IJMS, *Vol. 19, Nos. 3-4, (July-December 2020), pp. 333-346*

ISSN: 0972-754X

SOLVING OPTIMIZATION PROBLEM OF INVENTORY MODEL UNDER DELAY IN PAYMENTS AND IMPRECISE TRANSPORT IN COVID—19 PANDEMIC

A.Thangam*

Abstract: Optimization of business profit through inventory problems under trade credit in payments is popular topic in research. In real life situations, the inventory related costs such as ordering cost, holding cost, etc are imprecise (fuzzy) due to lack of adequate stock information in the global market. The interest rate is also imprecise due to uncertainty in financial policy, inflation and monetary policy. The uncertainty in shipping risks associated with unusual circumstances such as Covid-19 pandemic, have received special attention among the global traders. So this paper addresses an EOQ inventory model with fuzzy inventory costs, fuzzy interest earned rate, fuzzy interest payable rate and fuzzy defective rate due to disruption in transport. The retailer's profit is maximised and optimal replenishment policy is derived into mathematical equations. Finally, numerical examples are provided to illustrate the results.

Keywords: Fuzzy number, EOQ, trade credit, Disruption;

1. INTRODUCTION

Recently, in 2020, Xu and Song [31] developed integrated optimization for production capacity, raw material ordering and production planning under quantity uncertainty . Global traders such as Wal-Mart, Target, Home Depot, Costco and Dollar General use to ship commodities from various parts of the world in order to minimize the purchase cost. In transport, some of the items are defected due to unusual circumstances (such as Covid-19 pandemic, terrorist attack, earth quake, mishandling in transport, shipping damage, misplacing products etc.,) that may result a risk in delivery from the supplier to a retailer. The number of defective items is imprecise due to disruption in transport. The inventory cost parameters are not fixed due to inflation in the global market and fluctuations in demand of the commodity. So the inventory cost parameters are imprecise (fuzzy) numbers in real life situations.

Modern marketing business environment is mostly associated with permissible delay in payments. A supplier provides the retailer a delay period for settling the payments. The retailer can accumulate revenue and earn interest by delaying the payment until the last moment of this permissible delay period. In global market, the prices of commodities are imprecise due to fluctuations in production and marketing. The interest rate is also affected by the growth rate of nation's economy. When the economy is keeping to improve, the demand for the capital is increasing; it boosts up the interest rate. During economic decline, demand for capital and interest rate will come down. Money flow between nations affects the interest rate. The supply of money within the nation will also affect the interest rate. Therefore in real world, the commodity prices, interest earned rate and interest payable rate are not well known. In this paper, an Economic Order Quantity (EOQ) inventory model is developed under the considerations of fuzzy inventory cost parameters, fuzzy interest rate, fuzzy interest payable rate and fuzzy defective rate. The fuzzy variables are treated as trapezoidal fuzzy numbers.

To the best of knowledge, no paper exists in the literature for the investigation of retailer's inventory model under the above mentioned real life scenario.

2. A) LITERATURE REVIEW

To handle the uncertainty in inventory parameters, researchers used fuzzy set theory. Pertrovic and Sweeney [1] considered the demand rate, lead time and inventory level into triangular fuzzy numbers, and they determined the optimal order quantity with the fuzzy propositions method. Yao *et al*. [2] developed the Economic Lot Size Production model with customer demand as a fuzzy variable. Yao *et al*. [3] established a fuzzy inventory system without the backorders in which both the order quantity and the total demand were fuzzified as the triangular fuzzy numbers. Chang [4] created the Economic Order Quantity (EOQ) model with imperfect quality items by applying the fuzzy sets theory, and proposed the model with both a fuzzy defective rate and a fuzzy annual demand. Chang *et al.* [5] considered the mixture inventory model involving variable lead time with backorders and lost sales. They fuzzified the random lead-time demand to be a fuzzy random variable and the total demand to be the triangular fuzzy number. Based on the centroid method of defuzzification, they derived an estimate of the total cost in the fuzzy sense. Chen *et al*. [6] introduced a fuzzy economic production quantity model with defective products in which they considered a fuzzy opportunity cost, trapezoidal fuzzy cost and quantities in the context of the traditional production inventory model. Maiti [7] developed a multi-item inventory model with stock-dependent demand and two-storage facilities in a fuzzy environment (where purchase cost, investment amount and storehouse capacity are imprecise) under inflation and incorporating the time value of money. Other related articles on this topic can be found in work by Chen and Wang [8], Vujosevic *et al*. [9], Gen *et al*. [10], Roy and Maiti [11], Ishii and Konno [12], Lee and Yao [13], Yao and Lee [14], Chang *et al*. [15,16,17], Ouyang *et al.*[18,19], Yao *et al*. [20] and other literatures [21,22,23,24,25,26,27,28,29,30] .

2 B) PRELIMINARIES

Here, we use some definitions which are well known in fuzzy set theory.

Definition 1 . A **fuzzy set** F on the given universal set X is set of ordered pairs

$$F = \{(x, \mu_F(x)), x \in X\}$$

$where,\quad \mu_F : X \to [0,1]$ is the membership function.

Definition 2. A fuzzy number F is a fuzzy set which satisfies the following conditions:

1. F is normal, that is, **there exists** $x \in R$ such that $\mu_F(x) = 1$
2. $\mu_F(x)$ is piece-wise continuous function.
3. F is convex fuzzy set.

Definition 3. A trapezoidal fuzzy number F =(a, d, c, d) is represented with the following membership function

$$\mu_F(x) = \begin{cases} L(x) = \dfrac{x-a}{b-a} & \text{if} \quad a \le x \le b \\ 1 & \text{if} \quad b \le x \le c \\ R(x) = \dfrac{d-x}{d-c} & \text{if} \quad c \le x \le d \\ 0 \ \text{otherwise} & \end{cases}$$

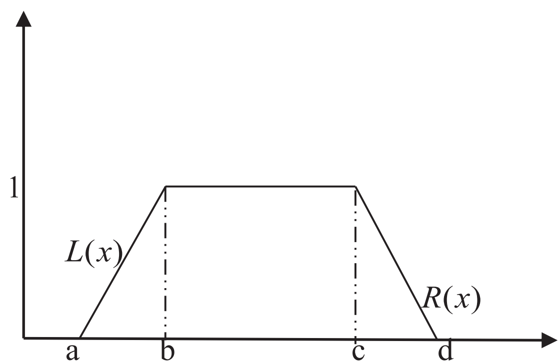

Fig 1 : Trapezoidal fuzzy membership function

Arithmetic Operations in fuzzy numbers:

Suppose $A=(a_1,a_2,a_3,a_4)$ and $B=(b_1,b_2,b_3,b_4)$ are two trapezoidal fuzzy numbers, then

$$A \oplus B=(a_1+b_1,a_2+b_2,a_3+b_3,a_4+b_4)$$

$$A \otimes B=(a_1b_1,a_2b_2,a_3b_3,a_4b_4)$$

$$A-B=(a_1-b_4,a_2-b_3,a_3-b_2,a_4-b_1)$$

$$kA=\begin{cases}(ka_1,ka_2,ka_3,ka_4) & \text{if } \mathrm{k}>0\\(ka_4,ka_3,ka_2,ka_1) & if \ \mathrm{k}\le 0\end{cases}$$

$$\frac{A}{B}=\left(\frac{a_1}{b_4},\frac{a_2}{b_3},\frac{a_3}{b_2},\frac{a_4}{b_1}\right)$$

Graded Mean Integration Method (Chen & Hsieh (1999)):

The graded mean integration method is used to defuzzify the total fuzzy inventory cost. Consider the trapezoidal fuzzy number $F = (a,b,c,d)$. The defuzzified value of F can be calculated as follows:

$$Z(F)=\left[\int_0^1 \alpha\,\frac{L^{-1}(\alpha)+R^{-1}(\alpha)}{2}\,d\alpha\right]\Big/\int_0^1 \alpha \ \mathrm{d}\alpha$$

$$=\frac{\mathrm{a+2b+2c+d}}{6}$$

1. Mathematical Modeling

We introduce some symbolic notations for various inventory parameters. They are used in the mathematical modelling of the proposed problem. Normally, there are some restrictions to build a mathematical model for an inventory system. To illustrate various real life situations in which the proposed model can be applied, we consider some assumptions.

Notations:

λ	-	Demand rate per annum
I(t)	–	Inventory level at time t
T	–	cycle time
Q	-	ordering quantity

A	–	Ordering cost
c	–	unit purchasing cost
s	–	unit selling price
h	–	inventory holding charges per \$ per unit item
I_e	–	Interest rate earned rate per \$ per unit item
I_p	-	Interest payable rate per \$ per unit item
M	-	Retailer's credit period offered by the supplier.
π	-	Defective cost, the unit cost per item due to defectiveness in disruption in transport,
x	-	Percentage of imperfect quality products due to disruption in transport,
TC(T)	–	Retailer's total cost as a function of T.

Assumptions:

1. Time horizon is infinite.
2. The demand rate is fixed constant.
3. Shortages are not allowed.
4. Replenishment of items in the inventory is instantaneous.
5. Lead time is negligible.
6. Supplier provides the retailer a fixed permissible delay period M to settle the accounts. If the retailer does not pay at time M, he has to pay penalty at rate I_p.
7. The inventory items got defects at rate 'x' due to uncertainty in transport.

3 (A.) CRISP MODEL

In this section, the annual total cost incurred at the retailer is estimated in terms of mathematical equations. The expenditures for the retailer come from ordering the items, storage of items, interest paid for the items which are not sold at delay period and defective cost due to probabilistic disruption in transport due to mishandling of items. The revenue comes from selling the items and interest earned due to permissible delay period offered by the supplier. This paper considers the maximization of total profit incurred at the retailer.

The total profit of the inventory system is calculated as below:

TP (T) = Sales Revenue – Purchase cost – Inventory holding cost + Interest earned – Interest Payable – Cost due to Defectiveness.

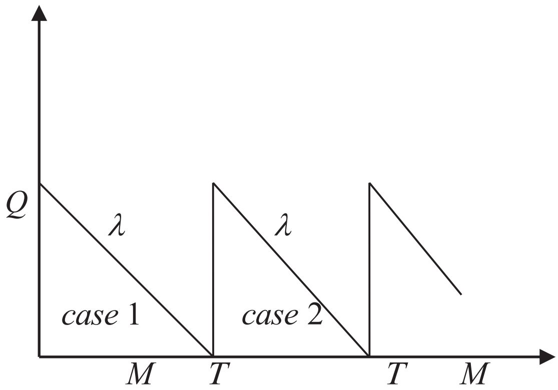

Fig 1: Classical EOQ Inventory

The inventory level is described by the following equations

$$I(t)=\begin{cases} Q & \text{if } t=0 \\ Q-\lambda t & \text{if } 0<t<T \\ 0 & \text{if } t=T \end{cases}$$

where $Q = \lambda T$.

We estimate the retailer's revenue and inventory costs as below:

1. Annual Sales Revenue $= s\lambda$
2. Annual Purchase cost $= c\lambda$
3. Annual holding cost $= \dfrac{h}{T}\int_{o}^{T} I(t)\,dt = \dfrac{h\lambda T}{2}$
4. **Interest earned rate (Case A) When M** $\leq$ T

The retailer settles his account at time M, the interest earned (IE) is

$$IE = \frac{sI_e \lambda M^2}{2T}$$

(Case B) When $M \geq T$

After the completion of cycle time T, all the items are sold and retailer pays at time M. So he earns interest (IE) :

$$IE = \frac{sI_e}{T}\left[\frac{\lambda T^2}{2} + \lambda T(M-T)\right] = \frac{sI_e \lambda}{T}(2M-T)$$

5. INTEREST PAYABLE

Case A: When M $\leq$ T

Since the retailer pays for the items purchased before the cycle time, he has to borrow for the payment of items sold after M. Hence, the interest payable (IP) is

$$IP = \frac{cI_k \lambda (T-M)^2}{2T}$$

Case B: When $M \geq T$

Here is no interest payable, since all the items are sold at time T and the retailer can pay for the items without any loan.

6. **Cost due to the defectiveness of items in transport** = $\pi x \lambda T$

From the above discussions, the total profit can be estimated as

$$TP(T) = \begin{cases} TP_1(T) & \text{if } \mathrm{M} \leq \mathrm{T} \\ TP_2(T) & \text{if } \mathrm{M} \geq T \end{cases} \tag{1}$$

where

$$TP_1(T) = (s-c)\lambda - \frac{A}{T} - \frac{h\lambda T}{2} + \frac{sI_e \lambda M^2}{2T} - \frac{cI_k \lambda (T-M)^2}{2T} + \pi x \lambda T \tag{2}$$

$$TP_2(T) = (s-c)\lambda - \frac{A}{T} - \frac{h\lambda T}{2} + \frac{sI_e \lambda}{2}(2M-T) + \pi x \lambda T \tag{3}$$

3 (B). FUZZY MODEL

Here, the crisp inventory parameters are treated as trapezoidal fuzzy numbers.

$\tilde{c} = (c_1, c_2, c_3, c_4)$, $\tilde{s} = (s_1, s_2, s_3, s_4)$, $h = (h_1, h_2, h_3, h_4)$, $\pi = (\pi_1, \pi_2, \pi_3, \pi_4)$

$$x=(x_1,x_2,x_3,x_4)\,,\; I_e=(ie_1,ie_2,ie_3,ie_4)\,,\;\; I_p=(Ip_1,Ip_2,Ip_3,Ip_4)\,.$$

The total profit is

$$TP(T)=\begin{cases} TP_1(T) & \text{if } M\le T \\ TP_2(T) & \text{if } M\ge T \end{cases} \tag{4}$$

where

$$TP_1(T)=(\tilde{s}-\tilde{c})\lambda-\frac{A}{T}-\frac{h\lambda T}{2}+\frac{\tilde{s}I_e\lambda M^2}{2T}-\frac{\tilde{c}I_k\lambda(T-M)^2}{2T}-\pi x\lambda T \tag{5}$$

$$TP_2(T)=(\tilde{s}-\tilde{c})\lambda-\frac{A}{T}-\frac{h\lambda T}{2}+\frac{\tilde{s}I_e\lambda}{2}(2M-T)-\pi x\lambda T \tag{6}$$

Let

$$\beta=(\beta_1,\beta_2,\beta_3,\beta_4)=[1,2,2,1]$$

Using graded mean integration, the profit function TP(T) is defuzzified into:

$$F\left[TP_1\right]=\frac{\lambda}{6}\left[\sum_{i=1}^{4}\beta_i(s_i-c_{5-i})+\sum_{i=1}^{4}\beta_i(c_iIp_iM)\right]+\frac{1}{2T}\left[\frac{\lambda M^2}{6}\sum_{i=1}^{4}\beta_is_iIe_i+\frac{\lambda M^2}{6}\sum_{i=1}^{4}\beta_ic_iIp_{5-i}+\frac{1}{3}\sum_{i=1}^{4}\beta_iA_{5-i}\right] \tag{7}$$
$$+\frac{\lambda T}{12}\left[\sum_{i=1}^{4}\beta_i(h_{5-i}+c_{5-i}Ip_{5-i}+2\pi_{5-i}x_i)\right]$$

$$F\left[TP_2\right]=\frac{\lambda}{6}\left[\sum_{i=1}^{4}\beta_i(s_i-c_{5-i})+\sum_{i=1}^{4}\beta_i(s_iIe_iM)\right]+\frac{\lambda T}{12}\left[\sum_{i=1}^{4}\beta_i(h_{5-i}+s_{5-i}Ie_{5-i}+2\pi_{5-i}x_i)\right]+\frac{1}{6T}\sum_{i=1}^{4}\beta_iA_{5-i} \tag{8}$$

Let

$$X_1=\frac{\lambda}{6}\left[\sum_{i=1}^{4}\beta_i(s_i-c_{5-i})+\sum_{i=1}^{4}\beta_i(c_iIp_iM)\right]$$

$$Y_1=\frac{\lambda M^2}{6}\sum_{i=1}^{4}\beta_is_iIe_i+\frac{\lambda M^2}{6}\sum_{i=1}^{4}\beta_ic_iIp_{5-i}+\frac{1}{3}\sum_{i=1}^{4}\beta_iA_{5-i}$$

$$Z_1=\lambda\sum_{i=1}^{4}\beta_i(h_{5-i}+c_{5-i}Ip_{5-i}+2\pi_{5-i}x_i)$$

$$X_2=\frac{\lambda}{6}\left[\sum_{i=1}^{4}\beta_i(s_i-c_{5-i})+\sum_{i=1}^{4}\beta_i(s_iIe_iM)\right]$$

$$Y_2=\frac{\lambda}{12}\sum_{i=1}^{4}\beta_i(h_{5-i}+s_{5-i}Ie_{5-i}+2\pi_{5-i}x_i)$$

$$Z_2=\frac{1}{6}\sum_{i=1}^{4}\beta_iA_{5-i}$$

Then

$$F\left[TP_1\right] = X_1 + \frac{Y_1}{2T} + \frac{T}{2}Z_1 \tag{9}$$

and

$$F\left[TP_2\right] = X_2 + Y_2\mathrm{T} + \frac{Z_2}{\mathrm{T}} \tag{10}$$

To find the optimum value of cycle time T, the conditions are:

$$\frac{d}{dT}\left(F\left[TP_1\right]\right) = 0, \frac{d}{dT}\left(F\left[TP_2\right]\right) = 0$$

and $\dfrac{d^2}{dT^2}\left(F\left[TP_1\right]\right) < 0, \dfrac{d^2}{dT^2}\left(F\left[TP_2\right]\right) < 0$

The optimal replenishment policies are obtained as below

$$T_1^* = \sqrt{\frac{Y_1}{Z_1}} \text{ and } T_2^* = \sqrt{\frac{Z_2}{Y_2}} \tag{13}$$

2. SPECIAL CASE - DISCUSSIONS

- If all the fuzzy numbers become constant, that is :

  $A_i = A, s_i = s, c_i = c, h_i = h, Ie_i = I_e, Ip_i = I_p, \pi_i = \pi$ for i=1,2,3,4, then

  we get the estimated cycle time as

$$\mathrm{T}_1^* = \sqrt{\frac{2A - sI_e\lambda M^2 + cI_p\lambda M^2}{\lambda(2\pi x - h - cI_p)}}$$

and

$$\mathrm{T}_2^* = \sqrt{\frac{2A}{\lambda(h + sI_e + 2\pi x)}}$$

These values are fit to the crisp inventory model .

- If all the items are transported without any contingency, that is $x_i = 0$ for i=1,2,3,4, then the optimal cycle time is

$$T_1^* = \sqrt{\frac{2A - sI_e\lambda M^2 + cI_p\lambda M^2}{\lambda(h + cI_p)}} \text{ and } T_2^* = \sqrt{\frac{2A}{\lambda(h + sI_e)}}$$

- If there is no permissible delay period offered to the retailer then M = 0, I_e=0, I_p=0. The optimal solutios are obtained as $T_1^* = T_2^* = \sqrt{\frac{2A}{\lambda h}}$. Then $Q^* = \sqrt{\frac{2\lambda A}{h}}$. This is classical EOQ lot size.

3. NUMERICAL EXAMPLE

To illustrate the proposed fuzzy inventory model, we consider the fuzzy inventory parameter values as below:

$$A = (48, 49, 50, 51); \tilde{s} = (10, 11, 12, 13); \tilde{c} = (9, 10, 11, 12); h = (0.8, 0.9, 1, 1.1, 1.2)$$

$$Ip = (0.12, 0.13, 0.14, 0.15); Ie = (0.18, 0.19, 0.2, 0.21); \pi = (0.9, 1, 1.1, 1.2);$$

$$x = (0.02, 0.03, 0.04, 0.05)$$

and crisp values M = 0.14; λ = 200. We obtain the optimal solutions using Eq.(13) as below:

Optimal cycle time = 0.4324 unit time, Optimal order Quantity = 86 items

Maximum Profit = \$ 218.88

Sensitivity Analysis

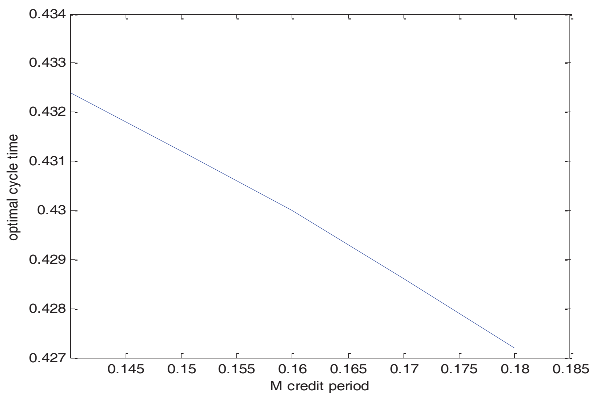

Fig 2. Effect of change in optimal cycle time Vs Credit Period M

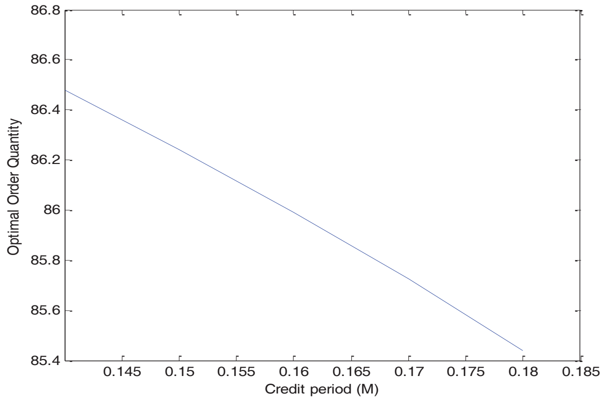

Fig 3. Effect of change in Optimal order Quantity vs credit period

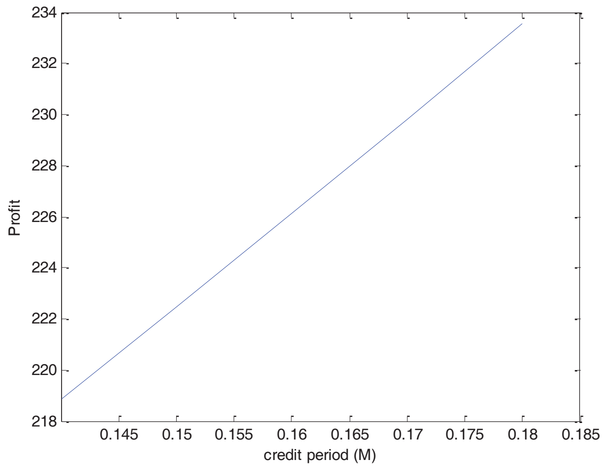

Fig 4. Effect of change in Profit Vs Credit period

From Fig 2, 3 & 4, we observe that

- **When credit period time increases the cycle time decreases; The retailer is selling the item as earlier as possible to earn the interest on revenue during the permissible delay period.**
- **When credit period increases the optimal order quantity increases; The retailer wants to buy more items when the credit period is large.**
- **When the credit period increases the profit also increases.**

4. CONCLUSIONS

In this paper, we discussed the fuzzy EOQ inventory model with permissible delay in payments and disruption in delivery of items. The defective rate of items, interest earned rate, interest payable rate and inventory costs are considered as trapezoidal fuzzy numbers. Using fuzzy arithmetic operations and graded mean integration method, we found optimal replenishment policy for the retailer. Special cases are discussed to derive the classical EOQ inventory models with and without permissible delay in payments when fuzzy numbers are considered to be crisp values. Finally numerical example is presented to illustrate mathematical solutions and sensitivity analysis.

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A.Thangam
Department of Mathematics,
Pondicherry University – Community College, Lawspet ,
Pondicherry - 605 008, India.
Email: thangamgri@yahoo.com