A Concept on Order Quantity at Varying Cost in Variable Rate of Production Situation

Dr. Rudresh Pandey, Shradha Goyal, Mayank Kumar Pandey

Abstract: The concept of EOQ is simply to tackle the management issues of inventory in various types of production systems. This is amongst the most popularly used models in the production houses for inventory. A major issue faced by stock manager is to design an effective policy for replacement, resulting outcome as lowest cost of inventory units. Traditional EOQ theory, assumes majorly two factors that is demand and per unit cost. It is assumed that demand remains constant and can be determined at any level. Secondly that per unit production cost does is not dependent on quantity of order for production.
This study is based on a model for stock with multi-item and when per unit cost is dependent on demand and crashing cost of leading time is dependent on lead time. Hence, model has been formulated having constraints of orders and production cost. Unit cost of production is considered fuzzy variable. The jist problem for optimizing the annual total cost has been considered with Karush Kuhn-Tucker conditions method. Mathematical derivations and analysis have been made for one unit, along with testing done from Sensitivity analysis. Illustrations have been taken on random basis.
Index Terms: - Inventory, cost, stock, Demand, optimization

I. INTRODUCTION

The model concept of EOQ is simply to tackle the management issues of inventory in various types of production systems. This is amongst the most popularly used models in the production houses for inventory. A major issue faced by stock manager is to design an effective policy for replacement, resulting outcome as lowest cost of inventory units. Traditional EOQ theory, assumes majorly two factors that is demand and per unit cost. It is assumed that demand remains constant and can be determined at any level. Secondly that per unit production cost does is not dependent on quantity of order for production.

The company stock contributes as a substantial sharein the total assets of a production house. It is also a crucial concept in the theory of supply chain management. Therefore, because of this importance, an effective inventory management becomes an integral part of the organization’s total profit. Usually the problem in EOQ is to resolve and define the optimum value for order quantity and the inventory cost to the minimum.

Generally, factors like cost, demand, quantity, profit are associated with inventory management. Accordingly, the problems of stock management under ambiguous environment can be resolved by accordingly giving fuzzy value to these parameters. For instance, Ishii & Konno (1998) studied model based on EOQandfuzzy cost coefficients.Also, Petrovic et aland Park (1987) (1996) discussed the Newsboy modeling theory with fuzzy demand and cost coefficients.Yao & Chiang (2003) investigated a fuzzy EOQ model with fuzzy demand and rate of defects model. Hang (2004) discussed a with fuzzy holding cost and demand through various solutions.

Traditional models for inventory have deterministic factors as assumptions. However, in reality, there are many variations that occur and cannot be ignored during study. EOQ modeling usually undertakes probabilistic approach to resolve these uncertain situations. By Probabilistic methods, the uncertainty and variations in carrying and holding costs are assumed under definite probability distribution. Although the uncertain factors are not associated with any cost in inventory theory.

In earlier times the Lead time was considered as a fixed parameter in inventory, whereas from past few years it is now taken as a variable which is to be determined by the working inventory model. Although this recent development gives a competitive approach in today’s flickering demand in industry and market.

This study is based on a model for stock with multi-item and when per unit cost is dependent on demand and crashing cost of leading time is dependent on lead time. Hence, model has been formulated having constraints of orders and production cost. Per unit cost of production is considered fuzzy variable. The jist problem for optimizing the annual total cost has been considered with Karush Kuhn-Tucker conditions method. Mathematical derivations and analysis have been made for one unit, along with testing done from Sensitivity analysis. Illustration has been taken on random basis.

II. OBJECTIVES

For foundation the research workis done to consider different production rate process as stated in the model given by Shukla et. al. [1]. This study explores various factors including cost, demand, production and time with an objective to explore nonlinear functional relationship. Elementaryintention of this study is to explore and develop a mathematical model with nonlinear/ hyperbolic cost function.This research paper also aims to develop and work on giving advanced models with considerations of costfor to optimizing and improvingdifferent total cost in relation to profit, production, and any other costs invarious organizational functions.

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III. LITERATURE REVIEW

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This study is based on a model for stock with multi-item and when per unit cost is dependent on demand and crashing cost of leading time is dependent on lead time. Hence, model has been formulated having constraints of ordersand cost of production. Per unit cost of production is considered fuzzy variable. The jist problem for optimizing the annual total cost has been considered with Karush Kuhn-Tucker conditions method. Mathematical derivations and analysis have been made for one unit, along with testing done from Sensitivity analysis. Illustration has been taken on random basis.

IV. PROBLEM DESIGN

A. Assumption and Notations

Following assumptions and notations are considered in the model, as,

1. Demand can be determined.
2. Zero Lead time. Assuming one time order delivery.
3. Constant and limited production rate λ, strictly greater than the demand rate (D).
4. Constant cost of set up per unit..
5. Not to allow Backorders.

D is the per day Demand
P is the per unit Selling price
λ is the production Rate \
C_s is the per unit set up cost
T is the cycle time of production.
N_i is the queue size, at i^{th} operation
P_i is the lot size, at i^{th} operation
Q is the lot numbers
O_i is the part Value, at i^{th} operation
R is the holding cost/day
M_i is the cost of set up material.
L_i is the set up labour rate
S_i is the integrated Set up time
k is the summed operations

B. Model Development

This study is based on a model for stock with multi-item and when per unit cost is dependent on demand and crashing cost of leading time is dependent on lead time. Hence, model has been formulated having constraints of orders and cost of production. Per unit cost of production is considered fuzzy variable. The jist problem for optimizing the annual total cost has been considered with Karush Kuhn-Tucker conditions method. Mathematical derivations and analysis have been made for one unit, along with testing done from Sensitivity analysis. Illustration has been taken on random basis.

C. Methodology

Objective is to reduce the total expected annual cost to minimum, total expected annual costis the sum of order of production, lead time crashing costs and inventory carrying cost; according to EOQ and its basic assumptions following is the cost details -

$$TC\left(D_i, Q_i, L_i\right) = \sum_{i=1}^{n}\left\{p_i D_i + \frac{S_i D_i}{Q_i} + \left[\frac{Q_i}{2} + K\sigma\sqrt{L_i}\right]H_i + \frac{D_i}{Q_i}R\left(L_i\right)\right\} \quad (1.1)$$

Substituting pi and R (Li) in Equation (1) gives

$$TC\left(D_i, Q_i, L_i\right) = \sum_{i=1}^{n}\left[AD_i^{1-\beta} + \frac{S_i D_i}{Q_i} + \left[\frac{Q_i}{2} + K\sigma\sqrt{L_i}\right]H_i + \frac{D_i}{Q_i}\alpha L_i^{-b_i}\right] \quad (1.2)$$

Using Karush Kuhn-Tucker conditions method for a single item, the problem can be formulated as:

$$MinTc(D,Q,L) = AD^{1-\beta} + \frac{SD}{Q} + \left[\frac{Q}{2} + K\sigma\sqrt{L}\right]H + \frac{D}{Q}\alpha L^{-b}$$

(1.3)

subject to the inequality constraints

$$AD^{-\beta}Q \le B \quad (1.4)$$

$$\frac{D}{Q} \le t \quad (1.5)$$

This is a minimization problem for a single item without shortage under two constraints. It can be solved by using Karush Kuhn-Tucker approach.

By using Karush Kuhn-Tucker method the above function can be restated as

$$G = AD^{1-\beta} + \frac{SD}{Q} + \left[\frac{Q}{2} + K\sigma\sqrt{L}\right]H + \frac{D}{Q}\alpha L^{-b} - \lambda_1\left(B - AD^{-\beta}Q - s_1^2\right) - \lambda_2\left(t - DQ^{-1} - s_2^2\right)$$

(1.6)

Differentiating (6) partially with respect to D, Q and L we get the following equations

$$\frac{\partial G}{\partial D} = (1-\beta)AD^{-\beta} + SQ^{-1} + \alpha Q^{-1}L^{-b} - \beta\lambda_1 AD^{-\beta-1}Q + \lambda_2 Q^{-1}$$

$$\frac{\partial G}{\partial D} = -SDQ^{-2} + 0.5H - \alpha DQ^{-2}L^{-b} + \lambda_1 AD^{-\beta} - \lambda_2 DQ^{-2}$$

$$\frac{\partial G}{\partial D} = 0.5K\sigma L^{-0.5}H - \alpha bDQ^{-1}L^{-b-1} \quad (1.7)$$

The necessary conditions for KKT conditions are

$$\frac{\partial G}{\partial D} = 0 \Rightarrow (1-\beta)AD^{-\beta} + SQ^{-1} + \alpha Q^{-1}L^{-b} - \beta\lambda_1 AD^{-\beta-1}Q + \lambda_2 Q^{-1} = 0$$

(1.8)

$$\frac{\partial G}{\partial D} = 0 \Rightarrow -SDQ^{-2} + 0.5H - \alpha DQ^{-2}L^{-b} + \lambda_1 AD^{-\beta} - \lambda_2 DQ^{-2} = 0$$

(1.9)

$$\frac{\partial G}{\partial D} = 0 \Rightarrow 0.5K\sigma L^{-0.5}H - \alpha bDQ^{-1}L^{-b-1} = 0$$

(1.10)

Solving the above set to Equations (1.7), (1.8) and (1.9) gives the optimal solution of the decision variables D, Q and L.

For solving these equations the Newton Raphson method has been applied to obtain the solution of the transcendental equation.

D. Policy: For Variable P and D

For solving these equations the Newton Raphson method has been applied to obtain the solution of the transcendental equation.

$$\frac{D}{Q} \le t \quad \text{where t is constant} \quad (1.10)$$

The demand function is represented as,

For, P, D > 0 => D = Pf
(1.11)

The demand function (1.11) is minimization problem for a single item without shortage under two constraints.

Hence (1.10) and (1.11) shows demand function for fixed mark – up of prices,

D = Qf

Case 1

Here let,

a) Variable D.

b) Fixed P

c) Cost with Quantity Discounts

Then profit function Z (Q) can be calculated from equation (1.9) and equation (1.12)

$$Z(Q) = (\theta - 1)(CQ)f\ CQ - \frac{C_0}{\alpha} - \frac{k}{\alpha\lambda\theta} \quad (13)$$

Let us consider, D = $KP^{-\eta}$ (14)

Where η is the elasticity of demand $\epsilon\ (0, \infty)$

Therefore, (1.13) and (1.14) gives,

Z(Q)=

$$K\theta^{-\eta}(\theta - 1)(CQ)^{\eta+1} - \left[\sum_{i=1}^{k}(N_i + P_i)QO_iR - \frac{1}{\lambda}\sum_{i=1}^{k}(N_i + P_i)QO_iRK\theta^{-\eta}(CQ)^{-\eta} + \sum_{i=1}^{k}\frac{(L_iS_i + M_i)K(CQ)^{-\eta}}{Q\theta^{\eta}})\right] \quad (1.15)$$

Consider C(Q) = $C_0 - \alpha Q$, then (13) becomes,

Z(Q) = K(

$$\theta - 1)\theta^{-\eta}C_0 - \alpha Q^{-\eta+1} - \sum_{i=1}^{k}(N_i + P_i)QO_iR + \frac{K}{\lambda\theta^{\eta}}\sum_{i=1}^{k}(N_i + P_i)QO_iRC_0 - \alpha Q^{-\eta} - \frac{K}{Q\theta^{\eta}}\sum_{i=1}^{k}(L_iS_i + M_i)(C_0 - \alpha Q)^{-\eta}$$

(1.16)

Differentiating equation (13), Finding $\frac{\partial Z}{\partial Q} = 0$, gives

K=

$$\frac{\partial G}{\partial D} = (1-\beta)AD^{-\beta} + SQ^{-1} + \alpha Q^{-1}L^{-b} - \beta\lambda_1 AD^{-\beta-1}Q + \lambda_2 Q^{-1}$$

$$\frac{\partial G}{\partial D} = -SDQ^{-2} + 0.5H - \alpha DQ^{-2}L^{-b} + \lambda_1 AD^{-\beta} - \lambda_2 DQ^{-2}$$

$$\frac{\partial G}{\partial D} = 0.5K\sigma L^{-0.5}H - \alpha bDQ^{-1}L^{-b-1}$$

(1.17)

We get a rectangular Hyperbola in Demand Curve for $\eta = 1$ for each point on the curve; therefore (1.17) becomes,

$$\frac{\partial G}{\partial D}=0\Rightarrow(1-\beta)AD^{-\beta}+SQ^{-1}+\alpha Q^{-1}L^{-b}-\beta\lambda_1 AD^{-\beta-1}Q+\lambda_2 Q^{-1}=0$$

(1.18)

As $\lambda\to\infty$, equation (1.18) reduces to,

$$\frac{\partial G}{\partial D}=0\Rightarrow -SDQ^{-2}+0.5H-\alpha DQ^{-2}L^{-b}+\lambda_1 AD^{-\beta}-\lambda_2 DQ^{-2}=0$$

(1.19) gives and considers

$H_2=\frac{2C_0}{\alpha}$

$H_1=\frac{C_0^2}{\alpha^2}$

$H_4=\frac{2k\sum_{i=1}^{k}(L_iS_i+M_i)}{\alpha\theta\sum_{i=1}^{k}(N_i+P_i)O_iR}$

$H_4=\frac{C_0 k\sum_{i=1}^{k}(L_iS_i+M_i)}{\alpha^2\theta\sum_{i=1}^{k}(N_i+P_i)O_iR}$

Considering rate of production to be finite, equation (1.14) becomes,

$$Q^4-H_5Q^3+H_6Q^2+H_7Q-H_8=0 \qquad (1.19)$$

Where

$H_5=\frac{2C_0}{\alpha}$

$H_6=\frac{C_0}{\alpha}-\frac{k}{\alpha\lambda\theta}$

$H_7=\frac{2k\sum_{i=1}^{k}(L_iS_i+M_i)}{\alpha\theta\sum_{i=1}^{k}(N_i+P_i)O_iR}$

$H_8=\frac{C_0 k\sum_{i=1}^{k}(L_iS_i+M_i)}{\alpha^2\theta\sum_{i=1}^{k}(N_i+P_i)O_iR}$

Using Karush Kuhn-Tucker conditions method for a single item, the problem can be formulated as:

1. Now let η=1 be taken when considering constant cost,

$$Q_c^*=\sqrt{\frac{K\sum_{i=1}^{k}(L_iS_i+M_i)}{C_0\theta\sum_{i=1}^{k}(N_i+P_i)O_iR(1+\frac{k}{\lambda\theta C_0})}} \qquad (19)$$

$$\frac{\partial(TIC)}{\partial T^2}=-\frac{2}{T^3}\left[k+\frac{s\alpha(T-T_1)^2}{2}+\frac{\alpha(h+c^*\theta)}{\theta+\beta}\left\{\frac{e^{(\theta+\beta)T_1}-1}{\theta+\beta}-T_1\right\}\right]+\frac{s\alpha}{T^2}(2T_1-T)>0$$

(1.20)

2. Let $\lambda\to\infty$, then (1.20) reduces to,

Case of Hyperbolic Function

For variable cost,

$$CQ=b+\frac{d}{Q}\ (Q_0\le Q<\infty)$$

The profit function becomes,

$$ZQ=K(\theta-1)Q^{-\eta}\left(b+\frac{d}{\theta}\right)^{-\eta+1}$$

$$\frac{\partial(TIC)}{\partial T}=-\frac{1}{T^2}\left[k+\frac{s\alpha(T-T_1)^2}{2}+\frac{\alpha(h+c^*\theta)}{\theta+\beta}\left\{\frac{e^{(\theta+\beta)T_1}-1}{\theta+\beta}-T_1\right\}\right]+\frac{s\alpha(T-T_1)}{T}$$

(1.22)

$\Rightarrow \quad \frac{\partial Z}{\partial Q}=0$ gives,

$$\frac{1}{Q^2}k(\theta-1)\theta^{-\eta}(\eta-1)+\frac{d}{Q}^{-\eta}$$
$$+\sum_{i=1}^{k}(N_i+P_iO_iR)+\frac{k}{\lambda\theta^{\eta}}$$
$$\sum_{i=1}^{k}(N_i+P_iO_iR)+\left(b+\frac{d}{Q}\right)^{-\eta-1}\left(b+\frac{d}{Q}+\frac{d\eta}{Q}\right)$$
$$+\frac{K}{\theta^{\eta}Q^2}\sum_{i=1}^{k}(L_iS_i+M_i)\left(b+\frac{d}{Q}\right)^{-\eta-1}$$
$$\left(b+\frac{d}{Q}-\frac{d\eta}{Q}\right)=0 \qquad (1.23)$$

For special case $\eta=1$ eqn. (1.23) becomes,

$$-\sum_{i=1}^{k}N_i+P_iO_iR+\frac{K}{\lambda\theta}\qquad\sum_{i=1}^{k}N_i+P_iO_iR+\left(b+\frac{d}{Q}\right)^{-2}$$
$$\left(b+\frac{2d}{Q}\right)+\frac{kb}{\theta Q^2}$$

$$\sum_{i=1}^{k}(L_iS_i+M_i)\left(b+\frac{d}{Q}\right)^{-2}=0$$

Simplifying further,

$$\sum_{i=1}^{k}N_i+P_iO_iR+\left(1-\frac{k}{\lambda\theta}\right)\left(b+\frac{d}{Q}\right)^{-2}\left(b+\frac{2d}{Q}\right)+\frac{kb}{Q\theta^2}$$

$$\sum_{i=1}^{k}\left(L_i S_i + M_i\right)\left(b+\frac{d}{Q}\right)^{-2}$$

$$\Rightarrow \frac{\partial^2(\text{TIC})}{\partial \text{T}^2} > 0, \qquad (1.24)$$

Substituting (1.24) in (1.22), gives Q^* relative to Z^*

Cost as Constant Function

In $CQ = b + \frac{d}{Q}$, assume d = constant; $\left(Q_0 \le 1 < \infty\right)$

Hence for $\eta = 1$ & constant cost,

$$Q_c^* = \left[\frac{Kb\sum_{i=1}^{k} L_i S_i + M_l}{\theta\sum_{i=1}^{k} N_i + P_i Q_l R\left(b^2 - \frac{Kb}{\lambda\theta}\right)}\right]^{1/2} \qquad (1.25)$$

And

$$\frac{\partial^2(\text{TIC})}{\partial \text{T}\partial \text{T}_1} = \frac{\alpha}{\text{T}^2}\left\{\text{sT}_1 + \frac{\left(\text{h}+\text{c}^*\theta\right)}{\theta+\beta}\left(\text{e}^{(\theta+\beta)\text{T}_1} - 1\right)\right\} < 0$$

$$\text{TIC} = \frac{1}{\text{T}}\left[\text{OC}+\text{SC}+\text{HC}+\text{CD}\right]$$

$$+\frac{K}{\lambda\theta b}\sum_{i=1}^{k}\left(N_i + P_i Q_c^* O_i R\right) - \frac{K}{\theta b}\frac{\sum_{i=1}^{k}\left(L_i S_i + M_i\right)}{Q_c^*}$$

If $\lambda \to \infty$, then (1.24) & (1.25) becomes,

$$2\text{k} - \text{s}\alpha\left(\text{T}^2 - \text{T}_1^2\right) + \frac{2\alpha\left(\text{h}+\text{c}^*\theta\right)}{\theta+\beta}\left(\frac{\text{e}^{(\theta+\beta)\text{T}_1} - 1}{\theta+\beta} - \text{T}_1\right) = 0$$

(1.26) And

$$\left(\text{h}+\text{c}^*\theta\right)\left(\theta+\beta\right)\text{T}_1^2 + 2\left(\text{h}+\text{s}+\text{c}^*\theta\right)\text{T}_1 - 2\text{sT} = 0$$

(1.27)

V. PROBLEM

Suppose that the following information is given:
D = 54 Units, = 60 Units, P= .3 Rs. / Unit, R= 0.01, K= 5, the following results can be calculated.
For Variable P and D Cost function is linearly taken as,

Table 1 Results for Linear Costs Function

Case	θ	C_0	Q^*	Z^*
Case (a)	2	5	19.79	18.42
	3	5	16.14	28.01
	4	5	13.97	32.88
	5	5	12.49	35.87
Case (b)	2	4	22.15	17.72
	2	3	25.63	16.62
	2	2	31.5	14.76
	2	1	45.03	10.68
Case (c)	3	4	18.06	27.38
	4	3	18.06	31.55
	5	2	19.79	33.48
Case (d)	6	2	18.06	35.72
	5	3	16.14	34.67
	4	4	15.62	32.34

Hyperbolic Cost Function for Variable P and D

Table 1b Results for Hyperbolic Costs Function

Case	θ	b	Q^*	Z_c^*
Case (a)	2	10	13.97	20.38
	3	10	11.4	29.56
	4	10	9.86	34.22
	5	10	8.82	37.08
Case (b)	2	8	15.62	19.84
	2	6	18.06	19.05
	2	4	22.15	17.72
	2	2	31.5	14.76
Case (c)	3	11	10.86	29.74
	5	9	9.3	36.92
	7	7	8.91	39.9
Case (d)	11	3	10.86	41.86
	9	5	9.3	41.36
	7	7	8.91	39.9

VI. RESEARCH LIMITATION

The basic limitation of this research is that it has been devloped with different variables and it needs more application data in real and working conditions in various SMEs (small and medium industries).
It is observed that SMEs do not have EOQ models which are optamised in contrast to large scale industries which use and have access to various models for inventory. Real time data will make this model more robust and useful.

VII. CONCLUSION

With the help of sensitivity analysis, the outcome of equation (1.15) for cost in hyperbolic function is compared to the output of equation (1.12) for cost in linear functions.This is shown in table (1a) and table (1b) respectively, fourgraphs are drawn in four different situations. The graphs can also be used toshow that hyperbolic cost function will give an optimized value of Profit and Quantity both it is also compared to output from Cost Function which is linear.

VIII. FUTURE SCOPE

This paper has done basic work to develop an optimized EOQ model for small and medium enterprises (SMEs). SMEs do not have access to EOQ models. This paper gives an opportunity to develop an EOQ model which is optimized to the requirments of different industries. Further studies can be done to implement ths model in practical conditions.

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AUTHORS PROFILE

Dr. Rudresh Pandey has over 16 years of experience in corporate, management education and entrepreneurship. He has diverse experience in the areas of general management, marketing, entrepreneurship, B2B marketing, research and advertising. Dr. Pandey’s corporate work experience has been in the field of education rating, women entrepreneurship and education technologies including MNCs and Top Indian companies like - Reed Business Information, India Today (Living Media Group) in Mumbai. ONICRA Credit Rating Agency of India Ltd and Impact Marketing Services Pvt Ltd in Delhi/NCR.

Entrepreneurship has been his area of special interest and his Phd topic had been Women Entrepreneurship. He had been instrumental in setting up Entrepreneurship cell in various colleges where he served as a Professor.

Dr. Shradha Goyal has over 10 years of rich experience in Academics. Dr. Goyal completed her doctorate from Jagannath University and is Graduate and Post Graduate in Mathematics honors from Panjab University Campus, Chandigarh She has participated and presented Papers in various seminar and conferences of National & International repute. She has published several research papers in refereed and reputed journals indexed in UGC and SCOPUS. She has also authored a book titled “Basics of Linear Programming”. Dr. Shradha Goyal is associated with Jagannath International Management School, Kalkaji, New Delhi. She is committed towards her responsibilities and gives a mentorship support in Progress of students.

Mr. Mayank Kr. Pandey has over 12 years of rich experience in industry and management education. Mr. Pandey completed his B Com. (2002) from Deen Dayal Upadhyay Gorakhpur University, Gorakhpur, and secured his MBA (2007) from Uttar Pradesh Technical University, Lucknow. He is pursuing Ph.D., he has participated and presented various seminar and conferences of National & International repute. He has published several research papers in reputed journals, he has also authored a book for management students and with all his eccentric efforts corrected the abysmal of his students. Acclaiming concentric & specific managerial skills Mr. Mayank Kumar Pandey is an adapt in handling experiences with his commitment, Mr. Pandey is acclimatized to support students and society’s growth.