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An Inventory Model with Price and Time Dependent Demand with Fuzzy Valued Inventory Costs Under Inflation

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Abstract. In this paper, we have developed a fuzzy inventory model for deteriorating items with price and time dependent demand considering inflation effect on the system. Shortages if any are allowed and partially backlogged with a variable rate dependent on the duration of waiting time up to the arrival of next lot. The corresponding problem has been formulated as a nonlinear constrained optimization problem, all the cost parameters are fuzzy valued and solved. A numerical example has been considered to illustrate the model and the significant features of the results are discussed. Finally, based on these examples, a sensitivity analyses have been studied by taking one parameter at a time keeping the other parameters as same.

Keywords: Inventory, deterioration, time dependent demand, partially backlogged shortage, inflation, fuzzy valued inventory costs

AMS Mathematics Subject Classification (2010): 90B05

1. Introduction

According to the existing literature of inventory control system, most of the inventory models have been developed 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. In real life situation, this assumption is not always true due to the effect of deterioration in the preservation of commonly used physical goods like wheat, paddy or any other type of foodgrains, vegetables, fruits, drugs, pharmaceuticals, etc. A certain fraction of these goods are either damaged or decayed or vaporized or affected by some other factors, etc. and are not in a perfect condition to satisfy the 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 (1963) first developed an inventory model for exponentially decaying inventory. Then Emmons (1968) 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 (1973), Giri et al. (2003),Ghosh and Chaudhari (2004). On the other hand, Chakrabarty et al. (1998), Giri et al.(1999), Sana et al. (2004), Sana and Chaudhari (2004) and others developed inventory models for deteriorating items with there-parameter weibull distributed deterioration. Misra (1975) developed an EOQ model with weibull deterioration rate for perishable product without considering shortages. These investigations were followed by several researchers like, Deb and Chaudhari (1986), Giri et. al. (1996), Goswami and Chaudhari (1991), Mandal and Phaujdar (1989a), Padmanabhan and Vrat (1995), Pal et al.(1993), Mandal and Maiti (1997), Goyal and Gunasekaran (1995), Sarkar et al.(1997), Bhunia and Maiti [1998a,1998b], Pal et al. (2005, 2006), Mishra and Tripathy (2010), Kawale and Bansode (2012), Bhunia et al. (2013a, 2013b), Sharma and Chaudhary (2013), Amutha and Chandrasekaran (2013) etc., where a time-proportional deterioration rate was considered.

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 observed that lower 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 variations and the advertisement on the demand rate of items. Kotler (1971) incorporated marketing policies into inventory decisions and discussed the relationship between economic order quantity and pricing decision. Ladany and Sternleib (1974) studied the effect of price variation on selling and consequently on EOQ. However, they did not consider the effect of advertisement. Subramanyam and Kumaraswamy (1971), Urban (1992), Goyal and Gunasekaran (1995), Abad (1996) and Luo (1998), Pal et al. (2007), Bhunia and Shaikh (2011) developed inventory models incorporating the effects of price variations and advertisement on demand rate of an item.

Apart from the rate of deterioration, other practically important factors which have been widely accepted by the researchers to have crucial impact on the inventory policy decisions are inflation and time value of money. Buzacott(1975) and Misra(1979) proposed inventory models with the consideration of inflation for all the associated costs. After two years, an EOQ model with the incorporation of the effect of inflation and time value of money was developed by Bierman and Thomas(1977). Misra(1979) developed an inventory model with the assumption of different inflation rates for different associated costs and constant demand. Vrat and Padmanabhan(1990) developed an EOQ model for items with stock dependent consumption rate and exponential decay. Datta and Pal(1991) proposed an inventory model with linear time dependent demand rate and shortages by considering the effects of inflation and time value money. Wee and Law(1999,2001) developed inventory models for deteriorating items by taking into account the time value of money. In addition to these, researchers like Yang, Teng and Chern(2001), Yang(2004,2006), Jaggi, Aggarwal and Goel(2006), Hsieh, Dye and Ouyang(2008), Dey, Mondal and Maiti(2008), Jaggi, Khanna and Verma(2011) and others have also contributed to this field of research.

Yang (2004) proposed a two warehouse inventory model with constant demand rate for deteriorating items under inflation by considering two alternative situations. In the first situation he assumed a model which starts with an instant order and ends with shortages. In the second situation the model begins with shortages and ends without shortages. These models were extended by Yang(2006) with the incorporation of partial backlogging. Considering partial backlogging, Taleizadeh et al.(2012) and Taleizadeh et al.(2013 a, b) developed single warehouse inventory models. Recently, Jaggi, Khanna and Verma (2011) proposed an inventory model considering a linear time dependent demand rate for deteriorating items, inflation and partial backlogging rate in a two warehouse system.

In this paper, we have developed an inventory model for deteriorating items with frequency of advertisement dependent demand considering inflation effect on the system. Shortages if any are allowed and partially backlogged with a variable rate dependent on the duration of waiting time up to the arrival of next lot. The corresponding problem have been formulated as a nonlinear constrained optimization problem and solved. A numerical example has been considered to illustrate the model and the significant features of the results are discussed. Finally, based on these examples, the effects of different parameters on the initial stock level, shortage level, cycle length along with the optimal profit have been studied by sensitivity analyses taking one parameter at a time keeping the other parameters as same.

2. Assumptions and notations

The following assumptions and notations are used to develop the proposed model:

(i) The entire lot is delivered in one batch.
(ii) Inflation effect of the system.
(iii) The demand rate $D(p,t)$ is dependent on time. It is denoted by $D(p,t) = a - bp + ct,\ a,b,c > 0$.
(iv) The deteriorated units ware neither repaired nor refunded.
(v) The inventory system involves only one item and one stocking point and the inventory planning horizon is infinite.
(vi) Replenishments are instantaneous and lead time is constant.
(vii) The replenishment cost (ordering cost) is constant and transportation cost does not include for replenishing the item.
(viii) The inventory costs parameters are fuzzy valued.

Notations:

$I(t)$	Inventory level at time t
S	Highest stock level at the beginning of stock-in period
R	Highest shortage level
θ	Deterioration rate ($0 < \theta << 1$)
$\tilde{C}_o$	Fuzzy replenishment cost per order
δ	Backlogging parameter
$\tilde{C}_p$	Fuzzy purchasing cost per unit

p	Selling price per unit of item
$D(p,t)$	Time dependent demand
$\tilde{C}_h$	Fuzzy holding cost per unit per unit time
$\tilde{C}_b$	Fuzzy shortage cost per unit per unit time
$\tilde{C}_{ls}$	Fuzzy opportunity cost due to lost sale
t_2	Time at which the stock level reaches to zero
T	Time at which the highest shortage level reaches to the lowest point
r	Inflation rate
$\tilde{Z}$	The total average cost

3. Inventory model with shortages

In this model, 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 $t = t_2$ when it reaches the zero level. The decline in inventory during the closed time interval $0 \le t \le t_2$ occurs due to the customer's demand and deterioration of the item. After the time $t = t_2$, shortage occurs and it accumulates at the rate $\left[1+\delta\left(T-t\right)\right]^{-1}$, ($\delta > 0$) 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 $I\left(t\right)$ be the instantaneous inventory level at any time $t \ge 0$. Then the inventory level $I\left(t\right)$ at any time *t* satisfies the differential equations as follows:

$$\frac{dI(t)}{dt} + \theta I(t) = -D\left(p,t\right), \quad 0 \le t \le t_1 \tag{1}$$

$$\frac{dI(t)}{dt} = \frac{-D(p,t)}{[1+\delta(T-t)]}, \quad t_1 < t \le T \tag{2}$$

with the boundary conditions

$$I\left(t\right) = S \text{ at } t = 0 \text{ , } I(t) = 0 \text{ at } t = t_1 \text{ .} \tag{3}$$

$$\text{and } I\left(t\right) = -R \text{ at } t = T \text{.} \tag{4}$$

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

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

$$\begin{aligned} I(t) &= S - D(A,p)t & & 0 \le t \le t_1 \\ &= \frac{D(A,p)}{\theta}\left\{e^{\theta(t_2-t)} - 1\right\} & & t_1 \le t \le t_2 \\ &= \frac{D(A,p)}{\delta}\log\left|1+\delta(T-t)\right| - R, & & t_2 < t \le T \end{aligned}$$

Using continuity condition we have

$$S = D(A,p)t_1 + \frac{D(A,p)}{\theta}\left\{e^{\theta(t_2-t_1)} - 1\right\} \tag{5}$$

From the continuity condition, we have

$$R = \frac{D(A,p)}{\delta}\log\left|1+\delta(T-t_1)\right| \tag{6}$$

The total number of deteriorated units is given by
Now the total inventory holding cost for the entire cycle is given by

$$\tilde{C}_{hol} = \tilde{C}_h \int_0^{t_1} e^{-rt} I(t)\,dt$$

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

$$\tilde{C}_{sho} = \tilde{C}_b \int_{t_1}^{T} \left\{-e^{-rt} I(t)\right\} dt$$

Cost of lost sale OCLS over the entire cycle is given by

$$\tilde{O}CLS = \tilde{C}_{ls} \int_{t_2}^{T} e^{-rT}\left\{1 - \frac{1}{1+\delta(T-t)}\right\} D(t)dt$$

Total cost during the entire cycle is given by
<ordering cost> + <purchasing cost> + <inventory holding cost> + < cost of lost sale>+< inventory shortage cost>

i.e., $\tilde{X} = \tilde{C}_4 + \tilde{C}_p(S+R) + \tilde{C}_{hol} + \tilde{O}CLS + \tilde{C}_{sho}$

Average cost during the entire cycle is given by $\tilde{Z} = \dfrac{\tilde{X}}{T}$

Hence the corresponding constrained optimization problem is given by

Problem-1: Minimize $\tilde{Z}(t_1, T) = \dfrac{\tilde{X}_1}{T}$

subject to $T > 0$

4. Numerical example

For numerical illustration of the proposed inventory model, we have considered the following example.

Example 1.
$\tilde{C}_o = (495, 500, 505)$, $\tilde{C}_h = (1, 1.5, 2)$, $\tilde{C}_p = (25, 30, 35)$, $\tilde{C}_b = (10, 15, 20)$, $a = 45$, $b = 5$, $c = 10$
$\tilde{C}_{ls} = (10, 15, 20)$, $\theta = 0.5$, $r = 0.06$, $\delta = 1.5$.

Example 2.

$\tilde{C}_o = (490, 495, 500)$, $\tilde{C}_h = (2, 2.5, 3)$, $\tilde{C}_p = (25, 30, 35)$, $\tilde{C}_b = (10, 12, 14)$, $a = 50$, $b = 5$, $\tilde{C}_{ls} = (10, 15, 20)$, $\theta = 0.5$, $r = 0.06$, $\delta = 1.5$.

Example 3.

$\tilde{C}_o = (540, 550, 560)$, $\tilde{C}_h = (1, 1.5, 2)$, $\tilde{C}_p = (30, 35, 40)$, $\tilde{C}_b = (10, 15, 20)$, $a = 45$, $b = 5$, $\tilde{C}_{ls} = (10, 15, 20)$, $\theta = 0.5$, $r = 0.06$, $\delta = 0.6$.

According to the solution procedure, the optimal solution has been obtained with the help of LINGO software for different examples. The optimum values of t_1, T, S and R along with minimum average cost are displayed in **Table 1**.

Examples	*S*	*R*	t_1	*T*	*Z*
1	53.6081	24.8696	0.9515	1.6561	2121.981
2	91.8766	4.0366	1.7579	1.8300	2298.648
3	39.2629	36.5827	0.7014	1.5997	2139.171

Table 1: Optimal solution for different examples

5. Sensitivity analysis

For the given example mentioned earlier, sensitivity analysis has been performed to study the effect of changes (under or over estimation) of different parameters like demand, deterioration, inventory cost parameters and mark-up rate on maximum initial stock level, 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 4**.

Parameter	% changes of parameters	% changes in Z^*	% changes in		
			R^*	S^*	T^*
C_h	– 20	39.55	20.87	111.15	105.74
	– 10	14.58	18.78	70.06	67.69
	10	-0.07	-1.53	-5.13	-5.54
	20	-0.41	-1.79	-9.10	-14.97
C_b	– 20	0.20	1.43	-0.34	-0.19
	– 10	0.10	0.74	-0.17	-0.08
	10	-0.10	-0.61	0.17	0.13
	20	-0.20	-1.27	0.34	0.23
C_p	– 20	422.37	-36.56	93.67	-38.01
	– 10	231.17	-0.58	48.4	-27.71
	10	---	---	---	---
	20	---	---	---	---

C_4	– 20	35.53	-17.86	-13.70	-14.34
	– 10	17.31	-9.44	-9.32	-9.75
	10	-13.38	18.32	36.32	35.56
	20	-24.31	28.32	57.25	57.55
a	– 20	---	---	---	---
	– 10	---	---	---	---
	10	344.54	3.14	48.18	-31.93
	20	744.36	-15.63	92.46	-43.40
b	– 20	661.44	-12.71	82.46	-41.85
	– 10	306.95	1.38	41.25	-30.63
	10	---	---	---	--
	20	---	---	---	---
r	– 20	-1.95	-3.72	-5.24	-5.65
	– 10	-0.81	-2.20	-2.58	-2.87
	10	10.90	21.55	58.31	56.28
	20	24.45	25.87	78.08	76.89

(---) indicates infeasible solution

Table 4: Sensitivity analysis with respect to different parameters with respect to *m=1.3.*

6. Concluding remarks

This paper deals with a deterministic inventory model for deteriorating items with variable demand inflation effect of the system.

In this models, the demand rate is taken as $D(A,p)=A^{\nu}(a-bp)$. It is well known that $D(A,p)\propto(a-bp)$ for fixed *A*. But, why should we take $D(A,p)\propto A^{\nu}$ 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 $D(A,p)\propto A^{\nu}$ for fixed *p*.

The present model is also applicable to the problems where the selling prices of the items as well as the advertisement of items affect the demand. It is applicable for fashionable goods, two level and single level credit policy approach also.

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