Imperfect Production Inventory Model with Stock Dependent Demand and Price Discount Offer on Items of Minor Defect in Reworking

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ABSTRACT: In this paper a manufacturing inventory model with constant production rates and without shortages is developed for single item where defective items are produced in regular production process with a proportion of defectives as scrap. Defective items are reworked just after the regular production stops. Deterioration starts after some time of regular production and deteriorated items are sold with price discount. Demand rate of perfect items is assumed to be stock dependent. Reworked items are serviceable items with minor defect having constant demand rate. In order that reworked items can be completely sold before the next cycle starts, the demand is enhanced by offering a price discount on reworked items. Numerical examples with tables, graphs and sensitivity analysis are presented to illustrate the model.

Key words: Deterioration, Stock dependent demand, Price discount, Imperfect production, Reworking process

INTRODUCTION

In the existing literature so many inventory models have been formulated where the demand rate is taken as constant, time-dependent and independent of the stock level. But it has been observed that glamorous display of large number of goods in a modern way attracts people to buy more units. Recent inventory managers also recognizes this relationship and thus many researchers have focused on the analysis of the inventory problems which describes the demand rate dependent on the displayed stock level. In recent time for attracting more consumers, it is a trend to increasing shelf space for displaying an item. It occurs to maintain variety, visibility and popularity. Conversely, if stock of certain items is not enough then it might be thought that goods are not fresh. Therefore, the demand rate may be affected by the inventory level for some type of inventory. So many authors have considered the pattern of demand depending on the stock level. Levin et al. (17) showed that large piles of consumer goods demonstrated in a market attract the customer to buy more. Padmanabhan and Vrat (21) analyzed a multi-item inventory model with stock-dependent demand. Mandal and Maity (20) developed an inventory model of damageable items with stock dependent demand with variable replenishment rate. Teng and Chang (33) developed an EPQ model for deteriorating items with price and stock dependent demand. Soni and Shah (31) introduced a progressive payment scheme with stock dependent demand under optimal ordering policy. Min et.al. (19) developed an inventory model with two level trade credit and stock dependent demand. Ghiami et.al. (8) developed an inventory model for deteriorating items with stock dependent demand and partial backlogging. Krommyda et al (15) developed an inventory model where demand is affected by the instantaneous inventory level. Pal and Chandra (22) developed a periodic review inventory model with trade credit, inventory level dependent demand and price discount on backorder.

In the existing literature, in maximum inventory models for deteriorating items it is assumed that the deterioration occurs as soon as the commodities arrive in inventory. However, in real life, most goods would have a span of maintaining quality or original condition and deterioration starts after that span. This phenomenon is termed as ‘non-instantaneous deterioration’, given by Wu et al. (36). This type of phenomena can be commonly observed in food stuffs, fruits, green vegetables and fashionable goods, which have a span of maintaining fresh quality & during that period there is almost no spoilage and after some time some of the items will start to decay. For these kinds of items the assumption that the deterioration starts from the instant of arrival in stock may cause retailers to make inappropriate replenishment policy. Due to the importance of the feature of non-instantaneous deterioration, the authors considered the pattern of demand depending on the stock level. The demand rate may be affected by the inventory level for some type of inventory.
instantaneous deterioration in inventory control problems many researchers have worked in this field. Liu and Shi (18), Castro & Alfa (5), Chang et al. (6) and many others are researchers who involved the phenomenon of non-instantaneous deterioration in preparing their inventory models. In profit maximizing problems of inventory control, selling price plays an important role in demand factor. Price discount is also a key factor which is beneficial for customers and for sellers. The customers can buy more units by expanding the same money while due to the effect of price discount demand is increased to a large extent which results in maximizing the profit. Ardalan (2), Pan and Hsiao (23), Panda et al. (24), Garg, Vaish and Gupta (7), Annadurai and Uthayakumar (1), Vaish and Agarwal (34), Pal and Chandra (22) included the price discount factor in their inventory models. Pandey and Vaish (25) presented an inventory control problem with demand depending on time and price and offering price discount on back orders.

In most of the existing EPQ models found in literature, production quality was considered to be perfect through the whole production. But reality is that some defective items are produced along with the perfect items in real production process. In other words some time production process is imperfect. In latest inventory models the feature of imperfect production is involved by many researchers like Gupta and Chakraborty (9), Porteus (26), Rosenblatt and Lee (27) ,Zhang and Gerchak (37), Lee et al. (16), Hayek and Salameh (10) , Jamal et al. (11), Barzoki et. al.(3) , Cardenas-Barron (4). Krishnamoorthi and Panayappan (12) and Krishnamoorthi and Panayappan (13) developed EPQ models with imperfect production process with a proportion of scrap .Tai (32) formulated an economic production quantity model for imperfect product with rework. Sivashankari and Panayappan (30) gave rework model with shortages. Seyedi et al.(29) introduced a reworking inventory model considering the effect of inflation. Further it is experienced that the items which have minor defect in reworked process of an imperfect production are sold in low price market. Due to price discount effect items with minor defect have a great sale in market. The inventory models with this feature can be rarely found in the existing literature.

In the present paper a manufacturing inventory model for single item is developed considering a small proportion of regular production process as defective items and a proportion of defectives as scrap. Production rates of regular production and reworking process are assumed to be constant. Production rate of regular production is assumed to be greater than the reworking process rate. Deterioration is assumed to starts after some time of regular production and deteriorated inventory is sold out with some price discount. Demand rate of perfect items is assumed to be stock dependent. Imperfect inventory for reworking is kept aside during screening process and scrap is disposed off. Defective items are reworked after the regular production. Reworked items are serviceable items with minor defect having constant demand rate. In order that reworked items can be completely sold in the same cycle, the demand is enhanced by offering a price discount on reworked items. Profit maximization technique is used to solve the model. Numerical example with tables, graphs and sensitivity analysis is presented to illustrate the model.

II. ASSUMPTIONS AND NOTATIONS

The item is a single product; it does not interact with any other inventory items. The regular production rate $P_1$ is always greater than the sum of the demand rate and the rate at which defective items are produced. One type of defective is produced in each cycle. The reworking process is performed with rate $P_2$ ($P_2<<P_1$) just after the regular production is finished. A constant proportion $\theta (\theta < 1)$ of the on hand inventory deteriorates per unit time after some time of completion of regular production and deteriorated items are sold with price discount $d_1 \%$. A certain fraction of defective items produced at the production process is scrap and cannot be reworked so it is disposed off and the remaining fraction except scrap of defectives are reworked and all reworked items have minor defect and are serviceable with price discount. The demand rate of perfect items is stock dependent $i.e D(t) = a + b l(t)$, where $a>0$ is a scaling factor and $0<b<1$. Demand rate of reworked items becomes $(1-d_j)^n a$ where $d_j$ is the percentage discount offered on each reworked item and $n>1$ is any real number. All reworked items are sold out within the inventory cycle. Other notations applied in the model are as follows:

- $T$: Infinite length of the cycle.
- $X$: Proportion of defective items from regular production and scrap.
- $\omega$: Proportion of defective items which is scrap.
- $A_p$: Setup cost for regular production.
- $A_r$: Setup cost for reworking process.
- $Q$: Total production quantity.
- $Q_d$: Quantity of defective items.
- $Q_s$: Quantity of scrap items.
\(C_p\)  Production cost per unit,
\(C_c\)  Screening cost per unit of defective items from regular production.
\(t_1\)  The time at which regular production stops and reworking process starts,
\(t_2\)  The length of time to complete the reworking process of defective items
\(t_3\)  The length of time during which reworking process is completed and all reworked items are sold out. \(t_1 + t_3 \leq T\)
\(I_p(t)\)  Inventory level of perfect items at any time \(t\) in the cycle \([0,T]\).
\(I_m(t)\)  Inventory level of imperfect items at any time \(t\) in the interval \([t_1, t_1 + t_2]\).
\(I_r(t)\)  Reworked Inventory
\(T_pQ\)  Total production quantity of each cycle
\(PQ\)  Perfect production quantity of each cycle
\(RQ\)  Total reworked quantity of each cycle
\(Sc\)  Scrap of total production quantity of each cycle
\(t_1\)  Length of time after the regular production at which deterioration of perfect inventory starts
\(h_p\)  Holding cost for perfect inventory per unit time
\(h_r\)  Holding cost for reworked inventory per unit time
\(h_m\)  Holding cost for imperfect inventory per unit time
\(SR\)  Sales revenue per cycle
\(F(t)\)  Profit per unit time

**FORMULATION and ANALYSIS of the MODEL:**

The behavior of the inventory level \(I_p(t)\), \(I_r(t)\) and \(I_m(t)\) during cycle \(T\) is depicted in figure (1) and figure (2).

The differential equations governing the inventory level of perfect inventory \(I_p(t)\), reworking inventory \(I_r(t)\) and imperfect inventory \(I_m(t)\) at any time \(t\) of inventory cycle \(T\) are as follows:

**Model Formulation for Perfect inventory**

\[
\frac{dI_p(t)}{dt} = (1-s)p - (a+bI_p(t)) \\
\text{for } 0 \leq t \leq t_1
\]

\[
\frac{dI_p(t)}{dt} = -(a+bI_p(t)) \\
\text{for } t_1 \leq t \leq t_1 + \mu
\]

\[
\frac{dI_p(t)}{dt} + \theta I_p(t) = -(a+bI_p(t)) \\
\text{for } t_1 + \mu \leq t \leq T
\]
with boundary condition \( I_r(0) = 0, I_r(T) = 0 \)

**Model Formulation for reworking inventory**

\[
\frac{dI_r}{dt} = (P_r - X) \quad 0 \leq t \leq t_r \quad \ldots (4)
\]

\[
\frac{dI_r}{dt} = -X \quad t_r \leq t \leq t_1 \ldots (5)
\]

where \( X = a(1-d_t)^n \)

with boundary condition \( I_r(0) = 0, I_r(t_1) = 0 \)

**Model Formulation for imperfect inventory to be reworked**

\[
\frac{dI_a}{dt} = (1 - \omega)xP_1 \quad 0 \leq t \leq t_1 \ldots (6)
\]

\[
\frac{dI_a}{dt} = -P_1 \quad t_1 \leq t \leq t_1 + t_2 \ldots (7)
\]

with boundary condition \( I_a(0) = 0, I_a(t_1 + t_2) = 0 \)

**The solution of equations of the perfect inventory model formulation is given by**

\[
I_r(t) = \frac{(1-x)P_r - a}{b}(1-e^{-\mu t}) \quad 0 \leq t \leq t_r \ldots (8)
\]

\[
I_r(t) = \frac{a}{b}e^{-\beta t} + \frac{(1-x)P_r}{b}(e^{-\beta t} - 1) \quad t_r \leq t \leq t_1 + \mu \ldots (9)
\]

\[
I_r(t) = \frac{a}{(\theta + b)}(e^{(\theta + b)t - 1} - 1) \quad t_1 + \mu \leq t \leq T \ldots \ldots (10)
\]

From eq. (9) and eq. (10) equating value of \( I_r(t_1 + \mu) \) the value \( T \) can be obtained as

\[
T = (t_1 + \mu) + \frac{1}{(\theta + b)} \log\left\{1 + \frac{(\theta + b)}{b}(e^{-\beta (t_1 + \mu)} - 1) + \frac{P_1(\theta + b)(1-x)}{ab}(e^{(\theta + b)(t_1 + \mu)} - 1)\right\} \ldots \ldots (11)
\]

**Holding cost for perfect inventory is given by**

\[
H_r = h_r \left[ \int_{t_r}^{t_1} I_r(t) \, dt + \int_{t_1}^{T} \left( I_r(t) + \int_{t_1}^{t} I_r(\tau) \, d\tau \right) \, dt \right]
\]

\[
H_r = h_r \left[ \frac{(1-x)P_r - a}{b^2}(bt_1 + e^{-\beta t_1} - 1) - \frac{a\mu}{b} + \frac{1}{b^2}(1-x)P_1(e^{-\beta t_1} - 1) + a(e^{-\beta t_1} + e^{-\beta (t_1 + \mu)}) \right] \ldots \ldots (12)
\]

\[
+ \frac{a}{(\theta + b)^2}(e^{(\theta + b)(t_1 + \mu)} - 1 - (\theta + b)(T - (t_1 + \mu)))\]

**The solution of equations of the reworked inventory model formulation is given by**

\[
I_r(t) = (P_r - X) \quad 0 \leq t \leq t_r \ldots (13)
\]

\[
I_r(t) = X(t_r - t) \quad t_r \leq t \leq t_2 \ldots (14)
\]

Total defective items produce in time \( t_1 \), total reworked in time \( t_2 \)

or \((1 - \omega)xP_1t_1 = P_1t_2\)

From eq. (13) and eq. (14) equating value of \( I_r(t_2) \)

the value \( t_2 \) can be obtained as

\[
t_2 = \frac{P_1t_1}{X} \quad (1 - \omega)xP_1t_1 = \frac{(1 - \omega)xP_1t_1}{X} \ldots (15)
\]

**Holding cost for Reworked inventory is given by**

\[
H_r = h_r \left[ \int_{t_r}^{t_1} I_r(t) \, dt + \int_{t_1}^{t_2} \left( I_r(t) + \int_{t_1}^{t} I_r(\tau) \, d\tau \right) \, dt \right]
\]

\[
H_r = h_r \left[ \frac{(1-x)P_r - a}{b^2}(bt_1 + e^{-\beta t_1} - 1) - \frac{a\mu}{b} + \frac{1}{b^2}(1-x)P_1(e^{-\beta t_1} - 1) + a(e^{-\beta t_1} + e^{-\beta (t_1 + \mu)}) \right] \ldots \ldots (16)
\]
Solution of imperfect inventory to be reworked is given by:

\[ I_{n}(t) = (1 - \omega)xP_{t}t, \quad 0 \leq t \leq t_{1} \]  

... (17)

\[ I_{n}(t) = P_{t}(t_{1} + t_{2}) - t), \quad t_{1} \leq t \leq t_{1} + t_{2} \]  

... (18)

Holding cost for imperfect inventory to be reworked is given by:

\[ H_{n} = h_{n}\left\{ \int_{t_{1}}^{t_{1} + t_{2}} I_{n}(t)dt + \int_{t_{1} + t_{2}}^{t} I_{n}(t)dt \right\} \]

\[ DQ = I(t_{1} + \mu) - \int_{t_{1}}^{t_{1} + t_{2}} (a + b I_{n}(t))dt \]

\[ DQ = \frac{a\theta}{(\theta + b)} \left\{ (e^{(\theta+b)(T-(t_{1}+\mu))} - 1) - (\theta + b)(T - (t_{1} + \mu)) \right\} \]

... (19)

Sales Revenue:

\[ SR = p(1 - x)P_{t}t_{1} - DQ + p(1 - d_{r})(1 - \omega)xP_{t}t_{1} + p(1 - d_{r})DQ \]

\[ SR = pP_{t}t_{1}\left\{ (1 - x) + (1 - d_{r})(1 - \omega)x \right\} - pd_{r}\frac{a\theta}{(\theta + b)} \left\{ (e^{(\theta+b)(T-(t_{1}+\mu))} - 1) - (\theta + b)(T - (t_{1} + \mu)) \right\} \]

... (20)

The profit per unit time for the system can be calculated as follows:

\[ F(t_{1}) = \frac{1}{T} \left[ SR - H_{n} - H_{s} - H_{i} - A_{\omega} - A_{x} - C_{p}P_{t_{1}} - C_{p}P_{t_{1}} \right] \]

\[ F(t_{1}) = \frac{1}{T} \left[ pP_{t_{1}}\left\{ (1 - x) + (1 - d_{r})(1 - \omega)x \right\} - pd_{r}\frac{a\theta}{(\theta + b)} \left\{ (e^{(\theta+b)(T-(t_{1}+\mu))} - 1) - (\theta + b)(T - (t_{1} + \mu)) \right\} \\ - b_{2}\left\{ \frac{(1 - x)P_{t} - a}{b} \right\}\left\{ b_{1}e^{-b_{1}t} + 1\right\} - \frac{a\mu}{b}\left\{ (1 - x)P_{t}(e^{b_{1}t} - 1) + a(e^{b_{1}t} + e^{-b_{1}t}) \right\} \\ + \frac{a}{(\theta + b)}\left\{ (e^{(\theta+b)(T-(t_{1}+\mu))} - 1) - (\theta + b)(T - (t_{1} + \mu)) \right\} - b_{2}\left\{ \frac{(1 - \omega)xP_{t_{1}}}{2} \right\}\left\{ P_{t} - X \right\} \\ - b_{2}\left\{ \frac{(1 - \omega)xP_{t_{1}}}{2} + \frac{P_{t_{1}}^{2}}{2} \right\}\left\{ A_{\omega} - A_{x} - C_{p}P_{t_{1}} - C_{p}P_{t_{1}} \right\} \right] \]

Solution Procedure to obtain the optimal total profit per unit time

Optimal value of \( t_{1} \) is obtained by solving the equation

\[ \frac{dF(t_{1})}{dt_{1}} = 0 \quad \text{... (21)} \]

\[ \text{Provided} \quad \frac{d^{2}F(t_{1})}{dt_{1}^{2}} < 0 \quad \text{... (22)} \]

Numerical Illustration:

To illustrate the model the following parametric values are considered: \( h_{n} = 0.2 \text{ rs/unit/time} \), \( h_{s} = 1.3 \text{ rs/unit/time} \), \( h_{i} = 2.5 \text{ rs/unit/time} \), \( p = 820 \text{ rs} \), \( P_{t} = 180 \), \( P_{t} = 200 \), \( b = 0.02 \), \( a = 100, A_{\omega} = 80, A_{x} = 20, C_{p} = 500\text{rs/unit} \), \( C_{p} = 0.2\text{rs/unit} \), \( d_{r} = 0.6, x = 0.2, n = 1.8, d_{r} = 0.20, \omega = 0.25, \mu = 0.12, \theta = 0.009 \). Applying the solution procedure described above the optimal values obtained are as follows:

\( t_{1}^{*} = 0.712585 \text{ month} \), \( t_{2}^{*} = 0.118764 \text{ month} \), \( T = 1.1349 \text{ month} \), \( F(t_{1}) = 33153.90 \text{ rs} \), \( TPQ^{*} = 142.57, \text{ PQ}^{*} = 114.014 \), \( RQ^{*} = 21.3776 \), \( Q^{*} = 7.12585 \).
Effects of various parameters on optimal profit are discussed as follows:

### Effects of parameter "ω" on Total Profit per Unit Time

<table>
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*(Table-1)*

### Effects of parameter "b" on Total Profit per Unit Time

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*(Table-2)*

### Effects of parameter "μ" on Total Profit per Unit Time

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*(Table-3)*

### Effects of parameter "x" on Total Profit per Unit

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*(Table-4)*

### Effects of parameter "Cₚ" on Total Profit per Unit Time

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*(Table-5)*

*(Fig-3)* *(Fig-4)* *(Fig-5)* *(Fig-6)* *(Fig-7)*
### Sensitive analysis table

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(Table-6)

### III OBSERVATIONS

1. Table (1) reveals that as the parameter ($\omega$) increases, profit per unit time of the system decreases.
2. From table (2) it is observed that demand coefficient ($b$) increases, profit per unit time of the system also increases.
3. Table (3) shows that as the parameter ($\mu$) increases, profit per unit time of the system also increases.
4. From table (4) it is observed that the parameter ($x$) decreases, the unit time profit of the system increases.
5. Table (5) reveals that the parameter ($C_p$) decreases, the unit time profit of the system also increases.
6. From sensitivity table (6) it has been observed $F(t_1)$ is negligible sensitive to ($x$), ($b$), ($\mu$) and moderately sensitive to ($\omega$) And ($C_p$)

### III. CONCLUSION

In the present paper an imperfect production inventory model with constant production rates for single item is developed with a proportion of defectives as scrap. Production rates of regular production are assumed to be greater than the reworking process rate. Deterioration is assumed to starts after some time of regular production and deteriorated inventory is sold out with some price discount. Demand rate of perfect items is assumed to be stock dependent. Disposing off scrap from defective items during screening process, items to be reworked are kept aside during regular production. Defective items are reworked immediately after the regular production. Reworked items are serviceable items with minor defect having constant demand rate.

In order that reworked items can be completely sold in the same cycle, the demand is enhanced by offering a price discount on reworked items. Profit maximization technique is used to solve the model. Numerical example with tables, graphs and sensitivity analysis is presented to illustrate the model. The results obtained in tables, figures and sensitivity analysis are very much close to real situations of imperfect production and reworking processes. It might be thought that present model may be beneficial in some manufacturing industry.

Further the present inventory model can be analyzed for some other practical situations of manufacturing industry by changing some assumptions of the model.
REFERENCES


