AN INVENTORY MODEL WITH PRICE DEPENDENT DEMAND RATES AS POWER LAW FORM USING ANT COLONY OPTIMIZATION

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ABSTRACT

The main object of keeping inventories is to meet market demands using Ant Colony Optimization for Traveling Salesman Problem. Typically, retailers face a wide range of demands for different types of goods. These demands are not under the control of the organization using Ant Colony Optimization for Traveling Salesman Problem. In the present paper, demand taken as price dependent as power law form as well as time. The rate of deterioration and holding cost are considered also time dependent using Ant Colony Optimization for Traveling Salesman Problem. Shortages are allowed with partial backlogged using Ant Colony Optimization for Traveling Salesman Problem. Results are illustrated along with sensitivity analysis.

Keywords: Inventory; Price dependent demand rates; Ant colony optimization; Traveling salesman problem.

INTRODUCTION

Normally every businessman, maintain stock of goods for smooth running of business operation. The EOQ models are most successful models because they are very simple to understand and apply. But the situation of demand is different in today market where demand is always varies with time and selling price etc. So, in the present inventory model, the authors decided to take variable demands rate i.e. time and price dependent demand rate, which better match with real market situations.

There are many inventory models already developed under the considering time dependent demand rate. Demand of any product uniformly change in linear time-dependence demand rate, which is not always, happens in the actual market for any product. However, demand rate in quadratic time-dependence is seems better compare with linear. Finally, there is extraordinarily high change in demand due to exponential rate which can’t see in real market. The time dependent demand rate oriented researches are very restrictive. Silver and Meal (1969) first introduced an inventory model for time varying demand pattern. After that, there are many contributions came from researchers in this direction. Lin et al. (2000); Goyal and Giri (2003); Singh and Pattnayak (2014) presented a model for two warehouses with linear rate of demand. Sicilia (2015) presented an inventory system with power law rate of demand and uniform replenishment. Tripathi et al. (2017); and Xu et al. (2018) present a model considering the demand rate as stock dependent.

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Recently, Wang et al. (2019) gives a model taking time dependent demand rate under trade credit and inflation. Now, we know that cost of any item is an important part to decide the item demand. In general, product with higher price has less demandable and converse. For defective goods, this argument is more applicable whose demand is always price dependent. Therefore, price decisions are useful as well as essential. Whitin (1955) first introduced a model taking price dependent demand depend rate. Heydari and Norouzinasab (2015) presented a model considering demand as price-sensitive. The authors feel that the demand of items much better represented by time and selling price of item. So, in present model, we are taken the demand rate as inversely proportional to price. When item will be out of stock the demand will be dependent on only price. The conditions like deterioration, variable holding cost and partial backlogging also considered. Minimization cost technique considered. Supply chain management can be defined as: "Supply chain management is the coordination of production, stock, location and transportation between actors in supply chain to achieve the best combination of responsiveness and efficiency to a given market. Many researchers in the inventory system have focused on products that do not exceed deterioration. However, there are a number of things whose significance does not remain the same over time. The deterioration of these substances plays an important role and cannot be stored for long (Yadav et al., 2020a,b,c). Deterioration of an object can be described as deterioration, evaporation, obsolescence and loss of use or limit of an object, resulting in lower stock consumption compared to natural conditions. When commodities are placed in stock as inventory to meet future needs, there may be deterioration of items in the system of arithmetic that may occur for one or more reasons, etc. Storage conditions, weather or humidity (Yadav et al., 2019a,b). Inach it is generally claimed that management owns a warehouse to store purchased inventory. However, management can, for a variety of reasons, buy or give more than it can store in its warehouse and name it OW, with an additional number in a rented warehouse called RW located near OW or slightly away from it (Yadav et al., 2016; 2017a,b). Inventory costs (including holding costs and depreciation costs) in RW are usually higher than OW costs due to additional costs of handling, equipment maintenance, etc. To reduce the cost of inventory will economically use RW products as soon as possible. Actual customer service is provided only by OW, and in order to reduce costs, RW stocks are first cleaned. Such arithmetic examples are called two arithmetic examples in the warehouse (Yadav and swami, 2018a,b; 2019a,b). Impact of liquidity and management efficiency on profitability: An empirical study of selected power distribution utilities in India (Azhar, 2015). Impact of financial leverage on market value added: empirical evidence from India (Pandya, 2016). Inference of FDI in Indian retail sector: Some Reflections (Deshpande et al., 2014). Job Satisfaction in IT Department of Mellat Bank: Does Employer Brand Matter? (Tajpour et al., 2021). Studying the influence of emotional intelligence on the organizational innovation (Tajpour et al., 2018).

ASSUMPTIONS AND NOTATIONS

Assumptions and notations for present model-

1. '$\widehat{C}$'= the purchase cost/unit taken as constant of the item.
2. 'K'= the cost of order per cycle.
3. Lead time is zero.
4. $h(t) = h_0 + ht$, where h_0 is the initial holding cost and $0 \le h < 1$.
5. 'p'= the selling price for every unit item.

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6. $d(p,t)=\begin{cases}\alpha p^{-\beta}e^{\mu t}, & 0\le t<T_1\\ \alpha p^{-\beta}, & T_1\le t<T\end{cases}$, $0\le\mu<1$, α be the scale and β be the shape parameter of demand curves.
7. $\lambda(t)=a+bt+ct^2$, $0\le a<1$, $0\le b<1$, $0\le c<1$ is the decay rate.
8. 'T' is the cycle length.
9. Q_T be the highest stock level.
10. Shortages with backlogged rate are permitted defined by $\frac{1}{1+\gamma(T-t)}$ where $0\le\gamma<1$.
11. T_1 Shortage starting time.
12. 's' shortage cost/unit/year.
13. 'π' per unit opportunity cost for lost sales.

THE MODEL AND SOLUTION

In this section, a perishable item replenishment policy with partial backlog is considered. The Figure 1 shows the behavior of the inventory system.

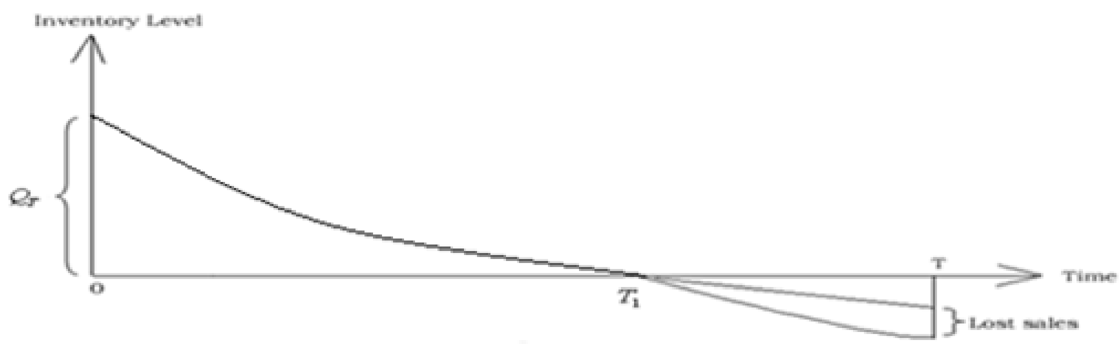

FIGURE 1

THE BEHAVIOR OF THE INVENTORY SYSTEM

Let I(t) be the level of inventory at any time t. The change in inventory w.r.to t defined as

$$\frac{dI(t)}{dt}=\begin{cases}-\left(a+bt+ct^2\right)I(t)-\alpha p^{-\beta}e^{\mu t} & when\ \ 0\le t<T_1\\ -\dfrac{\alpha p^{-\beta}}{1+\gamma(T-t)} & when\ \ T_1\le t<T\end{cases} \quad (1)$$

Under condition, $I(T_1)=0$ (2)

Now, from (1),

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$$I(t) = -\alpha p^{-\beta}\left[t + \frac{1}{2}(\mu + a)t^2 + \frac{1}{6}bt^3 + \frac{1}{12}ct^4\right]e^{-\left(at + \frac{1}{2}bt^2 + \frac{1}{3}ct^3\right)} + I(0)e^{-\left(at + \frac{1}{2}bt^2 + \frac{1}{3}ct^3\right)}$$

When $0 \le t < T_1$ (3)

And

$$I(t) = -\frac{\alpha p^{-\beta}}{\gamma}\log\left(\frac{1 + \gamma(T - T_1)}{1 + \gamma(T - t)}\right), \quad \text{When } T_1 \le t < T \quad (4)$$

Where I(0) is consider as initial stock. Ignoring the power more than one of a, b, c and μ . Taking Z(t) be the stock which are loss due to deterioration of items during the interval [0, t].

$$Z(t) = I(t)\left[e^{\left(at + \frac{1}{2}bt^2 + \frac{1}{3}ct^3\right)} - 1\right] + \alpha p^{-\beta}\left(\frac{1}{2}at^2 + \frac{1}{6}bt^3 + \frac{1}{12}ct^4\right) \quad (5)$$

Using equation (2) in equation (5), we have

$$Z(T_1) = \alpha p^{-\beta}\left(\frac{1}{2}aT_1^2 + \frac{1}{6}bT_1^3 + \frac{1}{12}cT_1^4\right) \quad (6)$$

Also the total demand in the interval $0 \le t < T_1$

$$= \alpha p^{-\beta}\left(T_1 + \frac{1}{2}\mu T_1^2\right) \quad (7)$$

Therefore, ordered quantity per cycle is

$Q_T = \text{Total decay} + \text{Total demand in the interval}[0, T_1]$

$$= \alpha p^{-\beta}\left[T_1 + \frac{1}{2}(\mu + a)T_1^2 + \frac{1}{6}bT_1^3 + \frac{1}{12}cT_1^4\right] \quad (8)$$

Since $I(0) = Q_T$

Therefore, from equation (3), we can

$$I(t) = \alpha p^{-\beta}\left[(T_1 - t) + \frac{1}{2}(\mu + a)(T_1^2 - t^2) + \frac{1}{6}b(T_1^3 - t^3) + \frac{1}{12}c(T_1^4 - t^4)\right]e^{-\left(at + \frac{1}{2}bt^2 + \frac{1}{3}ct^3\right)}$$

$$0 \le t < T_1 \quad (9)$$

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Therefore

$$I(t)=\begin{cases}\alpha p^{-\beta}\left\{(T_1-t)+\frac{1}{2}(\mu+a)(T_1^2-t^2)+\frac{1}{6}b(T_1^3-t^3)+\frac{1}{12}c(T_1^4-t^4)\right\}e^{-\left(at+\frac{1}{2}bt^2+\frac{1}{3}ct^3\right)}, & 0\le t<T_1\\ -\frac{\alpha p^{-\beta}}{\gamma}\log\left(\frac{1+\gamma(T-T_1)}{1+\gamma(T-t)}\right), & T_1\le t<T\end{cases} \tag{10}$$

The average system cost is given by

$$C(T_1,T,p)=\frac{1}{T}\left[K+\hat{C}\alpha p^{-\beta}\left\{\frac{1}{2}aT_1^2+\frac{1}{6}bT_1^3+\frac{1}{12}cT_1^4\right\}+\frac{1}{\gamma^2}(s+\pi\gamma)\alpha p^{-\beta}\left(\gamma(T-T_1)-\log\{1+\gamma(T-T_1)\}\right)\right.$$
$$\left.+\alpha p^{-\beta}\left(h_0\left\{\frac{1}{2}T_1^2+\frac{1}{3}\left(\mu+\frac{1}{2}a\right)T_1^3+\frac{1}{12}bT_1^4+\frac{1}{20}cT_1^5\right\}+h\left\{\frac{1}{6}T_1^3+\frac{1}{8}\left(\mu+\frac{1}{3}a\right)T_1^4+\frac{1}{40}bT_1^5+\frac{1}{60}cT_1^6\right\}\right)\right] \tag{11}$$

Also, the order rate is

$$\frac{Q_T}{T}=\frac{1}{T}\alpha p^{-\beta}\left[T_1+\frac{1}{2}(\mu+a)T_1^2+\frac{1}{6}bT_1^3+\frac{1}{12}cT_1^4\right] \tag{12}$$

Now, the behavior of the order rate w.r.to a, b, c and μ is determined by

$$\frac{\partial}{\partial a}\left(\frac{Q_T}{T}\right)=\frac{1}{2T}T_1^2\alpha p^{-\beta}>0,\ \frac{\partial}{\partial b}\left(\frac{Q_T}{T}\right)=\frac{1}{6T}T_1^3\alpha p^{-\beta}>0$$

$$\frac{\partial}{\partial c}\left(\frac{Q_T}{T}\right)=\frac{1}{12T}T_1^4\alpha p^{-\beta}>0 \text{ and } \frac{\partial}{\partial \mu}\left(\frac{Q_T}{T}\right)=\frac{1}{2T}T_1^2\alpha p^{-\beta}>0$$

Also with respect to price ‘p’ is

$$\frac{\partial}{\partial p}\left(\frac{Q_T}{T}\right)=-\frac{1}{T}\alpha\beta p^{-\beta-1}\left[T_1+\frac{1}{2}(\mu+a)T_1^2+\frac{1}{6}bT_1^3+\frac{1}{12}cT_1^4\right]\le 0 \tag{13}$$

Thus, the order rate increase if increases in a, b, c and μ and decrease with increase in p. Now, our objective is to obtain values of T_1, T and p which make $C(T_1,T,p)$ as minimum. The necessary condition for $C(T_1,T,p)$ as minimum are

$$\frac{\partial C(T_1,T,p)}{\partial T_1}=0=\frac{\partial C(T_1,T,p)}{\partial T}=\frac{\partial C(T_1,T,p)}{\partial p}$$

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$$\text{Now, } \frac{\partial C(T_1, T, p)}{\partial T_1} = 0, \text{ gives}$$

$$\hat{C}\left\{aT_1 + \frac{1}{2}bT_1^2 + \frac{1}{3}cT_1^3\right\} - \frac{(s+\pi\gamma)(T-T_1)}{1+\gamma(T-T_1)} + h_0\left\{T_1 + \left(\mu + \frac{1}{2}a\right)T_1^2 + \frac{1}{3}bT_1^3 + \frac{1}{4}cT_1^4\right\} \quad (14)$$

$$\frac{\partial C(T_1, T, p)}{\partial T} = 0, \text{gives } \frac{\alpha\, p^{-\beta}(s+\pi\gamma)}{T}\left\{\frac{T-T_1}{1+\gamma(T-T_1)}\right\}$$

$$-\frac{1}{T^2}\left[\begin{array}{l} K + \alpha\, p^{-\beta}\left[\hat{C}\left\{\frac{1}{2}aT_1^2 + \frac{1}{6}bT_1^3 + \frac{1}{12}cT_1^4\right\} + \frac{1}{\gamma^2}(s+\pi\gamma)\left[\gamma(T-T_1) - \log\{1+\gamma(T-T_1)\}\right]\right] \\ + \alpha\, p^{-\beta}\left(\begin{array}{l} h_0\left\{\frac{1}{2}T_1^2 + \frac{1}{3}\left(\mu + \frac{1}{2}a\right)T_1^3 + \frac{1}{12}bT_1^4 + \frac{1}{20}cT_1^5\right\} \\ + h\left\{\frac{1}{6}T_1^3 + \frac{1}{8}\left(\mu + \frac{1}{3}a\right)T_1^4 + \frac{1}{40}bT_1^5 + \frac{1}{60}cT_1^6\right\} \end{array}\right) \end{array}\right] = 0 \quad (15)$$

$$\text{And } \frac{\partial C(T_1, T, p)}{\partial p} = 0, \text{ gives}$$

$$\hat{C}\left\{\frac{1}{2}aT_1^2 + \frac{1}{6}bT_1^3 + \frac{1}{12}cT_1^4\right\} + \frac{1}{\gamma^2}(s+\pi\gamma)\left[\gamma(T-T_1) - \log\{1+\gamma(T-T_1)\}\right]$$

$$+ h_0\left\{\frac{1}{2}T_1^2 + \frac{1}{3}\left(\mu + \frac{1}{2}a\right)T_1^3 + \frac{1}{12}bT_1^4 + \frac{1}{20}cT_1^5\right\} + h\left\{\frac{1}{6}T_1^3 + \frac{1}{8}\left(\mu + \frac{1}{3}a\right)T_1^4 + \frac{1}{40}bT_1^5 + \frac{1}{60}cT_1^6\right\} = 0 \quad (16)$$

Solving (14), (15) and (16) simultaneously and find T_1, T & p for which function $C(T_1, T, p)$ will be minimum.

Working of ACO for TSP

Initially, each ant is placed at random on a city. When developing a viable solution, the ants select the next city to visit using a probabilistic decision rule. When an ant k declares in city i and constructs the partial solution, the probability of moving to the next neighboring city j i is given by

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$$[p_0]_{ij}^{k}(k)=\begin{bmatrix} \dfrac{\left\{[B_0]_{ij}(t_0)\right\}^{\alpha_3}\left\{[C_0]_{ij}\right\}^{\beta_3}}{\sum_{[u_0]\in J_k(t_0)}\left\{[B_0]_{ij}(t_0)\right\}^{\alpha_3}\left\{[C_0]_{ij}\right\}^{\beta_3}} & \text{if } j\in J_k(i) \\ 0 & \text{otherwise} \end{bmatrix} \quad (17)$$

Where $[B_0]_{ij}$ is the intensity of trails between edge (i,j) and $[C_0]_{ij}$ is the heuristic visibility of the edge (i, j), and $[C_0]_{ij}=\frac{1}{d_{ij}}$ α_3 Is the influencing factor of pheromones, β_3 is the influence of the local node, and $J_k(i)$ is a set of cities that remain to be visited when the ant is in city i. Once each ant has completed their turn, the amount of pheromones on each path will be adjusted with the following equation.

$$[B_0]_{ij}(t_0+1)=(1-\rho_0)[B_0]_{ij}(t_0)+\Delta[B_0]_{ij}(t_0) \quad (13)$$

is pheromone evaporation coefficient andρwhere

$$\Delta[B_0]_{ij}(t_0)=\sum_{k=1}^{m}\Delta[B_0]_{ij}^{k}(t_0) \quad (14)$$

$$\Delta[B_0]_{ij}^{k}(t_0)=\begin{bmatrix} \dfrac{Q_0}{[L_0]_k} & \text{if } (i,j)\in \text{tour done by ant k} \\ 0 & \text{otherwise} \end{bmatrix} \quad (18)$$

(1-ρ) is the decay parameter of pheromones (0<ρ<1) where it represents the evaporation of the track when the ant chooses a city and decides to move. Lk is the length of the turn for each formed per ant k and m is the number of ants. Q is the pheromone deposition factor.

Case Study

In this section, we consider numerical examples with data same as reference research with appreciate units to illustrate the models numerically.

$K = Rs\ 200, \hat{C} = Rs\ 40,\ h = Rs\ 5,\ h = 0.5, \mu = 0.1, \gamma = 0.1, s = Rs\ 4, \pi = Rs\ 5, a = 0.01, b = 0.02, c = 0.03, p = 70, \alpha = 10^5, \beta = 1.5$

Then the optimal result of the model is

$T = 0.96983\ years,\ T_1 = 0.40449 years, Q_T = 70.6507\ units$ and $C =$ Rs 411.145

Sensitivity Study

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The aim of present section is to identify parameters to the changes of which the solution of the model is sensitive.

TABLE 1
SENSITIVITY STUDY α

Parameter Value	% Change	T	T_1	Q_T	C
80000	-20	1.08385	0.44729	62.65580	367.87000
90000	-10	1.02208	0.42422	66.76390	390.11200
110000	+10	0.92488	0.38734	74.73440	431.14800
120000	+20	0.88567	0.37226	77.88210	450.25900

TABLE 2
SENSITIVITY STUDY FOR β

Parameter Value	% Change	T	T_1	Q_T	C
1.20	-20	0.51416	0.22352	138.22600	776.26300
1.35	-10	0.70617	0.30173	99.09240	564.89400
1.65	+10	1.33248	0.53726	50.00220	299.26400
1.80	+20	1.83340	0.70511	35.04770	217.78700

TABLE 3
SENSITIVITY STUDY FOR μ

Parameter Value	% Change	T	T_1	Q_T	C
0.08	-20	0.97146	0.40670	70.76290	410.74800
0.09	-10	0.97064	0.40559	70.70650	410.94700
0.11	+10	0.96903	0.40340	70.59550	411.34100
0.12	+20	0.96824	0.40233	70.54100	411.53600

OBSERVATIONS

From above Tables 1,2 & 3, we observed that:

- It is observed that duration of the cycle length have negative correlation corresponding to the parameters α and μ but have positive correlation corresponding to the parameters β Also, model is more sensitive for the parameters β comprising to other parameters.
- The average cost of the system has negative correlation with respect to the parameter β but have positive correlation w.r.to α and μ. Also it is noted that the model is more sensitive for the parameters β comprising to other parameters.
- From the above points, we can say that sufficient care should be about parameter β in conducting model.

CONCLUSIONS

This model developed under considering the demand rate as time and price during available inventory and price dependent during shortages with backlog rate depend on waiting time using

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Ant Colony Optimization for Traveling Salesman Problem. Demand function have negative derivative with respect to price i.e. demand is a decreasing when selling price of items is increasing using Ant Colony Optimization for Traveling Salesman Problem. Variable holding cost is taken in account. To find approximate results cost minimization technique is applied using Ant Colony Optimization for Traveling Salesman Problem. The problems are illustrated numerically. In, future studies the present model will be more realistic after considering such as stock dependent demand rate, life time items, trade credit policy, lead time, Weibull distribution and considering inflation etc.

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Citation Information: Kumar, S., Yadav, A. S., Sharma, V., Ahlawat, N., & Govindarajan, A. (2021). An inventory model with price dependent demand rates as power law form using ANT colony optimization. *Journal of Management Information and Decision Sciences, 24*(6), 1-10.