Procedure International Journal of Science and Technology

(International Open Access, Peer-reviewed & Refereed Journal)

(Multidisciplinary, Monthly, Multilanguage)

ISSN : 2584-2617 (Online)

Volume- 1, Issue- 7, July 2024

Website- www.pijst.com DOI- https://doi.org/10.62796/pijst.2024v1i7003

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

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Abstract- In this work, we have created a fuzzy inventory model for degrading goods that takes the system's impact of inflation into account and includes price and time-dependent demand. If there are any shortages, they are permitted and will be partially backlogged at a variable rate based on how long it takes for the next lot to arrive. The corresponding problem has been presented as an optimisation problem with constraints that is nonlinear; all of the cost parameters have been addressed with fuzzy values. To demonstrate the paradigm, a numerical example has been examined, and the key findings are highlighted. Ultimately, using these instances as a basis, sensitivity assessments were conducted by examining one parameter at a time while maintaining the same values for the other parameters.

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

Introduction-

The majority of inventory models have been established under the premise that an item's life span is limitless while it is in storage, meaning that once an item is in stock, it remains unmodified and completely useable for satisfying future demand, according to the literature currently available on inventory control systems. Due to the influence of deterioration in the preservation of regularly used physical items like wheat, rice or any other form of foodgrains, vegetables, fruits, medications, pharmaceuticals, etc., this assumption is not always accurate in real life situations. A portion of these products aren't in perfect condition to meet demand since they've been harmed, degraded, evaporated, or affected by other circumstances, among other things. Therefore, in the examination of the inventory system, the loss resulting from this natural phenomena (i.e., the deterioration effect) cannot be disregarded. The first inventory model for exponentially decaying inventory was created by Ghare and Schrader in 1963. Next This kind of variable deterioration model, which adheres to the two-parameter Weibull distribution, was proposed by Emmons in 1968. Several researchers, including Covert and Philip (1973), Giri et al. (2003), and Ghosh and Chaudhari (2004), expanded and enhanced these models. Conversely, Md. Anwar Hossen, Md. Abdul Hakim, S.S. Ahmed, and M. Sharif Uddin 22; Giri et al. (1999); Sana et al. (2004); and Chakrabarty et al. (1998) Inventory models for degrading objects with a one-parameter Weibull distributed deterioration were developed by Sana and Chaudhari (2004) and others.

The public's demand for an item can be altered in the current competitive market by marketing policies and conditions including price fluctuations and product advertising. People are motivated to buy more when an item is promoted and canvassed through sales agents and advertisements in well-known media like radio, newspapers, magazines, television, and movies. One of the deciding criteria when choosing an item for use is also its selling price. It is well known that whereas higher selling prices have the opposite impact, lower selling prices lead to an increase in demand.

Thus, it may be said that the requirement for an item is dependent upon its selling price, quantity of advertisements, and inventory that is on display in a showroom. Very few researchers studying OR and Practitioners investigated how price changes and advertisements affected the pace at which products were demanded. In addition to discussing the connection between pricing decisions and economic order quantities, Kotler (1971) integrated marketing policies into inventory decisions. In 1974, Ladany and Sternleib conducted research on how price variation affects sales and, in turn, EOQ. They did not, however, take the impact of advertising into account.

Inventory models combining the impacts of price fluctuations and advertisement on an item's demand rate were established by Subramanyam and Kumaraswamy (1971), Urban (1992), Goyal and Gunasekaran (1995), Abad (1996) and Luo (1998), Pal et al. (2007), and Bhunia and Shaikh (2011). In addition to the rate of degradation, inflation and the time value of money are two realistically significant elements that experts generally agree have a significant impact on the decisions made about inventory strategy. Misra (1979) and Buzacott (1975) presented inventory models that took inflation into account for all related expenditures.

Two years later, Bierman and Thomas (1977) created an EOQ model that included the time value of money and the impact of inflation. Misra (1979) created an inventory model based on the hypotheses of varying inflation rates for various related costs and steady demand. An EOQ model for products with stock dependent consumption rate and exponential decay was created by Vrat and Padmanabhan in 1990. In 1991, Datta and Pal presented an inventory model that took time value of money and inflation into account, along with a linear demand rate and shortages. Wee and Law (1999, 2001) created inventory models that considered the time value of money for items that were deteriorating.

In addition to these, additional scholars who have made contributions to this field of study include 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. Yang (2004) took into consideration two distinct scenarios and suggested a two warehouse inventory model with constant demand rate for degrading products under inflation. In the first instance, he made the assumption that there would be shortages at the end of an instantaneous order. The model starts with shortages in the second scenario and finishes with none. Yang (2006) expanded these models by using partial backlogging.

Taleizadeh et al. (2012) and Taleizadeh et al. (2013 a, b) developed single warehouse inventory models taking partial backlog into consideration. In a two-warehouse system, Jaggi, Khanna, and Verma (2011) have suggested an inventory model that takes inflation, a partial backlog rate, and a linear time-dependent demand rate for degrading items into account. In this research, we have built an inventory model for degrading items that takes into account the system's inflation effect and frequency-dependent demand for advertisements. If there are any shortages, they are permitted and will be partially backlogged at a variable rate based on how long it takes for the next lot to arrive. The related issue has been solved after being stated as a nonlinear constrained optimisation problem.

To demonstrate the paradigm, a numerical example has been examined, and the key findings are highlighted. Finally, using these instances as a basis, sensitivity analyses have been performed, one parameter at a time, while maintaining the same values for the other parameters. The impacts of the various factors on the initial stock level, shortage level, cycle length, and optimal profit have been investigated.

Assumptions and notations

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

(i) The entire shipment is delivered in a single batch.

(ii) The system accounts for the effect of inflation.

(iii) The demand rate D(p,t)D(p,t)D(p,t) depends on time and is represented as D(p,t)=a”bp+ctD(p,t) = a - bp + ctD(p,t)=a”bp+ct, where a,b,c>0a, b, c > 0a,b,c>0.

(iv) Deteriorated units are neither repaired nor refunded.

(v) The inventory system includes only one item and one stocking point, with an infinite planning horizon.

(vi) Replenishments occur instantly, and the lead time is constant.

(vii) The replenishment (ordering) cost is constant, and transportation costs for replenishing the item are not included.

(viii) The inventory cost parameters have fuzzy values.

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 ($0<\theta<<1$)
$\tilde{C}_1$	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

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 $0 \leq t \leq t_2$ occurs due to the customer's demand and deterioration of the item. After the timet = t2, shortage occurs and it accumulates at the rate $[1+ \delta(T-t)]^{-1}$, ($\delta>0$) 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(t) be the instantaneous inventory level at any timet ≥0. Then the inventory level I(t) at any time t satisfies the differential equations as follows:

$$\frac{dI(t)}{dt}+\theta 1(t) = -D(p,t), 0\leq t\leq t_1 \qquad (1)$$

$$\frac{dI(t)}{dt} = \frac{-D(p,t)}{[1+\delta(T-t)}, \; t_1<t\leq T \qquad (2)$$

with the boundary conditions

$$I(t) = S \text{ at } t=0,\; I(t)=0 \text{ at } t=t_1 \qquad (3)$$

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

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

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

$$I(t)=S - D(A, p)t \qquad 0\leq t \leq t_1$$

$$\frac{D(AP)}{\theta}\{e^{\theta(t^1-t)} -1\} \qquad t_1\leq t \leq t_2$$

$$\frac{D(AP)}{\delta}\text{-}\log|1+8(T-t)|-R, \qquad t_2<t\leq T$$

Using continuity condition we have

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

From the continuity condition, we have

$$R = \frac{D(A,P)}{\delta} \text{-log} \mid 1+\delta\ (T-t_1) \mid \quad (6)$$

The total number of deteriorated units is given by

Now the total inventory holding cost for the entire cycle is given by

$$C_{hol} = \tilde{C}_b \int_{t_1}^{T} e^{-rt}\, I D(t)dt$$

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

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

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

$$OCLS = \tilde{C}_b \int_{l\delta}^{T} e^{-rt} \left\{1 - \frac{1}{1+\delta\ (T-t)}\right\} D(t)dt$$

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., $\tilde{X} = \tilde{C}_4 + \tilde{C}_P(S + R) + C_{hol} + OCLS + \tilde{C}_{sho}$

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

Hence the corresponding constrained optimization problem is given by

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

subject to $T > 0$

4. Numerical example

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

Example 1

$\tilde{C}_a = (495{,}500,\ 505)$, $\tilde{C}_b = (1{,}1.5{,}2)$, $\tilde{C}_p = (25{,}30{,}35)$, $\tilde{C}_b = (10{,}15{,}20)$, a=45,

b=5,c=10

$\tilde{C}_{Is} =$ (10,15,20), $\theta = 0.5$, r = 0.06, δ=1.5.

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Example 2

$\tilde{C}_1$=(490,495,500), $\tilde{C}_h$ =(2,2.5,3), $\tilde{C}_p$ =(25,30,35), $\tilde{C}_h$=5, $\tilde{C}_1$=(10,15,20), a = 50,

b=5, $\tilde{C}_{Is}$ = (10,15,20), θ =0.5, r = 0.06, δ = 1.5 ,

Example 3

$\tilde{C}_a$ =(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,$\tilde{C}_{Is}$ =(10,15,20), θ=0.5, r = 0.06,δ = 0.06,

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

In the previously discussed example, a sensitivity analysis was conducted to examine how variations (both under and over estimations) in different parameters—such as demand, deterioration, inventory cost parameters, and mark-up rate—affect the maximum initial stock level, shortage level, cycle length, advertisement frequency, and overall system profit. This analysis involved adjusting (both increasing and decreasing) the parameters by -20% to +20%, either individually or in combination, while keeping 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^*
	–20	39.55	20.87	111.15	105.74
C_h	–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
	–20	0.20	1.43	-0.34	-0.19
C_b	–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
	–20	422.37	-36.56	93.67	-38.01
C_p	–10	231.17	-0.58	48.4	-27.71
	10	---	---	---	---
	20	---	---	---	---

	–20	35.53	-17.86	-13.70	-14.34
C_4	–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
	–20	---	---	---	---
a	–10	---	---	---	---
	10	344.54	3.14	48.18	-31.93
	20	744.36	-15.63	92.46	-43.40
	–20	661.44	-12.71	82.46	-41.85
b	–10	306.95	1.38	41.25	-30.63
	10	---	---	---	--
	20	---	---	---	---
	–20	-1.95	-3.72	-5.24	-5.65
	–10	-0.81	-2.20	-2.58	-2.87
r	10	10.90	21.55	58.31	56.28
	20	24.45	25.87	78.08	76.89

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 these models, the demand rate is represented as $D(A,p)=A^{V}(a-bp)$. It is well-known that $D(A,p)\propto(a-bp)$ for a fixed AAA. But why should we consider $D(A,p)\propto$ for fixed value of P? Typically, item demand fluctuates due to advertisement in well-known media such as radio, TV, newspapers, magazines, and cinema. As the frequency of advertisements increases, the demand for items also rises, being directly proportional to the number of advertisements. Therefore, we take $D(A,p)\propto AV$ for fixed p. This model is also relevant to scenarios where both the selling prices of items and their advertisements influence demand. It is applicable to fashionable goods and both two-level and single-level credit policy approaches.

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Cite this Article-

Mandeep Singh, Dr. Ravendra Kumar, Gaurav Gupta, "An Inventory Model with Fuzzy Valued Inventory Costs under Inflation Price and Time Dependent Demand", Procedure International Journal of Science and Technology (PIJST), ISSN: 2584-2617 (Online), Volume:1, Issue:7, July 2024.

Journal URL- https://www.pijst.com/

DOI- https://doi.org/10.62796/pijst.2024v1i7003

Published Date- 08/07/2024