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Analyzing the Impact of Price-Dependent Demand and Deterioration in a Two-Warehouse Inventory System

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ABSTRACT: This paper addresses the two-warehouse inventory problem, considering warehouses A and B. In this model, Raw materials are first consumed from Warehouse A and then from Warehouse B. The demand is modeled as a function of the selling price and assumed to follow an exponential trend over time t. The inventory holding cost is time-dependent, and the deterioration rate is assumed to follow a Weibull distribution.The study aims to minimize inventory costs to maximize profit. The model considers various parameters that influence material deterioration and their impact on profitability. Additionally, A graphical analysis of profit over time (t) is presented, considering parameters such as holding cost (HC), order quantity (Q), and others.

Key Words: Inventory, two-warehouse, Weibull distribution, deterioration, holding cost, demand rate.

Contents

1. Introduction

Inventory level management is a concern when handling two warehouses simultaneously. [1] The study by D. Yadav, S.R. Singh, and R. Kumari (2012) their study focuses on improving inventory management through data-driven methods, specifically using machine learning techniques. [2] S. R. Singh,Himanshu Rathore (2014) proposed a model that addresses inventory management in a reliable production process with producing and holding inventory varies based on the stock levels. [3] Govind Shay Sharma, Randhir Baghel(2023) proposed an approach for predicting optimum stock levels by utilizing Artificial Neural Networks (ANNs). Their study revolves around improving inventory management through data-driven methods, specifically using machine learning techniques. [4] Evgenii.G. Anisimov, Murat R. Gapov, Evgeniia.S. Rodionova,Tatiana.N. Saurenko (2019) proposed a model that addresses inventory management with a focus on a fixed replenishment period and periodic demand. Their model offers several key innovations and features that distinguish it from traditional inventory models. [5] Sachin Kumar Verma, Mohd. Rizwanullah, Chaman Singh (2018) developed an inventory model incorporating time-dependent linear holding costs. Their model focuses on optimizing inventory management by considering how holding costs change over time [6] Satish Kumar, Dipak Chakraborty,A K Malik (2017) developed a two-warehouse inventory model designed to handle non-instantaneous deteriorating items. This type of model is particularly relevant in industries dealing with goods that deteriorate over time but do not spoil immediately. [7] A.K. Bhuniaa, Ali Akbar Shaikha, A.K. Maitib and M.Maitib (2013) focused on a deterministic inventory model for deteriorating items with two separate storage facilities: an owned warehouse (with limited capacity) and a rented warehouse. [8] R Susanto(2018) proposed a method aimed at minimizing the total inventory cost, which consists of two key components: ordering cost and carrying cost. The

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method focuses on optimizing inventory levels and aligning the number of raw materials ordered with the actual production needs, making the inventory management process more economically efficient. [9] Ajay Singh Yadav, Anupam Swami(2013) developed a two-warehouse inventory model specifically designed for deteriorating items, which incorporates several key assumptions and features to address the complexities of managing perishable goods. [10] R.P. Tripathia and S.M. Mishra (2014) proposed an order level inventory model focusing on a single warehouse where shortages are allowed and all shortages are completely backlogged. The model operates within a finite planning horizon and aims to identify an optimal cycle time that minimizes the total inventory cost per cycle. [11] Ban, G. Y., Rudin, C. investigate the data-driven news vendor problem when one has n observations of p features related to the demand as well as historical demand data. [12] Jackson, I., Tolujevs, J., & Kegenbekov, Z. (2020) delved into the timeline of inventory control models and the various methodologies employed to derive optimal control parameters. Their analysis highlights how different methodologies contribute to improving inventory management systems, enhancing efficiency, and minimizing costs. [13] Lilian Tundura, Daniel Wanyoike (2016) explored three key inventory control strategies: cycle counting, inventory coding, and computerized inventory accuracy. [14] Aamir Rashid Hashmi, Noor Aina Amirah,Yusnita Yusof Tengku & Noor Zaliha (2020) investigated the dimensions of disruptive factors affecting inventory control in public healthcare facilities. Their research aims to identify the challenges that these facilities face in managing their inventory effectively, which is crucial for ensuring the availability of medical supplies and equipment. This paper is organized as follows, section 2,describes the symbols used in the formulation of the model.Here we define the Weibull distribution and the demand function, which is proportional to the selling price and exponential with time. In Section2, we prepare model to maximize the profit and calculate the total cost. In section 3, we present the sensitive analysis and present in graphical manner. These graph prepare with the MATLAB and showing the relation between different parameters like Q, p, t. In section 4, we put the observation of the graph which help to get the results. section5 conclude the paper, here the total cost of inventory HC is vary with the inventory cost I_1 and I_2.

2. Notation and Model Formulation

The mathematical notation for the two-warehouse inventory model is as follows: C = the purchase cost

C_o = Inventory order cost per order
s = the selling price per unit, where (s> c)
w = the capacity of owned warehouse
Q = the ordering quantity
R = the maximum inventory level per cycle.
$h_1 = a_1 + b_1 t$ the holding cost per unit per unit time in warehouse B
$h_2 = a_2 + b_2 t$ the holding cost per unit per unit time in warehouse A, $(h_2 > h_1)$
C_p = the backlog cost per unit per unit time
T = the length of the replenishment cycle
t_1 = the time at which the inventory level reach to zero in A
t_2 = the time at which the inventory level reach to zero in B
I_1 = Inventory level at time
I_2 = Inventory level at time
The demand rate $D(p,t)$ is a function of the selling price and time, and can be expressed as... $D(s,t) = Ae^{nt} + bs, s > 0$ is sells price
Inventory holding cost depends on time, and the deterioration rate follows the Weibull distribution as

$$\theta = \alpha\beta t^{\beta-1}, \ \ (0 < \alpha < 1, 0 < \beta)$$
$$D(t) = Ae^{nt} + bs$$
$$-D(t) = \frac{dI_1(t)}{dt} + \beta I_1(t),$$
$$\frac{dI_1(t)}{dt} + \beta I_1(t) = Ae^{nt} + bs, \tag{2.1}$$

$$\frac{dI_2(t)}{dt} + \alpha I_2(t) = 0, \tag{2.2}$$

by equation (2.1), we get the solution

$$I_1(t) = -\frac{Ae^{nt}}{n+\beta} + \frac{bs}{\beta} + ce^{-\beta t}. \tag{2.3}$$

Now with the equation (2.2)

$$\frac{dI_2(t)}{dt} = -\alpha I_2(t),$$
$$I_2(t) = we^{-\alpha t}, \tag{2.4}$$

Now, during time interval (t_1, t_2), the inventory in A warehouse can be calculate by

$$\frac{dI_2(t)}{dt} + \alpha I_2(t) = (-Ae^{nt} + bs) \tag{2.5}$$

again with the condition at time t_2 the inventory will be zero, so $I_2 = 0$. Now we put the condition in eqs.(2.5), then we have

$$I_2(t) = -\frac{A}{n+\alpha}\left(e^{nt} - e^{(n+\alpha)t_2}\right) + \frac{bs}{\alpha}\left(1 - e^{\alpha t_2}\right), \tag{2.6}$$

At the time interval $(0, t_1)$ and (t_1, t_2), the value of $I_2(t)$ are equal to zero. That means the inventory level of ware house B will be reach at zero. This represents the crucial condition for placing a new order. Thus, at times t_1 and t_2, the I_2 values must be comparable.

$$we^{\alpha t_1} = -\frac{A}{n+\alpha}(e^{nt} - e^{n+\alpha t_2} + \frac{bs}{\alpha}(1 - e^{\alpha t_2}), \tag{2.7}$$

$$\frac{we^{-\alpha t_1}(n+\alpha)}{A} = e^{(n+\alpha)t_2} - e^{nt} + \frac{bs}{\alpha} - \frac{bse^{\alpha t_2}}{\alpha}, \tag{2.8}$$

by solving the equation

$$t_2 = \frac{1}{n} log\left(\frac{wbse^{-\alpha t_1}(n+\alpha)}{A\alpha} + \frac{bse^{nt_1}}{\alpha} - \frac{b^2s^2}{\alpha^2}\right), \tag{2.9}$$

This equation shows that t_2 depends on t_1. Taking the first-order derivative t_2 with t_1, we get

$$\frac{dt_2}{dt_1} = \frac{wbs(n+\alpha)e^{-\alpha t_1}}{nA\left(\frac{wbs(n+\alpha)e^{\alpha t_1}}{A\alpha} + \frac{bse^{nt_1}}{\alpha} - \frac{b^2s^2}{\alpha^2}\right) + \frac{nbse^{nt_1}}{\alpha}} < 1 \tag{2.10}$$

$$\frac{dt_2}{dt_1} < 1. \tag{2.11}$$

So the situation be holds at time t_2, then both A and B warehouse inventories be zero. So at the time t_2 order must be placed.The total inventory be hold to run the system smoothly is $I = I_1 + I_2$ and the ordering cost c'. Holding cost per cycle in warehouse A be HC_1, then we have

$$HC_1 = \int_0^{t_1} h_2 I_1(t)dt, \tag{2.12}$$

$$HC_1 = \int_0^{t_1} h_2\left(\frac{-Ae^nt}{n+\beta} + \frac{bs}{\beta} + \frac{Ae^{(n+\beta)t_1}}{n+\beta} - \frac{bse^{\beta t_1}}{\beta}\right)dt, \tag{2.13}$$

put $h_2 = (a_2 + b_2 t)$ in this eqs.(2.13), then we get

$$\begin{aligned}
HC_1 &= \int_0^{t_1} (a_2 + b_2 t) \left(\frac{-Ae^{nt}}{n+\beta} + \frac{bs}{\beta} + \frac{Ae^{(n+\beta)t_1}}{n+\beta} - \frac{bse^{\beta t_1}}{\beta} \right) dt, \\
HC_1 &= \int_0^{t_1} a_2 \left(\frac{-Ae^{nt}}{n+\beta} + \frac{bs}{\beta} + \frac{Ae^{(n+\beta)t_1}}{n+\beta} - \frac{bse^{\beta t_1}}{\beta} \right) dt \\
&\quad + \int_0^{t_1} b_2 t \left(\frac{-Ae^{nt}}{n+\beta} + \frac{bs}{\beta} + \frac{Ae^{(n+\beta)t_1}}{n+\beta} - \frac{bse^{\beta t_1}}{\beta} \right) dt \\
&= - e^{nt} \frac{(n + nt - 1)}{n^2} + \frac{a_2 bst_1}{\beta} + a_2 A t_1 \frac{e^{(n+\beta)} t_1}{(n+\beta)\beta} e^{\beta} t_1 + b_2 bs \frac{t_1^2}{2\beta} \\
&\quad - \frac{bsb_2 e^{(\beta t_1)}}{\beta} \frac{t_1^2}{2}. \qquad (2.14)
\end{aligned}$$

Holding cost per cycle in B warehouse in two time interval$[0, t_1]$ and $[t_1, t_2]$ is given by

$$\begin{aligned}
HC_2 &= \int_0^{t_1} h_1 I_2 dt + \int_{t_1}^{t_2} h_1 I_2 dt \\
&= \int_0^{t_1} (a_1 + b_1 t) I_2 dt + \int_{t_1}^{t_2} (a_1 + b_1 t) I_2 dt \\
&= \int_0^{t_1} (a_1 + b_1 t) \ we^{-\alpha t} \ dt + \int_{t_1}^{t_2} (a_1 + b_1 t) \left(-\frac{A}{n+\alpha} \left(e^{nt} - e^{(n+\alpha)t_2} \right) \right) dt \\
&\quad + \int_{t_1}^{t_2} (a_1 + b_1 t) \left(\frac{bs}{\alpha} \left(1 - e^{\alpha t_2} \right) \right) dt, \qquad (2.15)
\end{aligned}$$

after solving the integration, we obtain

$$\begin{aligned}
HC_2 =& Ab_1 n^2 (-e^{(\alpha+n)} t_1^2 t_2 + e^{(\alpha+n) t_2^3})/2 - Ab_1 (2e^{(nt_1)} - 2e^{(nt_2)})/2 + (Ab_1 n (2t_1 e^{(nt_1)} \\
&- 2t_2 e^{(nt_2)}/2)/(n^2(\alpha+n)) + b_1 w (1/\alpha^2 - (e^{(-\alpha t_1)}(\alpha t_1 + 1))/\alpha^2) \\
&- (a_1 w (e^{(-\alpha t1)} - 1))/\alpha + (A a_1 (e^{(nt_1)} - e^{(nt_2)})/(n(\alpha+n)) \\
&- (A a_1 t_2 e^{(\alpha+n)(t_1 - t_2)})/(\alpha+n) + (bb_1 s (t_1^2 - t_2^2)(e^{(\alpha t_2)} - 1))/(2\alpha) \\
&+ a_1 bs (t_1 - t_2)(e^{(\alpha t_2)} - 1)/\alpha. \qquad (2.16)
\end{aligned}$$

The holding cost of material over the interval $[0, t_2]$ can be obtained by adding equations (2.14&2.26) $HC = HC_1 + HC_2$. Now the inventory cost for both warehouses are

$$\begin{aligned}
HC =& \left[-e^{nt} \frac{(n + nt - 1)}{n^2} + \frac{a_2 bst_1}{\beta} + a_2 A t_1 \frac{e^{(n+\beta)t_1}}{(n+\beta)} \frac{e^{\beta t_1}}{\beta} + b_2 bs \frac{t_1^2}{2\beta} - \frac{bsb_2 e^{(\beta t_1)}}{\beta} t_1^2 \right] \\
&+ Ab_1 n^2 (-e^{(\alpha+n) t_1^2} t_2 + e^{(\alpha+n) t_2^3})/2 - (Ab_1 (2e^{nt_1} - 2e^{nt_2}/2) \\
&+ Ab_1 n (2t_1 e^{(nt_1)} - 2t_2 e^{(nt_2)}/2)/(n^2(\alpha+n)) + b_1 w (1/\alpha^2 - (e^{(-\alpha t_1)}(\alpha t_1 + 1))/\alpha^2) \\
&- a_1 w (e^{(-\alpha t1)} - 1)/\alpha + A a_1 (e^{(nt_1)} - e^{(nt_2)})/(n(\alpha+n)) \\
&- (A a_1 t_2 e^{(\alpha+n)(t_1 - t_2)}/(\alpha+n) \\
&+ bb_1 s (t_1^2 - t_2^2)(e^{\alpha t_2} - 1))/(2\alpha) + (a_1 bs (t_1 - t_2)(e^{\alpha t_2} - 1))/\alpha. \qquad (2.17)
\end{aligned}$$

Now, the total inventory quantity at time $t = 0$ be defined by Q, then $Q = I_1(0) + I_2(0)$ where

$$I_1(0) = \left(\frac{A}{n+\beta} + \frac{bs}{\beta} \right), \qquad (2.18)$$

$$I_2(0) = \frac{A}{n+\alpha} (1 - e^{(n+\alpha)t_2}) + \frac{bs}{\alpha} (1 - e^{\alpha t_2}), \qquad (2.19)$$

now, the ordering quantity at the time when inventory be zero is

$$Q = \left(\frac{A}{n+\beta} + \frac{bs}{\beta} + \frac{A}{n+\alpha}(1-e^{(n+\alpha)t_2}) + \frac{bs}{\alpha}(1-e^{\alpha t_2})\right), \tag{2.20}$$

if the cost per cycle is C, then the purchase cost is

$$PC = CQ = C\left[(\frac{A}{n+\beta} + \frac{bs}{\beta}) + \frac{A}{n+\alpha}(1-e^{(n+\alpha)t_2}) + \frac{bs}{\alpha}(1-e^{\alpha t_2})\right]. \tag{2.21}$$

Sales revenue per cycle can be taken as SR if the price P, then

$$SR = p\left[\int_0^{t_2}(Ae^{nt}+bs)dt\right], \tag{2.22}$$

$$SR = p\left[-\frac{A}{n} + \frac{Ae^{nt_2}}{n} + bst_2\right] \tag{2.23}$$

The total profit per unit time period t is given by
$P(0,t_2) = \frac{1}{t}$ [Sales-ordering cost-holding cost-purchase cost]. total profit per unit during time period

$$p = \frac{1}{t}[SR - C_0 - HC - PC], \tag{2.24}$$

after putting the values eqs.(2.25), we found that

$$\begin{aligned} p =& \frac{1}{t}(p)[-\frac{A}{n} + \frac{Ae^{nt_2}}{n} + bst_2] \\ &- C_0 - HC - C[(\frac{A}{n+\beta} + \frac{bs}{\beta}) \\ &+ \frac{A}{n+\alpha}(1-e^{(n+\alpha)t_2}) + \frac{bs}{\alpha}(1-e^{\alpha t_2})]] \end{aligned} \tag{2.25}$$

Put the value of HC in eqs(2.26), then we have

$$\begin{aligned} =& \frac{1}{t}\left\{p\left[-\frac{A}{n} + \frac{Ae^{nt_2}}{n} + bst_2\right] - C_0\right\} \\ &- \left\{ - e^{nt}\frac{(n+nt-1)}{n^2} + \frac{a_2bst_1}{\beta} + a_2At_1\frac{e^{(n+\beta)t_1}}{(n+\beta)}\frac{e^{\beta t_1}}{\beta} \right. \\ &+ b_2bs\frac{t_1^2}{2\beta} - \frac{bsb_2e^{\beta t_1}}{\beta}\frac{t_1^2}{} \\ &\left. + \frac{Ab_1n^2\left(-e^{(\alpha+n)t_1^2t_2} + e^{(\alpha+n)t_2^3}\right)}{2}\right\}, \\ =& -\left(Ab_1\left(2e^{nt_1} - 2e^{nt_2}\right)/2\right) + \left(Ab_1n\left(2t_1e^{nt_1} - 2t_2e^{nt_2}\right)/2\right)/\left(n^2(\alpha+n)\right) \\ &+ b_1w\left(\frac{1}{\alpha^2} - \frac{e^{-\alpha t_1}(\alpha t_1+1)}{\alpha^2}\right), \\ =& -\frac{a_1w\left(e^{-\alpha t_1}-1\right)}{\alpha} + \frac{Aa_1\left(e^{nt_1}-e^{nt_2}\right)}{n(\alpha+n)} - \frac{Aa_1t_2e^{(\alpha+n)(t_1-t_2)}}{\alpha+n} \\ &+ \frac{bb_1s\left(t_1^2-t_2^2\right)\left(e^{\alpha t_2}-1\right)}{2\alpha}, \\ =& \frac{a_1bs\left(t_1-t_2\right)\left(e^{\alpha t_2}-1\right)}{\alpha} - C\left[\frac{A}{n+\beta} + \frac{bs}{\beta} + \frac{A}{n+\alpha}\left(1-e^{(n+\alpha)t_2}\right) + \frac{bs}{\alpha}\left(1-e^{\alpha t_2}\right)\right]. \end{aligned} \tag{2.26}$$

This equation represents the net profit during the process over the interval $[0, t2]$, expressed as the total margin per cycle. we can apply $\frac{\delta P}{\delta t_1} = 0$ and $\frac{\delta P}{\delta t_2} = 0$.
Provided they satisfy the following conditions $\frac{\delta^2 P}{\delta t_1^2} > 0$ and $\frac{\delta^2 P}{\delta t_2^2} > 0$.

3. Sensitivity Analysis

To understand the effects of parameter changes on the profit margin, an analysis can be performed. In this section, we analyze the percentage change in profit with respect to different parameters such as order quantity (Q), holding cost (HC), and inventory duration (t) in both warehouses.

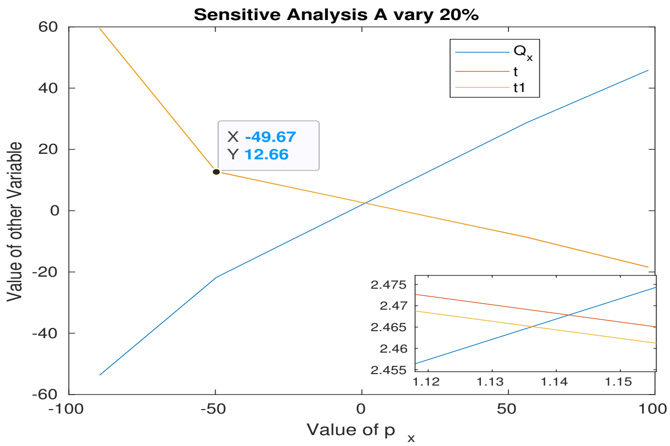

Figure 1: Relation between profit margin, time and order quantity when A vary 20 percent

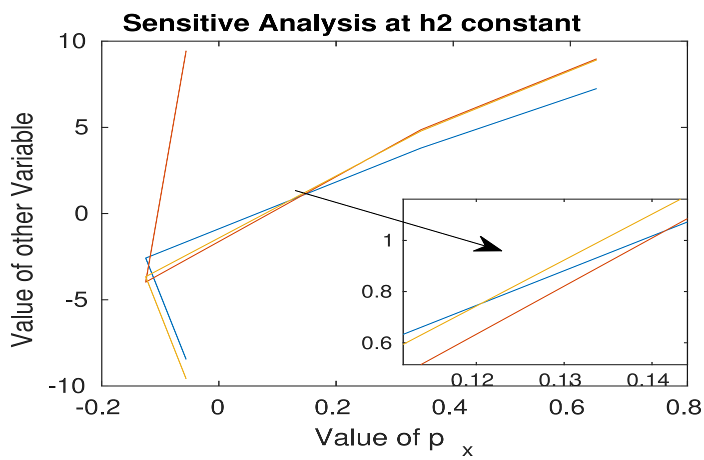

Figure 2: Relation between profit margin, time and order quantity when h_2 constant

4. Observation

1. The profit $P(t_1, T)$ is sensitive with the demand rate coefficient A. In fig.1 showing the change in cost and profit when A is varying with 20 percent.

2. $P(t_1, T)$ profit sensitive analysis at h_2 holding cost constant. In fig 2. showing the change in cost and profit, holding cost h_2 for ware house B is constant. It shows a linear progression in $P(t_1, T)$ and $Q(t_1, T)$.

3. The change in profit $P(0, T)$ with A demand rate coefficient constant. The cost and profit both linear degradation with A.

4. The profit increase with linear progression and cost decrease in linear mode showing in fig.4.

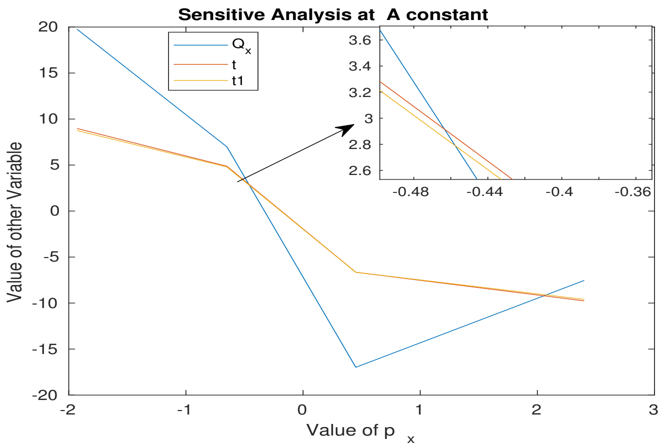

Figure 3: Relation between profit margin, time and order quantity when A constant

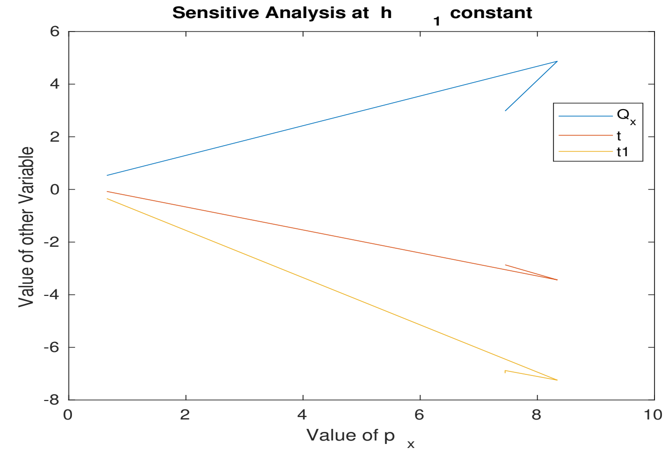

Figure 4: Relation between profit margin, time and order quantity when h_1 constant

5. Conclusion

This model presents the inventory problem of two warehouses. A single item inventory model with constant replenishment rate, exponential demand with proportional sell price in pair warehouses with maximize the profit of the system was presented in this paper. The total cost HC divided in the two parts of warehouse A and B costs HC_1 & HC_2. The cost of both warehouse contribute by ordering cost, holding cost and it effect on the total revenue of the system.The profit is calculated over the time span t, divided into two intervals: $[0, t1]$ and $[t1, t2]$. Here we analyze the model with different parameters such as h_1, h_2 and A. For further study, we can extend this research for three warehouses and the parallel warehouses problems.

Conflict of interest There is the declaration of the author regarding the publication of the given paper that there is no conflict of interest.

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