A Deterministic Inventory Model For Weibull Deteriorating Items with Selling Price Dependent Demand And Parabolic Time Varying Holding Cost

Vipin Kumar, Anupama Sharma, C.B.Gupta

Abstract- This paper with development of an inventory model when deterioration rate follows Weibull two way parameter distributions. It is assumed that demand rate is function of selling price and holding cost is parabolic in terms of time. In this models both the cases with shortage and without shortage are taken into consideration. Whenever shortage allowed is completely backlogged. To illustrate the result numerical examples are given .the sensitive analysis for the model has been performed to study the effect of changes the value of parameters associated with the model. Mathematics Subject Classification: - 90B05

Keywords: - EOQ model, deteriorating items, Weibull distribution, shortage, price dependent demand, parabolic holding cost.

I. Introduction

These days researcher are paying more attention to the inventory model of deteriorating items. It's not easy to neglect the effect of deterioration, as it is a realistic feature and is very common in daily routine life. So have to consider it. Wee HM [1993] is the first one who define deteriorating items refers to the items that become decayed, damaged, evaporative, expired, invalid, devaluation and so on by the passing time. Traditionally, it was considered that the items can preserve their characteristics while they kept stored in inventory. But it is not true for all. Considering this fact, now a days it's a great challenge to control and maintain the inventory of deteriorating items for the decision makers. The first EOQ inventory model was developed by Harris [1915], which was further generalized by Wilson [1934] to obtain formula for economic order quantity. Within [1957] studied the deterioration of the fashion goods at the end of the prescribed shortage period. Ghare and Schrader [1963] developed a model for an exponentially decaying inventory. Mishra [1975] develop a model with Weibull deterioration rate without backordering. Moving further, Dave and Patel [1981] were the first to study a deteriorating inventory with linear increasing demand when shortages are not allowed. This model was further generalized by Sachan[1984] with allowed shortages. Further, work in this field has been done by Chung and Ting [1993]; Wee [1995] studied an inventory model with deteriorating items. Chang and Dye [1999] developed an inventory model with time-varying demand and partial backlogging. Goyal and Giri[2001] gave recent trends of modeling in deteriorating item inventory.

They classified inventory models on the basis of demand variations and various other conditions or constraints. With exponential declining demand and partial backlogging, Ouyang and Cheng [2005] developed an inventory model for deteriorating items. Alamri and Balkhi[2007] studied the effects of learning and forgetting on the optimal production lot size for deteriorating items with time-varying demand and deterioration rates. Dye [2007] find an optimal selling price and lot size with a varying rate of deterioration and exponential partial backlogging. They assume that a fraction of customers who backlog their orders increases exponentially as the waiting time for the next replenishment decreases.

Roy [2008] developed a deterministic inventory model when the deterioration rate is time proportional. Demand rate is a function of selling price, and holding cost is time dependent. Liao [2008] gave an economic order quantity (EOQ) model with non instantaneous receipt and exponential deteriorating item under two level trade credits. Pareek et al. [2009] developed a deterministic inventory model for deteriorating items with salvage value and shortages. Skouri et al. [2009] developed an inventory model with ramp-type demand rate, partial backlogging, and Weibull's deterioration rate. Mishra and Singh [2010] developed a deteriorating inventory model for waiting time partial backlogging when demand and deterioration rate is constant. Tripathy and Mishra [2010] give the model for deteriorating items with price dependent demand and linear holding cost. Mandal [2010] gave an EOQ inventory model for Weibull-distributed deteriorating items under ramp-type demand and shortages. Hung [2011] gave an inventory model with generalized-type demand, deterioration, and backorder rates. Mishra and Singh [2011] gave an inventory model for ramp-type demand, time-dependent deteriorating items with salvage value and shortages and deteriorating inventory model for time-dependent demand and holding cost with partial backlogging.

In this paper, we extend the paper of Tripathy, Mishra[2010]. we developed generalized EOQ model for deteriorating items where deterioration rate follows two-parameter Weibull distribution and holding cost are expressed as parabolic functions of time and demand rate considered to be function of selling price. For the model where shortages are allowed they are completely backlogged. Here we have considered both the case of with shortage and without shortage in developing the model.

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II. ASSUMPTIONS AND NOTATIONS

The fundamental assumptions of this model are as follows:-

b) The deterioration of units follows the two parameter Weibull distribution $\theta(t)=\alpha\beta t^{\beta-1}$ where 0<α<1 is the shape parameter
c) Demand rate is function of selling price.
d) Shortage whenever allowed, are completely backlogged.
e) Holding cost h(t)per item per time- unit is time dependent and is assumed to be $h(t)=h+\delta t^2$ where δ>0,h>0.
f) Selling price p follows an increasing trend, demand rate possess the negative derivative throughout its domain where demand rate is $f(p)=(a-p)$>0

a) The deterioration rate is proportional to time

g) T is the completelength of cycle.
h) Replenishment is instantaneous and lead time is zero.
i) The order quantity in one cycle is q.
j) A is the cost of placing an order.
k) The selling price per unit item is p.
l) C_1 is the unit cost of an item.
m) The inventory holding cost per unit per unit time is h(t).
n) C_2 is the shortage cost per unit per unit time..
o) Inventory is depleted due to deterioration and demand of the item. At time t_1 the inventory becomes zero and shortage starts occurring.

Mathematical formulation and solutions :-

Let Q(t) be the inventory level at time t ($0\le t\le T$). The differential equations to describe instantaneous state over (0,T) are given by

$$\frac{dQ(t)}{dt}+\alpha\beta t^{\beta-1}Q(t)=-(a-p) \qquad 0\le t\le t_1 \qquad \text{......... (1)}$$

$$\frac{dQ(t)}{dt}=-(a-p) \qquad t_1\le t\le T \qquad \text{..........(2)}$$

With $Q(t)=0 \; at \; t=t_1$

Solving equation (1) and equation (2) and neglecting higher power of α, we get

$$Q(t)=(a-p)(1-\alpha t^{\beta})\left\{(t_1-t)+\frac{\alpha}{\beta+1}(t_1^{\beta+1}-t^{\beta+1})\right\} \qquad 0\le t\le t_1$$

And

$$Q(t)=(a-p)(t_1-t) \qquad t_1\le t\le T$$

Now stock loss due to deterioration is given by:-

$$D=\int_0^t \alpha\beta t^{\beta-1}Q(t)dt$$

$$=(a-p)\left\{\frac{\alpha t_1^{\beta+1}}{\beta+1}\right\} \qquad \text{.....(3)}$$

Ordering quantity is given by:-

$$q=D+\int_0^T (a-p)dt$$

$$q=(a-p)\frac{\alpha t^{\beta+1}}{\beta+1}+(a-p)T$$

$$q=(a-p)\left[\frac{\alpha t^{\beta+1}}{\beta+1}+T\right]$$

Holding costis :-

$$H=\int_0^t (h+\delta t^2)Q(t)dt$$

$$=\int_0^{t_1}(h+\delta t^2)\left[(a-p)(1-\alpha t^{\beta})\left\{(t_1-t)+\frac{\alpha}{\beta+1}(t_1^{\beta+1}-t^{\beta+1})\right\}\right]dt$$

Neglecting higher power of $\alpha(\alpha^3 and\ higher)$, we get

$$H=h(a-p)\left[\frac{t_1^2}{2}+\frac{\alpha\ \beta\ t_1^{\beta+2}}{(\beta+1)(\beta+2)}-\frac{\alpha^2 t_1^{2\beta+2}}{2(\beta+1)^2}\right]+\ \delta(a-p)\left[\frac{t_1^4}{12}+\frac{\alpha\beta\ t_1^{\beta+4}}{3(\beta+3)(\beta+4)}-\frac{\alpha^2 t_1^{2\beta+4}}{(\beta+3)(2\beta+4)}\right] \quad .....(4)$$

Now Shortage cost during the cycle:-

$$S=\int_{t_1}^T Q(t)dt$$

$$S=(a-p)\frac{(t_1-T)^2}{2} \quad ....(5)$$

From equation (3), (4) and (5). Total profit per unit time is given by

$$P(T,t_1,p)=p(a-p)-\frac{1}{T}(A+C_1q+H+C_2S)$$

$$=p(a-p)-\frac{1}{T}\left[\begin{array}{l}A+C_1\left\{(a-p)\frac{\alpha t_1^{\beta+1}}{\beta+1}+(a-p)T\right\}+\\(a-p)\left\{h\left(\frac{t_1^2}{2}+\frac{\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)}-\frac{\alpha^2\beta t_1^{2\beta+2}}{2(\beta+1)^2}\right)+\delta\left(\frac{t_1^4}{12}+\frac{\alpha\beta\ t_1^{\beta+4}}{3(\beta+3)(\beta+4)}-\frac{\alpha^2 t_1^{2\beta+4}}{(\beta+3)(2\beta+4)}\right)\right\}+\\C_2\left\{\frac{1}{2}(a-p)(t_1-T)^2\right\}\end{array}\right]$$

..........(6)

Let $t_1=\gamma T$ $0<\gamma<1$

$$P(T,p)=p(a-p)-\frac{1}{T}\left[\begin{array}{l}A+C_1\left\{(a-p)\frac{\alpha\gamma^{\beta+1}T^{\beta+1}}{\beta+1}+(a-p)T\right\}+\\(a-p)\left\{\frac{h\gamma^2T^2}{2}+\frac{h\alpha\beta\gamma^{\beta+2}T^{\beta+2}}{(\beta+1)(\beta+2)}-\frac{h\alpha^2\gamma^{2\beta+2}T^{2\beta+2}}{2(\beta+1)^2}+\frac{\delta T^4\gamma^4}{12}+\frac{\delta\alpha\beta T^{\beta+4}\gamma^{\beta+4}}{3(\beta+3)(\beta+4)}-\frac{\delta\alpha^2T^{2\beta+4}\gamma^{2\beta+4}}{(\beta+3)(2\beta+4)}\right\}+\\C_2\left\{\frac{1}{2}(a-p)T^2(\gamma-1)^2\right\}\end{array}\right]$$

...........(7)

This equation gives the profit function P(T,p). In order to maximize the profit function P(T,p). the necessary conditions for are given by

$$\frac{\partial P(T,p)}{\partial T}=0 \text{ and } \frac{\partial P(T,p)}{\partial p}=0$$

We get

$$-\frac{A}{T^2}+C_1\left[\frac{(a-p)\alpha\gamma^{\beta+1}\beta T^{\beta-1}}{(\beta+1)}\right]+(a-p)\left[\begin{array}{l}\frac{h\gamma^2}{2}+\frac{h\beta\gamma^{\beta+2}T^{\beta+1}}{(\beta+2)}-\frac{h\alpha^2(2\beta+1)T^{2\beta}\gamma^{2\beta+2}}{(\beta+1)^2}+\frac{3\delta T^2\gamma^4}{12}+\\ \frac{\delta\alpha(\beta+2)}{(\beta+4)}T^{\beta+2}\gamma^{\beta+4}-\frac{\delta\alpha^2(2\beta+3)}{(\beta+3)(2\beta+4)}T^{2\beta+2}\gamma^{2\beta+4}\end{array}\right]+C_2\left[\frac{1}{2}(a-p)(1-\gamma^2)\right]=0 \quad \ldots\ldots\ldots (8)$$

And

$$(a-2p)-\frac{1}{T}\left[\begin{array}{l}C_1\left\{-\frac{\alpha\gamma^{\beta+1}T^{\beta+1}}{\beta+1}-T\right\}+\\ -h\left\{\frac{\gamma^2T^2}{2}+\frac{\alpha\beta\gamma^{\beta+2}T^{\beta+2}}{(\beta+1)(\beta+2)}-\frac{\alpha^2\beta\gamma^{2\beta+2}T^{2\beta+2}}{(\beta+1)^2}+\frac{\delta T^4\gamma^4}{12}\right\}-\delta\left\{\frac{\alpha(\beta+2)T^{\beta+4}\gamma^{\beta+4}}{(\beta+3)(\beta+4)}-\frac{\alpha^2T^{2\beta+4}\gamma^{2\beta+4}}{(\beta+3)(2\beta+4)}\right\}\\ -C_2\{(T^2-T^2\gamma^2)\}\end{array}\right]=0 \quad \ldots\ldots\ldots (9)$$

Using the software Mathematica-5.1 and Ms. Excel from the equations (8) and (9) we can calculate the optimum value of T^* and P^* simultaneously and the optimal value $P^*(T,P)$ of the average net profit is determined by (7) provided they satisfy thesufficiency conditions for maximizing $P^*(T,P)$ are $\frac{\partial^2 P(T,P)}{\partial T^2}<0$, $\frac{\partial^2 P(T,P)}{\partial P^2}<0$ ...…… (10)

And

$$\frac{\partial^2 P(T,P)}{\partial T^2}\frac{\partial^2 P(T,P)}{\partial T^2}-\left(\frac{\partial^2 P(T,P)}{\partial T\partial P}\right)>0 \text{ at } P=P^* \text{ and } T=T^* \quad \ldots\ldots\ldots\ldots(11)$$

If the solution obtained from the equations (8) and (9) do not satisfy the sufficiency conditions (10) and (11), we conclude that no feasible solution will be optimal for the set of parameter values taken to solve equations (8) and (9). Such a situation will imply that the parameter values are inconsistent and there is some error in estimation.

Numerical Example

Case-I (with Shortage)

Example-1:

Let A=200, a=100, C_1=02, C_2=1.2, h=0.4, α=0.1, β=0.3, γ=0.95, δ=0.1

Based on these input data, the computed outputs are as follows:

$P^*(T,p)$= 2176.13098 , T^*=3.016752, p^*=61.37400909, q=128.2031048, t_1^*=2.8659144

Case-II (without shortage)

Example-2:

Let A=200, a=100, C_1=02, C_2=1.2, h=0.4, α=0.1, β=0.3, γ=0.95, δ=0.1

P^*(T,p)= 2176.08584 , T^*=3.020025, p^*=61.37274, q=128.3504332, t_1^*=2.86902375

III. SENSITIVE ANALYSIS

Change in parameters will affect the result also. So in order to find that change proper sensitive analysis is performed for this model. It is done by taking 20% and 50% variation in parameters. For this analysis one parameter is changed and others remain the same. Applying this concept how the result will fluctuate is shown in tables below. Table 1 shows the result with shortage and table 2 without shortage.

Table-1

Parameters	% change	profit(P)	Selling Price(p)	Time(T)	Ordering Quantity(q)
A	-50	2236.955	61.15092	2.1994796	93.23698
	-20	2197.618824	61.29666213	2.7399797	116.3720078
	20	2157.03013	61.4421507	3.2521502	138.249728
	50	2131.53398	61.5324196	3.55157005	150.999638
A	-50	374.0318456	36.85894075	4.51387209	66.02581247
	-20	1302.03042	51.48899303	3.4093714	107.3107794
	20	3253.22393	71.29443992	2.7319052	146.0033509
	50	5247.956586	86.20907549	2.4173191	168.6637566
C_1	-50	2250.656664	55.88924629	3.0856412	149.8437636
	-20	2213.443013	59.17923002	3.0378967	136.4637002
	20	2128.849308	63.57090155	3.0004886	120.4230574
	50	2039.259088	66.87162472	3.006128	109.5584425
C_2	-50	2176.108429	61.3734027	3.0183882	128.2767524
	-20	2176.121962	61.37380267	3.0174065	128.2325638
	20	2176.139965	61.37433564	3.0160986	128.173694
	50	2176.153435	61.38264982	3.01511856	128.1033277
H	-50	2172.800186	61.28782515	3.2313717	137.8915969
	-20	2175.849426	61.36588492	3.036919002	129.1110161
	20	2177.15061	61.40592948	2.9388363	124.700015
	50	2178.380326	61.45130286	2.82985692	119.8123853
Δ	-50	2169.684573	61.39021202	3.27794104	139.5645867
	-20	2174.040943	61.37929225	3.1058092	132.075309
	20	2177.806294	61.36989909	2.9412048	124.9197558
	50	2179.777823	61.36502367	2.8460173	120.7847718
α	-50	2186.202713	60.9222242	3.2258022	132.5022242
	-20	2180.165371	61.19528122	3.0984413	129.9517231

	20	2172.081007	61.55033486	2.9376101	126.4262034
	50	2165.962749	61.81015853	2.8236457	123.7269899
β	-50	2170.652767	61.3933897	3.2605175	138.197948
	-20	2173.967341	61.38286541	3.1153586	132.2649674
	20	2178.22253	61.36356811	2.9178894	124.1040955
	50	2181.152695	61.34441857	2.77167401	117.9929145
Γ	-50	2163.647708	60.903993	4.1436418	169.2681614
	-20	2168.910203	61.1331751	3.62118963	151.9225164
	20	2176.586133	61.65910658	2.5095107	107.7822901
	50	2165.48177	62.13238308	1.9614091	85.35600178

Study of the Table-1 reveals the following:-

(i) If value of parameter **A** increase, it will lead to increase in T^*, p^*, q^* and decrease in P^*.
(ii) If value of parameter **a** increase, it will lead to increase in p^*, q^* and decrease in T^*, P^*.
(iii) If value of parameter C_1 increase, it will lead to increase of p^* and decrease in T^*, P^*, q^*.
(iv) If value of parameter C_2 increase, it will lead to increase of p^*, P^* and decrease in T^*, q^*.
(v) If value of parameter **h** increase, it will lead to increase of p^*, P^* and decrease in T^*, q^*.
(vi) If value of parameter **δ** increase, it will lead to increase of p^* and decrease in T^*, P^* q^*.
(vii) If value of parameter **α** increase, it will lead to increase of p^* and decrease in T^*, q^*, P^*.
(viii) If value of parameter **β** increase, it will lead to increase of P^* and decrease in T^*, q^*, P^*.
(ix) If value of parameter **γ** increase, it will lead to increase of p^*, P^* and decrease in T^*, q^*.

Table-2

Parameters	**% change**	**profit(P)**	**Selling Price(p)**	**Time(T)**	**Ordering Quantity(q)**
A	-50	2236.902738	61.15007019	2.20249893	93.37022322
	-20	2197.569291	61.29549736	2.7432213	116.5168586
	20	2156.989936	61.44067126	3.2554191	138.3978786
	50	2131.501336	61.53075279	3.5548016	151.1475082
A	-50	374.0609137	36.85659808	4.5166688	66.0797463
	-20	1302.011763	51.48740959	3.4126051	107.4214039
	20	3253.154718	71.29328207	2.7351526	146.184999
	50	7696.189801	101.1458605	2.1866294	188.1150191
C_1	-50	2250.564302	55.8877906	3.08925694	150.0291324
	-20	2213.380205	59.17785348	3.04130303	136.6255137
	20	2128.820317	63.56960267	3.0080338	120.5569521
	50	2039..251893	66.87036202	3.0091046	109.6740385
H	-50	2172.735969	61.28632649	3.2351203	138.061362
	-20	2175.802489	61.36453646	3.0402381	129.260501

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	20	2177.112307	61.40465194	2.94193205	124.839072
	50	2178.351414	61.45010015	2.8327022	119.9398298
δ	-50	2169.593424	61.38886906	3.2825826	139.7726007
	-20	2173.982053	61.37795079	3.1094991	132.2411416
	20	2177.77145	61.36857535	2.9441595	125.0529418
	50	2179.7544	61.36371618	2.8486108	120.9018934
α	-50	2186.15188	60.9206783	3.2293634	132.6558868
	-20	2180.117475	61.19386535	3.1018323	130.1018847
	20	2172.03881	61.54907988	2.9407637	126.5703994
	50	2165.9253	61.80901448	2.82661697	123.8659165
β	-50	2170.594734	61.39182933	3.2641596	138.3599769
	-20	2173.916421	61.38124427	3.1187981	132.4190378
	20	2178.183783	61.36231581	2.9209759	124.2437297
	50	2181.124252	61.34327353	2.7744527	118.1196042
Γ	-50	2104.99109	60.68322211	5.9956571	247.5201975
	-20	2165.577008	61.09615503	3.7638321	158.1610021
	20	2176.576256	61.65037456	2.52424795	108.4603971
	50	2167.207683	62.06586609	2.0286134	88.54527991

Study of the Table-2 reveals the following:-

(i) If value of parameter **A** increase, it will lead to increasein**T***, p^*, q^* and decrease in P^*.
(ii) If value of parameter **a** increase, it will lead to increase of p^*, q^*, $P^*$and decrease in **T***.
(iii) If value of parameter C_1 increase, it will lead to increase of $p^*$and decrease in **T***, P^*, q^*.
(iv) If value of parameter **h** increase**,** it will lead to increase of p^*, P^* and decrease in **T***, q^*.
(v) If value of parameter **δ** increase, it will lead to increase of P^* and decrease in **T***, p^* q^*.
(vi) If value of parameter α increase, it will lead to increase ofp^* and decrease in **T***, q^*, P^*.
(vii) If value of parameter βincrease, it will lead to increase of P^* and decrease in **T***,q^*, P^*.
(viii) If value of parameter γincrease, it will lead to increase of p^*, P^* and decrease in **T***, q^*.

IV. CONCLUSION

In this paper we developed deterministic inventory model for deteriorating items for with shortage and without shortage cases. The deterministic demand rate is assumed to be a function of selling price. Whenever shortage are allowed, are completely backlogged and holding cost is assumed to be parabolic time dependent. We can make a good comparative study between the result of the with shortage and without shortage case. In the numerical examples, it is found that the optimum average profit in without shortage case is more than that of the with shortage case. From the above model one can calculate the optimum average profit margins for the shortage case and without shortage case for the deterministic inventory model with varying demand rate and holding cost subjected to the conditions.

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