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Inventory model with limited storage problem for deteriorating items

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Abstract:
In this paper, a production inventory model for perishable goods is developed. The problem of shortage is one of the major problems in inventory management, so to overcome this we have used two different warehouses, since the condition of the warehouses is also different, hence there are two different demands for different warehouses. To reduce the storage problem, one of the supplier warehouses has a limited quantity of goods in one warehouse which is Own Warehouse (OW), while the other warehouse is of inadequate capacity and has to be used as a rented warehouse (RW), Numerical examples have been used to understand the model in real life, and sensitivity analysis for some influential parameters is used.
Keywords: *Deteriorating items, Shortage, learning effect, warehouse*

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I. Introduction:

The classical EPQ model assumes that all the materials produced by the machine during production in the production plant are of high quality and exquisite. But, it has been observed many times that due to machine failure, raw material malfunction or human error, the machine can produce goods of imperfect quality. Therefore, the rate of production of all defective goods cannot be ignored. Defective goods can be classified into two categories, the first stage includes those goods that are sorted and made suitable for use, and are sent to the market. It has been observed many times that when there is an attractive discount on purchases, the demand for the goods becomes very high, which creates the problem of frequent purchases, in which case the management decides to buy the goods in large quantities. Due to limited storage capacity in the market, these items cannot be accommodated in their warehouse. In this situation additional warehouse is required for additional storage which is owned or rented, and we believe that the capacity of rented warehouse is more than own warehouse. Due to which the goods can be delivered to the consumer in any condition. Padiyar et al. (2022) developed a multi echelon supply chain model with inflation. Singh et al. (2018) presented an inventory model for deteriorating items having limited storage problem with time dependent demand under the effect of inflation. Roy et al. (2020) described a two -warehouse inventory model for deteriorating items with shortage and price discount policy under trade credit.

It is generally seen that due to the high demand of a commodity, fulfilment of customers wish or discount in inventory, people related to business like manufacturer, importer, exporter, wholesaler, transporter etc, ordered more quantity of goods, this extra inventory needs extra space to keep them which is called Rented House in Inventory Management. From the point of view of profit in business, this rented warehouse is close to the showroom so that there is no slack of inventory when required and timely arrival in the showroom. Apart from this, there is a functional and technical side of warehouses. Functional side includes activities like receipt, control, storage, ordering etc. in the warehouse and technical side includes racking, forklifting and software, hardware etc. Sarma (1987) presented limited storage deterministic inventory model for deteriorating items. Pakkala and Achary (1992) presented cooperative inventory model for deteriorating items with different deterioration rates in both warehouses under finite replenishment policy on developing the inventory models, demand is an important factor for this. Demands are of different kinds. Lots of research papers have been published by various authors by taking different demands. Rajan and Uthayakumar (2015) proposed an inventory model for deteriorating items having two warehouse system and exponential demands and permissible delay. Kumar et al. (2017) discussed a two-storage model having deteriorating items under shortage with inventory dependent demand.

Inventory whose life is up to a certain limit, those products are taken as perishable goods. These mainly include meat, all types of vegetables, all products of dairy products, and medicines etc. Many types of equipment are used to keep all such products safe, such as refrigerators are used for meat, vegetables and dairy products, and similarly for other substances, different types of equipment are present in the market, using which all these products are kept. Some researchers have made many research papers about perishable items, in which Duan et al. (2012) developed an inventory model with inventory level dependent demand rate for perishable items. Yang et al. (2013) developed an inventory model with stock dependent demand for perishable items under trade credit policy and inflation. Patriarca et al. (2020) introduced an EOQ model for perishable items. Lopez et al. (2021) developed an inventory model with price stock and time dependent demand for perishable items under nonlinear holding cost.In today's time, no item can be waited for a long time. This is a larger part of lost sales and profit is also low. So partial backlogging is important in today's scenario. Shastri et al. (2013) presented a multi echelon SCM with partial backordering of deteriorating items under the inflation. For long term business inflation plays an important role. Khurana et al. (2015) presented a partially backlogging shortage production model having deterioration and inflation. Singh and Rathore (2016) discussed an inventory model with preservation technology (PT) and partial backlogging under the limited storage problem. Bishi and sahu (2018) developed deteriorating inventory model having quadratic demand and partial backlogging. Sangal et al. (2016) formulated an inventory model with partial backlogging and learning effect in fuzzy environment. Demand acts as an important factor in the success of any production system.

1.1 Organisation

Apart from the introduction this paper has 7 sections. Notations and assumptions are there to understand the model in section 2. Mathematical model of the problem is given in section 3. Solution procedure and numerical analysis discussed in sections 4. The comparative interpretation of sensitivity analysis is provided in section 5. Observation of the research given in section 6. The Conclusion of this research is given in sections 7.

II. Notations and Assumptions:

2.1. Notations

- X: production rate(unit);
- Y: capacity of own warehouse;(unit);
- α: deterioration in own warehouse (OW);
- β: deterioration in rented warehouse (RW);
- X_1: demand rate in own warehouse (OW) ;
- $X_{2:}$ demand rate in rented warehouse (RW);

a, b : constant parameters of demand;

- $\left(A_P + \frac{A_0}{n^\delta}\right)$: production cost with learning effect;
- A_P : production cost
- δ: backlogging parameter;
- c: setup cost
- $c_{r:}$ present worth of holding cost in rented warehouse RW
- c_o : present worth of holding cost in rented warehouse OW
- d_p: present worth of deterioration cost
- u: present worth of shortage cost

2.2. Assumption

1. Single inventory item is consider
2. The OW has a fixed capacity while the RW has unlimited capacity.
3. Production rate X is dependent upon demand rate of corresponding warehouses. i.e. X= KX_i where i=1,2

4 Demand in RW is exponential which is represented by A_1=$ae^{bt}$and for OW it is depend on selling price which is represented by $A_2 = ap^{-b}$ where p is selling price, and a, b are constant.

III. Model formulation and solution

Both the warehouses are being used during the production cycle. Initially the level of inventory is t=0 and the production starts from t = 0 and goes up to W units. After t=t_1 whatever be the production quantity, it goes to the RW. After that the production is stopped, the level of the inventory decreases in the rented warehouse till the time t=t_2 and after that it reaches zero because of the mixed effect of demand and deteriorating on the inventory at t=$t_{3,}$ in OW the level of inventory comes to decrease due to deterioration at t= t_1 and then falls below W at t= t_3. The remaining inventory in OW will be fully exhausted at t= t_4 owing to demand and deteriorating, the level of inventory become zero. At this time the shortage start developing and at time t_5 it reaches to maximum shortage level, at this timefresh production start to clear the backlog by the time T. The inventory level for this model is depicted through Figure 1 and the inventory position can be represented as follows:

$\frac{dQ_1(t)}{dt}$ = X-A_1-α$Q_1(t)$,0≤ $t \leq t_1$ (1)

$\frac{dQ_2(t)}{dt}$ =X-A_2- $\beta Q_2(t)$, $t_1 \leq t \leq t_2$ (2)

$\frac{dQ_3(t)}{dt}$ = -A_2- $\beta Q_3(t), t_2 \leq t \leq t_3$(3)

$\frac{dQ_4(t)}{dt}$ = -α$Q_4(t)$. $t_1 \leq t \leq t_3$ (4)

$\frac{dQ_5(t)}{dt}$ = -A_1-α$Q_5(t)$. $t_3 \leq t \leq t_4$ (5)

$\frac{dQ_6(t)}{dt}$ = -$A_1 t_4 \leq t \leq t_5$ (6)

$\frac{dQ_7(t)}{dt} = X$ -A_1 $t_5 \leq t \leq T$ (7)

Solution of equation (1) to (7) by using the boundary conditions$Q_1(0)$ = 0, $Q_2(t_1) = 0$,$Q_3(t_3) = 0$,$Q_4(t_1) = A$,$Q_5(t_4) = 0$,$Q_6(t_4) = 0$,$Q_7(T)$ =0 are represented below:

Q_1(t)=$\frac{(K-1)a}{(b+\alpha)}\left[e^{bt} - e^{-\alpha t}\right]$(8)

Q_2(t)=$\frac{(K-1)ap^{-b}}{\beta}\left[1 - e^{\beta(t_1-t)}\right]$(9)

$Q_3(t) = \frac{ap^{-b}}{\beta}\left[e^{\beta(t_3-t)} - 1\right]$(10)

Q_4(t) = W$e^{\alpha(t_1-t)}$(11)

Q_5(t)=$\frac{a}{(b+\alpha)}\left[e^{bt_4}e^{\alpha(t_4-t)} - e^{bt}\right]$(12)

Q_6(t) =$\frac{a}{b}\left[e^{b(t_4-t)}\right]$(13)

Q_7(t) = $\frac{(K-1)a}{b}\left[e^{b(t-T)}\right]$(14)

The producer bears the material setup cost, holding cost for OW and RW, deterioration cost and production cost. The total cost function is given by the following components:

3.1. Production cost

$$^{S}\text{P.C.} = \left(A_P + \frac{A_0}{n^{\delta}}\right)\int_0^{t_2} Z\,dt$$

$$^{S}\text{P.C.}=\text{Ka}\left(A_P + \frac{A_0}{n^{\delta}}\right)\left[t_1 + \frac{bt_1{}^2}{2} + \frac{b^2 t_1{}^3}{6} + p^{-b}(t_2 - t_1)\right] \quad (15)$$

3.2. Holding cost for OW

$$^{SP}\text{H.C}_1 = c_0\left[\int_0^{t_1} I_1(t)dt + \int_{t_1}^{t_3} I_4(t)dt + \int_{t_3}^{t_4} I_5(t)dt\right]$$

$$^{SP}\text{H.C}_1 = c_0\left[\begin{array}{c}\frac{(K-1)a}{b+\alpha}\left(\frac{bt_1{}^2}{2} + \frac{b^2 t_1{}^3}{6} + \frac{\alpha t_1{}^2}{2}\right) + \\ A\left\{(t_3 - t_1) - \frac{\alpha}{2}(t_3 - t_1)^2\right\} + \\ \frac{a}{(b+\alpha)}\left\{\begin{array}{c} a(t_4 - t_3)^2 + \alpha(1 + bt_4)(t_4 - t_3)^2 \\ + \frac{b^2}{2}\left(\frac{2}{3}t_4{}^3 + \frac{1}{3}t_3{}^3 - t_4{}^2 t_3\right)\end{array}\right\}\end{array}\right] \quad (16)$$

3.3. Holding cost for RW

$$^{SP}\text{H.C}_2 = c_r\left[\int_{t_1}^{t_2} I_2(t)dt + \int_{t_2}^{t_3} I_3\,(t)dt\right]$$

$$^{SP}\text{H.C}_2 = c_r a p^{-b}\left[\begin{array}{c}(K-1)\left\{\frac{(t_1-t_2)^2}{2} + \frac{\beta}{6}(t_1 - t_2)^3\right\} + \\ \left\{\frac{(t_3-t_2)^2}{2} + \frac{\beta}{6}(t_3 - t_2)^3\right\}\end{array}\right] \quad (17)$$

3.4. Deterioration cost

$$^{SP}\text{D.C} = d_p \begin{bmatrix} \int_0^{t_1} \alpha t\, I_1(t)dt \ + \int_{t_1}^{t_2} \beta t\, I_2(t)dt + \int_{t_2}^{t_3} \beta t\, I_3(t)dt + \\ \int_{t_1}^{t_3} \alpha t\, I_4(t)dt \quad + \int_{t_3}^{t_4} \alpha t\, I_5(t)\,\mathrm{dt} \end{bmatrix}$$

$$^{SP}\text{D.C}=d_p \begin{bmatrix} \alpha(K-1)a\left[\frac{{t_1}^3}{3}+\frac{b^2{t_1}^4}{8(b+\alpha)}\right]-\beta(\mathrm{K}-1)ap^{-b}\left[\frac{t_1{t_2}^2}{2}-\frac{{t_2}^3}{3}-\frac{{t_1}^3}{6}\right]+ \\ ap^{-b}\beta\left[\frac{{t_2}^3}{3}+\frac{{t_3}^3}{6}-\frac{t_3{t_2}^2}{2}\right]+\frac{\alpha A}{2}\left[{t_3}^2-{t_1}^2\right]+ \\ \frac{a\alpha}{(b+\alpha)}\left[\frac{b}{6}{t_4}^3+\frac{b^2}{8}{t_4}^4-\frac{b}{2}{t_3}^2t_4-\frac{b^2}{4}{t_3}^2{t_4}^2+\frac{b}{3}{t_3}^3+\frac{b^2}{8}{t_3}^4\right] \end{bmatrix} \tag{18}$$

3.5. Shortage cost

$$^{SP}\text{S.C} = \mathrm{u}\left[\int_{t_4}^{t_5} I_6(t)dt + \int_{t_5}^{T} I_7(t)dt\right]$$

$$=\mathrm{u}\begin{bmatrix} \frac{a}{b}\left[(t_4-t_5)+\frac{b}{2}(t_4-t_5)^2+\frac{b^2}{6}(t_4-t_5)^3\right]+ \\ \frac{(K-1)a}{b}\left[(t_5-T)+\frac{b}{2}(t_5-T)^2+\frac{b^2}{6}(t_5-T)^3\right] \end{bmatrix} \tag{19}$$

3.6. Setup cost

^{SP}A.S= C(20)

Total relevant cost (TC) of the system is the sum of production cost, holding cost in OW and RW, deterioration cost setup cost and shortage cost which is represented by:

IV. Solution procedure and numerical example

4.1 Solution procedure

The total annual cost has two variables t_1 andt_3. To minimize the total annual cost the optimal values of p and t_1 can be obtained by solving the following equations simultaneously.

$$\frac{\partial TC}{\partial t_1} = 0(21)$$

And $\frac{\partial TC}{\partial t_3} = 0$ (22)

Provided they satisfied the following conditions

$$\left.\begin{array}{l} \frac{\partial^2 TC\,(t_1,t_3)}{\partial {t_1}^2} > 0\,, \qquad \frac{\partial^2 TC(t_1,t_3)}{\partial {t_3}^2} > 0 \\ \left(\frac{\partial^2 TC\,(t_1,t_3)}{\partial {t_1}^2}\right)\left(\frac{\partial^2 TC(t_1,t_3)}{\partial {t_3}^2}\right)-\left(\frac{\partial^2 TC(t_1,t_3)}{\partial t_1 \partial t_3}\right)^2 > 0 \end{array}\right\} \tag{23}$$

4.2 Numerical Example for crisp

a=350, t_5=20, C=1000\$/setup, , T= 50 days. b = 0.15, β= 0.01, α= 0.02, c_0 = 1.5, A_0 = 2.0\$/unit, δ = 0.05, A_p =1.5\$/day, s= 0.5\$/unit, k= 1.9, n=2,$\rho = 15$ t_2= 8 days, A= 500unit, d= 1.5\$/unit, c_r= 1\$/unit, t_4 =15 days,
Total cost =125675\$, t_1=5, t_3=10,

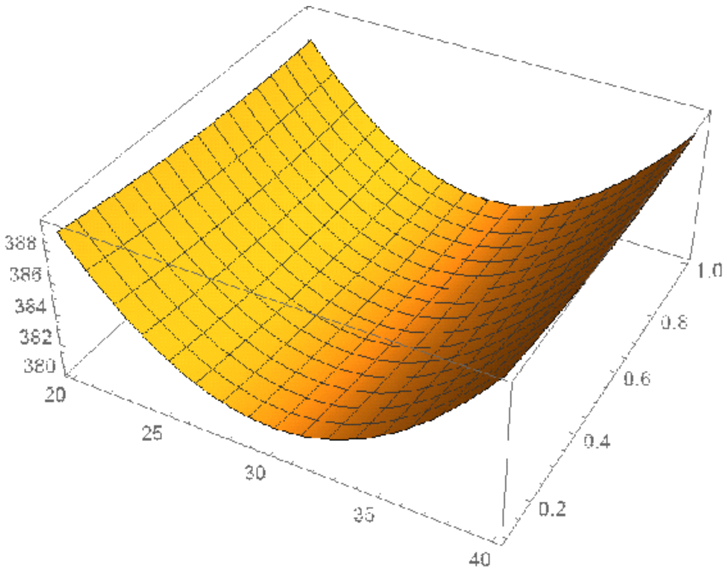

Fig. 1. The convexity graph of total cost function for crisp model

V. Sensitivity:

In the practical way the following value of various parameters are given for this model:

Parameters	% value	t_1	t_3	TC
α	-20%	2.675	10.76	125695.65
	-10%	3.467	10.15	125680
	0%	5	10	125675
	+10%	6.45	8.675	125670.80
	+20%	6.65	6.756	125564
c_0	-20%	4.67	10	115678
	-10%	5.675	10	126786
	0%	5	10	125675
	+10%	5.6785	10	125680
	+20%	5.45	10	125795.89
A_0	-20%	7.8	11.564	125682.85
	-10%	6.50	11.45	125681.5
	0%	5	10	125675
	+10%	4.30	6.98	125574
	+20%	2	5.23	125473.561
d	-20%	5.95	8.65	124675.92
	-10%	5.67	9.56	123675.35
	0%	5	10	125675
	+10%	4.85	11.65	128675.78
	+20%	3.96	12.52	129675.12
T	-20%	7.75	10	125678
	-10%	6.890	10	125678.9
	0%	5	10	125675
	+10%	4.452	10	125673
	+20%	1.65	10	125671.6
ρ	-20%	2.85	8.90	125575.74
	-10%	3.54	9.98	125675
	0%	5	10	125675
	+10%	8.50	10.65	125675
	+20%	9.85	11.65	125675

VI. Observation:

(1) The value of parameter α *is* increases with increasing time length t_1 but the time length t_3 and total cost TC are continuously decreasing.
(2) As the value of parameter holding cost c_0 is increases, the time length $t_1$and the value of total cost both are increasing but no change in time length t_3 has been observed through sensitivity analysis.
(3) When the value of parameter A_0 was increased slightly, it was observed that the values of time length t_1, t_3 as well as total cost (TC) were decreasing.
(4) When the value of parameter d was increased slightly, it was observed that both time length t_1 and total cost (TC) were decreasing but the value of time length t_3 is increasing.

(5)If the value of inventory cycle length T is slightly varied from its actual value, then it is seen that with increase in the value of T, production cycle length and total cost are decreasing, which is good and beneficial from business point of view.

VII. Conclusion:

In this paper, we have developed a production inventory model. This paper will prove useful for investigating those inventory situations where uncontrolled production process is going on in the production time interval, the concept of incomplete production process proves to be very realistic in different circumstances, hence it becomes very important to consider the impact of defective items also. RW is used to store additional luggage. Therefore, in this paper we considered two warehouses for the supplier, one of which is OW and the other is RW. Sensitivity analysis w.r.t. Various parameters have been studied in this research. After sensitivity it was found thatIf the value of inventory cycle length T is slightly varied from its actual value, then it is seen that with increase in the value of T, production cycle length and total cost are decreasing, which is good and beneficial from business point of view. Some limitations of this study are that this model is not designed for more than two supply chain members and it will not be used if there is any uncertainty in the holding cost of inventory. Also, if the inventory demand will depend on the selling price at that time, then for that also this model will not be considered in real life. But considering them in the future, a new direction can be given to the research.

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