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

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ABSTARCT : 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

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I. 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 resent 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 Maiti (20) developed an inventory model of damageable items with stock dependent time 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 in inventory control problems many researchers have worked in this field. Lui 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 extant which results in maximizing the profit. Ardalan (2), Pan and Hsiao (23), Panda et al. (24), Garg, Vaish and Gupta (7), Annadurai and Uthaykumar (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). Krishanmoorthi and Panayappan (12) and Krishanmoorthi 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 $\theta (0<\theta<<1)$ 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 $D(t) = a + b\, I(t)$.where $a > 0$ is a scaling factor and $0 < b < 1$. Demand rate of reworked items becomes $(1- d_r)^{-n} a$ where d_r 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
ω 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 costper unit,
C_r 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. $t_1 + t_3 \le T$
$I_p(t)$ 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 $[0, t_1 + t_2]$.
$I_r(t)$ Inventory level of reworked items at any time t in the interval $[t_1, t_1 + t_2]$.
TPQ 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
μ 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
$F(t_1)$ Profit per unit time

$t_1^*, F^*(t_1)$, *TPQ**, *PQ**, *RQ**, Q_s^* represents the optimal values of t_1, $F(t_1)$, *TPQ, PQ, RQ and* Q_s.

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)

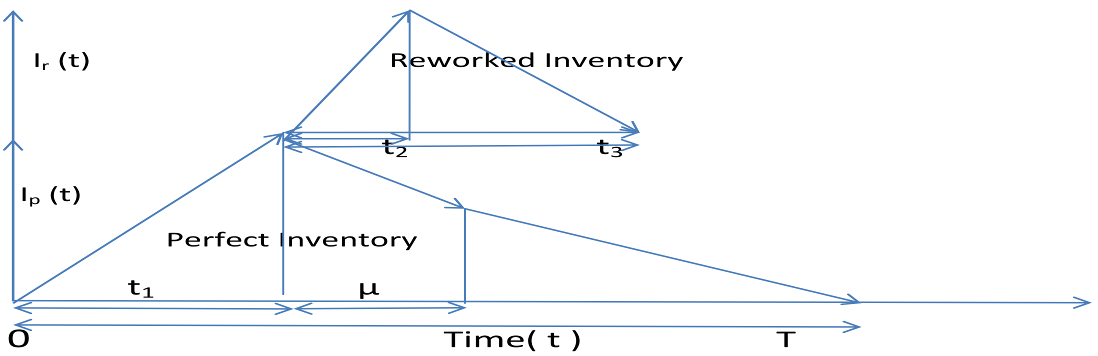


Fig. (1)

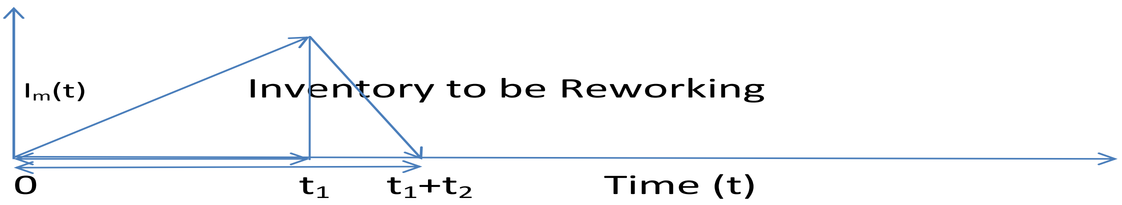


Fig. (2)

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

$$\frac{dI_p(t)}{dt} = (1-x)P_1 - (a + bI_p(t)) \qquad 0 \le t \le t_1 \qquad \ldots (1)$$

$$\frac{dI_p(t)}{dt} = -(a + bI_p(t)) \qquad t_1 \le t \le t_1 + \mu \qquad \ldots (2)$$

$$\frac{dI_p(t)}{dt} + \theta I_p(t) = -(a + bI_p(t)) \quad t_1 + \mu \le t \le T \qquad \ldots (3)$$

with boundary condition $I_p(0)=0, I_p(T)=0$

Model Formulation for reworking inventory

$$\frac{dI_r(t)}{dt}=(P_2-X) \quad 0\le t\le t_2 \quad \ldots(4)$$

$$\frac{dI_r(t)}{dt}=-X \quad t_2\le t\le t_3 \quad \ldots(5)$$

where $X=a(1-d_r)^{-n}$
with boundary condition $I_r(0)=0, I_r(t_3)=0$

Model Formulation for imperfect inventory to be reworked

$$\frac{dI_m(t)}{dt}=(1-\omega)xP_1 \quad 0\le t\le t_1 \quad \ldots(6)$$

$$\frac{dI_m(t)}{dt}=-P_2 \quad t_1\le t\le t_1+t_2 \quad \ldots(7)$$

with boundary condition $I_m(0)=0, I_m(t_1+t_2)=0$

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

$$I_p(t)=(\frac{(1-x)P_1-a}{b})(1-e^{-bt}) \quad 0\le t\le t_1 \quad \ldots(8)$$

$$I_p(t)=\frac{a}{b}(e^{-bt}-1)+\frac{(1-x)P_1}{b}(e^{bt_1}-1)e^{-bt} \quad t_1\le t\le t_1+\mu \quad \ldots(9)$$

$$I_p(t)=\frac{a}{(\theta+b)}(e^{(\theta+b)(T-t)}-1) \quad t_1+\mu\le t\le T \quad \ldots(10)$$

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

$$T=(t_1+\mu)+\frac{1}{(\theta+b)}\log\{1+\frac{(\theta+b)}{b}(e^{-b(t_1+\mu)}-1)+\frac{P_1(\theta+b)(1-x)}{ab}(e^{-b\mu}-e^{-b(t_1+\mu)})\} \quad \ldots(11)$$

Holding cost for perfect inventory is given by

$$H_p=h_p[\int_0^{t_1} I_P(t)dt+\int_{t_1}^{t_1+\mu} I_P(t)dt+\int_{t_1+\mu}^{T} I_P(t)\,dt]$$

$$H_p=h_p[\frac{((1-x)P_1-a)}{b^2}(bt_1+e^{-bt_1}-1)-\frac{a\mu}{b}+\frac{1}{b^2}\{(1-x)P_1(e^{bt_1}-1)+a)(e^{-bt_1}+e^{-b(t_1+\mu)})\} \quad \ldots(12)$$
$$+\frac{a}{(\theta+b)^2}\{(e^{(\theta+b)(T-(t_1+\mu))}-1)-(\theta+b)(T-(t_1+\mu))\}]$$

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

$$I_r(t)=(P_2-X)t \quad 0\le t\le t_2 \quad \ldots(13)$$

$$I_r(t)=X(t_3-t) \quad t_2\le t\le t_3 \quad \ldots(14)$$

Total defective items produce in time t_1 = total reworked in time t_2
or $(1-\omega)xP_1t_1=P_2t_2$
From eq. (13) and eq. (14) equating value of $I(t_2)$ the value t_3 can be obtained as

$$t_3=\frac{P_2t_2}{X}=\frac{(1-\omega)xP_1t_1}{X} \quad \ldots(15)$$

Holding cost for Reworked inventory is given by:

$$H_r=h_r[\int_0^{t_2} I_r(t)dt+\int_{t_2}^{t_3} I_r(t)dt]$$

$$H_r=h_r[\frac{((1-\omega)xP_1t_1)^2(P_2-X)}{2P_2X}] \quad \ldots(16)$$

Solution of imperfect inventory to be reworked is given by:

$$I_m(t) = (1-\omega)xP_1 t \quad 0 \le t \le t_1 \quad \dots (17)$$

$$I_m(t) = P_2((t_1+t_2)-t) \quad t_1 \le t \le t_1+t_2 \quad \dots (18)$$

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

$$H_m = h_m[\int_0^{t_1} I_m(t)dt + \int_{t_1}^{t_1+t_2} I_m(t)dt]$$

$$H_m = h_m[\frac{(1-\omega)xP_1 t_1^2}{2} + \frac{P_2 t_2^2}{2}]$$

Now, the following observations can be made about the model:

Total production quantity Qin time $t_1 = P_1 t_1$

Total production quantity screenedin time $t_1 = P_1 t_1$

Total defective items produced Q_d in time $t_1 = xP_1 t_1$

Total good items produced in time in time $t_1 = Q - Q_d$

Total scrap quantity produced Q_s in time$t_1 = \omega x P_1 t_1$

Total reworked quantity produced in time $t_1 = Q_d - Q_s = (1-\omega)xP_1 t_1$

Deteriorated Quantity:

$$DQ = I(t_1+\mu) - \int_{t_1+\mu}^{T} (\mathrm{a} + \mathrm{b}\, I_p(t))dt$$

$$DQ = \frac{a\theta}{(\theta+b)^2}\{(e^{(\theta+b)(T-(t_1+\mu))} - 1 - (\theta+b)(T-(t_1+\mu))\} \quad \dots (19)$$

Sales Revenue:

$$SR = p((1-x)P_1 t_1 - DQ) + p(1-d_r)(1-\omega)xP_1 t_1 + p(1-d_1)DQ$$

$$SR = pP_1 t_1\{(1-x) + (1-d_r)(1-\omega)x\} - pd_1\frac{a\theta}{(\theta+b)^2}\{(e^{(\theta+b)(T-(t_1+\mu))} - 1 - (\theta+b)(T-(t_1+\mu))\} \quad \dots (20)$$

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

$$F(t_1) = \frac{1}{T}[SR - H_p - H_m - H_r - A_p - A_r - C_p P_1 t_1 - C_r P_1 t_1]$$

$$F(t_1) = \frac{1}{T}[pP_1 t_1\{(1-x) + (1-d_r)(1-\omega)x\} - pd_1\frac{a\theta}{(\theta+b)^2}\{(e^{(\theta+b)(T-(t_1+\mu))} - 1 - (\theta+b)(T-(t_1+\mu))\}$$

$$-h_p\{\frac{((1-x)P_1 - a)}{b^2}(bt_1 + \mathrm{e}^{-bt_1} - 1) - \frac{a\mu}{b} + \frac{1}{b^2}\{(1-x)P_1(e^{bt_1} - 1) + \mathrm{a})(e^{-bt_1} + e^{-b(t_1+\mu)})\}$$

$$+\frac{a}{(\theta+b)^2}\{(\mathrm{e}^{(\theta+b)(T-(t_1+\mu)} - 1) - (\theta+\mathrm{b})(T-(t_1+\mu))\}\} - h_r\{\frac{((1-\omega)XP_1 t_1)^2(P_2 - X)}{2P_2 X}\}$$

$$-h_m\{\frac{(1-\omega)xP_1 t_1^2}{2} + \frac{P_2 t_2^2}{2}\} - A_p - A_r - C_p P_1 t_1 - C_r P_1 t_1]$$

Solution Procedure to obtain the optimal total profit per unit time

Optimal value of t1 is obtained by solving the equation

$$\frac{dF(t_1)}{dt_1} = 0 \quad \dots (21) \qquad \text{Provided } \frac{d^2F(t_1)}{dt_1^2} < 0 \quad \dots (22)$$

Numerical Illustration:

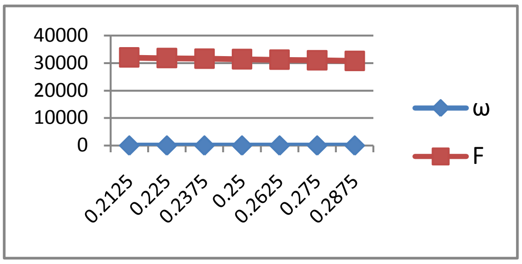
To illustrate the model the following parametric values are considered.h_m= 0.2 rs/unit/time, h_r= 1.3 rs/unit/time, h_p= 2.5rs/unit/time, p = 820 rs, P_2 = 180, P_1 = 200, b = 0.02,
a = 100, A_p = 80, A_r = 20, C_p=500rs/unit., C_r = 0.2rs/unit, d_1=0.6, x = 0.2, n = 1.8, d_r= 0.20, ω = 0.25,
μ = 0.12, θ = 0.009.Applying the solution procedure described above the optimal values obtained are as follows: t_1* = 0.712585month, t_2* = 0.118764 month, T = 1.1349 month, $F^*(t_1)$ = 31353.90rs, TPQ* =142.57, PQ* = 114.014,
RQ* = 21.3776, Q_s* =7.12585,

Effects of various parameters on optimal profit are discussed as follows:

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

%change in ω	ω	t_1	F
-15%	0.2125	0.698738	31971.5
-10%	0.225	0.703261	31765.7
-5%	0.2375	0.707876	31559.8
0	0.25	0.712585	31353.9
5%	0.2625	0.717392	31148
10%	0.275	0.7223	30942
15%	0.2875	0.727313	30736.1

(Table-1)

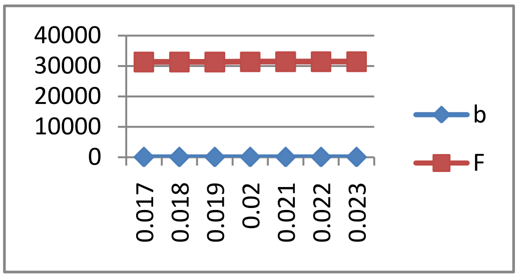


(Fig-3)

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

%change in b	b	t_1	F
-15%	0.017	0.94 2936	31280.6
-10%	0.018	0.853602	31307.5
-5%	0.019	0.777885	31331.8
0	0.02	0.712585	31353.9
5%	0.021	0.655463	31373.9
10%	0.022	0.604893	31392
15%	0.023	0.559666	31408.5

(Table-2)

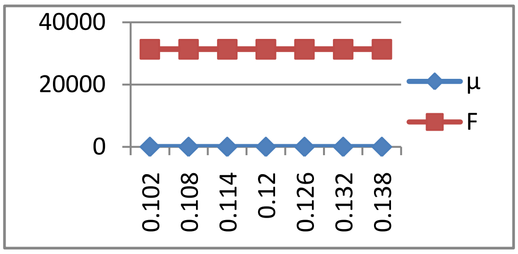


(Fig-4)

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

%change in μ	μ	t1	F
-15%	0.102	0.582369	31326.5
-10%	0.108	0.628765	31336.2
-5%	0.114	0.671978	31345.3
0	0.12	0.712585	31353.9
5%	0.126	0.751008	31362.0
10%	0.132	0.787564	31369.7
15%	0.138	0.822502	31377.1

(Table-3)

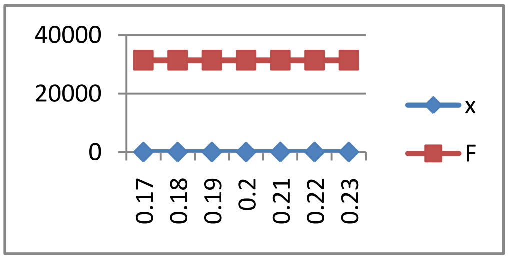


(Fig-5)

Effects of parameter"x" on Total Profit per Unit

%change in x	x	t1	F
-15%	0.17	0.667573	31361
-10%	0.18	0.681805	31358.7
-5%	0.19	0.696786	31356.3
0	0.2	0.712585	31353.9
5%	0.21	0.729281	31351.3
10%	0.22	0.74696	31348.7
15%	0.23	0.765724	31345.9

(Table-4)

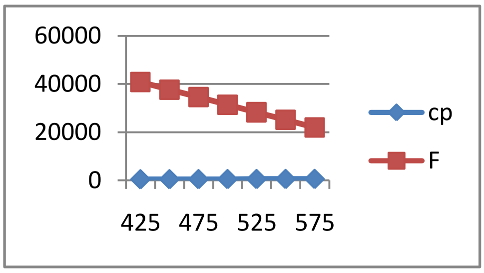


(Fig-6)

Effects of parameter"C_p" on Total Profit per Unit Time

%change in cp	cp	t1	F
-15%	425	0.557684	40766.5
-10%	450	0.597442	37630
-5%	475	0.647353	34492.5
0	500	0.712585	31353.9
5%	525	0.802912	28213.5
10%	550	0.939792	25070.9
15%	575	1.183581	21924.3

(Table-5)



(Fig-7)

Sensitive analysis table

parameter	% change	%change t_1	%change F(t1)
ω	-15	-0.009867164	0.019697709
	-5	-0.003355563	0.006566966
	5	0.003425396	-0.006566966
	15	0.010494952	-0.019704088
x	-15	-0.032074876	0.000226447
	-5	-0.01125813	0.00007654
	5	0.011897319	-0.0000829
	15	0.037866054	-0.000255152
b	-15	0.164144667	-0.002337827
	-5	0.046531801	-0.000704856
	5	-0.04070428	0.000637879
	15	-0.108967786	0.00174141
C_p	-15	-0.110380129	0.300205078
	-5	-0.046483345	0.10010238
	5	0.064365665	-0.100159789
	15	0.193110535	-0.300747275
μ	-15	-0.092789968	-0.000873894
	-5	-0.028935939	-0.000274288
	5	0.027379653	0.000258341
	15	0.078325205	0.00073994

(Table-6)

III OBSERVATIONS

1. Table (1) reveals that as the parameter (ω) 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 (μ) 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) , (μ) and moderately sensitive to (ω)
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.

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