An EPQ model with life-time items with multivariate demand with markdown policy under shortages and inflation

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Abstract—Shortages are quite common in command economics and inflation is a regular increment in the price of services and goods in an economy over a span of time. In this paper we established an EPQ model with life-time items with multivariate demand with markdown policy under shortages and inflation. We also discover an inventory model that gives the best markdown time with shortages and inflation and at the same time maximize annual profit. An inventory model by using mathematical tools is developed. The numerical experiments together with sensitivity analysis for relevant parameter is provided to show the behaviour of model.

Keywords—Shortages, Inflation, Multivariate demand, Markdown policy.

1. Introduction

Decay is a very important feature in our daily life and can be well-defined as spoilage, decomposition and loss of value from the unique form. The study of decaying inventory models started with Ghare and Schrader [1963]. They developed the regular inventory model with a continuous rate of decaying items. Covert and Philip [1973] enlarged Ghare and Schrader continuous decaying amount to a two-parameter Weibull distribution decaying rate. Dave and Patel [1981] established an inventory model for decaying items with time-proportional demand. Nahmias [1982], Goyal and Giri [2001] provided a whole and updated survey of work for the decaying inventory. Singh et al. (2017) represented a partially backlogged EPQ model with demand dependent production and non-instantaneous deterioration.

Shortages situations exists when the demand of good at the market price is bigger than supply. Either an increase in demand, decrease in supply. Shortages is a situation in which there is a demand of items but stock vanish. Samanta and Roy [2004] represented a constant production control inventory model for decaying items with shortages. Singh et al. [2016] represented an inventory model for decaying items having periodic and inventory level dependent demand with shortages. Kumar and Singh [2018] established an effect of salvage value on a two-warehouse inventory model for decaying items with inventory dependent demand rate and partial backlogging.

High inflation charges in some countries could destabilize the total economic development. In present time it is a global phenomenon. Now-a-days inflation has become a regular feature.Buzacott
[1975] first represented an EOQ model with inflation issue to different types of rating policies. Hou [2006] represented an inventory model with inventory dependent consumption rate instantaneously measured the inflation and time value of money when shortages are permitted over a stable planning horizon. Singh and Jain [2009] considerate supplier credits in an inflationary atmosphere when reserve money is obtainable. Kathuria and Singh [2018] represented Credit financing in optimum ordering policies with inflation in fuzzy environments.

In many conditions of real life the selling price may not be continuous. Therefore, it is important for a retailer to select pricing and replenishment policies when the demand rate is inventory dependent and sensitive with respect to selling price. Mandal and Phaujdar [1989] have recognised an EPQ model with linearly stock dependent demand. Padmanabhan and Vrat [1995] studies an inventory model for perishable items with inventory dependent selling rate. Urban and baker [1997] studies single items EOQ model in which the demand inventory dependent but becomes constant after a certain time. Baker and Urban [1988] represented an EOQ model with a power form stock level dependent demand. A general characteristics of these studies that they consider the decaying process in the inventory takes place at the direct of their arrival. In real life, the majority of goods has a time period for keeping their original condition. Omar and Zulkipli [2014] measured demand to be deterministic and positively dependent on the level of items presented in a just-in-time system [21 - 24].

Markdown policy are regular price discounts such that once the amount of a product is marked down, it may not be brought up to the same price level again in the same selling season. Srivastava and Gupta [2013] developed an EPQ model for decaying items with time and price dependent demand under discount policy. Kamaruzaman and Omar (2019) an EPQ model of delayed decaying items with price and stock level dependent demand under discount policy [25 - 28].

An EPQ model of delayed decaying items with price and inventory level dependent demand under markdown policy is developed by Kamaruzaman and Omar (2019). In this paper they established an EPQ model with life-time items with multivariate demand with markdown policy under shortages and inflation. The salvage value is incorporated to the failed units. They established a model that gives the best markdown time and at the same time maximizes annual profit. In our study we extended this work by applying the concept of shortages and inflation. The public perception about Inflation is the overall increase in the goods prices which creates the most continuous effect on the price level of goods prices.

2. The following notations have been used in this paper.

Notations:

$I(t)$ = Inventory level.

$\theta$ = Constant deterioration rate.
K = Constant production rate.

\( C_n \) = Unit holding cost.

\( C_s \) = Shortage cost.

\( \delta \) = Backlogging parameter.

\( C_l \) = Lost sale cost.

\( C_o \) = Unit ordering cost.

\( C_p \) = Unit production cost.

\( \alpha \) = Markdown rate.

\( \varepsilon \) = Increase price rate.

\( p \) = Initial price

\( \gamma \) = Markdown percentage.

\( \mu \) = production percentage.

\( r \) = Inflation rate.

The following assumptions have been used in this paper.

**Assumptions:**

(1) Demand rate is a function of price and inventory level. The demand at time \( t \) is assumed to be \( b(\alpha p)^{-\varepsilon} + \beta I(t) \), where \( \alpha \), \( b \) and \( \beta \) are positive constants with \( \alpha \), and \( \beta \) are between 0 and 1.

(2) Only single type of item is considered over given period of \( T \) units of time.

(3) Shortage are permitted and partially backlogged.

(4) Rate of deterioration, \( \theta \) is constant any time, where \( 0 \leq \theta < 1 \).

(5) All items are mandatory to be sold.

(6) Only unique time markdown price is applied and markdown price is known.

(7) The production up time is proportional to the cycle time where \( t_1 = \mu T \)

(8) Markdown time varies between \( (T - t_1) \) which is equivalent to \( t_2 = \gamma (T - t_1) \).

(9) Inflation rate is applied.

**3. Mathematical formulation**
In this model we consider inventory system at time $t$ as showed in figure 1. The production and supply start instantaneously and the production ends at time $t_1$ with the inventory level, $Q_1$, is reached. We assumed there is no deterioration during the production rate up-time. In the interval $(t_1, t_2)$ inventory level decrease due to deterioration and demand rate. At the time $((t_1, t_2))$ the markdown is offered to increase the demand rate. After that point $t_3$ shortages are allowed with partially backlog. The inventory level at time $t$ over a period $(0, T)$ is directed by these differential equations:

$$\frac{dI(t)}{dt} = k - (bp^{-\epsilon} + \beta I(t)) \quad 0 \leq t \leq t_1$$

(1)

With $\alpha = 1$ (no markdown) and boundary condition

$I(0) = 0, \quad I(t_1) = Q_1$

$I(t_2) = Q_2$

$$\frac{dI(t)}{dt} + \theta I(t) = -(bp^{-\epsilon} + \beta I(t)) \quad t_1 \leq t \leq t_2$$

(2)

$$\frac{dI(t)}{dt} + \theta I(t) = -(b(\alpha p)^{-\epsilon} + \beta I(t)) \quad t_2 \leq t \leq t_3$$

(3)

$I(t_3) = 0$

$$\frac{dI(t)}{dt} = -D \delta t_3 \leq t \leq T$$

(4)

$$\frac{dI(t)}{dt} = -\delta (b(\alpha p)^{-\epsilon} + \beta I(t)) t_3 \leq t \leq T$$

(5)
I(T) = -S

Solutions of these equations:

\[ I(t) = \frac{k-bp^e}{\beta} (1-e^{-\beta t}) \] \(0 \leq t \leq t_1\)  

(6)

\[ Q_1 = \frac{k-bp^e}{\beta} (1-e^{-\beta t_1}) \]  

(7)

\[ I(t) = \frac{-bp^e}{(\theta+\beta)} + (Q_2 + \frac{-bp^e}{(\theta+\beta)})(e^{(\theta+\beta)(t_2-t)}) \]  

(8)

\[ I(t) = \frac{bp^e}{(\theta+\beta)} e^{(\theta+\beta)(t_3-t)} - 1 \]  

(9)

\[ Q_2 = \frac{b(ap)^e}{(\theta+\beta)} e^{(\theta+\beta)(t_3-t_2)} - 1 \]  

(10)

\[ I(t) = \frac{b(ap)^e}{(\theta+\beta)} (e^{\delta \beta (t_3-t)} - 1) \]  

(11)

\[ I(T) = \frac{b(ap)^e}{\beta} (e^{\delta \beta (t_3-t)} - 1) \]  

(12)

\[ -S = \frac{b(ap)^e}{\beta} (e^{\delta \beta (t_3-T)} - 1) \]  

(13)

Sales revenue cost = \[ p \left( \int_{t_0}^{t_1} D(t)e^{-rt}dt + \int_{t_1}^{t_2} D(t)e^{-rt}dt + \int_{t_2}^{T} D(t)e^{-rt}dt \right) \]

(14)

Shortage Cost = \[-C_e \int_{t_3}^{T} I(t)e^{-rt}dt \]

(15)

Lost sale cost = \[ C_L (1-\delta) b(ap^e) \left( \int_{t_0}^{t_1} e^{-rt}d + \int_{t_1}^{t_2} e^{-rt}dt + \int_{t_2}^{t_3} I(t)e^{-rt}dt \right) \]

(16)

HoldingCost = \[ C_h \left( \int_{t_0}^{t_1} I(t)e^{-rt}dt + \int_{t_1}^{t_2} I(t)e^{-rt}dt + \int_{t_2}^{t_3} I(t)e^{-rt}dt \right) \]
\[ C_h \left[ \frac{k-bp^{-e}}{\beta} - \frac{e^{-rt_1}}{r} + \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r(\theta+\beta)} - \]

\[ = \frac{Q_2 e^{-rt_2}}{r(\theta+\beta+\gamma t_2 e^{-\gamma(\theta+\beta+r)t_1}} + \frac{bp^{-e}}{r} \frac{e^{-rt_2}}{r(\theta+\beta+\gamma t_2 e^{-\gamma(\theta+\beta+r)t_1}} - \]

\[ + b(\alpha p)^{-e} \frac{-e^{-rt_3}}{r(\theta+\beta+\gamma t_2 e^{-\gamma(\theta+\beta+r)t_2}} + \frac{e^{-rt_2}}{r} \left\{ \frac{Q_2 e^{-rt_2}}{r(\theta+\beta+\gamma t_2 e^{-\gamma(\theta+\beta+r)t_1}} + \right\} \]

\[ + C_h \left[ \frac{k-bp^{-e}}{\beta} - \frac{e^{-rt_1}}{r} + \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r(\theta+\beta)} - \]

\[ = C_d \left[ \frac{k-bp^{-e}}{\beta} - \frac{e^{-rt_1}}{r} + \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r(\theta+\beta)} - \]

\[ e^{-rt_1} \] \[ + \frac{Q_2 e^{-rt_2}}{r} \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r} \frac{e^{-t_2(\beta+r)}}{r} - \]

\[ + b(\alpha p)^{-e} \frac{e^{-t_3}}{r} \frac{e^{-t_2(\beta+r)}}{r} + \frac{e^{-rt_2}}{r} \left\{ \frac{Q_2 e^{-rt_2}}{r} \frac{e^{-t_1(\beta+r)}}{r} - \right\} \]

\[ \text{Deterioration Cost} = \int_0^1 t \theta(t) e^{-rt} dt + \int_{t_2}^{t_1} \theta(t) e^{-rt} dt + \int_{t_2}^{t_1} \theta(t) e^{-rt} dt \]

\[ \text{Setup cost} = \frac{C_0}{T} \]

\[ \text{Production cost} = \frac{K_{sT}}{T} \]

\[ \text{Total profit} = \text{Sale revenue cost} - \text{holding cost} - \text{deterioration cost} - \text{Shortage cost} - \text{Lost sale cost} - \text{setup cost} - \text{production cost} \]

\[ = \frac{1}{T} \left\{ \left[ Q_1 \frac{e^{-rt_1}}{r} + \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r} \frac{e^{-t_2(\beta+r)}}{r} - \right\} \]

\[ = \frac{1}{T} \left\{ \left[ Q_1 \frac{e^{-rt_1}}{r} + \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r} \frac{e^{-t_2(\beta+r)}}{r} - \right\} \]

\[ = \frac{1}{T} \left\{ \left[ Q_1 \frac{e^{-rt_1}}{r} + \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r} \frac{e^{-t_2(\beta+r)}}{r} - \right\} \]

\[ = \frac{1}{T} \left\{ \left[ Q_1 \frac{e^{-rt_1}}{r} + \frac{e^{-t_1(\beta+r)}}{r} - \frac{1}{r} \right] + bp^{-e} \frac{e^{-rt_2}}{r} \frac{e^{-t_2(\beta+r)}}{r} - \right\} \]
\[
\left[ \frac{e^{\delta t_3}e^{-\frac{\gamma rt_2}{r}}}{e^{-\frac{\gamma rt_2}{r}}} + \frac{e^{-\frac{\gamma rt_3}{r}}}{e^{-\frac{\gamma rt_3}{r}}} \right] - C_L \frac{1}{r}(1-\delta)b(\alpha p^{-\epsilon})\left[ \frac{e^{-\frac{\gamma rt_3}{r}}}{e^{-\frac{\gamma rt_3}{r}}} \right] + \left[ \frac{e^{\delta t_3}e^{-\frac{\gamma rt_2}{r}}}{e^{-\frac{\gamma rt_2}{r}}} + \frac{e^{-\frac{\gamma rt_3}{r}}}{e^{-\frac{\gamma rt_3}{r}}} \right] - \frac{C_0}{T} - K\frac{C_{pt_1}}{T}
\] (21)

TP is a function of $t_1$, $t_2$, and $t_3$. We optimize the TP function by following Srivastava and Gupta (2013) procedure where we rewrite:

$t_1 = \mu T$, $t_2 = \gamma(T-t_1)$, $t_3 = (1-\gamma)(1-\mu)T$

Srivastava and Gupta [2013] only varies T in order to find their optimal solution.

4. Numerical Example

In this section, a numerical example is considered to illustrate the model.

Let $\theta = .007$, $\beta = 0.7$, $r = 0.15$, $b = 10000$, $C_h = 2$, $p = 35$, $K = 300$, $C_L = .03$, $C_d = 0.5$, $\epsilon = 1.8$, $\delta = .82$, $\alpha = 0.6$, $C_p = 8$, $C_0 = 100$, $C_x = .02$, $\mu = 0.6$

The optimal value is $T = 7.89785$, $TP = 1455.96$, $\gamma = 0.665922$

And $t_1 = \mu T$, $t_2 = \gamma(T-t_1)$, $t_3 = (1-\gamma)(1-\mu)T$

$t_1 = 4.73871$, $t_2 = 2.10374083$, $t_3 = 1.05539917$, $Q_1 = 390.148$, $Q_2 = 216.486$

This graph show the concavity of the optimal profit.

5. Sensitivity Analysis

Sensitivity analysis w.r.to some involvement parameters is carried out to observe the change in Total cost with the change in different parameters, different level are choose as follows: +30%, +20%, +10% and -10%, -20%, -30%, respectively.
Table 1.1 Sensitivity analysis with respect to $\theta$

| $\theta$  | T   | $\gamma$ | TP   | $Q_1$ | $Q_2$ |
|----------|-----|----------|------|-------|-------|
| +30%     | 7.87734 | .605852 | 1542.42   | 390.021 | 98.702 |
| +20%     | 7.88423 | .625893 | 1545.53   | 390.64  | 131.507 |
| +10%     | 7.89106 | .645916 | 1544.71   | 390.106 | 170.871 |
| -10%     | 7.9046  | .685914 | 1547.28   | 390.189 | 273.936 |
| -20%     | 7.91134 | .70589  | 1548.68   | 390.231 | 340.373 |
| -30%     | 7.91809 | .725853 | 1460.16   | 390.272 | 418.882 |

Table 1.2 Sensitivity analysis with respect to $r$

| $r$    | T   | $\gamma$ | TP   | $Q_1$ | $Q_2$ |
|--------|-----|----------|------|-------|-------|
| +30%   | 6.75134 | .457734 | 1375.93   | 387.297 | -16.047 |
| +20%   | 7.09578 | .523984 | 1528.15   | 384.268 | 12.629  |
| +10%   | 7.47520 | .593232 | 1352.39   | 387.297 | 73.623  |
| -10%   | 8.37512 | .742488 | 1570.47   | 392.814 | 606.753 |
| -20%   | 8.92342 | .823262 | 1697.99   | 395.285 | 1837.87 |
| -30%   | 9.56733 | .908295 | 1841.26   | 397.546 | 6607.48 |

Table 1.3 Sensitivity analysis with respect to $C_h$

| $C_h$  | T   | $\gamma$ | TP   | $Q_1$ | $Q_2$ |
|--------|-----|----------|------|-------|-------|
| +30%   | 7.87335 | .582259 | 1383.62   | 389.996 | 66.098 |
| +20%   | 7.88247 | .610773 | 1407.61   | 390.053 | 104.606 |
| +10%   | 7.89060 | .638645 | 1431.72   | 390.103 | 154.24  |
| -10%   | 7.90430 | .692645 | 1480.31   | 390.188 | 299.246 |
| -20%   | 7.91004 | .718842 | 1504.78   | 390.223 | 402.647 |
| -30%   | 7.91514 | .744538 | 1529.00   | 390.254 | 533.53  |

Table 1.4 Sensitivity analysis with respect to $C_l$

| $C_l$  | T   | $\gamma$ | TP   | $Q_1$ | $Q_2$ |
|--------|-----|----------|------|-------|-------|
| +30%   | 7.89795 | .665759 | 1455.91   | 390.148 | 217.776 |
| +20%   | 7.89791 | .665813 | 1455.93   | 390.148 | 217.632 |
| +10%   | 7.89788 | .665868 | 1455.94   | 390.148 | 217.776 |
| -10%   | 7.89781 | .665977 | 1455.97   | 390.148 | 218.061 |
| -20%   | 7.89778 | .666032 | 1455.98   | 390.147 | 218.205 |
| -30%   | 7.89775 | .666086 | 1456.00   | 390.147 | 218.346 |
Table 1.5 Sensitivity analysis with respect to $C_s$

| $C_s$  | T    | $\gamma$ | TP    | $Q_1$  | $Q_2$  |
|--------|------|----------|-------|--------|--------|
| + 30%  | 7.89787 | .665343  | 1455.84 | 390.148 | 217.407 |
| + 20%  | 7.89786 | .665536  | 1455.88 | 390.148 | 216.898 |
| +10%   | 7.89786 | .665729  | 1455.92 | 390.148 | 217.407 |
| -10%   | 7.89784 | .666116  | 1455.99 | 390.148 | 218.431 |
| -20%   | 7.89783 | .666309  | 1456.03 | 390.148 | 218.943 |
| -30%   | 7.89782 | .666502  | 1456.07 | 390.148 | 219.455 |

Table 1.6 Sensitivity analysis with respect to $\delta$

| $\delta$ | T    | $\gamma$ | TP    | $Q_1$  | $Q_2$  |
|----------|------|----------|-------|--------|--------|
| + 30%    | 7.89909 | .663826  | 1455.43 | 390.156 | 212.492 |
| +20%     | 7.89765 | .666353  | 1456.06 | 390.147 | 219.049 |
| +10%     | 7.89774 | .666138  | 1456.01 | 390.147 | 218.484 |
| -10%     | 7.89795 | .665705  | 1455.90 | 390.148 | 217.349 |
| -20%     | 7.89806 | .665486  | 1455.85 | 390.149 | 216.777 |
| -30%     | 7.89818 | .665264  | 1455.80 | 390.150 | 216.199 |

6. Observation:
(1) If $\theta$ will be increase then $\gamma$, T and TP decrease and after this $Q_1$ increase and decrease both. If $\theta$ will be decrease then $\gamma$, T and TP increase and after this $Q_1$ increase and decrease both.
(2) If $r$ will be increase then $\gamma$, T and TP decrease and after this $Q_1$ increase and decrease both. If $r$ will be decrease then $\gamma$, T and TP increase and after this $Q_2$ increase and decrease both and show abnormal behaviour.
(3) If $C_h$ will be increase then $\gamma$, T and TP decrease and after this $Q_1$ increase and decrease both. If $C_h$ will be decrease then $\gamma$, T and TP increase and after this $Q_2$ increase and decrease both.
(4) If $C_s$ will be increase then $\gamma$, TP decrease and T increase after this $Q_1$ increase and decrease both. If $C_s$ will be decrease then $\gamma$, TP increase and T decrease and after this $Q_2$ increase and decrease both.
(5) If $C_s$ will be increase then $\gamma$ and TP decrease and T increase after this $Q_1$ constant. If $C_s$ will be decrease then $\gamma$ and TP increase and T decrease and after this $Q_2$ increase and decrease both.
(6) If $\delta$ will be increase then $\gamma$, TP decrease and T increase and after this $Q_1$ increase and decrease both. If $\delta$ will be decrease then $\gamma$, TP decrease and T increase after this $Q_2$ increase and decrease both.

7. Conclusion:
In this study, an EPQ model with life-time items with multivariate demand under inflation and markdown policy. It is clear that the inventory and maximize the profit, markdown policy is
introduced. The optimal replenishment time, optimal quantities, optimal markdown time as well as optimal annual profit have been derived. The previous studies, instead of fixing the markdown time, we study the markdown time as a variable together with the cycle length and it simply gives a better annual profit than fixing the value of it. It can also be concluded that policy maker must be very aware to set markdown rate as it is case dependent. The main purpose of this study is to maximize the total profit.

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