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Two Warehouse Inventory Model with Price Discount on Backorders under Stock Dependent Demand Environment

Sujan Chandra

Department of Statistics
Bethune College, Kolkata, India

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Abstract: In this paper, a two warehouse inventory model for deteriorating items is studied with stock dependent demand rate. Holding cost of rented warehouse (RW) has higher than the owned warehouse (OW) due to better preservation. Due to the improved services offer in RW, its deterioration rate is less than deterioration rate in OW. To reduce inventory cost, items of RW are consumed first and then the items of OW are consumed. When stock on hand is zero, the inventory manager offers a price discount to customers who are willing to backorder their demand. The study contains some features that are likely to be associated with certain types of inventory, like inventory of seasonal fruits and vegetables, newly launched fashion items, etc. The optimum ordering policy and the optimum discount offered for each backorder are determined by minimizing the total cost in a replenishment interval.
Keyword — Inventory/production model; two warehouses; stock dependent demand; deteriorating item; price discount on backorder.

1. INTRODUCTION

In classical inventory models it is assumed that organization have a single warehouse with the facility of unlimited storage capacity. But in reality, when suppliers provide attractive price discount for bulk purchase at a time, the inventory manager may purchase more goods. These large amount of goods can not to be stored in its own warehouse (OW) due to its limited capacity. For these excess quantities, additional warehouse is required and items are stored in rented warehouse (RW). Due to different preservation facilities the inventory costs in RW are assumed to be higher than those in OW. So, it will be economical for the inventory manager to store items in OW before RW, but the items of RW are consumed first and the items of OW are the next to reduce the inventory cost. Sarma (1987) developed two warehouse inventory model for deteriorating items with an infinite replenishment rate and shortage. Bhunia and Maiti (1998) considered a two warehouse inventory model for deteriorating items with linearly increasing demand and shortages. Zhou (2003) studied two warehouse inventory models with time varying demand. Wee, Yu, and Law (2005) presented a two warehouse model with constant demand and Weibull distribution deterioration under inflation. Shaikh, Cárdenas-Barrón, and Tiwari (2019) developed a two-warehouse inventory model for non-instantaneous deteriorating items with stock dependent demand under inflationary conditions. Subsequently, the ideas of two warehouse modelling were considered by some other authors, such as Pasandideh, Niaki, Nobil, and Cárdenas-Barrón (2015) , Tiwari, Cárdenas-Barrón, Khanna, and Jaggi (2016) , Jaggi, Cárdenas-Barrón, Tiwari, and Shafi (2017) , Panda, Khan, and Shaikh (2019) and others.

It is generally assumed that the demand rate is independent of factors like price of items, stock availability, etc. However, in real life, it is observed that for certain type of inventory, particularly consumer goods in supermarkets; customers are highly influenced by the stock level. The sale at a retail level is directly proportional to the amount of inventory displayed. Levin, McLaughin, Lemone, and Kottas (1972) pointed out that large piles of consumer goods displayed in a supermarket attract the customer to buy more. Pal and Chandra (2014) studied a periodic review inventory model for non-instantaneous deteriorating items with stock dependent and time decreasing demand. Aggarwal and Tyagi (2017) determined optimal inventory and credit decisions in an inventory system when demand is dependent on day-terms credit period as well as on instantaneous inventory-level. Bhunia, Shaikh, Dhaka, Pareek, and Cárdenas-Barrón (2018) considered the impact of marketing decisions and the displaced stock level on the demand in their inventory model. Tripathi (2018) proposed a model of deteriorating items with inventory induced demand and inflation.

*Corresponding author's e-mail: chandra.sujan@gmail.com

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Masud et al. (2018) studied inventory model with consideration of price, stock dependent demand, partially backlogged shortages, and two constant deterioration rates.

In classical inventory models with shortages, it is generally assumed that the unmet demand is either completely lost or completely backlogged. However, it is quite possible that while some customers leave, others are willing to wait till the fulfilment of their demand. In some situations, the inventory manager may offer a discount on backorders and/or reduction in waiting time to tempt customers to wait. Pan and Hsiao (2001) proposed a continuous review inventory model considering the order quantity and with negotiable backorders as decision variables. Ouyang, Chuang, and Lin (2003) developed a periodic review inventory model with backorder discounts to accommodate more practical features of the real inventory systems. Chuang, Ouyang, and Chuang (2004) discussed a distribution free procedure for mixed inventory model with backorder discount and variable lead time. Uthayakumar and Parvathi (2008) considered a model with only first two moments of the lead time demand known, and obtained the optimum backorder price discount and order quantity in that situation. Pal and Chandra (2012) studied a deterministic inventory model with shortages. They considered only a fraction of the unmet demand is backlogged, and the inventory manager offers a discount on it. Chandra (2017) studied an inventory model where holding cost is linearly increasing function of time and demand rate is a ramp type function of time with price discount on backorders.

Major contribution of the proposed model

Literature	Warehouse facility	Type of price discount on backorders	Demand rate
Aggarwal et al. (2017)	One	No shortage	Stock dependent
Jaggi et al. (2017)	Two	No shortage	Constant
Chandra (2017)	One	Fractional backorders price discount	Ramp Type
Masud et al. (2018)	One	partial backlogging	Stock dependent
Tripathi (2018)	One	No shortage	Stock dependent
Shaikh et al. (2019	Two	No shortage	Stock dependent
Panda et al. (2019)	Two	partial backlogging	Price and Stock dependent
This paper	Two	Fractional backorders price discount	Stock dependent

In this paper, a two warehouse inventory model for deteriorating items is considered with stock dependent demand. It is assumed that the items of rented warehouse are consumed first and then the items of owned warehouse are consumed because rented warehouse has higher unit holding cost than the owned warehouse. The manager offers his customer a discount in case he is willing to backorder his demand when there is a stock-out. The objective of this model is to find the best replenishment policies for minimizing the total appropriate inventory cost. The paper is organized as follows. Assumptions and notations are presented in Section 2. In Section 3, the model is formulated and the optimal value of decision variables are determined. In Section 4, numerical examples are cited to illustrate the policy. Concluding remarks are given in Section 5.

2. NOTATIONS AND ASSUMPTIONS

To develop the model, the following notations and assumptions have been used.
Notations

$I_0(t)$	= inventory level in owned warehouse (OW) at time point t
$I_r(t)$	= inventory level in rented warehouse (RW) at time point t
K	= ordering cost per order
b	= fraction of the demand backordered during stock out
b_0	= upper bound of backorder ratio
s_1	= backorder cost per unit backordered per unit time
s_2	= cost of a lost sale
π	= price discount on unit backorder offered
π_0	= marginal profit per unit
h_r	= inventory holding cost per unit per unit time in RW
h_0	= inventory holding cost per unit per unit time in OW
θ_1	= deterioration rate in RW, $0 < \theta_1 < 1$
θ_2	= deterioration rate in OW, $0 < \theta_2 < 1, \theta_2 > \theta_1$
T	= length of a replenishment cycle
T_1	= time taken for stock on hand to be exhausted at RW, $0 < T_1 < T$
T_2	= time taken for stock on hand to be exhausted at OW, $0 < T_1 < T_2 < T$
S	= maximum stock height in a replenishment cycle at OW

Assumptions

1. The model considers only one item in inventory.
2. Replenishment of inventory occurs instantaneously on ordering i.e., lead time is zero.
3. The OW has the limited capacity of storage (S) and RW has unlimited capacity.
4. Items of RW are consumed first and then the items of OW are consumed due to the more holding cost in RW than in OW $(h_r > h_0)$.
5. Due to the improved services offer in RW, the deterioration rate in RW is less than deterioration rate in OW $(\theta_2 > \theta_1)$.
6. Demand rate $R(t)$ at time t is

$$R(t) = \alpha + \beta I(t) \text{ for } 0 < t < T$$

   where α = fixed demand per unit time, $\alpha > 0$, β = fraction of total inventory demanded per unit time under the influence of stock on hand, $0 < \beta < 1$.

7. During the stock-out period, the backorder fraction b is directly proportional to the price discount π offered by the inventory manager. Thus,

$$b = \frac{b_0}{\pi_0}\pi \text{ , where } 0 \leq b_0 \leq 1, 0 \leq \pi \leq \pi_0.$$

3. MODEL FORMULATION

The planning period is divided into reorder intervals, each of length T units. Orders are placed at time points $0, T, 2T, 3T, \ldots$. At the beginning of the reorder interval order quantity being just sufficient to bring the stock height at OW to a certain maximum level S and the remaining order quantity in RW. Due to different preservation facilities the inventory costs (including holding cost and deterioration cost) in RW are assumed to be higher than those in OW. So, it will be economical for the inventory manager to store items in OW before RW, but the items of RW are consumed first and the items of OW are the next to reduce the inventory cost.
Depletion of inventory at RW occurs due to demand and deterioration during the period $(0, T_1)$, $T_1 < T$. Hence, the variation in inventory level at RW with respect to time is given by

$$\frac{d}{dt}I_r(t) + \theta_1 I_r(t) = -\alpha - \beta I_r(t), \text{ if } 0 \le t \le T_1$$

Since $I_r(T_1) = 0$, we get

$$I_r(t) = \frac{\alpha}{\theta_1 + \beta}\left(e^{(\theta_1+\beta)(T_1-t)} - 1\right), \text{ if } 0 \le t \le T_1 \tag{3.1}$$

Depletion of inventory at OW occurs due to deterioration during the period $(0, T_1)$, and due to demand and deterioration both during the period (T_1, T), $T_1 < T$. Hence, the variation in inventory level at OW with respect to time is given by

$$\begin{aligned}
&\frac{d}{dt}I_0(t) + \theta_2 I_0(t) = 0, && \text{if } 0 \le t \le T_1\\
&\frac{d}{dt}I_0(t) + \theta_2 I_0(t) = -\alpha - \beta I_0(t), && \text{if } T_1 \le t \le T_2\\
&\frac{d}{dt}I_0(t) = -b\alpha, && \text{if } T_2 \le t \le T
\end{aligned}$$

Since $I_0(0) = S$ and $I_0(T_2) = 0$, we get

$$\begin{aligned}
I_0(t) &= Se^{-\theta_2 t}, && \text{if } 0 \le t \le T_1\\
&= \frac{\alpha}{\theta_2 + \beta}\left(e^{(\theta_2+\beta)(T_2-t)} - 1\right), && \text{if } T_1 \le t \le T_2\\
&= b\alpha(T_2 - t), && \text{if } T_2 < t < T
\end{aligned} \tag{3.2}$$

Considering the continuity of $I_0(t)$ at $t = T_1$, it follows that

$$I_0(T_1) = Se^{-\theta_2 T_1} = \frac{\alpha}{\theta_2 + \beta}\left(e^{(\theta_2+\beta)(T_2-T_1)} - 1\right)$$

Hence,

$$T_2 = \frac{1}{\theta_2 + \beta}\ln\left(\frac{(\theta_2+\beta)Se^{-\theta_2 T_1}}{\alpha} + 1\right) + T_1 \tag{3.3}$$

Then,
Ordering cost during a cycle (OC) = K
Holding cost of inventories at RW during a cycle (HC$_r$)

$$\begin{aligned}
&= h_r \int_0^{T_1} I_r(t)dt\\
&= \frac{h_r\alpha}{\theta_1 + \beta}\left(\frac{1}{\theta_1 + \beta}\left(e^{(\theta_1+\beta)T_1} - 1\right) - T_1\right)
\end{aligned}$$

Holding cost of inventories at OW during a cycle (HC_0)

$$= h_0 \int_0^{T_2} I_0(t)dt = h_0 \left(\int_0^{T_1} I_0(t)dt + \int_{T_1}^{T_2} I_0(t)dt \right)$$
$$= h_0 \left(\frac{S}{\theta_2} \left(1 - e^{-\theta_2 T_1}\right) + \frac{\alpha}{\theta_2 + \beta} \left(\frac{1}{\theta_2 + \beta} \left(e^{(\theta_2+\beta)(T_2 - T_1)} - 1 \right) - (T_2 - T_1) \right) \right)$$

Deterioration cost of inventories at RW during a cycle (DC_r)

$$= \theta_1 \int_0^{T_1} I_r(t)dt$$
$$= \frac{\theta_1 \alpha}{\theta_1 + \beta} \left(\frac{1}{\theta_1 + \beta} \left(e^{(\theta_1+\beta)T_1} - 1 \right) - T_1 \right)$$

Deterioration cost of inventories at OW during a cycle (DC_0)

$$= \theta_2 \int_0^{T_2} I_0(t)dt = \theta_2 \left(\int_0^{T_1} I_0(t)dt + \int_{T_1}^{T_2} I_0(t)dt \right)$$
$$= S \left(1 - e^{-\theta_2 T_1}\right) + \frac{\theta_2 \alpha}{\theta_2 + \beta} \left(\frac{1}{\theta_2 + \beta} \left(e^{(\theta_2+\beta)(T_2 - T_1)} - 1 \right) - (T_2 - T_1) \right)$$

Backorder cost during a cycle (BC)

$$= -s_1 \int_{T_2}^{T} I_0(t)dt = \frac{s_1 b \alpha}{2} (T - T_2)^2$$

Lost sales cost during a cycle (LC) $= s_2(1-b)\alpha(T - T_2)$
Hence, the cost per unit length of a replenishment cycle is given by

$$C(S, T_1, b) = \frac{1}{T}[\text{OC} + \text{HC}_r + \text{HC}_0 + \text{DC}_r + \text{DC}_0 + \text{BC} + \text{LC}]$$
$$= \frac{1}{T} \left(\begin{array}{l} K + \frac{\alpha(h_r+\theta_1)}{\theta_1+\beta} \left(\frac{1}{\theta_1+\beta} \left(e^{(\theta_1+\beta)T_1} - 1 \right) - T_1 \right) + S \left(1 - e^{-\theta_2 T_1}\right) \left(\frac{h_0}{\theta_2} + 1 \right) \\ + \frac{\alpha(h_0+\theta_2)}{\theta_2+\beta} \left(\frac{S e^{-\theta_2 T_1}}{\alpha} - \frac{1}{\theta_2+\beta} \ln \left(\frac{(\theta_2+\beta) S e^{-\theta_2 T_1}}{\alpha} + 1 \right) \right) \\ + \frac{s_1 b \alpha}{2} \left(T - \frac{1}{(\theta_2+\beta)} \ln \left(\frac{(\theta_2+\beta) S e^{-\theta_2 T_1}}{\alpha} + 1 \right) - T_1 \right)^2 \\ + s_2(1-b)\alpha \left(T - \frac{1}{(\theta_2+\beta)} \ln \left(\frac{(\theta_2+\beta) S e^{-\theta_2 T_1}}{\alpha} + 1 \right) - T_1 \right) \end{array} \right)$$
$$= \frac{N_1(S, T_1, b)}{T}$$

The optimal values of S, T_1 and b, which minimize $C(S, T_1, b)$, must satisfy the following equations:

$$\frac{\alpha(h_0+\theta_2)}{\theta_2+\beta} e^{-\theta_2 T_1} \left(\frac{1}{\alpha} - \frac{\alpha}{\alpha + (\theta_2+\beta) S e^{-\theta_2 T_1}} \right) + \left(1 - e^{-\theta_2 T_1}\right) \left(\frac{h_0}{\theta_2} + 1 \right)$$
$$= \left(\frac{\alpha^2 e^{-\theta_2 T_1}}{\alpha + (\theta_2+\beta) S e^{-\theta_2 T_1}} \right) \left(\left(T - \frac{1}{\theta_2+\beta} \ln \left(\frac{(\theta_2+\beta) S e^{-\theta_2 T_1}}{\alpha} + 1 \right) - T_1 \right) s_1 b + s_2(1-b) \right) \tag{3.4}$$

$$\frac{\alpha(h_r+\theta_1)}{\theta_1+\beta} \left(e^{(\theta_1+\beta)T_1} - 1 \right) + S\theta_2 e^{-\theta_2 T_1}(h_0+\theta_2) \left(\frac{1}{\theta_2} + \frac{1}{\theta_2+\beta} \left(\frac{\alpha}{\alpha + (\theta_2+\beta) S e^{-\theta_2 T_1}} - 1 \right) \right)$$
$$= \alpha \left(1 - \frac{\theta_2 S e^{-\theta_2 T_1}}{\alpha + (\theta_2+\beta) S e^{-\theta_2 T_1}} \right) \left(\left(T - \frac{1}{\theta_2+\beta} \ln \left(\frac{(\theta_2+\beta) S e^{-\theta_2 T_1}}{\alpha} + 1 \right) - T_1 \right) s_1 b + s_2(1-b) \right) \tag{3.5}$$

$$T - T_1 - \frac{1}{\theta_2+\beta} \ln \left(\frac{(\theta_2+\beta) S e^{-\theta_2 T_1}}{\alpha} + 1 \right) = \frac{2 s_2}{s_1} \tag{3.6}$$

4. NUMERICAL ILLUSTRATION AND SENSITIVITY ANALYSIS

Since it is difficult to find closed form solutions to the sets of equations (3.4) - (3.6), we numerically find solutions to the equations for given sets of model parameters using the statistical software MATLAB. The following tables show the change in optimal inventory policy with change in a model parameter, when the other parameters remain fixed.

Table 1: Showing the optimal inventory policy for different values of θ_2, when $K = 500$, $\theta_1 = 0.04$, $\alpha = 100$, $\beta = 0.65$, $h_0 = 8$, $h_r = 15$, $s_1 = 16$, $s_2 = 12$ and $T = 15$.

$\boldsymbol{\theta_2}$	$\boldsymbol{S}$	$\boldsymbol{T_1}$	$\boldsymbol{b}$	$\boldsymbol{C(S, T_1, b)}$
0.05	138.92	0.0533	0.1581	1187.67
0.1	137.42	0.0566	0.2385	1188.56
0.2	134.46	0.0634	0.2187	1190.23
0.3	131.57	0.0701	0.2574	1191.75
0.4	128.68	0.0771	0.2398	1193.16
0.5	125.79	0.0844	0.2448	1194.46
0.6	122.93	0.0920	0.2535	1195.67
0.7	120.08	0.0998	0.2185	1196.80
0.8	117.21	0.1079	0.2484	1197.85

Table 2: Showing the optimal inventory policy for different values of s_2, when $K = 500$, $\theta_1 = 0.04$, $\theta_2 = 0.07$, $\alpha = 100$, $\beta = 0.65$, $h_0 = 8$, $h_r = 15$, $s_1 = 16$ and $T = 15$.

$\boldsymbol{s_2}$	$\boldsymbol{S}$	$\boldsymbol{T_1}$	$\boldsymbol{b}$	$\boldsymbol{C(S, T_1, b)}$
15	150.99	0.1760	0.1472	1466.00
20	171.77	0.3596	0.2081	1921.79
25	192.17	0.5239	0.2545	2369.07
30	212.25	0.6725	0.3185	2808.64
35	232.03	0.8083	0.3637	3241.16
40	251.54	0.9331	0.4125	3667.21
45	270.82	1.0487	0.4642	4087.25

Table 3: Showing the optimal inventory policy for different values of h_r, when $K = 500$, $\theta_1 = 0.04$, $\theta_2 = 0.07$, $\alpha = 100$, $\beta = 0.65$, $h_0 = 8$, $s_1 = 16$, $s_2 = 12$ and $T = 15$.

$\boldsymbol{h_r}$	$\boldsymbol{S}$	$\boldsymbol{T_1}$	$\boldsymbol{b}$	$\boldsymbol{C(S, T_1, b)}$
10	73.63	0.5045	0.1382	1186.51
12	100.06	0.2941	0.1465	1187.68
14	125.71	0.1265	0.1583	1188.00
17	148.67	0.0001	0.1758	1188.03
20	148.61	0.0005	0.1986	1188.03

Table 4: Showing the optimal inventory policy for different values of h_0, when $K = 500$, $\theta_1 = 0.04$, $\theta_2 = 0.07$, $\alpha = 100$, $\beta = 0.65$, $h_r = 15$, $s_1 = 16$, $s_2 = 12$ and $T = 15$.

h_0	S	T_1	b	$C(S, T_1, b)$
7	169.67	0.0003	0.1581	1183.13
8	138.32	0.0546	0.1588	1188.03
9	111.82	0.1186	0.1586	1192.01
10	90.45	0.1805	0.1586	1195.29
11	72.84	0.2406	0.1585	1197.98
12	58.04	0.2990	0.1587	1200.20

The above tables show that, for other parameters remaining constant,

(a) b, and hence π, increase with increase in s_2 and h_r;

(b) S is increasing in s_2 and h_r while S is decreasing in θ_2 and h_0.

(c) T_1 is increasing in θ_2, s_2 and h_0 while T_1 is decreasing in h_r.

The above observations indicate that, with a view to minimizing total cost, the policy should be to maintain high inventory level in OW for low holding cost and deterioration rate in OW but high holding cost in RW and lost sale cost. Also, for higher lost sales cost, higher price discount should be offered.

A fraction of the demand is backlogged, and the inventory manager offers a discount to each customer who is ready to wait till fulfilment of his demand. Some customers may be willing to wait till the stock is replenished (i.e., backorder case), while some may be impatient and satisfy their demand immediately from some other source (i.e., lost sales case). To hold his customer when a stock-out occurs, the inventory manager may offer a discount on backorders and/or a reduction in waiting time to tempt the customers to wait. Through controlling a price discount, inventory manager could generate high customer loyalty. This means that inventory manager could reduce cost of lost-sales and also reduce holding cost.

5. CONCLUSION

This paper studies two warehouse inventory model for deteriorating items under stock dependent demand environment. The study includes some features that are likely to be associated with certain types of inventory, like inventory of seasonal fruits and vegetables, newly launched fashion items, etc. A fraction of the demand is backlogged, and the inventory manager offers a discount to each customer who is ready to wait till fulfilment of his demand. Through numerical study, it is observed that the policy should be to maintain high inventory level in OW for low holding cost and deterioration rate in OW but high holding cost in RW and lost sale cost. It is also observed that for higher lost sales cost, higher price discount should be offered.

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