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An EOQ Model for two-parameter weibull distribution deteriorating item, advertisement and selling price depended demand, linearly time dependent holding cost with salvage value and shortages

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Abstract: In this paper, a deterministic inventory model have been developed for deteriorating item with two-parameter Weibull distribution deterioration with selling price and advertisement cost dependent demand. Shortages are allowed and partially backlogged. The backlogging rate is dependent on the waiting time for the next replenishment. The holding cost is considered as linearly time dependent .The salvage value is also used for deteriorated items in the system. Objective is to minimize the total inventory cost. The whole combination of the setup is very unique and more practical. Finally, numerical example is presented to demonstrate the developed model and sensitivity analysis have been carried out for showing the effect of variation of parameters. The procedure presented here may be applied to many practical situations.

Keywords: Deterioration, Linearlytime varying holding cost, Weibull distribution (2-parameter), partial backlogging, salvage value. Introduction

I. Introduction and Literature Review

Many Researchers have developed inventory models to maximize the income (or) to minimize the total cost for deteriorating objects with respect to time. In real life deterioration of item is common phenomenon. There are many products in real life that are subject to significant rate of deterioration. The rate of deterioration is little in some items like toys, steal objects and hardware. But some items such as fish, vegetable, bread, fruits and alcohol have finite shelf life and deterioration rapidly over time. Deterioration in each item cannot be completely avoided and the rate of deterioration for each item will vary. [1] Azizul Baten and Abdulbasah developed an inventory model in which the shortages are not allowed with constant demand and deterioration rate. Many Researchers were paying attention in taking weibull deteriorating rate (in two (or) three). [2]Azizul Baten and Abdulbasah also offered a review for Weibull distributed deterioration . Misra [3] adopted a two-parameter Weibull distribution deterioration to build up an inventory model with finite rate of replenishment. Some researchers Chen and Lin [4]; Samanta, Bhowmick, [5]; jain and kumar [6]; Sharma et al., [7] extended the models for deterioration which follows Weibull distribution.

Mishra [8] projected an inventory model of constant demand with Weibull rate of deterioration. He incorporated variable carrying cost considering shortages and salvage value. Vikas Sharma and Rekha [9] studied an EOQ model for time dependant demand for deteriorating products with Weibull deterioration rate, also considering shortages. Venkateswarlu and Mohan[10] proposed an EOQ model with 2- parameter Weibull deterioration, time dependent quadratic demand and salvage cost. Venkateswarlu and Mohan[11] developed an EOQ model for time varying deterioration and price dependent quadratic demand with salvage cost. Mohan and Venkateswarlu[12] studied an inventory management models with variable holding cost and salvage value. Mohan and Venkateswarlu[13],[21] proposed an inventory model for, time Dependent quadratic demand with salvage considering deterioration rate is time dependent.

When the shortage occurs, some clients are willing to stay for back order and others would turn to purchase from other sellers. Inventory model of deteriorating items with time proportional backlogging rate have been studied by Chang [14], Philip [15], Dye [23],Park [24] and Wang [25] studied shortages andpartial backlogging of items. Chakrabarty, Giri& Chuadhuri[16], studied an EOQ model for things with Weibull distribution deterioration, shortages and trended demand: an extension of Philip's model. Ghosh &Chaudhuri[17],calculated an order-level Inventory model for a deteriorating item with Weibull distribution deterioration, time-quadratic demand and shortages. An Economic Order Quantity form for Weibull deteriorating items with power demand and partial backlogging have been considered by Tripathy and Pradhan [18]. 2- parameter Weibull distribution demand was studied by Amutha &Chandrasekaran[20]. Weibull distribution deteriorating object, power pattern demand with shortage and time dependent holding cost was considered by Anil kumar

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sharma, Manojkumar sharma and Nisha ramani[19] . An inventory model with Weibull distribution deterioration and time-dependent demand considered by Vashistha [22]. An Economic order quantity model for Items with Weibull distribution Deterioration,Ramp-type Demand and Shortages have been studied by Sanni & Chukwu[26].

In the current competitive market, the selling policies and promotion of a product in the form of advertisement, put on display, etc. modify the demand pattern of that item amongst the clients and give a motivational effect on the people to purchase more. Also, the selling cost of an item is one of the significant parameters in selecting an item for use. It is commonly seen that higher selling price causes decrease in demand whereas lesser selling price has the reverse effect. Hence, it can be concluded that the demand of an item is a function of marketing cost and selling cost of an article. Kotler [27] incorporated marketing policies into inventory decisions and studied the relationship between economic order quantity and decision. Ladany [28] discussed the effect of price difference on demand and so on EOQ. Subramanyan [29], Urban [30], Goyal and Gunasekaran [31] and Luo [32] developed inventory models incorporating the effect of price variations and advertisement on demand.

An EPQ inventory model for non-instantaneous deteriorating items under trade credit policy studied by Vandana and Sharma [33].An inventory model for Non-Instantaneous deteriorating items with quadratic demand rate and shortages under trade credit policy studied by Vandana and Sharma [34]. An EOQ model for retailers partial permissible delay in payment linked to order quantity with shortages studied by Vandana, Sharma [35].

In this paper, we have considered an order level inventory problem when demand is deterministic function which includes selling price and advertisement cost, 2-parameter Weibull deterioration and linearly time variable holding Cost. Shortages are allowed and partially backlogged. The backlogging rate is variable and dependent on the waiting time for the next replenishment. The time horizon is infinite. Salvage price is also measured for the optimal total cost. Suitable mathematical example and sensitivity investigation are also carried out.

II. Assumptions and Notations

A. *Assumptions*

1. The inventory system deals with single item over the fixed period T.
2. The lead time is zero.
3. A finite planning horizon is assumed.
4. There is no replacement or repair of deteriorated items takes place in a given cycle but salvage value is considered.
5. The demand rate D is a deterministic function of selling price ζ and advertisement cost AC per unit of item i.e. $D(AC, \zeta) = A_c^{\eta}\gamma\, \zeta^{-\lambda}$, $\gamma > 0$, $\lambda > 1$, $0 \le \eta < 1$, γ is the scaling parameter, λ is the index of price elasticity and η is the shape parameter.
6. The rate of deterioration at any time t > 0 follows the two-parameter Weibull distribution as $\Theta(t)= \alpha\beta t^{\beta-1}$,where α $(0 < \alpha << 1)$ is the scalar parameter and $\beta > 0$ is the shape parameter. The rate of deterioration-time relationship for this distribution is as revealed in Fig. 1. It is seen from equation $\Theta(t)$ and Fig. 1 that the two-parameter Weibull distribution is suitable for an item with decreasing rate of deterioration only if the initial rate of deterioration is very high. Similarly, this distribution can also be used for an item with rising rate of deterioration only if the initial rate is more or less zero.

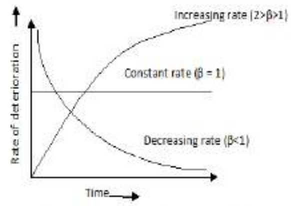

Fig. 1. Rate of deterioration-time relationship for a two-factor Weibull distribution.

Three parameter Weibull distribution deterioration rate can also be considered (Fig 2). It takes the following form:

$\Theta(t)=\alpha_1 \beta_1 (t - \gamma)^{\beta_1-1}$ where

α_1=scalar parameter, $\alpha_1>0$

β_1=shape parameter , $\beta_1>0$

t = time of demand , t >0

γ= location parameter , $t \ge \gamma$.

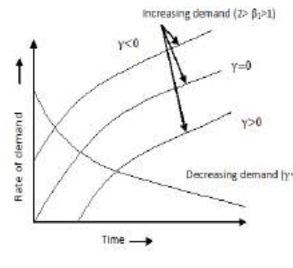

Fig. 2. Rate of demand-time relationship for 3-factor Weibull distribution.

7. Deterioration of the units is measured only after they have been collected into the inventory.

8. The demand rate in the shortage period is assumed to be constant 'μ'.
9. Carrying cost is a linear function of time H(t) =a + b t , a> 0,b> 0.
10. Shortages are allowed and during stock out period, the backlogging rate is variable and is dependent on the length of the waiting time for next replenishment, so that the backlogging rate for negative inventory is $B(t) = \frac{1}{1+\delta(T-t)}$ where δ is the backlogging parameter such that 0< δ <1 and the parameter (T-t) is waiting time $t_1 \le t \le T$.And the remaining fraction 1-B(t) is lost sale.

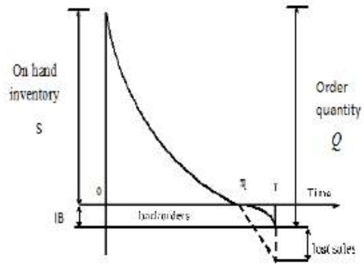

Fig.3. Graphical representation of the inventory system

B. Notations

$I_1(t)$	The inventory level at time 't' ,$0 \le t \le t_1$
$I_2(t)$	The inventory level at time 't ' , $t_1 \le t \le T$
Q	The order size per cycle
S	The initial inventory level
T	The length of the order cycle
p	Unit purchase cost
A	Ordering cost per order
C_1	The deterioration cost per unit per cycle
πC_1	Salvage price related with deteriorated units during a cycle time, $0 \le \pi < 1$.
C_2	The shortage cost for backlogged things per unit per cycle.
C_3	The unit cost of lost sales per unit
t_1	The length of the time in which the inventory has no shortage
H(t)	Holding cost
TC	Total average cost per unit time
δ	Backlogging parameter
B(t)	Backlog inventory level.

III. FORMULATION OF THE MODEL

The inventory structure is developed as follows: At the opening of each cycle the total amount of inventory produced or purchased is assumed to be Q. Let the initial inventory be S. The inventory level is dropping to zero due to demand and deterioration during the time interval $[0, t_1]$. Shortages take place due to demand in the period $[t_1, T]$,which is partially backlogged. The behaviour of the inventory model is established in figure-3.

Based on the above description, during the time interval $[0, t_1]$, the differential equation representing the inventory status is given

$$\frac{d I_1(t)}{dt} + \alpha\beta\, t^{\beta-1} I_1(t) = A_c^{\eta}\gamma\,\zeta^{-\lambda},\ 0 \le t \le t_1 \quad (1)$$

During the third interval $[t_1, T]$, shortage occurred and the demand is partially backlogged. That is, the inventory status at time t is governed by the subsequent differential equation:

$$\frac{d I_2(t)}{dt} = \frac{-\mu}{1+\delta(T-t)},\quad t_1 \le t \le T \quad (2)$$

The boundary conditions are

$$I_1(0) = s,\quad I_1(t_1) = 0\ \ and\ \ I_2(t_1) = 0 .$$

The solution of equation (1) is

$$I_1(t) = -A_c^{\eta}\gamma\,\zeta^{-\lambda}\left[t + \frac{\alpha}{\beta+1}\, t^{\beta+1}\right] + c_1$$

Using $I_1(0) = s$, We get $s = c_1$.

$$\therefore\ I_1(t) = \left[s - A_c^{\eta}\gamma\,\zeta^{-\lambda}\left(t + \frac{\alpha}{\beta+1}\, t^{\beta+1}\right)\right] e^{-\alpha t^{\beta}} \quad (3)$$

Also, $I_1(t_1) = 0$, We get $s = A_c^{\eta}\gamma\,\zeta^{-\lambda}\left[t_1 + \frac{\alpha}{\beta+1}\, {t_1}^{\beta+1}\right]$ (4)

Using (4) in (3), We get

$$I_1(t) = A_c^{\eta}\gamma\,\zeta^{-\lambda}\left[\begin{array}{c} t_1 - t - \alpha t_1 t^{\beta} + \alpha t^{\beta+1} + \frac{\alpha}{\beta+1}\, {t_1}^{\beta+1} - \frac{\alpha}{\beta+1}\, t^{\beta+1} \\ -\frac{\alpha^2}{\beta+1} {t_1}^{\beta+1}\, t^{\beta} + \frac{\alpha^2}{\beta+1} t^{2\beta+1} \end{array}\right] \quad (5)$$

The solution of equation (2) is

$$I_2(t) = -\mu\left[t - \delta T t + \frac{\delta t^2}{2}\right] + c_2$$

Using $I_2(t_1) = 0$, We get

$$c_2 = \mu\left[t_1 - \delta T t_1 + \frac{\delta {t_1}^2}{2}\right]$$

$\therefore\ I_2(t) = \mu(t_1 - t)\left[1 - \delta T + \frac{\delta}{2}(t_1 + t)\right]$

(6)

The maximum backordered inventory BI is attained at $t = T$, then from equation (6)

$\text{BI} = -\text{I}_2(\text{T}) = \mu(\text{t}_1 - \text{T})\left[1 + \frac{\delta}{2}(\text{t}_1 - \text{T})\right]$

(7)

Thus the order amount during total time interval $[0, T]$ is

$Q = \text{S} + \text{BI} = A_c^{\eta}\gamma\,\zeta^{-\lambda}\left[t_1 + \frac{\alpha}{\beta+1}t_1^{\beta+1}\right] + \mu(t_1 - T)\left[1 + \frac{\delta}{2}(t_1 - T)\right]$

(8)

Total average cost per cycle (TAC) = (Set-up cost + inventory holding cost + Purchase cost + deterioration cost + shortage cost + lost sales cost – Salvage value) / T.

(i) The Set-up cost during the period [0, T] is
Set-up cost = $\frac{A}{T}$

(ii) The holding cost during the period [0, T] is
Inventory holding cost

$= \frac{1}{T}\int_0^{t_1}(a + bt)\ I_1(t)\,dt$

$= \frac{A_c^{\eta}\gamma\,\zeta^{-\lambda}}{T}\left[\frac{a}{2}t_1^{2} + \frac{b}{6}t_1^{3} + \frac{a\alpha\beta}{(\beta+1)(\beta+2)}t_1^{\beta+2} - \frac{a\alpha^2}{2(\beta+1)^2}t_1^{2(\beta+2)} + \frac{b\alpha\beta(\beta-9)}{2(\beta+1)(\beta+2)(\beta+3)}t_1^{\beta+3} - \frac{b\alpha^2}{(\beta+2)(2\beta+3)}t_1^{2\beta+3}\right]$

(iii) The Purchase cost during the period [0, T] is
Purchase cost = $\frac{pQ}{T}$

$= p\frac{A_c^{\eta}\gamma\,\zeta^{-\lambda}}{T}\left[t_1 + \frac{\alpha}{\beta+1}t_1^{\beta+1}\right] + \frac{p\,\mu\,(t_1 - T)}{T}\left[1 + \frac{\delta}{2}(t_1 - T)\right]$

(iv) The deteriorating cost during the period [0, T] is
Deterioration cost = $\frac{C_1}{T}\left[s - \int_0^{t_1}D(t)dt\right]$

$= \frac{c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}}{T}\ \frac{\alpha}{\beta+1}\ t_1^{\beta+1}$

(v) Total shortage cost during the period [0, T] is given by Shortage cost = $-\frac{C_2}{T}\left[\int_{t_1}^{T}I_2(t)dt\right]$

$= \frac{C_2\mu\,(T - t_1)}{T}\left[\frac{T - t_1 + \delta T^2 - \delta t_1^2}{2} + \frac{\delta}{6}(T^2 + t_1^2) + \frac{2}{3}\delta T t_1 + \delta T\right]$

(vi) The lost sales cost during the period [0, T] is
Lost sales during the period (0,T)

$= \frac{C_3}{T}\int_{t_1}^{T}\left[1 - \frac{1}{1+\delta(T-t)}\right]\mu\,dt$

$= -\frac{C_3}{T}\delta\mu(T - t_1)t_1$

(vii) The Salvage value during the period [0, T] is
Salvage value = $\frac{\pi c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}}{\text{T}}\frac{\alpha}{\beta+1}\ t_1^{\beta+1}$

$\therefore\ \text{TAC}(t_1)$

$= \frac{1}{T}\left\{A + A_c^{\eta}\gamma\,\zeta^{-\lambda}\left[\frac{a}{2}t_1^{2} + \frac{b}{6}t_1^{3} + \frac{a\beta\alpha}{(\beta+1)(\beta+2)}t_1^{\beta+2} - \frac{a\alpha^2}{2(\beta+1)^2}t_1^{2(\beta+1)} + \frac{b\alpha\beta(\beta-9)}{2(\beta+1)(\beta+2)(\beta+3)}t_1^{\beta+3} - \frac{b\alpha^2}{(\beta+2)(2\beta+3)}t_1^{2\beta+3}\right] + pA_c^{\eta}\gamma\,\zeta^{-\lambda}\left[t_1 + \frac{\alpha}{\beta+1}t_1^{\beta+1}\right] + p\,\mu\,(t_1 - T)\left[1 + \frac{\delta}{2}(t_1 - T)\right] + c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}\frac{\alpha}{\beta+1}t_1^{\beta+1} + C_2\mu\,(T - t_1)\left[\frac{T - t_1 + \delta T^2 - \delta t_1^2}{2} + \frac{\delta}{6}(T^2 + t_1^2) + \frac{2}{3}\delta T t_1 + \delta T\right] - c_3\delta\mu(T - t_1)t_1 - \pi c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}\frac{\alpha}{\beta+1}t_1^{\beta+1}\right\}$

IV. *SOLUTION PROCEDURE*

The necessary and sufficient conditions for minimization of $\text{TAC}(t_1)$ are respectively $\frac{d\,\text{TAC}(t_1)}{dt_1} = 0$ *and* $\frac{d^2\ \text{TAC}(t_1)}{dt_1^{\,2}} > 0$.

$\frac{d\,\text{TAC}(t_1)}{dt_1} = 0 \Rightarrow$

$A_c^{\eta}\gamma\,\zeta^{-\lambda}\left[at_1 + \frac{b}{2}t_1^{2} + \frac{a\alpha\beta}{(\beta+1)}t_1^{\beta+1} - \frac{a\alpha^2}{(\beta+1)}t_1^{2\beta+1} + \frac{b\alpha\beta(\beta-9)}{2(\beta+1)(\beta+2)}t_1^{\beta+2} - \frac{b\alpha^2}{(\beta+2)}t_1^{2(\beta+1)}\right] + pA_c^{\eta}\gamma\,\zeta^{-\lambda}[1 + \alpha\,t_1^{\beta}] + p\,\mu\,[1 + \delta\,(t_1 - T)] + c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}\alpha\,t_1^{\beta} + C_2\mu\,[t_1 - T - \delta T + \delta t_1^{2} + 2\delta T t_1] - c_3\delta\mu(T - 2t_1) - \pi c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}\alpha\,t_1^{\beta} = 0$ (9)

$B = \frac{d^2\ \text{TAC}(t_1)}{dt_1^{\,2}} = \frac{1}{T}\left\{A_c^{\eta}\gamma\,\zeta^{-\lambda}\left[a + b\,t_1 + a\alpha\beta t_1^{\beta} - \frac{a\alpha^2(2\beta+1)}{(\beta+1)}t_1^{2\beta} + \frac{b\alpha\beta(\beta-9)}{2(\beta+1)}t_1^{\beta+1} - \frac{2b\alpha^2(\beta+1)}{(\beta+2)}t_1^{2\beta+1}\right] + pA_c^{\eta}\gamma\,\zeta^{-\lambda}\alpha\,\beta t_1^{\beta-1} + p\mu\,\delta + c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}\alpha\beta\,t_1^{\beta-1} + C_2\mu\,[2\delta(t_1 - T) + 1] + 2c_3\delta\mu - \pi c_1A_c^{\eta}\gamma\,\zeta^{-\lambda}\alpha\,\beta t_1^{\beta-1}\right\} > 0$

(10)

The optimal solution of the equations (9) and (10) can be obtained by using the Mathematical software. This has been illustrated by the following numerical example.

V. *NUMERICAL EXAMPLE AND SENSITIVITY ANALYSIS*

In this section, a numerical example and sensitivity analysis are given to illustrate the proposed model.

A. *Numerical example*

The above theory can be illustrated by considering the following numerical examples.

EXAMPLE 1

Consider an inventory system with the following data:

$T = 5$, α=0.06, β=3.5, a=5, b=4, p=19, μ =2, δ=0.5, $\pi = 0.75$, c_1=15, c_2=7, c_3=5, A=15, ζ = 25, Ac = 80, η = 0.04, γ = 400, λ = 2.5.

Based on these input data, the outputs (optimal values) are:

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t_1=2.10668, B = 6.99 , Q =300.367,TAC(t_1) = Rs.3608.80.

EXAMPLE 2

Consider an inventory system with the following data: T = 5.2; α=0.08,β=3.7,a=5.3,b=4.2,p=21,μ=2.1,δ=0.53, $\pi = 0.8$, c_1=16,c_2=9,c_3=7,A=14, ζ = 28, Ac = 85, η = 0.05, γ = 410, λ = 2.6.

Based on these input data, the outputs (optimal values) are: t_1=2.33524, B = 7.20 , Q =321.514,TAC(t_1) = Rs.3728.25.

EXAMPLE 3

Consider an inventory system with the following data: T = 5.6 ;α=0.03,β=3.9,a=5.6,b=4.3,p=25,μ=2.5,δ=0.6, $\pi = 0.84$, c_1=19,c_2=6,c_3=8,A=12, ζ = 29, Ac = 83, η = 0.01, γ = 411, λ = 2.9.

Based on these input data, the outputs (optimal values) are: t_1=2.78542, B = 6.42 , Q =317.002,TAC(t_1) = Rs.3876.16.

B. Sensitivity analysis

We studied the effects due to change in parameters α, β, μ and δ and on the optimal values of t_1, T , Q and TAC(t_1).

Table 1: **Effect of scale parameter (α):**

α	t_1	Q	TAC(t_1)
0.08	2.20583	364.301	4291.64
0.09	2.16104	332.919	3967.65
0.10	2.10668	300.367	3608.80
0.11	2.03841	265.392	3192.13
0.12	1.94605	225.665	2674.87
0.13	1.80182	176.654	1972.90

Table 2: **Effect shape parameter(β):**

β	t_1	Q	TAC(t_1)
2.9	2.16113	319.922	3797.19
3.0	2.10668	300.367	3608.80
3.1	2.05423	281.740	3421.70
3.2	2.00346	263.944	3234.87
3.3	1.95403	246.895	3047.38
3.4	1.90563	230.524	2858.47

Table 3: **Effect of parameter (μ):**

μ	t_1	Q	TAC(t_1)
0.80	2.11103	289.653	3431.23
0.90	2.10891	295.121	3520.87
1.00	2.10668	300.367	3608.80
1.10	2.10437	305.392	3695.22
1.20	2.10201	310.192	3780.27
1.30	2.09964	314.761	3864.09

Table 4: **Effect of backlogging parameter (δ):**

δ	t_1	Q	TAC(t_1)
1.10	1.86481	218.499	2083.04
1.20	2.10668	300.367	3608.80
1.30	2.20534	335.477	4521.17
1.40	2.26035	354.426	5132.44
1.50	2.29274	364.635	5540.06
1.60	2.31160	369.556	5804.35

VI. MANAGERIAL IMPLICATIONS

From the above tables, we survey some interesting facts. We notice that quantity ordered Q and total average cost TAC(t_1) of the system decrease with the increment in parameters α and β while these parameters increase with the increment in parameters μ and δ. Parameter $t_1$decreases with the increment in parameters α, β and μ while t_1 increases with the increment in parameter δ.

VII. CONCLUSION

This paper deals an order level inventory model for deteriorating items with two parameter weibull distribution deterioration with selling price and advertisement dependent demand. In the present situation, advertisement and selling price are also main parameters. In keeping with this reality, these parameters are incorporated in the present model. Also, shortage is permitted and can be partially backlogged, where the backlogging rate is a function of time of waiting for the next replenishment. Holding cost is taken as function of time. Different costs have been calculated and the numerical example and sensitive analysis are carried out.

The procedure presented here may be applied to many practical circumstances. Retailers in supermarket face this type of problem to deal with highly perishable seasonal products. Furthermore, this model can be adopted in the inventory control of retail business such as food industries, seasonable cloths, domestic goods, automobile, electronic components etc.This paper can be extended in several ways, for instance, we may extend the model by considering the non – zero lead time. Also, we may consider three parameters Weibull distribution deterioration in the model. Finally, we can expand the model by allowing demand function as stochastic.

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