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Economic Order Quantity Model with Imperfect Items under Fuzzy Inflationary Conditions

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ABSTRACT

This study develops a new inventory model to determine ordering policy for imperfect items with fuzzy defective percentage under fuzzy discounting and inflationary conditions. In the real world, especially for long term investment and forecasting, the inflation rates will be increase in high uncertainty conditions and therefore, the fluctuations of the inflation rates cannot be disregarded. The developed Mathematical model has been derived to obtain the optimal number of cycles in finite time horizon so that the present value of the total profit leads to maximum. The objective function is fuzzy and we employ the signed distance method of defuzzification to estimate the present value of total profit during planning time horizon. The signed distance method is more applicable than the other methods of defuzzification, especially, when the fuzzy number has been located in the denominator. Because the obtained function after defuzzification is very complicated, we can't use the classical optimization methods and therefore, a new algorithm has been proposed to obtaining the solution. The numerical example has been provided for evolution and validation of the theoretical results. It has been concluded that the number of cycles increase in the case of noninflationary and non defective items and so, the economic order quantity will be decreases. Also, the larger lot sizes and higher inventory levels are recommended when the uncertainty increases.

Key words: Inventory, uncertain optimization, time vale of money, imperfect items, signed distance

INTRODUCTION

In the classical EOQ model, it is assumed that the received items have perfect quality. However, it may not always be a realistic assumption. Due to the imperfect production process, natural disasters, damage or breakage in transit, or for many other reasons, the received lot sizes may contain some defective items. Several researchers have been considered the above scenarios to formulate the production/inventory systems and have been studied the effect of imperfect quality on the lot sizing policy. Rosenblatt and Lee (1986) developed the first model considering the effect of defective products and concluded that the presence of these products motivates smaller lot sizes. Schwaller (1988) presented a procedure and assumed that defectives of a known proportion were present in incoming lots and that fixed and variable inspection costs were incurred in finding and removing the items. Zhang and Gerchak (1990) considered a joint lot sizing and inspection policy for the inventory model where a random proportion of units are defective. They considered that the defective units cannot be used and thus, must be replaced by non defective ones. Salameh and Jaber (2000) assumed that the defective items could be sold as a single batch at a discounted price prior to receiving the next shipment and found that the economic lot size quantity tends to increase as the average percentage of imperfect quality Items increases. Chang (2004a,b) proposed an EOQ model with imperfect quality items where the defective rate is presented as a fuzzy number. He also presents a model with fuzzy defective rate and fuzzy annual demand. Chung and Huang (2006) developed the work of Salameh and Jaber (2000) considering the permissible delay in payment. Lo *et al*. (2007) presented a production\inventory model with an imperfect process, stochastic deteriorating rate and partial backlogging. Chung *et al*. (2009) established a new inventory model with two warehouses and imperfect quality. Jaber *et al*. (2009) applied the concept of entropy cost to extend a ew model under the assumptions of perfect and imperfect quality. Jaber *et al*. (2008) extended Salameh and Jaber (2000) and assumed the percentage defective per lot reduces according to a learning curve.

The inventory models by considering the time value of money have been caused by economic changes and inflationary conditions. According to high inflation rates, it is important to investigate how the time value of money influences various inventory policies. Since 1975 a series of related papers appeared that considered the effects of inflation on the inventory system. Before the 1990s, the earlier efforts have been considered simple situations. The pioneer research in this direction was Buzacott (1975), who developed an EOQ model with inflation subject to different types of pricing policies. In the same year, Misra (1977), also, developed an EOQ model incorporating inflationary effects. Padmanabhan and Vrat (1990) developed an inventory model under a constant inflation rate for initial stock-dependent consumption rate. Datta and Pal (1991) developed a model with linear time-dependent demand rate and shortages to investigate the effects of inflation and time value of money on ordering policy over a finite time horizon. Hariga (1996) extended Datta and Pal (1991) model by relaxing the assumption of equal inventory carrying time during each replenishment cycle and modified their mathematical formulation. Hariga and Ben Daya (1996) extended Hariga (1996) by removing the restriction of equal replenishment cycles and provided two solution procedures with and without shortages. Horowitz (2000) introduced inflation uncertainty into a basic EOQ model. Roy *et al*. (2009) established an inventory model for a deteriorating item with displayed stock dependent demand under fuzzy inflation and time discounting over a random planning horizon. Maity and Maiti (2008) proposed a numerical approach to a multi-objective optimal inventory control problem for deteriorating multi-items under fuzzy inflation. Mirzazadeh *et al*. (2009) developed an inventory model under stochastic inflationary conditions with variable probability density functions (pdfs) over the time horizon and the demand rate is dependent to the inflation rates (any arbitrary pdfs can be used). Their model, also, implicates to a finite replenishment rate, finite time horizon, deteriorating items with shortages. The objective is the minimization of the expected present value of costs over the time horizon. Hou and Li-Chiao (2009) developed a deterministic inventory model when a delay in payments is permissible and the effects of the inflation, deterioration and delay in payments are discussed. Mirzazadeh (2010) assumed the inflation is time-dependent and demand rate is assumed to be inflation-proportional.

PRELIMINARIES

Before presenting the fuzzy inventory model, we introduce signed distance defuzzification method, which has recently used by some researchers in inventory models (Yao and Chiang, 2003; Yao *et al*., 2003). The definitions are from Yao and Wu (2000) and Chang (2004a).

Definition1: The fuzzy set a_α of R,0≤α≤1, is called a level α fuzzy point if:

$$\mu_{a_\alpha}(x) = \begin{cases} \alpha, & x = a \\ 0, & x \neq a \end{cases} \quad (1)$$

Let $F_p(\alpha)$ be the family of all α level fuzzy points.

Definition 2: The fuzzy set $[a_\alpha, b_\alpha]$ of R, 0≤α≤1, is called a level α fuzzy interval if:

$$\mu[a_\omega b_\alpha(x) = \begin{cases} \alpha, & \alpha \le x \le b \\ 0, & \text{Otherwise} \end{cases} \quad (2)$$

For each α∈[0,1], let $F_I(\alpha) = \{[a_\omega b_\alpha] \mid \forall a<b,\ a,\ b \in R\}$.

Definition 3: For any a and 0∈R, define the signed distance from *a* to 0 as a = d0(a, 0). If a>0 the distance from a to 0 is $a = d_0(a, 0)$. If a<0 the distance from *a* to 0 is $-a = -d_{0(a,\ 0)}$. Hence, $d_{0(a,0)} = a$ is called the signed distance from a to 0.

Let Ω be the family of all fuzzy sets B defined on R with which the a-cutB(α) = $[B_l(\alpha), B_u(\alpha)]$ exists for every α∈ [0, 1] and both $B_l(\alpha)$ and $B_u(\alpha)$ are continuous functions on α ∈[0,1]. Then, for any B∈Ω, we have:

$$B = U_{0\le\alpha\le1}[B_l(\alpha)_\alpha, B_u(\alpha)\alpha] \quad (3)$$

From Definition 3, the signed distance of two end points, $B_l(\alpha)$ and $B_u(\alpha)$, of the α-cutB(α) = $[B_l(\alpha), B_u(\alpha)]$ of B to the origin 0 is $d_0(B_l(\alpha), 0) = B_l(\alpha)$ and $d0(B_u(\alpha), 0) = B_u(\alpha)$, respectively.

Their average, $(B_l(\alpha),0)+B_u(\alpha))/2$, is taken as the signed distance of $[B_l(a), B_u(\alpha)]$ to 0.

That is, the signed distance of interval $[B_l(\alpha), B_u(\alpha)]$ to 0 is defined as:

$$d_0([B_l(\alpha), B_u(\alpha)], 0) = [d_0(B_l(a),0)+d_0(B_u(\alpha),0)+d_0(B_u(\alpha), 0)]/2 = (B_l(\alpha)+B_u(\alpha))/2 \quad (4)$$

In addition, for every α∈[0, 1], there is a one-to-one mapping between the α-level fuzzy interval $[B_l(\alpha)\omega B_u(\alpha)_\alpha]$ and the real interval $[B_l(\alpha)], B_u(\alpha)]$, that is, the following correspondence is one-to-one mapping:

$$[B_u(\alpha)_\alpha, B_u(\alpha)_\alpha] \leftrightarrow [B_l(\alpha), B_u(\alpha)] \quad (5)$$

Also, the 1-level fuzzy point σ_1 is mapping to the real number 0. Hence, the signed distance of $[B_l(\alpha)_\alpha, B_u(\alpha)_\alpha]$ to σ_1 can be defined as $d([B_l(\alpha)_\alpha, B_u(\alpha)_\alpha], \sigma_1) = d_0(B_l(\alpha)_\alpha), B_u(\alpha)_\alpha], 0) = (B_l(\alpha)+B_u(\alpha))/2$. Moreover, for $\tilde{B} \in \Omega$, since, the above function is continuous on ≤α≤1, we can use the integration to obtain the mean value of the signed distance as follows:

$$\int_0^1 d([B_l(\alpha)_\alpha, B_u(\alpha)_\alpha], \tilde{0}1)d\alpha = \frac{1}{2}\int_0^1 d([B_l(\alpha) + B_l(\alpha)d\alpha \qquad (6)$$

Property 1: For the trapezoidal fuzzy number $\tilde{B}$ = (p,q,r,s) the signed distance of $\tilde{B}$ to $\tilde{0}_1$ is:

$$d([\tilde{B},(0_1) = \frac{1}{2}\int_0^1[p + (q-p)\alpha + s - (s-r)\alpha]d\alpha = \frac{1}{4}(p+q+r+s) \qquad (7)$$

THE ASSUMPTIONS AND DESCRIPTION OF THE MODEL

Let the lot size, y, is delivered instantaneously with the purchasing price of c per unit and the ordering cost of K. It is assumed that the received lot size contains the percentage of defective items, p, which is not known precisely because of production process failures, different transportation, natural disasters, etc. so it is represented as a trapezoidal fuzzy number. The selling price of good-quality items per unit is s. A 100% screening process of the lot is conducted at the rate of x units per unit time and cost of d; items of poor quality are kept in stock and sold prior to the next replenishment in a single batch with a lower price of í per unit. The length of screening time is t. The inflation and discount rates are shown by i and r, respectively. So the net discount rate is R = r-i. Lead time is negligible and no shortages are allowed. We use a simple algorithm to maximize the present value of total profit in the finite time horizon with the length of T. The inventory level is shown in Fig. 1 (Salameh and Jaber, 2000).

In Fig. 1 we can see that: a batch is ordered in time 0, hence the lead time is zero, the ordered batch is received instantly in time 0 and the inventory level rises to y. The screening process is starting and simultaneously the inventory level is decreasing in the rate of -D. In time t screening process is finished and the imperfect items are sold in a single batch, so we have an instant reduction of size yp in inventory level. The inventory reduction occurs in the same rate as one in the first interval of the cycle ([0,t]), -D and the inventory level comes to zero at the end of the cycle and is repeated in the time horizon, H. Our objective is determining the number of cycles in the time horizon which maximizes the present value of total profit. Other important notations are: h, holding cost per unit per unit time, τ, time, N, number of the cycles in planning horizon.

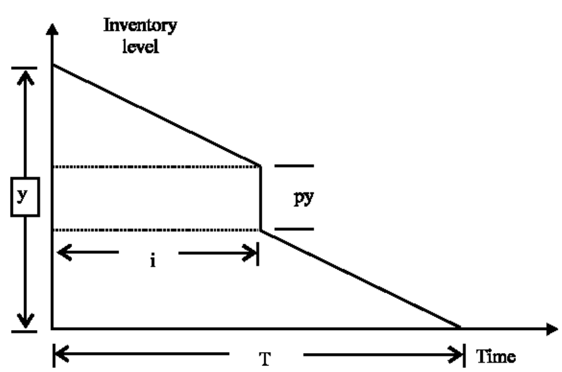

Fig. 1: Inventory level

THE MATHEMATICAL MODEL

As Salameh and Jaber (2000) shown in their model, N(y,p) is the number of good items in each order, which is represented by:

$$N(y, p) = y\text{-}py = (1\text{-}p)y \tag{8}$$

They assume that N(y,p) is at least equal to the demand of screening time t, because no shortages are allowed, so,

$$N(y, p) \geq Dt \tag{9}$$

where, D is the demand rate per unit time.

Present value of total revenue: The revenues per cycle are obtained from selling good quality items and imperfect quality items. The revenue of imperfect items in a cycle is:

$$TRIc(y) = vyp \tag{10}$$

The present value of total revenue of imperfect items in planning horizon, using the factor of the net discount rate, is:

$$PVTRI(y) = \Sigma_{j=1}^{N}(vyp)e^{-R(T(j-1)+t)} \tag{11}$$

where, t is the time of finishing screening items, y/x'.

To calculate the present value of perfect items revenue we assume that we get it in the middle of each cycle, so it can be written as:

$$PVTRP(y) = \Sigma_{j=1}^{N}(sy(1-p)e^{-R((j-1)T+\frac{T}{2})} \tag{12}$$

Present value of total cost: The procurement and ordering costs per cycle is:

$$Pc_c(y) = K+cy \tag{13}$$

So, the present value of procurement and ordering costs is:

$$PVPG(y) = \Sigma_{j=1}^{N}(K+cy)e^{-RT(j-1)} \tag{14}$$

If we haven't considered the effect of inflation in our model, the screening cost would be added to procurement cost for each item. But now because this cost occurs in the interval of [0,t], not in the beginning of the cycle (like procurement cost), the screening cost per cycle would be as:

$$PVSC = \Sigma_{j=1}^{N}dye^{-R((j-1)T+\frac{t}{2})} \tag{15}$$

Here, we assumed that screening cost is in the middle of screening cycle.

To get the holding cost per cycle we should first derive the inventory level relationship in each moment of the cycle. A change in inventory level is caused from demand, so we can write this change's slope as below:

$$\frac{dI(\tau)}{\tau} = -D. \qquad 0 \le \tau \le t \tag{16}$$

Inventory level in intervals [0,t] and [t, T] are parallel lines with different initial points. The relations of these two lines are:

$$I_1(\tau) = y\text{-}D\tau, \qquad 0 \le \tau \le t \tag{17}$$

$$I_2(\tau) = y(1\text{-}p)\text{-}D\tau, \qquad 0 \le \tau \le t \tag{18}$$

So, the present value of holding cost in planning horizon is:

$$PVTSH(y) = \Sigma_{j=1}^{N}\left(\int_{(j-1)*T}^{(j-1)*T+t} I_1(\tau)*e^{-R\tau}d\tau + h*\int_{(j-1)*T+t}^{j*T} I_2(\tau)*e^{-R\tau}d\tau\right) \tag{19}$$

Present value of total profit: Now the present value of total profit in planning horizon using Eq. 11-12, 14-15 and 19 is represented as:

$$\begin{aligned} PVTP(y) = &\left(\sum_{j=1}^{N}\left((vyp)e^{-R((j-1)T+t)}\right) + \sum_{j=1}^{N}\left(sy(1-p)e^{-R((j-1)T+\frac{T}{2})}\right)\right) - \left(\Sigma_{j=1}^{N}\left((K+cy)e^{-RT(j-1)}\right)\right) - \Sigma_{j=1}^{N}\left(dye^{-R((j-1)T+\frac{t}{2})}\right) - \\ &\Sigma_{j=1}^{N}\left(\left(h*\int_{(j-1)*T}^{(j-1)*T+t} I_1(\tau)*e^{-R\tau}d\tau\right) + \left(h*\int_{(j-1)*T+t}^{j*T} I_2(\tau)*e^{-R\tau}d\tau\right)\right) \end{aligned} \tag{20}$$

SOLUTION METHODOLOGY

Since, the percentage of imperfect items, inflation and discount rates are fuzzy numbers the objective function becomes fuzzy. So we can't use common methods to maximize it. We first use the signed distance method to defuzzify objective function. Then since the derived function is complicated, instead of finding the optimal T, as many previous researches have done, we use a simple algorithm to find optimal solution for N, which is a discrete variable.

Now we modify the crisp model shown in Eq. 20 by incorporating the fuzziness of defective rare, inflation rate and discount rate. For fuzzifying problem, we consider p and r and i as trapezoidal fuzzy numbers, so, R = r-i becomes a trapezoidal fuzzy number too:

$$\tilde{p} = (r-\Delta_1, r, q+\Delta_2), \qquad \tilde{R} = (m-\Delta_3, m, n, n+\Delta_4)$$

where, $0<\Delta_1<r<q$, $0<\Delta_2<1<q$, $0<\Delta_3<m$, $0<\Delta_4<1\text{-}n$ and Δ_1, Δ_2 Δ_3 Δ_4 are determined by decision makers. In this case, the present value of total profit in planning horizon is also a fuzzy value, $P\tilde{V}TP(y)$, which is expressed as:

$$P\tilde{V}TP(y) = \left(\Sigma_{j=1}^{N}\left(vy\tilde{p}\right)e^{-((j-1)T+t)}\right) + \Sigma_{j=1}^{N}\left(sy\left(1-\tilde{p}\right)e^{-((j-1)T\frac{T}{2})}\right) - \left(\Sigma_{j=1}^{N}\left(\left(K+cy\right)e^{-\tilde{R}T(j-1)}\right)\right) - \Sigma_{j=1}^{N}\left(dye^{-\tilde{R}((j-1)T+\frac{t}{2})}\right) - \Sigma_{j=1}^{N}\left(\left(h*\int_{(j-1)*T}^{(j-1)*T+t} I_1(\tau)*e^{-\tilde{R}\tau}d\tau\right)+\left(h*\int_{(j-1)*T+t}^{j*T} I_2(\tau)*e^{-\tilde{R}\tau}d\tau\right)\right) \tag{21}$$

The final resultant function is very complicated so we only show the procedure for $d(p,\tilde{0}_1)$ and $d(e^{-\tilde{R}},\tilde{0}_1)$ as exemplary.

According to relation Eq. 7, the signed distance of fuzzy number $\tilde{p}$ to $\tilde{0}_1$ is measured as:

$$d(\tilde{p},\tilde{0}_1) = \frac{1}{4}(r-\Delta_1+r+q+q+\Delta_2) = \frac{1}{4}(2r+2q+\Delta_2-\Delta_1) \tag{22}$$

To measure the signed distance of fuzzy number $e^{-\tilde{R}}$ to $\tilde{0}_1$ we should find the left and right end points of the a-cut ($0\le\alpha\le1$) of $\tilde{R}$ at first:

$$R_l(\alpha) = (m-\Delta_3)+\alpha\Delta_3>0,\ Ru(\alpha) = (n+\Delta_4)-\alpha\Delta_4>0 \tag{23}$$

where $0<R_l(\alpha)<R_u(\alpha)$. Now, we can write the left and right end points of the α-cut ($0\le\alpha\le1$) of $e^{-\tilde{R}}$ as:

$$\left(e^{-\tilde{R}}\right)_l(\alpha) = e^{-R_u(\alpha)} = e^{-((n-\Delta_4))},\ \left(e^{-\tilde{R}}\right)_u(\alpha) = e^{-R_l(\alpha)} = e^{-((m-\Delta_3)+\alpha\Delta_3)} \tag{24}$$

Substituting Eq. 21 in 3 we have:

$$d\left(e^{-\tilde{R}},\tilde{0}_1\right) = \frac{1}{2}\int_0^1\left(e^{-((n+\Delta_4)-\alpha\Delta_4)}+e^{-((m+\Delta_3)-\alpha\Delta_3)}\right)da = \left(\frac{1}{2}\right)*\frac{-e^{-n+\Delta_4}*\Delta_3 e^{-m+\Delta_3}*\Delta_4+e^{-n}*\Delta_3-e^{-m}*\Delta_4}{\Delta_4*\Delta_3} \tag{25}$$

After substituting all fuzzy terms with related signed distances, we have an estimate of the present value of total profit in planning horizon in the fuzzy sense, which is shown by Z in the algorithm. Because the resultant function is very complicated we can't use first derivative method to find optimal cycle length, T, we define the objective of the problem as determining the optimal number of cycles in planning horizon, N, such that maximizes the profit function. Hence N is a discrete variable; we can apply a simple algorithm to find optimal solution. The proposed algorithm is:

```
1   Set W = -M (lower bound which ensures Z won't exceed it, where M is a big number), y = 1, q = 0
2   Set n=1
3   Set y = D*H/N(1-p)
4   Evaluate Z = d( Z̃, 0_1)
5   If Z≥W
6   Set W = Z
7   N = n+1
8   Go to 3
9   End if
10  End algorithm
```

Table 1: Results for $\tilde{R}$ = (0.03,0.04,0.05,0.06)

N	y	z
1	25220	2.7506e+008
2	12610	2.9739e+008
3	8406	3.0525e+008
6	4203	3.1338e+008
10	2522	3.1671e+008
15	1681	3.1831e+008
20*	1261*	3.1920e+008*
21	1200	3.1907e+008

*The optimal solution

Table 2: Results for $\tilde{R}$ = (0.07,0.08,0.011,0.12)

N	y	z
1	25248	1.0096e+008
2	12624	1.2258e+008
3	8416	1.3076e+008
6	4208	1.3948e+008
10	2524	1.4307e+008
15	1683	1.4495e+008
20	1262	1.4585e+008
24*	1052*	1.4636e+008*
25	1009	1.4632e+008

* The optimal solution

THE NUMERICAL EXAMPLE

The following numerical example is provided to clarify how the proposed model is applied. Let demand rate, D = 5000 units year^{-1}, ordering cost, K = 500 cycle^{-1}, holding cost, h = 0.1 $/unit year^{-1}, screening rate, x = 15000 units year^{-1}, screening cost, d = 0.5 $ unit^{-1}, purchase cost, c = 25 $ unit^{-1}, selling price of good quality items, s = 50 $ unit^{-1}, selling price of imperfect quality items, v = 20 $ unit^{-1}. We assume that the defective rate is a trapezoidal fuzzy number and is $\tilde{p}$ = (0.007, 0.008, 0.01, 0.011). The results are shown in Table 1-2.

DISCUSSION

Comparing the values of Table 1 and 2, we find that increasing in the inflation rate and thus decreasing in $\tilde{R}$, results in less quantity for N* and larger lot size, y*. It is a true outcome in the real situations because rising in R values means higher inflation rates and lower discount rates. So, the firm tends to have more inventories to be able to have proper reaction in uncertain high inflationary conditions which has also explained in Horowitz (2000), fears of inflation or uncertainty about inflation encourage manager to purchase more at current prices. The results of Chang (2004b) indicate that a higher value of inflation rate implies higher values of order quantity, replenishment cycle and total relevant cost which support our results. Yang (2004) considered the two-warehouse inventory problem for deteriorating items with constant demand rate and shortages under inflation. Their study shows that the proposed model is less expensive to operate than the traditional one in the case of the inflation rate is greater than zero. Our proposed model shows that considering higher fuzzy inflation rates causes more profits in planning time horizon.

CONCLUSION

This study presented an inventory model which accounts on the imperfect quality items and the effect of inflation and discount rates when using the EOQ formula for the first time. The defective rate, inflation rate and discount rate are represented as trapezoidal fuzzy numbers. We employed the signed distance method of defuzzification to estimate present value of total profit during planning horizon and then optimal numbers of cycles in planning horizon is derived. As illustrated in Chang (2004a), using the signed distance method is more applicable than other methods used previously in researches mostly the centroid method. Finally, it is shown that the economic lot size quantity increases and the number of cycles in planning horizon decreases as the inflation rate increases and the discount rate decreases.

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