory Model, this study leverages the Bacterial Foraging Optimization (BFO) algorithm. Inspired by the foraging behavior of bacteria, BFO offers a nature-inspired approach to problem-solving. By simulating the movement and interaction of bacteria in a search space, BFO seeks to find optimal solutions efficiently. This research delves into the synergy between the Two-Warehouse Inventory Model, deteriorating items, generalized exponential demand, partial backlogging, and inflation. The objective is to employ BFO to fine-tune the decision variables of the model, providing businesses with a robust tool for inventory optimization in dynamic and challenging environments. Through the lens of this model, organizations can enhance their responsiveness to market dynamics, reduce costs, and ultimately bolster their competitiveness in the ever-evolving landscape of supply chain management.

Supply chain management (SCM) is defined as the coordination of production, storage, location, and transportation among supply chain participants to achieve the optimal balance of responsiveness and efficiency for a specific market. While many researchers have concentrated on products that do not spoil, certain items experience changes over time. Yadav et al. [1-10] highlighted that the deterioration of these items is significant, limiting their storage duration. Yadav et al. [11-20] further explained that deterioration can manifest as spoilage, evaporation, obsolescence, or loss of functionality, leading to reduced inventory usage compared to natural conditions. When raw materials are stocked for future demands, various factors such as storage conditions, weather, and humidity can cause deterioration. Yadav et al. [21-53] discuss that management typically maintains a warehouse for storing purchased goods. However, for various reasons, they may acquire or lease more items than can be accommodated in the warehouse, referring to the excess as overflow (OW), while the additional stock in a rented warehouse is termed rented warehouse (RW), located near or adjacent to OW. Yadav and Swami [54-61] found that the inventory costs associated with RW, including maintenance and depreciation, are generally higher than those of OW due to added operational and maintenance expenses. To minimize inventory costs, it is important to quickly utilize RW stock. Actual customer service is provided solely by OW, so to lower expenses, RW inventory is prioritized for turnover. These scenarios illustrate what are referred to as two inventory examples within the system. Yadav and Kumar [62] focused on managing the supply of electronic storage devices while integrating environmental and network considerations. Yadav, A.S. [63-65] analyzed seven measures of supply chain management to enhance the inventory of electronic storage devices. This analysis involved assessing financial impacts through the application of genetic algorithms (GA) and particle swarm optimization (PSO). Additionally, the research examined inventory improvement and equipment management using genetic computation, alongside a model design for inventory analysis that addressed economic challenges in transporting goods. Swami et al. [66-68] formulated inventory policies that address inventory requirements and associated costs, taking into account allowable payments and delays in inventory. They provided an example of depreciation across various goods and services, considering business loans and an inventory model that is less sensitive to pricing needs, while comparing inventory costs to inflation-related business expenses. Meanwhile, Gupta et al. [69-70] defined objectives for a Multiple Objective Genetic Algorithm and particle swarm optimization (PSO) aimed at enhancing supply levels and addressing deficits and inflation, along with a calculation model that leverages genetic algorithms to assess scarcity and low inflation scenarios. Singh et al. [71, 72] examined cases involving the depreciation of two types of stock concerning asset and inventory costs while updating particle data, as well as scenarios with two inventories focusing on property damage and inventory costs under inflation, utilizing soft computing techniques. Kumar et al. [73-75] addressed delays in managing alcohol supply, refining particles, and developing a green cement supply system, while also tackling inflation through particle enhancement and the use of an electronic inventory system and distribution center with genetic computations. Chauhan and Yadav [76-77] provided an example of depreciation across two stores and warehouses, utilizing a genetic stock and vehicle stock to manage demand and inflation across two distribution centers. Pandey et al. [78] analyzed the improvement of industrial reserves for marble using genetic technology and enhanced multiple particle approaches. Ahlawat, et. al. [79] studied the white wine industry in supply chain management through nerve networks. Singh, et. al. [80] examines the best policy to import damaged goods immediately and pay for conditional delays under the supervision of two warehouses.

The research by Yadav et al. [81] centers on improving inventory management for perishable commodities through the lens of green technology investments, considering factors such as selling price, carbon emissions, and time-sensitive demand. In another analysis, Yadav, Yadav, and Bansal [82] utilize an interval number technique to explore a two-warehouse inventory management model for perishable goods, addressing demand and cost uncertainties. Their optimization methods highlight how investing in preservation technology can reduce waste and enhance inventory efficiency. Focusing on a two-warehouse approach to optimize inventory levels, Yadav, Yadav, and Bansal [83] and Negi and Singh [86] present a model that addresses the deterioration of goods during storage, emphasizing the importance of managing degradation costs to improve overall inventory performance.

2. Notations and assumptions

2.1. Notations

The following notations are used in this model.

Parameters	Descriptions
A	Ordering cost coefficient
h_1	Coefficient of holding cost of Rented Warehouse (RW).
h_2	Coefficient of holding cost of Owned Warehouse (OW).
C_P	Purchasing cost.
C_S	Shortage cost.
C_L	Coefficient of cost of lost sale.
θ	Constant rate of deterioration
C_D	Deterioration cost per unit.
R	Inflation factor
q_1	Positive height of inventory of (RW) with $I(t=0)$
q_2	Positive height of inventory of (OW) with $I(t=0)$
q_3	The Negative height of inventory with $I(t=T)$
Q	Total order quantity of order.
T	Total cycle time (Total cycle length).
t_1	The time where inventory height of rented Warehouse becomes zero.
t_2	The time where inventory height of Owned Warehouse becomes zero.
$I_1(t)$	The height of inventory in rented warehouse between time intervals $[0, t_1]$
$I_2(t)$	The height of inventory in owned warehouse between time intervals $[0, t_1]$
$I_3(t)$	Height of inventory in owned warehouse between the time intervals $[t_1, t_2]$
$I_4(t)$	Level of inventory in owned Warehouse between the time intervals $[t_2, T]$
PC	Cost of purchasing
HC	Cost of holding of inventory.
SC	Cost of shortage of the inventory.
LC	Cost of lost sale cost of inventory.
TAC	Present total Average cost.

2.2. Assumptions

The following assumptions are used in this paper.

1. The demand rate is generalized exponential increasing function of time in nature and taken as the following form : $D(t) = ke^{a+bt}$; $k > 0$, $a > 0$, $b > 0$.
2. The partially backlogged Shortages are allowed and where backlogging rate is $B(t) = e^{-\delta t}$; $\delta > 0$.
3. Infinite Time horizon is considered.
4. Lead time is zero with Infinite Replenishment rate is taken.
5. Warehouse (OW) has the limited space is allowed. On other hand the unlimited space area for rented warehouse has been permitted.
6. The holding cost (h_1) of the of Rented Warehouse is greater than the holding cost (h_2) of Owned Warehouse.
7. The charges for transportation and time between Rented Warehouse and Owned Warehouse are completely ignored.

3. FORMULATION AND SOLUTION OF THE MODEL

The suggested model allows for a partial backlog and optimizes a two-warehouse system for deteriorating items using a generalized exponential function of demand. The model looks for the best ordering procedures for both warehouses in order to minimize overall expenses while taking inflation into consideration. Presumably, one warehouse houses the major stock, while the other houses the backup. The three primary decision variables"order quantity, reorder points, and backordering level"are optimized using Bacterial Foraging Optimization (BFO). The rate at which products decay, generalized exponential demand, and inflationary effects make inventory cost management more challenging over time. By addressing these issues, the model seeks to balance stock levels, cut waste, and boost overall cost efficiency in a real-world supply chain environment. The proposed model shown in Fig. 1. The following is the formulation of the proposed model:

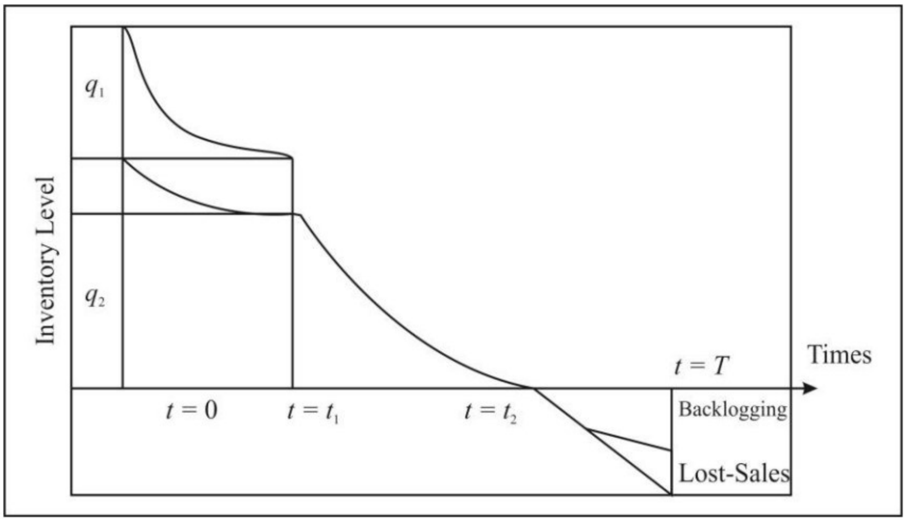

Figure 1: *Graphical representation of two-warehouses inventory model.*

$$\frac{dI_1}{dt} + \theta I_1 = -ke^{a+bt}, \qquad 0 \le t \le t_1 \tag{1}$$

$$\frac{dI_2}{dt} + \theta I_2 = 0, \qquad 0 \le t \le t_1 \tag{2}$$

$$\frac{dI_3}{dt} + \theta I_3 = -ke^{a+bt}, \qquad t_1 \le t \le t_2 \tag{3}$$

$$\frac{dI_4}{dt} = -ke^{a+bt} \cdot e^{\delta t}, \qquad t_2 \le t \le T \tag{4}$$

The boundary conditions are given by $I_1(t_1) = 0,\ I_2(0) = q_2,\ I_3(t_2) = I_4(t_2) = 0$.
Using the above boundary conditions, the solutions of (1), (2), (3) and (4) are given by

$$I_1(t) = e^{-\theta(t_1 - t)} \left(\frac{Ke^{a+bt_1}}{b+\theta} \right) - \frac{Ke^{a+bt}}{b+\theta} \tag{5}$$

$$I_2(t) = q_2 e^{-\theta t} \tag{6}$$

$$I_3(t) = e^{-\theta(t_2 - t)} \left(\frac{Ke^{a+bt_2}}{b+\theta} \right) - \frac{Ke^{a+bt}}{b+\theta} \tag{7}$$

$$I_4(t) = \frac{Ke^{a+(b-\delta)t_2}}{b+\delta} - \frac{Ke^{a+(b-\delta)t}}{b+\delta} \tag{8}$$

Positive inventory level of rented warehouse with $I_1(0) = q_1$and Eqs. (5) given by

$$q_1 = e^{\theta t_1} \left(\frac{Ke^{a+bt_1}}{b+\theta} \right) - \frac{Ke^{a}}{b+\theta} \tag{9}$$

Negative inventory level with $I_4(T) = -q_3$ and Eqs. (8) given by

$$q_3 = \left(\frac{Ke^{a+(b-\delta)T}}{b-\delta} \right) - \frac{Ke^{a+(b-\delta)t_2}}{b-\delta} \tag{10}$$

Next, we calculate all the associated inventory costs as follow:

1. Ordering Cost (OC):

$$OC = A \tag{11}$$

2. Purchasing Cost (PC):

$$PC = C_P \left[e^{\theta t_1} \left(\frac{Ke^{a+bt_1}}{b+\theta} \right) - \frac{Ke^{a}}{b+\theta} + q_2 + \left(\frac{Ke^{a+(b-\delta)T}}{b-\delta} \right) - \frac{Ke^{a+(b-\delta)t_2}}{b-\delta} \right] \tag{12}$$

3. Shortage Cost (SC):

$$SC = -C_S \int_{t_2}^{T} I_4(t) \cdot e^{-Rt} dt$$

$$SC = -C_S \int_{t_2}^{T} \left[\frac{Ke^{a+(b-\delta)t_2}}{b+\delta} - \frac{Ke^{a+(b-\delta)t}}{b+\delta} \right] .e^{-Rt} dt$$

$$SC = -\frac{KC_S}{(b-\delta)} \left[\frac{e^{a+(b-\delta)t_2 - RT}}{-R} - \frac{e^{a+(b-\delta-R)T}}{b-\delta-R} - \frac{(b-\delta)e^{a+(b-\delta-R)t_2}}{R(b-\delta-R)} \right] \tag{13}$$

4. Lost sales Cost (LC):

$$LC = -C_L \int_{t_2}^{T} (1 - B(t)) \cdot D(t) \cdot e^{-Rt} dt$$

$$LC = -KC_L \left[\left(\frac{e^{a+(b-R)T}}{b-R} - \frac{e^{a+(b-\delta-R)T}}{b-\delta-R} \right) - \left(\frac{e^{a+(b-R)t_2}}{b-R} - \frac{e^{a+(b-\delta-R)t_2}}{b-\delta-R} \right) \right] \tag{14}$$

5. Holding Cost (HC):

$$HC = \left[h_1 \int_0^{t_1} I_1(t).e^{-Rt} dt + h_2 \int_0^{t_1} I_2(t) \cdot e^{-Rt} dt + h_3 \int_0^{t_2} I_3(t).e^{-Rt} dt \right]$$

$$= \left\{ \frac{h_1 k}{(b+\theta)} \left[\frac{-(b+\theta) e^{a+(b-R)t_1}}{(\theta+R)(b-R)} + \frac{e^{a+(b-R)t_1}}{(\theta+R)} + \frac{e^a}{(b-R)} \right] + \frac{h_2 q_2}{(R+\theta)} \left(1 - e^{-(R+\theta)t_1} \right) + \frac{h_2 k}{(b+\theta)} \left[\frac{-(b+\theta) e^{a+(b-R)t_2}}{(\theta+R)(b-R)} + \frac{e^{a+(b+\theta)t_2-(\theta+R)t_1}}{(\theta+R)} + \frac{e^{a+(b-R)t_1}}{(b-R)} \right] \right\} \tag{15}$$

6. Deterioration Cost (DC):

$$DC = C_D \left[\theta \int_0^{t_1} I_1(t) \cdot e^{-Rt} dt + \theta \int_0^{t_1} I_2(t) \cdot e^{-Rt} dt + \theta \int_0^{t_2} I_3(t) \cdot e^{-Rt} dt \right]$$

$$= C_D \left\{ \frac{\theta k}{(b+\theta)} \left[\frac{-(b+\theta) e^{a+(b-R)t_1}}{(\theta+R)(b-R)} + \frac{e^{a+(b-R)t_1}}{(\theta+R)} + \frac{e^a}{(b-R)} \right] + \frac{\theta q_2}{(R+\theta)} \left(1 - e^{-(R+\theta)t_1} \right) + \frac{\theta k}{(b+\theta)} \left[\frac{-(b+\theta) e^{a+(b-R)t_2}}{(\theta+R)(b-R)} + \frac{e^{a+(b+\theta)t_2-(\theta+R)t_1}}{(\theta+R)} + \frac{e^{a+(b-R)t_1}}{(b-R)} \right] \right\} \tag{16}$$

$$TAC = \frac{1}{T} \left[OC + PC + HC + DC - SC + LSC \right] \tag{17}$$

4. Bacterial Foraging Optimization (BFO) Methodology

We can describe the algorithmic solution steps of BFO which are designed in the context of the described features and functions Sinha and Anand [84]. The following is the optimization process using Bacterial Foraging Optimization:

1. **Step 1 (Installation Phase):** Randomly dispense N pieces of bacteria particles (potential solution variables) into solution space. Algorithm parameters. Perform the necessary arrangements for the problem to be solved.
2. **Step 2:** Calculate the objective function value (fitness) according to the locations of the bacteria (potential solution variables).
3. **Step 3:** Perform the following steps, Repeat until: (in the context of each objective function size).
4. **Step 3.1 (Chemotaxis Phase):** Perform the following steps for each bacteria, up to the Nk value:
5. **Step 3.1.2:** The objective function of the bacterium related to the (fitness) cell to cell attractive effect of the update. Hold this value until swimming phase.
6. **Step 3.1.3 (Rolling Phase):** Generate random numbers up to the purpose function size in the range [-1, 1]. Run the rolling process for the respective bacteria.

7. **Step 3.1.4:** Calculate the objective function value (fitness) according to the location of the bacteria (potential solution variable). The purpose of the relevant bacterium is to update the value of the function function (fitness) from cell to cell with attractive effect.
8. **Step 3.1.5 (Swimming Phase):** Perform the following steps for the related bacteria, up to the Nyush value.
9. **Step 3.1.5.1:** If the final objective function value (fitness) of the bacteria is better than stored before the Swimming Phase, keep this new value.
10. **Step 3.1.5.2:** Update the held objective function value (fitness) of the relevant bacteria according to the displacement value to be calculated.
11. **Step 3.1.6:** If all bacteria have not been treated yet, switch to the next bacterium and return to Step 3.1.1.
12. **Step 3.2 (Reproduction Phase):** Calculate the health status of each bacterium and sort them all from small to small according to these values.
13. **Step 3.3:** Eliminate the worst bacteria according to the set criteria. Let the bacteria grow in the best condition. New bacteria are in place of their parents.
14. **Step 3.4:** If the nu value has not yet been reached, increase the counter for that value and go back to Step 3.1 and continue with the next generation.
15. **Step 3.5 (Elimination - Distribution Phase):** Transfer each bacterium to a new location according to the value oed.
16. **Step 4:** At the end of the processes, the value (s) obtained by the global best position is considered to be the optimum value (s). There are many studies and applications that are related with this optimization algorithm.

In Hezer and Kara [85], to determine the routes to be followed by the vehicles used in distribution and collection activities and to minimize the logistics costs, an algorithm has been developed with this optimization to solve the stated problem.

5. Graphical Representation

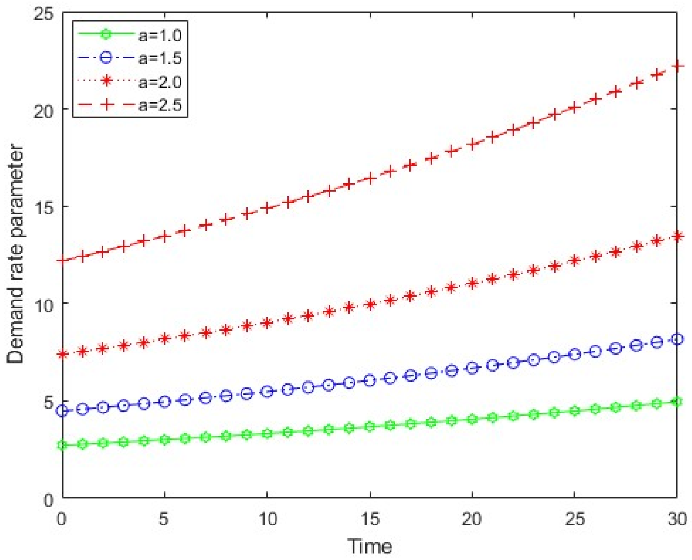

Figure 2: *Variation between time and demand rate, if changing a.*

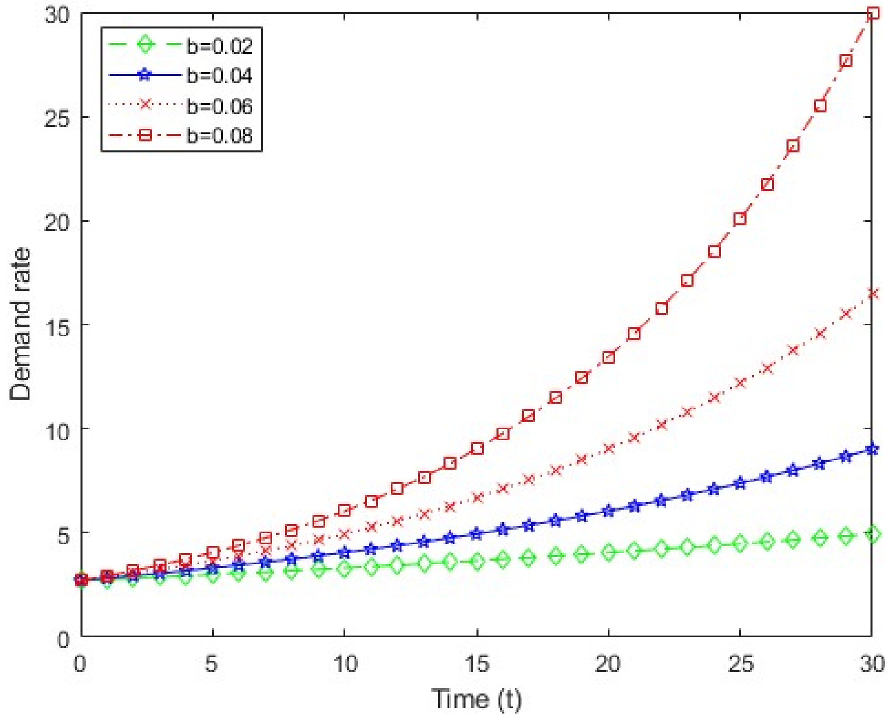

Figure 3: *Variation between time and demand rate, if changing b.*

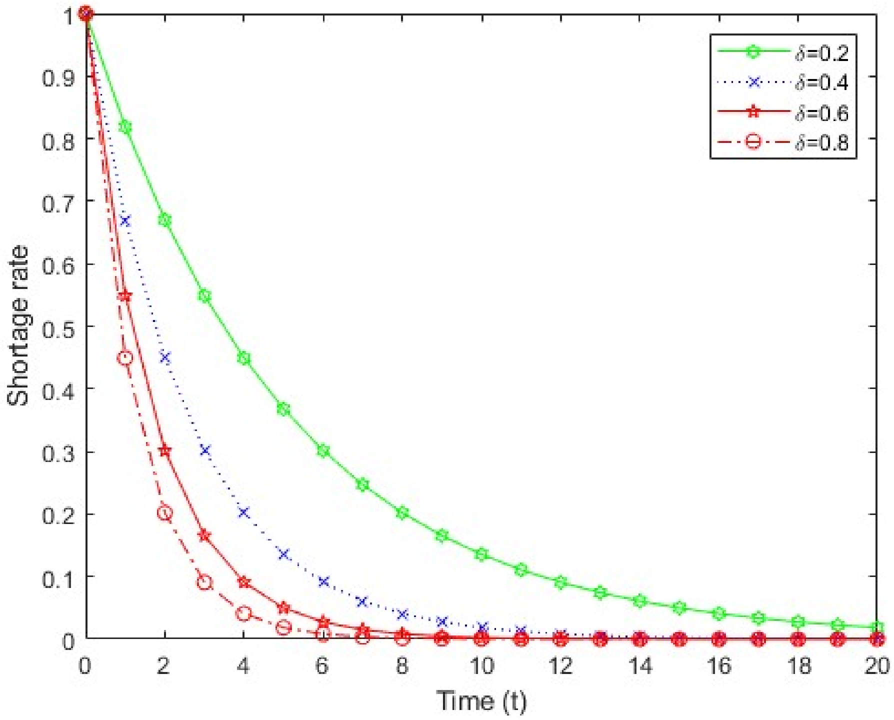

Figure 4: *Variation between time and shortage rate, if changing δ.*

The graphical depictions in this part provide a comprehensive grasp of the dynamics within the deteriorated inventory model of two-warehouses. Figure 2 and Figure 3 explains the link between demand rates and time, while Figure 4 illustrates how shortage impacts inventory management using different type of functions of time together with the adjustments needed to effectively balance demand, shortage, and time.

6. Conclusion

In conclusion, the Two-Warehouse Inventory Model for Deteriorating Items with a Generalized Exponential Increasing Demand and Partial Backlogging under Inflation, optimized through Bacterial Foraging Optimization (BFO), represents a comprehensive and adaptive approach to contemporary inventory management challenges. The model addresses the inherent complexities of managing deteriorating items across two warehouses, acknowledging the nuanced nature of demand with a generalized exponential increase. Incorporating partial backlogging recognizes the practical constraints of immediate fulfillment, introducing a realistic dimension to inventory control. The inclusion of inflationary factors enhances the model's relevance in a dynamic economic landscape. The decision to employ BFO as the optimization algorithm is strategic, harnessing the efficiency of nature-inspired algorithms in navigating complex solution spaces. By simulating bacterial foraging behaviors, BFO efficiently explores and exploits optimal solutions for the intricate parameters of the inventory model. Through this research, businesses gain a sophisticated tool for strategic decision-making in inventory management. The model provides a framework for minimizing losses associated with deteriorating items, adapting to fluctuating demands, and optimizing costs in the face of inflation. By leveraging BFO, organizations can fine-tune their inventory policies, ensuring an optimal balance between customer satisfaction and cost-effectiveness. As industries continue to evolve, characterized by rapid changes in consumer behavior, market dynamics, and economic conditions, the significance of robust inventory management models cannot be overstated. The Two-Warehouse Inventory Model, coupled with BFO optimization, positions businesses to not only navigate current challenges but also to proactively respond to future uncertainties. In essence, this research contributes to the advancement of inventory management methodologies, offering a tailored solution that aligns with the complexities of contemporary supply chain environments. It is our hope that businesses embracing this model will experience heightened efficiency, improved customer satisfaction, and a competitive edge in the dynamic landscape of global commerce.

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