ISSN: 0974-8571 Vol.13 No. 2 December, 2021

International Journal of Computational Intelligence in Control

A Particle Swarm Optimization based EOQ model in a imperfection production system with variable discount and shortages

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Date of Submission: 17th May 2021 Revised: 27th June 2021 Accepted: 26th July 2021

How to Cite: **Patro, R.R.., Patro , R., Nayak, M., and Patnaik, S., 2021. A Particle Swarm Optimization based EOQ Model in a Imperfection Production System with variable Discount and Shortages.** ***International Journal of Computational Intelligence in Control*****, 13(2).**

Abstract- **Present paper investigates an economic order Quantity (EOQ) inventory model where the lot produced with a fraction of imperfect items. Firstly, to explore this model two different categories are considered, without back order as well as backorder. Imperfect items are taken with a variable rate of discount. Then after an effective optimization procedure, Particle Swarm Optimization (PSO) has been implemented to optimize lot size and get maximum profit. Later numerical examples are provided to study the impact of different attributes on the optimal policy. Graphical representation also has been given to analyze the result obtained.**

Index Terms - EOQ, PSO, Imperfect quality, Inventory, Backorder, Proportionate discount, Probability Density Function (PDF).

INTRODUCTION

Inventory plays a vital role in all most all manufacturing organizations. Since last few decades model of EOQ was popularly used in inventory systems. EOQ model plays a vital role in modelling of inventory and inventory in manufacturing organizations/industries. In the current business scenario though the manufacturing and production systems are well developed; a proportion of item manufactured may have imperfectness. This directly effects inventory management. In general, the problems arise in maintenance of manufacturing system and different business transactions. Therefore, screening of the produced lot is required for the imperfect items.

The approach of PSO was originally proposed by James Kennedy and Russell Eberhart in 1995 [1]. Particle Swarm Optimization is a bio-inspired evolutionary algorithm, that is inspired by social behaviour of birds flocking. means behaviour of birds moving together in a crowd. Also having important properties like consistency, locality, collision free, matching the velocity. Aim of using such technique is to follow the bird which is nearest to the food while moving for food collection. It means finding best among different possible solutions. This is an intelligent based computational method used to solve optimization problems. Technique of PSO can be applicable in the research areas of science as well as engineering applications. This algorithm is very simple, easy to implement, and speed of search is very fast.

First EOQ model has been developed to measure the impact of items with a fraction of imperfection [2]. Once screening process done imperfect items are separated and as a whole batch was sold with a constant rate of discount [3]. An EOQ inventory model explored on basis of random number of imperfect items obtained at the end of screening [4]. Then after another EOQ model proposed where two types of items produced from the lot by [5]. With the extension of these basic approaches, a huge number of works has been done on modelling of inventory in order to meet competitive status of business industries during last two decades. Effect of learning while modelling an inventory in association with a variable rate of discount for the items of imperfection has given a base in this direction [6].

The modelling of EOQ with idea of imperfect production that allows shortage was initiated by [7]. An EOQ model with defective items that permits shortage and backorder condition in order to determine total profit expected was explored by [8]. Multiple screening process to establish the EOQ model for imperfect quality items introduced [9]. The concept of fuzzy was used for modelling the same, where the shortages were permitted under completely backlogged [10]. A deterministic model for inventory with a fixed rate of deterioration that permits shortages was developed [11]. An inventory problem was designed for defective items in consideration with deterioration as well as fully backlogging where demand is used as a function of selling price [12]. A model of EOQ has been established for imperfect items with the consideration of crisp as well as fuzzy with a variable rate of discount in association with learning effect in infinite time horizon by [13]. They allowed shortages that are partially backlogged.

In the past decades a massive research has been explored /focused on various inventory situations with meta heuristic approaches like PSO. An EPQ fuzzy model with back order along with PSO technique explored [14]. PSO algorithm is implemented to find the combined impact of time- varying demand and purchase cost [15]. The technique of PSO has been used for modelling of inventory for deteriorating items and partially backlogged strategies by [16]. An idea was explored for rework of defective items by taking interval valued numbers in an imperfect production develop an EPQ model [17]. An EOQ model implemented by considering interval valued numbers for two types of imperfect items [18]. An inventory model by allowing shortages partially with preservation technology to avoid deterioration impact was proposed [19].

So far, the researchers applied different meta heuristic algorithms to explore EOQ models with interval valued numbers, reworkable items with shortages, two types of defectives without shortages, two warehouse problems etc. The above-mentioned literatures did not used proportionate discount on imperfect items along with optimization techniques for shortages which supports to move a step ahead in research direction of inventory.

In this paper We focused on EOQ models of items with imperfection by using a meta heuristic approach PSO, in both without and with backorder where variable rate of discount is considered for defectives. The sample taken for the proposed model comprises some fraction of defectives. A hundred percentage of screening carried out for the sample. Numerical analysis has been done to know the effect of parameters used in the present model. Also, a graphical analysis has been given to show the comparison of proposed work with existing work.

NOTATIONS

D	demand
L_s	lot size
P_c	purchase cost
O_c	ordering cost
H_c	carrying cost
p	% of defective items in L
$f(p)$	p.d.f. of p
S	selling price of good item unit wise
r	rate of screening
S_c	screening cost per unit
T	period of one cycle
B_c	shortage cost per unit
S_L	expected shortage level
MI	maximum level of inventory
V_i^k	current velocity of particle
X_i^k	current position of particle
PB_i^k	best fitness of particle itself
GB^k	best fitness value among all particle
C_1 & C_2	coefficient factors
w	weight factor

THE MATHEMATICAL MODEL

Now, we will consider the items of frequently used item set, which are delivered instantaneously with the order size of L_s.

The number of items of good quality= the size of lot- the items of defective quality

$$L_s - pL_s = (1-p)L_s \tag{1}$$

To ignore shortages of good items, $(1-p)L_s$ is at least equal to the demand at the time of screening t [2]. i.e.,

$$(1-p)L_s \geq Dt, \tag{2}$$

$$p \leq 1 - \frac{D}{r} \tag{3}$$

Case1: without backorder

The total cost per cycle for the proposed economic order quantity model is:

$$TC(L_s) = O_c + P_c L_s + S_c L_s + H_c\left(\frac{L_s(1-p)T}{2} + \frac{pL_s^2}{r}\right) \quad (4)$$

The total revenue is defined as the cycle wise which is stated as follows:

$TR(L_s) =$ Total sales with regard to good quality items in addition with total sales with regard to defective items.

$$TR(L_s) = \frac{2SL_s^2 + \left\{ O_c + P_c L_s + S_c L_s + H_c\left(\frac{L_s(1-p)T}{2} + \frac{pL_s^2}{r}\right) \right\}(L_s p + 1)}{2L_s + L_s p + 1} \quad (5)$$

We can determine the cycle wise total profit as: $TP(L_s) = TR(L_s) - TC(L_s)$ (6)

$$TP(L_s) = \left[\frac{2SL_s^2 + \left\{ O_c + P_c L_s + S_c L_s + H_c\left(\frac{L_s(1-p)T}{2} + \frac{pL_s^2}{r}\right) \right\}(L_s p + 1)}{2L_s + L_s p + 1} \right]$$

$$-\left[O_c + P_c L_s + S_c L_s + H_r\left(\frac{L_s(1-p)T}{2} + \frac{pL_s^2}{r}\right)\right] \quad (7)$$

Total profit $TPU(L_s)$ unit wise formulated by

$$TPU(L_s) = TP(L_s)/T \quad (8)$$

where, $T = \frac{L_s(1-p)}{D}$

$$TPU(L_s) = \frac{2D(SL_s - O_c - P_c L_s - S_c L_s)}{2L_s + L_s p + 1}\left(\frac{1}{1-p}\right) - \frac{H_c L_s^2}{2L_s + L_s p + 1}(1+p) \quad (9)$$

As % of imperfect items p is random in nature having a known probability distribution function $f(p)$, the expected value of $TPU(L_s)$ can be found as:

$$ETPU(L_s) = \frac{2D(SL_s - O_c - P_c L_s - S_c L_s)}{2L_s + L_s E[p] + 1} E\left(\frac{1}{1-p}\right) - \frac{H_c L_s^2}{2L_s + L_s E[p] + 1}(1 + E[p]) \quad (10)$$

In this the optimality condition signifies the concavity of the expected total profit with respect to a unit time and is computed using the first derivative of Eq. (10).

Case2: Backorder

Using the assumption considered [13], the total cost cycle wise is computed as:

$f(L_s, S_L)$ = ordering cost + unit wise purchase cost +screening cost with regard to cycle wise lot size + carrying cost +Shortage cost

$$f(L_s, S_L) = O_c + P_c L_s + S_c L_s + H_c \times \left(\frac{L_s(1-p) - S_L}{2} t_1 + \frac{pL_s^2}{r}\right) + \frac{S_L B_c}{2} t_2 \quad (1$$

Total revenue cycle wise is calculated by adding total sales of both good and imperfect quality items which is specified as:

$$g(L_s, S_L) = \frac{2SL_s^2 + \left(O_c + P_c L_s + S_c L_s + H_c \times \left(\frac{L_s(1-p) - S_L}{2} t_1 + \frac{pL_s^2}{r}\right) + \frac{S_L B_c}{2} t_2 \right)(L_s p + 1)}{2L_s + (L_s p + 1)}$$

The total profit $\pi(L_s, S_L)$ cycle wise is formulated as:

$$\pi(L_s, S_L) = g(L_s, S_L) - f(L_s, S_L)$$

$$\pi(L_s, S_L) = \frac{2SL_s^2 - 2L_s\left(O_c + P_c L_s + S_c L_s + H_c \times \left(\frac{L_s(1-p) - S_L}{2} t_1 + \frac{pL_s^2}{r}\right) + \frac{S_L B_c}{2} t_2 \right)}{2L_s + (L_s p + 1)} \quad (12)$$

The total profit per unit time is $\pi_u(L_s, S_L)$ is formulated as

$$\pi_u(L_s, S_L) = \frac{\pi(L_s, S_L)}{T}$$

Where $T = \frac{L_s(1-p)}{D}$ and by replacing t_1 and t_2 by $\frac{L_s(1-p)-S_L}{D}$ and $\frac{S_L}{D}$ respectively eq. (12) can be written as:

$$\pi_u\left(L_s, S_L\right) = \frac{2D[SL_s - O_c - P_cL_s - S_cL_s]}{(1-p)(2L_s + L_s p + 1)} - \left[\frac{H_cL_s}{2L_s + L_s p + 1}\{L_s + pL_s - 2S_L\} + \frac{S_L^2(B_c + H_c)}{(1-p)(2L_s + L_s p + 1)}\right] \quad (13)$$

As p is the % of defectives, with a known probability density functions, then the eq. (13)., is written as follows:

$$E\pi_u\left(L_s, S_L\right) = \frac{2D[SL_s - O_c - P_cL_s - S_cL_s]}{(1-E[p])(2L_s + L_sE[p] + 1)} - \left[\frac{H_cL_s\{L_s + E[p]L_s - 2S_L\}}{2L_s + L_sE[p] + 1} + \frac{S_L^2(B_c + H_c)}{(1-E[p])(2L_s + L_sE[p] + 1)}\right] \quad (14)$$

The optimality condition for the nonlinear problem and the expected total profit per unit time mentioned in eq. (6), is represented by computing the 1st and 2nd partial derivatives of $E\pi_u\left(L_s, S_L\right)$ with respect to L_s, S_L are obtained.

By equating $\frac{\partial ETPU(L_s, S_L)}{\partial L_s}$ and $\frac{\partial ETPU(L_s, S_L)}{\partial S_L}$ to zero, we found:

$$L_s^* = \sqrt{\frac{\begin{pmatrix} 2DS - 2DP_c - 2DS_c + \\ 4DO_c + 2DO_cE[p] \end{pmatrix}}{\begin{pmatrix} 2H_c + 2H_cE[p] - 3H_c(E[p]^2) - \\ H_c\left(E[p]^3\right) - \frac{2B_cH_c^2(1-E[p])^2}{\left(B_c + H_c\right)^2} \end{pmatrix} - \frac{2H_c^3(1-E[p])^2}{\left(B_c + H_c\right)^2} - \frac{B_cH_c^2E[p](1-E[p])^2}{\left(B_c + H_c\right)^2} - \frac{H_c^3E[p](1-E[p])^2}{\left(B_c + H_c\right)^2}}} \quad (15)$$

$$S_L^* = \left(\frac{H_cL_s(1-E[p])}{B_c + H_c}\right) \quad (16)$$

$$IM = L_s - S_L \quad (17)$$

The maximum level of inventory is obtained by putting the value of eq. (15) and eq. (16) in
eq.(17) and is given as:

$$IM^* = \frac{L_s^*(B_c + H_cE[p])}{B_c + H_c} \quad (18)$$

Now, Hessian matrix H, is used to examine the second-order sufficient conditions for maximum value R.Patro et al. (2018), as follows:

$$H = \begin{bmatrix} \frac{\partial^2 E\pi_u\left(L_s, S_L\right)}{\partial L_s^2} & \frac{\partial^2 E\pi_u\left(L_s, S_L\right)}{\partial L_s \partial S_L} \\ \frac{\partial^2 E\pi_u\left(L_s, S_L\right)}{\partial S_L \partial L_s} & \frac{\partial^2 E\pi_u\left(L_s, S_L\right)}{\partial S_L^2} \end{bmatrix} \quad (19)$$

After getting the 1st and 2nd principal minor of H, at point (L_s^*, S_L^*) the Hessian Matrix H is negative definite, that indicates existence of unique values of L_s^* eq.(10) and S_L^* eq.(11) that maximize eq.(14).

SOLUTION PROCEDURE

The approach of PSO was first proposed by James Kennedy and Russell Eberhart [1]. Particle Swarm Optimization is a meta heuristic algorithm, that is inspired by social behaviour of birds flocking. means behaviour of birds moving together in a crowd. This is a computational method used to solve optimization problems. Aim of using such technique is to follow the bird which is nearest to the food while moving for food collection. It means finding best among different possible solutions. During the search process the particle changes its position by adjusting the velocity. The velocity can be updated based upon best past experience of it' s owns as well as it' s neighbour. A brief explanation of PSO technique which was introduced by [1] is given here.

Let us assume a d-dimensional search space with a population size N. V_i^k is the current velocity X_i^k is the current position of ith particle at kth iteration. PB_i^k is the best fitness value of each particle itself. GB^k is the best fitness value among all particles. With each iteration velocity and position of each individual particle changed based upon the past experience by taking the formula given below:

$$V_{i+1}^k = wV_i^k + C_1 * rand() * (PB_i^k - X_i^k) + C_2 * rand() * (GB^k - X_i^k) \quad (20)$$

$$X_{i+1} = X_i + V_{i+1} \quad (21)$$

Where, w: inertia weight, C_1 and C_2 are the coefficient factors with respect to own influence and social influence. Usually range of these coefficients set in between 1.5 to 2.5. These values can be differed to enhance the performance.

I. Algorithm of PSO

Step1: Define the objective function

Step2: Initialize the PSO parameters and specify the range of each variable.
Step3: Initialize randomly velocity and position of each particle.
Step4: Evaluate and find the fitness of particles.
Step5: Calculate local best and global best.
Step6: Update velocity and position based upon previous local best and global best positions using equation 20 and 21.
Step7: Evaluate the objective function and compute fitness function.
Stap8: Update local best and global best position.
Step9: Check for stopping criteria. If condition satisfies then stop the search process otherwise go to step6 and repeat 7and 8 till reaching the condition.
Step10: Store the best value and position obtained from PSO.

We adopted PSO, a meta- heuristic algorithm [1] to find solution of our problem. Two cases of EOQ models i.e., without and with shortages are considered. Objective of using PSO in both cases is to maximize the expected profit unit wise. To get an improved profit value, the profit function given in eq (10) and eq (14) are considered as the fitness function or objective function for implementation in PSO. During this search process lot size is optimized for the 1st case (when shortages are not allowed), lot size and shortage level are the two variables that optimized for 2nd case (when shortages are allowed). Initially value of each variable is generated randomly. Later was updated with in the search domain. Population size (no of solutions) is user defined. Then after fitness value of each variable is calculated with the help of the initialized values and fitness function. The variable with the best fitness value is considered which is the global best. As our problem is a case of maximization, global best is the maximum value of the solution. The initial value of each variable updated. Again, the fitness value is computed for each variable and compared with the previous fitness value to get the maximum value. This process repeated until reaching the stopping criteria. All of these above processes carried out according to the process of PSO. We also taken some constant parameters such as: purchase cost, ordering cost, carrying cost, annual demand, selling price etc.

NUMERICAL RESULTS

We considered the following example for analysis of our present work. A meta heuristic approach PSO is considered in order to find EOQ for imperfect items.

I. Case1: without back order

We used the values for the parameters needed for analysing this inventory situation according to [6].
D =50,000, r =175200units/year, S =50/unit,
S_c =0.5/unit, P_c =25/unit, O_c =100/cycle,
H_c = \$5/unit/year, $E[p]=0.02$
and $E\left[1/(1-p)\right]=1.02055$

By considering these values and optimizing eq. (10) with PSO techniques we got improved values of expected total profit unit wise. Some of which are given in Table I.

TABLE I
WITHOUT BACKORDER

L_s	$ETPU(L_s)$
1497.935526785	1230234.504239452
1497.956976688	1230234.504202246
1497.972918152	1230234.504173590
1497.431558968	1230234.504667619
1497.594679087	1230234.504622704

II. Case2: with back order

We adopted the parameter values to analyze the backorder condition from [R.Patro et al., 2018] which are as follows:
D =50,000 units/year, O_c =100/cycle, H_c = \$5/unit/year,
r =1unit/min, S_c =0.5/unit, P_c =25/unit
B_c =\$20/unit, S =\$50/unit, w =175200units/year,
$E[p]=0.02$ and $E\left[1/(1-p)\right]=1.02055$

Using PSO we also Optimized profit function given in eq. (14) to maximize the profit. A few improved values of expected unit wise profit are given in Table II.

TABLE II
WITH BACK ORDER

L_s	S_L	$E\pi_u(L_s, S_L)$
1372.009971446	360.699616042	1230827.905212061
1798.627733729	315.009609515	1230827.811393279
1658.154584006	448.275209153	1230827.807086575
2010.419371394	377.344467908	1230827.903240091
2059.668620844	370.542646536	1230827.830368957

III. Graphical representation

We have shown the result obtained from PSO technique graphically in Figure 1. Graph plotted among lot size and unit wise expected total profit. Profit obtained after implementing with PSO search technique are better as compared to the state-of-art model [R.Patro et al., 2018].

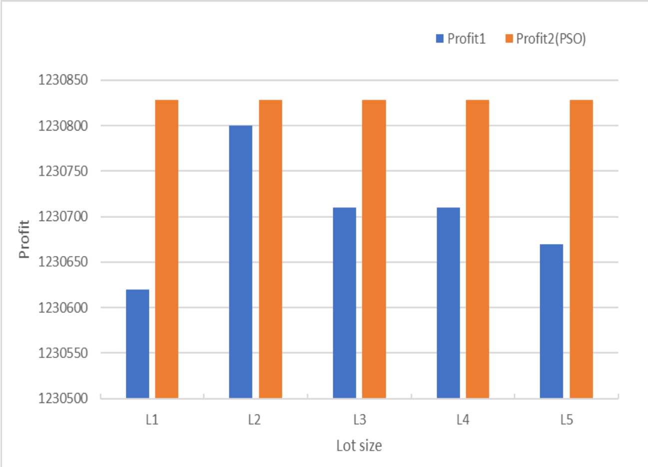

FIGURE 1
COMPARISON OF THE PROPOSED MODEL (WITH PSO) AND EXISTING MODEL

IV. Managerial insights

During evaluation of objective function for both without backorder and backorder by using PSO search technique, when we increased the population size and number of iterations, we obtained a better optimum solution. In the first case i.e., without backorder, either lot size is more or less, expected total profit unit wise increases. So, manufacturer can gain maximum profit by reducing the lot size. When shortages are allowed, with the increase of lot size and shortage level total profit per unit increases. In some certain cases also, it has been observed that the profit increases with decrease of the shortage level.

CONCLUSION

In the present paper, PSO a meta- heuristic approach is used to optimize the lot size and enhance total profit. We considered the inventory situations of without shortages and with shortages in association with proportionate discount in order to analyze our problem. To perform the presented task a number of attributes are considered, such as: different cost, selling price, demand per year, etc. The method of PSO has been implemented using MATLAB. Multiple executions are carried out for both the cases and the best results among all are considered in each one. Lot size is optimized for computing without backorder situation. Moreover, when shortages are allowed lot size and shortage level are optimized to measure the profit. It is observed that, in both the situations total expected profit increases as compared to the existing models.

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