An EOQ Model of Selling-Price-Dependent Demand for Non-Instantaneous Deteriorating Items during the Pandemic COVID-19

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Abstract

A pricing factor plays a dominant role in consumer behavior in most countries affected by the COVID19 pandemic. People have lost their job while others renegotiated for low-paying jobs during this pandemic. Thus, this article aims to develop a viable model to consider various aspects of the COVID19 pandemic. Here, we develop an optimal ordering quantity inventory model of deteriorating items, which are still in demand depending upon the selling price of the product. The items are assumed to be non-instantaneous deteriorating. The shortage is allowed in lead time and is partially backlogged. A solution procedure is presented to determine an optimal cycle, order quantity, and total average cost. A realistic numerical example is given to validate the proposed model by changing different systems of parameters, where sensitivity analysis has been carried out. The effectiveness of the system has been observed through graphical representation.

Keywords: Deterioration, Shortage, Partially-backlogged, Selling-price-dependent demand, Pandemic, COVID-19, EOQ model

Introduction

Nowadays, the business environment is in a havoc situation caused by the COVID19 pandemic. The medium and small-scale businesses of different small cities of low-income countries, like India, Pakistan, Afghanistan, Bangladesh, Nepal, Bhutan, Maldives, Thailand, Myanmar, and the Maldives are going into financial crises due to the shutdown and lockdown implemented by their respective administrations. These businesses must have collected non-instantaneous products like vegetables, fish, meats from small farmers in different villages. Due to the lockdown and shutdown phases, the market is only open five days a week with 11 to 12 working hours per day. Also, the boundaries of different cities are closed by the government for safety purposes. Meanwhile, vegetables, bakery, fish, and meats start to deteriorate due to this lockdown. Therefore, small and medium-scale entrepreneurs need the most affordable EOQ inventory model for items that are non-instantaneous to sustain their business. For efficient management, the inventory system has been the most vital job for any business firm irrespective of small- or large-scale industries.

To relax some particular boundaries of the product’s specification, several academicians and researchers developed many models on EOQ. Harris [1] made the 1st attempt to develop an EOQ model in 1913. Within [2], developed an inventory system for un-conventional items, i.e., the items will become
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old-fashioned periodically after a specific period of time. However, the main goal to develop EOQ/EPQ models was to control defective products' capacity. Rosenblatt and Lee [3] demonstrated a model in which, after a certain time of continuous manufacturing, the system becomes out of control and starts producing imperfect- items. Hayek and Salameh [4] have taken a proper investigation to work on defective produced items in the previous EOQ models. Goyal et al. [5] developed a model by taking the ordering policy as a stock level and price under partially backlogging conditions. Singh et al. [6] proposed an inventory model on EOQ for deteriorating items where preservation technology is applied to reduce the amount of deterioration. Due to the high stock level in a supermarket shelf attracting maximum customers to purchase the product, they considered stock-dependent-demand with trade credit policy. Tiwari et al. [7] developed a model for non-instantaneous deteriorating -items with selling- price-dependent- demand under a fuzzy environment where green technology is used to reduce carbon emissions affecting the total profit. Henceforth many researchers are working on EOQ based models by analyzing the developed theory to get more quality items. Some of the works were developed by Manna et al. [8], Mukhopadhaya and Goswami [9], Pasandideh et al. [10], Nobil et al. [11], Cardenas-Barron et al. [12], and many more.

Deterioration is a process of reducing the quality from higher to lower levels. It suggests change, obsolescence, spoilage, loss of utility, or loss of minor estimation of merchandise, resulting in the loss of their value. The deterioration rate is not almost insignificant for items like toys, glassware, hardware, and steel, but it is much more effective for items like vegetables, natural products, drugs, unpredictable fruits, blood, and innovative items. Deteriorated items have different physical highlights in which a large portion of products undergo deterioration over time. This phenomenon is especially valid for items like natural products, like vegetables. Some specific items continuously deteriorate through the mortification process, whereas consumption rates are very large in products like gasoline, alcohol, and turpentine. Hence, deterioration assumes a vital role in the inventory model that should not be ignored. Also, in real life, deterioration is a common phenomenon. In fact, research on deteriorating items is going on continuously since 1963. Share and Schrader [13] have developed a model with a constant deterioration rate, which validated with no shortages. A rapid change in the deterioration like exponential function was introduced by Liao [14] in 2008. Tripathy and Pandey [15] considered an inventory model with deteriorating items under trade credit policy. By assuming the deterioration as constant, Agarwal and Jaggi [16] developed a model.

In the last two decades, many papers have been published in which demand is price dependent. Chen and Chen [17] proposed an inventory model with finite deteriorating- items over a finite- horizon. Chang et al. [18] developed a model for deteriorating items with partial backlogging for the retailer’s optimal pricing and lot-sizing policies. Dye [19] considered a logic over an infinite time horizon with allowable back-ordering. Similar papers were developed by Panda et al. [20], Tsao and Sheen [21], Lin et al. [22], Dye and Ouyang [23], Wang and Lin [24], Ghoreishi et al. [25], Soni and Patel [26], Srivastava and Gupta [27], Wang and Huang [28], Bai et al. [29], Bhunia et al. [30], Rabbani et al. [31], Indrajitsingha et al. [32,33]. Recently one work was developed by Rahamann and Duary [34] to handle the fluctuating customer demand (selling price dependent). As per the present situation, the foods having perishable nature are decaying due to uncertainty caused by the lockdown and shutdown during the COVID-19 pandemic.

In the present study, a model is developed for non-instantaneous deterioration products with selling-price-dependent demand rate and shortages under partially backlogged by making different combinations of these above system parameters. The study’s main objective is to optimize by minimizing the total-average- cost per unit time.

The present paper is organized as follows: In section 2, we provide the notations and assumptions which are considered to develop the model. In section 3, a mathematical model is established with a valid solution procedure. Numerical examples are given in section 4. In section 5, the optimal solution's sensitivity analysis and managerial insights with respect to major parameters are carried out by using Mathematica 11.1 software. Lastly, in section 6, the article ends with some concluding remarks and suggestions for future research.
Materials and methods

Notations and assumptions:
The following notations and assumptions are considered throughout the paper:

Notations
\( \alpha \) : Demand coefficient
\( \gamma \) : Demand constant, \( \gamma \geq 1 \)
\( s \) : Selling-price (in ₹/unit)
\( m \) : Time during which there is no deterioration
\( h \) : Holding cost (in ₹/unit)
\( \theta \) : Deterioration coefficient, \( 0 \leq \theta \leq 1 \)
\( v \) : The time at which the inventory level reaches to zero
\( \xi \) : Lost-sale cost (in ₹/unit)
\( R \) : Ordering-cost (in ₹/order)
\( p \) : Purchasing-cost (in ₹/unit)
\( T \) : Length of cycle
\( Q \) : Ordering quantity
\( q_i \) : On-hand inventory
\( q_s \) : Back-order inventory
\( r \) : Shortage-cost (in ₹/unit)
\( \eta \) : Rate of backlogging

\( I_1(t) \) : Inventory level, at any time \( t \), during \([0,m]\)
\( I_2(t) \) : Inventory level, at any time \( t \), during \([m,v]\)
\( I_3(t) \) : Inventory during the shortage period \([v,T]\)
\( K(v) \) : Total average inventory cost (in ₹)

Assumptions
(i) The market demand depends upon the selling-price of the non-instantaneous deteriorating products, and it is of the form \( D(s) = \frac{\alpha s^\gamma}{s^\gamma}, s > 0, \gamma \geq 1 \). As the items are non-instantaneous deteriorating in nature, the selling-price depends upon the quality of the product.
(ii) There is no deterioration during the time interval \([0,m]\) and after that period deterioration starts at a rate \( \theta \).
(iii) No replenishment is required during the deterioration time.
(iv) The lead time is assumed to be zero.
(v) Shortages, allowed and partially backlogged.

Model formulation
In this section, we have described the development of an economic order quantity model of non-instantaneous deteriorating products which starts after some time interval. It is assumed that the experiment is started with \( q_i \) units of in-hand inventory and \( q_s \) units of backorder inventory and assumed to be at the beginning of each cycle. Let \( T \) be the length of each cycle. Let in the time interval \([0,m]\), there will be no deterioration of the product. The deterioration starts at \( t = m \) and att \( = v \), there will no inventory. Hence for \( t > v \), shortages appears and it happens up to the end of the cycle. To fulfill this shortage partially backlogging is taken with a rate \( \eta \). Let \( I_1(t) \) and \( I_2(t) \) be the inventory level at any time \( t \) in the time interval \([0,m]\) and \([m,v]\), respectively. The behavior of the model is shown in Figure 1.
Thus, we have the following differential equations for the proposed inventory system:

\[ \frac{dI_1(t)}{dt} = -\frac{\alpha s^2 y}{s}, \quad 0 \leq t \leq m \]  

\[ \frac{dI_2(t)}{dt} = -\theta t I_2(t) - \frac{\alpha s^2 y}{s}, \quad m \leq t \leq v \]  

\[ \frac{dI_3(t)}{dt} = -\frac{\alpha s^2 y}{s}, \quad v \leq t \leq T \]  

with boundary conditions;

\[ I_3(v) = 0, I_2(v) = 0, I_1(m) = I_2(m) \]  

The solutions of the above Eqs. (1) - (3) with the help of boundary condition (4) are given by;

\[ I_1(t) = \frac{\alpha s^2 y}{s} (m-t) + \frac{\alpha s^2 y}{s} \left((v-m) + \frac{\theta}{6} (v^3 - m^3)\right) e^{-\frac{\theta m^2}{2}}, \quad 0 \leq t \leq m \]  

\[ I_2(t) = \frac{\alpha s^2 y}{s} \left((v-t) + \frac{\theta}{6} (v^3 - t^3)\right) e^{-\frac{\theta t^2}{2}}, \quad m \leq t \leq v \]  

\[ I_3(t) = \frac{\alpha s^2 y}{s} (v-t), \quad v \leq t \leq T \]  

Using the initial condition \( I_1(0) = q_i \), we have;

\[ q_i = \frac{\alpha s^2 y}{s} m + \frac{\alpha s^2 y}{s} \left((v-m) + \frac{\theta}{6} (v^3 - m^3)\right) e^{-\frac{\theta m^2}{2}} \]  

Total average cost per unit time for the model during a cycle is given by;

\[ K(v) = \frac{1}{T} \left[ \text{Buying cost} + \text{Inventory holding cost} + \text{Shortage cost} + \text{Lost sales cost} + \text{Ordering cost} \right] \]  

Now we estimate the following costs;

(i). Buying cost (BC):
We have the total ordering quantity $Q$ is the sum of on-hand inventory and back-order inventory which is $Q = q_i + q_s$.

Hence the total buying cost can be formulated as;

$$BC = Qp = [q_i + q_s]p$$

Here, we have;

$$q_i = \frac{\alpha}{s^s} m + \frac{\alpha}{s^s} \left( (v - m) + \frac{\theta}{6} (v^3 - m^3) \right) e^{-\frac{\theta m^2}{2}}$$

$$q_s = \int_{v}^{T} \frac{\alpha}{s^s} \theta dt = \frac{\alpha}{s^s} \theta (T - v)$$

Therefore;

$$BC = \left[ \frac{\alpha}{s^s} m + \frac{\alpha}{s^s} \left( (v - m) + \frac{\theta}{6} (v^3 - m^3) \right) e^{-\frac{\theta m^2}{2}} + \frac{\alpha}{s^s} \theta (T - v) \right] p$$

(ii). Inventory holding-cost (IHC);

We have;

$$IHC = h \left[ \int_{0}^{m} l_1(t) dt + \int_{m}^{v} l_2(t) dt \right]$$

$$= h \left[ \frac{\alpha t^2}{s^s} + \frac{\alpha}{s^s} \left( \frac{(vm - m^2)}{2} \right) + \frac{\theta}{6} (v^3 - m^3) m - \frac{\theta}{2} (vm^2 - m^3) m \right]$$

$$+ \frac{\alpha}{s^s} \left( \frac{v^2}{2} + \frac{\theta v^4}{8} - \frac{\theta v^3}{24} - \frac{(vm - m^2)}{2} \right)$$

$$+ \frac{\alpha}{s^s} \left( \frac{\theta v^3 m}{4} - \frac{\theta}{6} (v^3 m - m^4) + \frac{(vm^3 - m^4)}{4} \right)$$

(iii). Shortage-cost (ISC);

The shortage-cost is given by;

$$ISC = r \int_{v}^{T} \frac{\alpha}{s^s} r dt = \frac{\alpha}{s^s} r (T - v)$$

(iv). Lost-sale-cost (LSC);

We have the Lost-sale-cost as;

$$LSC = \int_{v}^{T} (1 - \eta) \frac{\alpha}{s^s} \xi dt = (1 - \eta) \frac{\alpha}{s^s} \xi (T - v)$$

(v). Ordering-cost (OC);

$$OC = R$$

Hence the total average cost of the system per unit time is given by;
For minimizing the total average cost $K(v)$, value of $v$ can be obtained by solving the differential equation;

$$\frac{dK(v)}{dv} = 0$$  \hspace{1cm} (16)

Satisfying;

$$\frac{d^2K(v)}{dv^2} > 0$$  \hspace{1cm} (17)

Eqs. (16) and (17) are equivalent to;

$$\frac{1}{T} \left[ -\frac{\alpha}{s^\gamma} r + p \left( -\frac{\alpha}{s^\gamma} \theta + \frac{\alpha}{s^\gamma} \left( 1 + \frac{v^2 \theta}{2} e^{-\frac{\theta m^2}{2}} \right) \right) - \frac{\alpha}{s^\gamma} \xi (1 - \eta) \\ + h \left( \frac{\alpha}{s^\gamma} \left( m + \frac{v^2 m \theta}{2} - \frac{\theta m^3}{2} \right) + \frac{\alpha}{s^\gamma} \left( v - \frac{v^2 \theta}{8} + \frac{v^3 \theta}{2} - m - \frac{v^2 m \theta}{2} + \frac{\theta m^3}{6} \right) \right) \right] = 0$$

and

$$\frac{1}{T} \left[ \frac{\alpha}{s^\gamma} v^2 \theta e^{-\frac{\theta m^2}{2}} + h \left( \frac{\alpha}{s^\gamma} v \theta m + \frac{\alpha}{s^\gamma} \left( 1 - \frac{v \theta}{4} + \frac{3 v^2 \theta}{2} - v \theta m \right) \right) \right] > 0,$$

respectively.

**Solution procedure**

We have solved the abovementioned problem by using the algorithm given below:

\[
K(v) = \frac{1}{T} \left[ \frac{\alpha}{s^\gamma} m + \frac{\alpha}{s^\gamma} \left( v - m + \frac{\theta}{6} (v^3 - m^3) \right) e^{-\frac{\theta m^2}{2}} + \frac{\alpha}{s^\gamma} \theta (T - v) \right] p + \frac{\alpha}{s^\gamma} \left( \frac{v^2}{2} + \frac{\theta v^4}{8} - \frac{\theta v^3}{24} - \frac{(vm - m^2)(vm - m^2)m}{2} \right) + \frac{\alpha}{s^\gamma} \theta \left( \frac{1}{T} - v \right) + (1 - \eta) \frac{\alpha}{s^\gamma} \xi (T - v) + R
\]
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Algorithm

Step-1: Start

Step-2: Input the values of the parameters $\alpha, \gamma, s, m, h, \theta, \xi, R, p, T, r$ and $\eta$

Step-3: Find $\frac{dK(v)}{dv}$

Step-4: Solve the equation $\frac{dK(v)}{dv} = 0$ and find the value of $v$

Step-5: Find $\frac{d^2K(v)}{dv^2}$

Step-6: If the value of $\frac{d^2K(v)}{dv^2} > 0$, then we get minimum solution and go to Step-8

Step-7: Otherwise, we go to Step-2

Step-8: Stop

Numerical examples

To validate the result of the model considered the following example:

Example

$\alpha = 1300, \gamma = 2.3, s = 5, m = 5, \theta = 0.02, \xi = 6, h = 0.3, R = 150, \eta = 0.5, r = 8, p = 3$. The values of different parameters considered here are realistic, though these are not taken from any case study. By using Mathematica 11.1 software we get the unique $v = 11.2011$, and $Q = 515.061$ with optimum total average cost $K(v) = ₹280.812$. The convexity of the function is not possible to prove using mathematical analytic approach, the graphical analytic approach is used in the Figure 2.

Figure 2 Total average cost versus $v$ and $Q$.
Results and discussion

Sensitivity analysis

From the numerical example mentioned above, the following sensitivity analysis has been carried out to reveal the following managerial insights by changing the parameters one at a time keeping other unchanged.

Table 1 Sensitivity analysis for different parameter.

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Figure 3 Demand parameter ($\gamma$) Vs $K(v)$&$Q$.

Figure 4 Time parameter ($m$) Vs $K(v)$&$Q$.
EOQ Model of Selling-Price-Dependent Demand during COVID-19
Susanta Kumar INDRAJITSINGHA et al.
http://wjst.wu.ac.th

**Figure 5** Selling price ($s$) Vs $K(v)$&$Q$.  

**Figure 6** Deterioration coefficient ($\theta$) Vs $K(v)$&$Q$.  

**Figure 7** Lost sale cost ($\xi$) Vs $K(v)$&$Q$.  

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Figure 8: Holding cost \((h)\) Vs \(K(v)\&Q\).

Figure 9: Ordering cost \((R)\) Vs \(K(v)\&Q\).

Figure 10: Purchasing cost \((p)\) Vs \(K(v)\&Q\).
The following observations are found from Table 1 and from the corresponding Figure:

1) When the demand parameter $\gamma$ increases, then total average cost $e$ increases and ordering quantity $Q$ decreases with constant $v$.

2) When the value of the parameter $m$ increases, it is observed that $v$ increases with decrease of total average cost function $K(v)$ and ordering quantity $Q$ of the products.

3) When the selling price increases, then both the ordering quantity $Q$ and the total average cost $K(v)$ decrease with constant $v$ of the products. That is, the increase in selling price means the increase in the total profit.

4) By increasing the value of $\theta$, the total average cost $K(v)$ of the products such as vegetables, bakeries, fishes, meats increases. But $v$, the time at which the inventory level becomes 0, the order quantity also decreases.

5) When the lost sale cost $\xi$ increases, the total average cost $K(v)$ increases with an increase of order quantity and $v$.

6) When the holding cost $h$ increases, the total average cost $K(v)$ per unit time of the products increases with the decrease in ordering quantity $Q$ and the time at which the inventory level becomes 0($v$).

7) When the value of the ordering cost $R$ increases, it is observed that the total average cost $K(v)$ increases which is obvious in nature with constant ordering quantity $Q$. 
8) When the purchasing cost $p$ increases, it is observed that the total average-cost $K(v)$ increases with decrease of ordering-quantity $Q$ and $v$.

9) When the shortage cost $r$ increases, it is concluded that $K(v)$ increases with increase of the parameters $Q$ and $v$.

10) If the backlogging-parameter $\eta$ increases, the ordering-quantity $Q$ increases and $K(v)$ decreases with slightly decrease in the value of the parameter $v$.

Conclusions

In most countries, the economic situation has greatly changed due to the COVID-19 pandemic. Medium and small-scale entrepreneurs are mostly affected by the pandemic. A country’s economy will develop if it focuses on the businessmen, who are the grass root of the economy. Owing to the above discussion, we develop an economic order quantity model of selling-price-dependent demand rate. Since items such as vegetables, bakery, fish, and meats do not deteriorate instantaneously, we consider the products which are non-instantaneous decaying. A procedure for getting the solution is provided to get the optimum total average cost, and practical application examples support the application of the proposed model to support decision-making. It is observed that the present result illustrates the usefulness of the model in determining optimal ordering policy. It can also be used in inventory control of some non-instantaneous decaying items which exhibit selling price-dependent demand. It is suggested that for further research in this line, one can take the problem to study the impact of time-varying deterioration on optimal policy.

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References


