

An Inventory Model for Deteriorating Items with Non-Linear Selling Price Dependent Demand and Exponentially Partial Backlogging Shortage

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Abstract. In this paper, we have developed an inventory models for deteriorating items with non-linear price dependent demand and frequency of advertisement of items. It is allowed and partially backlogged with an exponential rate on the duration of waiting time up to the arrival of next lot. In this model, the deterioration rate follows three-parameter weibull distribution and the transportation cost is considered explicitly for replenishing the order quantity. The transportation cost is dependent on the lot-size as well as the distance from the source to the destination of the located shop. The corresponding non-linear model are formulated and solved by considering the transportation cost for replenishing the items. A numerical example is given to illustrate the results and the significant features of the result are discussed. Finally, we have performed the sensitivity analysis taking one or more parameters at a time.

Keywords: EOQ model, Deterioration, Weibull distribution, non-linear price dependent demand, Partially backlogged shortage

AMS Mathematics Subject Classification (2010): 90B05

1. Introduction

In the existing literature of inventory, generally most of the researchers have developed the inventory model under the assumption that the life time of an item is infinite while it is in storage i.e., an item once in stock remains unchanged and fully usable for satisfying future demand of the customers. But in reality, this assumption is not always true due to the effect of deterioration in the preservation of commonly used physical goods and these goods are not in a perfect condition to satisfy the customer demand. As a result, the loss due to this natural phenomenon (i.e., the deterioration effect) can't be ignored in the analysis of the inventory system. Ghare and Schrader [1] first introduce these concepts and developed an inventory model for exponentially decaying inventory. Then Emmons [2] proposed this type of model with variable deterioration which follows two-parameter weibull distribution. These models were extended and improved by several researchers, viz. Covert and Philip [3], Giri et al. [4], Ghosh and Chaudhari [5]. On the other hand, Chakrabarty et al. [6], Giri et al.[7], Sana et al. [8], Sana and Chaudhari [9] and others

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developed inventory models for deteriorating items with three-parameter weibull distributed deterioration. Misra [10] developed an EOQ model with a weibull deterioration rate for perishable product without considering backlogging situation. These investigations were followed by several researchers like, Deb and Chaudhari [11], Giri et al. [12], Goswami and Chaudhari [13], Mandal and Phaujdar [14], Padmanabhan and Vrat [15], Pal et al. [16], Mandal and Maiti [17], Goyal and Gunasekaran [18], Sarkar et al. [19], Bhunia and Maiti [20,21], Bhunia and Shaikh [22,23,24], Pal et al. [25], Bhunia et al. [26], Bhunia and Shaikh [27], Bhunia et al [28], etc., where a time-proportional deterioration rate was considered. We also consider the work of Chakraborty, Pal and Nayek [48-52].

In the present competitive market, the effect of marketing policies and conditions such as the price variations and the advertisement of an item change its demand pattern amongst the public. The propaganda and canvassing of an item by advertisement in the well-known media such as Newspaper, Magazine, Radio, T.V., Cinema, etc. and also through the sales representatives have a motivational effect on the people to buy more. Also, the selling price of an item is one of the decisive factors in selecting an item for use. It is commonly seen that lesser selling price causes increase in demand whereas higher selling price has the reverse effect. Hence, it can be concluded that the demand of an item is a function of displayed inventory in a show-room, selling price of an item and the advertisement expenditures frequency of advertisement. Very few OR researchers and practitioners studied the effects of price variation and the advertisement on the demand rate of items. Kotler [29] incorporated marketing policies into inventory decisions and discussed the relationship between economic ordering quantity and pricing decision. Ladany and Sternleib [30] studied the effect of price variation on selling and consequently on EOQ. However, they did not consider the effect of advertisement. Subramanyam and Kumaraswamy [31], Urban [32], Abad [33] and Luo [34] developed inventory models incorporating the effects of price variations and advertisement on demand rate of an item. In this connection we may refer some recent works such as Shaikh [35], Bhunia et al. [36, 37, 38, 39], Bhunia and Shaikh [40], Shaikh et al. [41, 42, 43, 44], Bhunia et al. [45], Tiwari et al. [46], Mishra et al. [47], etc.

In this paper, we have developed an inventory model for deteriorating items with non-linear variable demand dependent on the selling price of items and frequency of advertisement. Shortages are allowed partially with a variable rate dependent on the duration of waiting time up to the arrival of next lot. In this model, the deterioration rate follows a three-parameter weibull distribution and the transportation cost is considered explicitly for replenishing the order quantity. In real-life situation, it is observed that a fixed cost is incurred for a transport mode such as truck, wagon. Therefore, the transportation cost is dependent on the lot-size as well as the distance from the source to the destination. The corresponding models are formulated and solved by considering the transportation cost for replenishing the items. A numerical example is considered to illustrate the model and the significant features of the result are discussed. Finally, based on these examples, we have performed a sensitivity analysis and make a fruitful conclusion.

2. Assumptions and notations

We have developed the paper by considering the following assumption as notations:

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Assumption:

- (i) Replenishments are instantaneous.
- (ii) Lead time is negligible.
- (iii) The inventory planning horizon is infinite and the inventory system involves only one item.
- (iv) The deterioration occurs when the item is effectively in-stock and the rate of deterioration follows a three-parameter weibull distribution.
- (v) The deteriorated units are not replaced or not repaired.
- (vi) The replenishment cost (ordering cost) is constant and does not include the transportation cost for replenishing the item.
- (vii) The demand rate $D(A, p)$ is dependent on selling price (p) of an item and the frequency of advertisement (A). We assume it as follows:

$$D(A, p) = A^v ap^{-b}, a, b, v \geq 0.$$
- (viii) C_t be the transportation cost for full load of the transport vehicle and C_{tF} be the transportation cost per unit item.
- (ix) U be the upper break point, some quantity loss than k but more than U , the transportation cost for whole quantity is C_t .

Hence $U = \frac{C_t}{C_{tF}} (< k)$ where $\left[\frac{C_t}{C_{tF}} \right]$ represents the greatest integer value which is less than or equal to C_t / C_{tF} .

Notations:

Notations	Units	Description
C_o	\$/order	Ordering cost
a	Constant	Demand parameter ($a > 0$)
b	Constant	Demand parameter ($b > 0$)
p	\$/unit	Selling price per unit and it is denoted $p=mC_p$
C_p	Units	Purchase cost per unit
C_l	\$/unit	Opportunity cost per unit
C_b	\$/unit	Shortage cost per unit
C_h	\$/unit /unit time	Holding cost per unit
R	Units	Maximum backlogged units
S	Units	Maximum inventory level
C_{ad}	\$/unit /unit time	Advertisement cost per advertisement
A	unit	Frequency of advertisement
L	Km	Be the distance between the shop and the source of the items/commodities from where

		items/commodities to be transported.
n	unit	Number of fully loaded vehicle.
k	unit	Capacity of the transport vehicle.
Z	\$/year	Total profit per unit time.
Decision variables		
t_1	Years	Time at which the stock in RW reaches to zero
T	Years	The length of the replenishment cycle

3. Mathematical model

In this model, shortages are allowed and partially backlogged and backlogging rate is dependent on the length of the waiting time up to the arrival of fresh lot. By considering this situation, the rate is defined as $e^{-\delta(T-t)}$, $\delta > 0$.

Initially, it is assumed that after fulfilling the backorder quantity, the on-hand inventory level is S at $t=0$ and it declines continuously up to the time $t=t_1$ when it reaches the zero level. The decline in inventory during the closed time interval $0 \leq t \leq t_1$ occurs due to the customer's demand and deterioration of the item. After the time $t=t_1$, shortage occurs and it accumulates at the rate $e^{-\delta(T-t)}$, ($\delta > 0$) up to the time $t=T$ when the next lot arrives. At time $t=T$, the maximum shortage level is R . This entire cycle then repeats itself after the cycle length T .

Let $q(t)$ be the inventory level at any time $t \geq 0$. Then the inventory level $q(t)$ at any time t satisfies the differential equations

$$q'(t) + \theta(t)q(t) = -D(A, p), \quad 0 \leq t \leq t_1 \quad (1)$$

$$q'(t) = -D(A, p)e^{-\delta(T-t)}, \quad t_1 < t \leq T \quad (2)$$

with the boundary conditions

$$q(t) = S \text{ at } t = 0, \quad q(t) = 0 \text{ at } t = t_1. \quad (3)$$

$$\text{and } q(t) = -R \text{ at } t = T. \quad (4)$$

Also, $q(t)$ is continuous at $t = t_1$.

Using the conditions (3) and (4), the solutions of the differential equations (1)-(2) are given by

$$q(t) = D(A, p)e^{-\alpha(t-\gamma)^\beta} \int_t^{t_1} e^{\alpha(t-\gamma)^\beta} dt, \quad 0 \leq t \leq t_1$$

$$= \frac{D(A, p)}{\delta} \left\{ 1 - e^{-\delta(T-t)} \right\} - R, \quad t_1 < t \leq T$$

From (2), we have $q(t) = S$ at $t = 0$.

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$$\text{Then, } S = D(A, p) e^{-\alpha(-\gamma)^\beta} \int_0^{t_1} e^{\alpha(t-\gamma)^\beta} dt \quad (5)$$

From the continuity condition, we have

$$R = \frac{D(A, p)}{\delta} \{1 - e^{-\delta(T-t_1)}\} \quad (6)$$

The total number of deteriorated units is given by

$$D' = \int_0^T \theta(t) q(t) dt$$

The total inventory cost per cycle of the system consists of the following components and which given below:

(i) ordering cost, (ii) purchasing cost, (iii) inventory holding cost, (iv) advertisement cost, (v) transportation cost, (vi) shortage cost, (vii) opportunity cost.

Ordering cost: Since there is only one item and one stocking point, the ordering cost is C_o .

Purchasing cost: Since the ordering quantity per cycle is $S+R$, the total purchase cost is $C_p(S+R)$.

Inventory holding cost: The inventory holding cost per unit time is the product of the inventory level and holding cost per unit time. Thus the total inventory holding cost for the entire cycle is given by

$$C_{hol} = C_h \int_0^{t_1} q(t) dt$$

where

$$\begin{aligned} \int_0^{t_1} q(t) dt = & \frac{t_1^2}{2} + \frac{\alpha^2 t_1 (t_1 - \gamma)^{2\beta+1}}{2(2\beta+1)} - \frac{\alpha (t_1 - \gamma)^{\beta+2}}{(\beta+1)(\beta+2)} - \frac{\alpha^2 (t_1 - \gamma)^{2\beta+2}}{2(2\beta+1)(2\beta+2)} \\ & - \frac{\alpha^2 (t_1 - \gamma)^{2\beta+2}}{(\beta+1)^2} + \alpha(-\gamma)^\beta \left\{ \frac{t_1^2}{2} - \left(\frac{\beta}{\gamma} \right) \frac{t_1^3}{3} \right\} \\ & + \frac{\alpha^2 (t_1 - \gamma)^{2\beta+2}}{(\beta+1)(2\beta+2)} + \frac{\alpha^2 t_1 (t_1 - \gamma)^{2\beta+1}}{2(2\beta+1)} - \frac{\alpha^2 (-\gamma)^{2\beta}}{2} \left\{ \frac{t_1^2}{2} - \left(\frac{2\beta}{\gamma} \right) \frac{t_1^3}{3} \right\} \\ & + \frac{\alpha(-\gamma)^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{\alpha^2 (-\gamma)^{2\beta+2}}{2(2\beta+1)(2\beta+2)} + \frac{\alpha t_1 (-\gamma)^{\beta+1}}{(\beta+1)} \\ & + \frac{\alpha^2 (t_1 - \gamma)^{\beta+1} (-\gamma)^{\beta+1}}{(\beta+1)^2} - \frac{\alpha^2 (-\gamma)^{2\beta+2}}{(\beta+1)(2\beta+2)} - \frac{\alpha^2 t_1 (-\gamma)^{2\beta+1}}{2(2\beta+1)} \end{aligned} \quad (7)$$

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Advertisement cost: The total advertisement cost C_{adv} is given by

$$C_{adv} = C_{ad}A$$

Again, the total shortage cost C_{sho} over the entire cycle is given by

$$C_{sho} = c_b \left[\left(R - \frac{D(A, p)}{\delta} \right) (T - t_1) + \frac{D(A, p)}{\delta^2} \{ 1 - e^{-\delta(T-t_1)} \} \right]$$

Total opportunity cost OCL during the entire cycle is given by

$$OCL = c_l D(A, p) \left[(T - t_1) - \frac{1}{\delta} \{ 1 - e^{-\delta(T-t_1)} \} \right]$$

The total inventory cost (TC) of the system is given by

$TC = \langle \text{ordering cost} \rangle + \langle \text{purchasing cost} \rangle + \langle \text{inventory holding cost} \rangle + \langle \text{advertisement cost} \rangle + \langle \text{transportation cost} \rangle + \langle \text{inventory shortage cost} \rangle + \langle \text{Opportunity cost} \rangle$

$$= C_o + C_p(S + R) + C_h \int_0^{t_1} q(t) dt + C_{ad}A + C_{tran} + C_{sho} + OCL$$

The profit function

The net profit (X) for the entire system is the difference between the sale revenue per cycle and the total cost of the system i.e.,

$$X = pA^V(a - bp)T - TC \quad (8)$$

Therefore the profit function $Z(n, A, t_1, T)$ (average profit per unit time for the entire cycle) of the inventory system is given by

$$Z(n, A, t_1, T) = \frac{X}{T}$$

i.e.,

$$Z(n, A, t_1, T) = \left[pA^V(a - bp) - \left\{ C_4 + C_3(S + R) + C_1 \int_0^{t_1} q(t) dt + C_5A + C_{tran} + C_{sho} \right\} \right] / T \quad (9)$$

Here the profit function is a function of three continuous variables m , t_1 , T and two integer variables n , A . Clearly, the above function is an increasing function with respect to m . Hence our problem is to determine the optimal values of n , A , t_1 , T and S by solving the following mixed integer nonlinear optimization problem.

$$\left. \begin{array}{l} \text{Maximize } Z(n, A, t_1, T) \\ \text{subject to } t_1 < T, n, A, t_1 > 0 \text{ and } n, A \text{ are integers} \end{array} \right\} \quad (10)$$

where

$$\begin{aligned} C_{tran} &= nC_t + (S + R - nk)C_{tf} \quad \text{when } nk < S + R \leq nk + U \\ &= (n+1)C_t \quad \text{when } nk + U < S + R \leq (n+1)k \end{aligned}$$

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The optimal solution of the above problem can be obtained with the help by using GRG method.

4. Numerical example

To illustrate the model with partially backlogged shortages, a numerical example with the following data has been considered.

$C_h = \$0.5$ per unit per unit time, $C_b = \$3$ per unit per unit time, $C_p = \$10$ per unit, $C_o = \$250$ per order, $C_{ad} = \$50$ per advertisement, $C_t = \$100$ per transport vehicle, $C_{tF} = \$1.25$ per unit, $\alpha = 0.05$, $\beta = 2$, $\gamma = 2$, $a = 200$, $b = 0.4$, $k = 100$ units. $L = 50$ km, $\delta = 0.5$, $\nu = 0.2$, $c_l = 10$.

Like first model (no-shortage case), the values of different parameters considered here are realistic, through these are not taken from any case study.

The optimal solution has been obtained with the help of GRG method for different values of m . The optimum values of n , A , t_1 , T , S and R along with maximum average profit are displayed in Table 1.

Table 1: Optimal solution for different values of mark-up rate m

m	n	A	S	R	t_1	T	Z
1.20	2	3	249.1748	9.459095	3.134379	3.239685	102.6714
1.25	2	4	264.0838	10.77343	3.186983	3.302367	144.8516
1.30	2	4	260.9001	10.55784	3.198131	3.312978	187.7306
1.35	3	5	273.3519	11.80916	3.252002	3.377038	231.1069
1.40	3	6	284.1465	13.01357	3.305546	3.440684	274.5462

5. Sensitivity analysis

For the above given example which mentioned earlier, a sensitivity analysis has performed to study the effect of changes of different parameters such as demand, deterioration, inventory cost parameters and mark-up rate an maximum initial stock level, maximum shortage level, cycle length, frequency of advertisement along with the maximum profit of the system. This analysis has been carried out by changing (increasing and decreasing) the parameters from -20% to $+20\%$, taken one or more parameters at a time making the other parameters at their more parameters at a time and making the other parameters at their original values. The results of this analysis are shown in **Tables 2**.

Table 2: Sensitivity analysis with respect to different parameters respectively for $m=1.30$

Parameter	% changes of parameters	changes in Z^*	A^*	change in			
				R^*	S^*	t_1^*	T^*
C_h	-20	293.0494	6	7.147983	296.3262	3.441484	3.514578
	-10	283.2320	6	7.827862	290.2666	3.374168	3.454356
	10	264.4581	6	9.134675	278.9782	3.247114	3.341008
	20	255.6162	5	8.763741	260.2522	3.143647	3.237063

<i>a</i>	- 20	175.1816	4	8.135646	207.0298	3.266033	3.379959
	- 10	214.8252	5	8.954198	240.1934	3.222276	3.328669
	10	297.9600	6	9.555894	294.3700	3.117090	3.206280
	20	341.1073	7	10.34144	328.8051	3.094898	3.180616
<i>b</i>	- 20	356.6081	7	10.25904	336.1535	3.074381	3.156937
	- 10	302.8004	6	9.531061	296.6894	3.109684	3.197709
	10	214.7515	5	8.954522	240.1566	3.222430	3.328848
	20	178.9123	4	8.120331	208.9209	3.256746	3.369053
<i>v</i>	- 20	163.6026	3	7.198948	188.0141	3.244208	3.354347
	- 10	170.3811	4	8.154974	204.5861	3.278226	3.394292
	10	---	---	---	---	---	---
	20	200.8546	6	9.996173	246.2678	3.293985	3.412843
<i>C_o</i>	- 20	193.2101	5	8.059360	216.1079	3.222583	3.329028
	- 10	186.3893	4	7.594324	206.0525	3.213083	3.317922
	10	---	---	---	---	---	---
	20	---	---	---	---	---	---

6. Concluding remarks

In this paper, we have described an inventory model for deteriorating items with variable non-linear demand dependent on the selling price and the frequency of advertisement of the item. In practical situations transportation costs of goods/raw material are fixed for a finite capacity of a transport mode such as a truck or other vehicles. A fixed cost is incurred when a truck is deployed whether it is utilized fully or partially for a ceiling quantity or more. For quantities less than the ceiling quantity, a uniform rate per unit is charged.

In this model, the demand rate is taken as $D(A, p) = A^V ap^{-b}$. It is well known that $D(A, p) \propto ap^{-b}$ for fixed A . But, why should we take $D(A, p) \propto A^V$ for fixed values of p ? Generally, the demand of items varies due to the advertisement in the well known media such as Radio, T.V., Newspaper, Magazine, Cinema, etc. The demand of items increases with the increase of frequency of advertisement and is directly proportional to the number of advertisement. Hence, we take $D(A, p) \propto A^V$ for fixed p .

The problem of inventory and transportation interactions is a potential field of research. We cannot ignore this cost in inventory analysis. The following can be potential problems that can be stated below:

- (i) The possibility of single truck supplying the products to more than one stocking point.
- (ii) The possibility of inter-depot transportation can be incorporated from the following points of view.
 - (a) The inventory – distribution costs can be minimized.
 - (b) This provides another alternative to deal with the space constraint that is operative at some of the stoking point.

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