Operational Research in Engineering Sciences: Theory and Applications
Vol. 5, Issue 2, 2022, pp. 85-98
ISSN: 2620-1607
eISSN: 2620-1747
DOI: https://doi.org/10.31181/oresta210322106s

A DETERIORATING INVENTORY MODEL UNDER OVERTIME PRODUCTION AND CREDIT POLICY FOR STOCK- AND PRICE SENSITIVE DEMAND FUNCTION

Nita H. Shah, Kavita Rabari, Ekta Patel

Department of Mathematics, Gujarat University, Ahmedabad-380009, Gujarat, India

Received: 28 October 2021
Accepted: 15 March 2022
First online: 21 March 2022

Research paper

Abstract: *This paper develops an overtime production model for demand rate to be a function of price and stock-level. Companies manufacturing rate fluctuates with the change in stock-level and demand rate. To control the deterioration up to some extent, the system introduces preservation technology investment. The article permits a two-level credit policy for flexible financing. The model calculates feasible profit value under preservation technology investment, production period and selling price. Conclusively, a sensitivity analysis related to different inventory parameters is performed to study the dependency of optimal values on parameters.*

Key words: *Overtime production, Production period, Conservation investment time, Deterioration, Stock- and vending worth dependent time, Sensitivity.*

1. Introduction

Inventory management is challenging when the model pacts with perishable products. Products such as chemicals, pharmaceuticals, and dairy products are at high risk and deteriorate with time. Henceforth, the products are discarded over time as they cannot satisfy customer's expectations and demands. Consequently, the harm cannot be ignored. One can control the decay rate by preservation technology investment, that is the company may capitalize further to store the goods with better cure and freshness keeping efforts. Instead of a deterioration rate, the system also changes with change in consumption rate. These days' people are more interested in buying the products from the showroom having large quantities; this supports to lift the consumption rate. Along with stock-level, one can notice that sales of the goods are inversely proportional to the selling price. More will be priceless will be the demand.

* Corresponding author.
nitahshah@gmail.com (N. H. Shah), kavitagalchar1994@gmail.com (K. Rabari), ektapatel1109@gmail.com (E. Patel)

Many inventory models were developed under constant manufacturing rate. But, in reality the order may change according to the situation and demand. Moreover, to grab the attention, the company develops a certain strategy to conceive consumer's attention. The model deals with a two-level credit system to enhance the sale by permitting them to pay the bill under a certain allowable period. This paper introduces a perishable inventory model, assuming demand rate to be a function of stock and selling price with overtime production. The paper provides managerial insights corresponding to sensitivity analysis. The purpose is to evaluate optimum profit value. Countless scholars functioned for the overtime manufacture rate under constant consumption rate. Thus, for the first time, the study talks the overtime manufacture model for unpreserved goods, taking into consideration the simultaneous outcome of trade credit policy and preservation investments on a company's revenue function.

The paper is designed as: Section 2 contains literature review. Required notations and assumptions are introduced in Section 3. Section 4 discussed inventory model. Computational algorithm is defined in section 5. A numerical example with sensitivity analysis is included in section 6. Finally, section 7 provides a conclusion along with future scope.

2. Literature Review

Demand function plays a vital role in making tactics for inventory models. It fluctuates with respect to different parameters like time, quality, promotional offers etc. Large displays in shops tend to grab consumer's attention. Moreover, the consumption level is directly proportional to the product's selling price. Setting higher power reduces demand rate. Dey *et al.* (2018) investigated rebate, stock-level and price dependent demand. They analysis a comparison between static and dynamic rebate. Chang (2013) revisit burwell contribution and put a note for quantity and freight discounts where demand is price-sensitive. Ouyng *et al*. (2008) developed a non-instantaneous deteriorating problem under stock-dependent demand, considering all unit quantity discount. Jaggi *et al*. (2017) established perishable products ordering policy under selling price dependent consumption rate. Li *et al.* (2019) proposed a replenishment policy for perishable goods. Mishra *et al.* (2018) presented an inventory model under credit periods considering preservation investment and pricing policy. Liu *et al.* (2015) considered a time-dependent assessing policy where the goods decay with period. Seifert *et al.* (2013) had reviewed trade credit literature. Yang *et al.* (2015) examined a deteriorating system seeing conservation strategy and credit plan. Halim *et al.* (2021) established an overtime strategy for the inventory problems dealing with decay products. Khan et al. (2020) deals with time-sensitive stock cost and advanced payment policy under advertisement scenario. Lee and Dye (2021) developed a simple algorithm to solve replenishment schedules and preservation technology costs for decay products assuming stock-sensitive demand rate. Tsao *et al.* (2021) proposed a network design problem assuming credit policy and freshness-keeping strategy. The model evaluated the total cost function by continuous approximation. Dye and Hseih (2012) formulated a worsening stock problem with salvation strategies and partial backordering. Mishra *et al*. (2017) suggested a model for partly and totally tolerable backordering under demand as a function of store level. Geetha and Udayamkumar (2015) formulated a credit model for dynamic demand.

Nowadays, many business enterprises focus on various promotional strategies to increase their sales. In inventory models, promotional policy is the basic requirement in business scenarios to compete with others. In the trade credit scheme, the seller offers some delay period to the retailer at the same time the retailer also permits the consumer to pay the bill within some permissible time interval to stimulate consumer's need and demand. During the permissible credit period, retailers can earn interest from the sold products and gather revenue. A high interest is charged, if the amount is not settled at the end of the cycle period. Credit period strategy makes financial sense and allows retailers to settle the account at the last moment of the allowable time. The approach is used to promote the products. Chung *et al.* (2014) introduced an article, to minimize total price under permissible credit periods for decay items. Soni *et al.* (2013) developed a stock-sensitive demand function under replenishment and credit policies when stock is limited. Shaikh *et al.* (2020) studied an EPQ model for credit policy and permissible shortages. The model calculated optimization problems using the gradient method. Pervin et al. (2020) formulated a production model considering safeguarding assets to overcome the decay rate for storage-and cost-related claims. The model evaluated the total profit function for optimal preservation investment and cycle length. Rapolu and Kandpal (2020) designed an inventory model for decay products having three-parameter Weibull distribution. A simple algorithm is generated to evaluate optimal decision variables. The model is developed incorporating advertisement policy and joint assessing policy to increase profit level. Mahata and De (2016) proposed an ordering strategy model for cost sensitive consumption rate.

3. Notations and Assumptions

The article uses the following assumptions and notations given in Table 1:

Table 1. Notations

C_{np}	Per unit normal production cost (in \$)
C_{op}	Overtime making charge per piece (in \$)
C_d	Worsening rate per piece (in \$)
P	Vending worth per piece (in \$)
A	Set up fee per demand (in \$)
h	Stock charge per element per year (in \$)
μ	Preservation investment rate per cycle
θ	Constant deterioration rate, $0 \le \theta < 1$
α	Scale demand, $\alpha > 0$
β	Stock-dependent parameter, $\beta > 0, \beta << \alpha$
$R(P,I(t))$	Stock and Price sensitive demand
Q	Order quantity
t_p	production period (in years)
T	Rotation period (in years)

$I(t)$	Inventory at a time t during the interval $[0,T]$
I_e	Interest made per year (in $/ year)
I_c	Interest paid per year (in $/year)
M	Time given by trader to vendor(in years)
N	Time given by vendor to customer (in years)
TP	Total profit per unit time (in $/year)

- The system is generated for a single product.
- The demand rate is a function of products price and stock available and is specified through

  $R(P,I(t))=(\alpha+\beta I(t))P^{-\eta}, \alpha>0, \beta>0, \beta>>\alpha, \eta>0$.
- The model is formulated for the overtime production rate. The expression is

  $P_o(t)=\{P_r+(-\gamma I(t)+\xi R(P,I(t)))\}$, where $P_r, \xi>0$ *and* $0\le\gamma\le 1$.
- The article does not permit refunding, replacement, or reworking of imperfect products.
- The deterioration rate is a constant function.
- To overawed destruction rate, the system includes salvation investment.

4. Mathematical Model

Here, the model is developed for dynamic production rate, taking into account the rate to be dependent on demand and stock level i.e., $P_o(t)=\{P_r+(-\gamma I(t)+\xi R(P,I(t)))\}$ for P_r to be continuous and $(-\gamma I(t)+\xi R(P,I(t))$ is overtime manufacturing rate. The demand rate is a non-linear function of product vending worth and storage level. i.e., $R(P,I(t))=(\alpha+\beta I(t))P^{-\eta}$ for $\alpha>0, \beta>0$.

In the beginning, the storage amount is supposed to be zero. The manufacture takes place during period $t=0$ and continuous up to time $t=t_p$, where the stock reaches its saturation point. Hence, the manufacturing rate terminates at the time $t=t_p$, that becomes zero at the end of cycle period i.e. T due to the simultaneous effect of demand and deterioration.

The inventory during the period interval $[t_p,\mathrm{T}]$ and $[t_p,\mathrm{T}]$ is taken as $I_1(t)$ and $I_2(t)$ respectively. The mathematical expression for the different inventory are as follows:

$$\frac{dI_1(t)}{dt}+(\theta-\theta m(\mu))I_1(t)=P_o(t)-R(P,R(t)) \tag{1}$$

$$\frac{dI_2(t)}{dt}+(\theta-\theta m(\mu))I_2(t)=-R(P,R(t)) \tag{2}$$

With boundary conditions $I_1(t)=0$ at $t=0$ and $I_2(t)=0$ at $t=T$. At time $t=t_p$ the inventory level preserves the continuity i.e. $I_1(t_p)=I_2(t_p)$. Using boundary conditions, the solution of equation (1) and (2) are mentioned as follows:

$$I_1(t)=\frac{P_r+(\xi-1)\alpha P^{-\eta}}{B}\left(1-e^{-Bt}\right) \tag{3}$$

$$I_2(t)=\frac{-\alpha P^{-\eta}}{F}\left(1-e^{A(T-t)}\right) \tag{4}$$

Using the continuity at $t=t_p$, the cycle time is defined as:

$$T=\frac{1}{F}log\left(\frac{F}{\alpha P^{-\eta}e^{-t_pA}}\left(\frac{\left(P_r+(\xi-1)\alpha P^{-\eta}\right)\left(1-e^{-At_p}\right)}{B}+\frac{\alpha P^{-\eta}}{F}\right)\right) \tag{5}$$

where $F=\theta\left(1-m(\mu)\right)+\beta P^{-\eta}, B=\theta\left(1-m(\mu)\right)+\gamma-(\xi-1)\beta P^{-\eta}$.

The order quantity is

$$Q=\int_0^{t_p}\left(\alpha+\beta I_1(t)\right)P^{-\eta}dt+\int_{t_p}^{T}\left(\alpha+\beta I_2(t)\right)P^{-\eta}dt \tag{6}$$

Moreover, the holding cost for the entire cycle period is given by

$$HC=h\left(\int_0^{t_p}I_1(t)dt+\int_{t_p}^{T}I_2(t)dt\right) \tag{7}$$

The production cost, preservation investment cost and ordering cost are as shown:

$$PC=C_{np}P_rt_p+C_{op}\left(\int_0^{t_p}\left(-\gamma I_1(t)+\xi\left(\alpha+\beta I_1(t)\right)P^{-\eta}\right)dt\right. \tag{8}$$

$$PIC=\mu\left(\int_0^{t_p}I_1(t)dt+\int_{t_p}^{T}I_2(t)dt\right) \tag{9}$$

$$OC=A \tag{10}$$

The cost related to deteriorated items over the entire cycle period is evaluated as

$$DC=C_d\left(\int_0^{t_p}\theta I_1(t)dt+\int_{t_p}^{T}\theta I_2(t)dt\right) \tag{11}$$

The sales revenue for the proposed inventory model is

$$SR = P\left(\int_{0}^{t_p}\left(\alpha+\beta I_1(t)\right)P^{-\eta}dt+\int_{t_p}^{T}\left(\alpha+\beta I_2(t)\right)P^{-\eta}dt\right) \tag{12}$$

The two cases take place under a two-level credit period system i.e., case 1 and case 2.

Case 1: $M < N$

Here, we have three different possibilities defined as (1.1) $0 < M < N < t_p < T$, (1.2) $0 < t_p < M < N < T$, and (1.3) $0 < t_p < T < M < N$. First, let's discuss each subcase.

Sub-case 1.1. $0 < M < N < t_p < T$

With $[0,M]$, retailers earned some interest over the revenue function defined as

$$IE_{11} = PI_e\left(\int_{0}^{M}\left(\alpha+\beta I_1(t)\right)P^{-\eta}tdt\right)$$

Here, the retailer will finance all the costs between $[M,T]$. Hence, the interest charged is calculated as

$$IC_{11} = \left(C_{np}+C_{op}\right)I_c\left(\int_{M}^{t_p}I_1(t)dt\right)+C_{op}I_c\left(\int_{t_p}^{T}I_2(t)dt\right)$$

Hence, the entire revenue function is

$$TP_{11} = \frac{1}{T}\left(SR-OC-PC-HC-DC-PIC+IE_{11}-IC_{11}\right) \tag{13}$$

Sub-case 1.2. $0 < t_p < M < N < T$

In this case, the interest is earned for the time interval $[0,M]$, and the interest is charged for the interval $[M,T]$. The expression for interest made and interest paid are

$$IE_{12} = PI_e\left(\int_{0}^{t_p}\left(\alpha+\beta I_1(t)\right)P^{-\eta}tdt\right)+PI_e\left(\int_{t_p}^{M}\left(\alpha+\beta I_2(t)\right)P^{-\eta}tdt\right)$$

$$IC_{12} = C_{np}I_c\left(\int_{M}^{T}I_2(t)dt\right)$$

Here, the total profit function in this case is

$$TP_{12} = \frac{1}{T}\left(SR-OC-PC-HC-DC-PIC+IE_{12}-IC_{12}\right) \tag{14}$$

Subcase 1.3. $0 < t_p < T < M < N$

One can observe that in this case $M > T$ implies that the products are vended formerly the permitted credit period. So, the total interest paid is nil. i.e., $IC_{13} = 0$. The interest rate is

$$IE_{13} = PI_e\left(\int_0^{t_p}\left(\alpha + \beta I_1(t)\right)P^{-\eta}tdt + \int_{t_p}^{T}\left(\alpha + \beta I_2(t)\right)P^{-\eta}tdt + T\int_T^M Qdt\right)$$

The entire revenue function is

$$TP_{13} = \frac{1}{T}\left(SR - OC - PC - HC - DC - PIC + IE_{13} - IC_{13}\right) \tag{15}$$

Case 2: $N < M$

Here, we have only one case to discuss .i.e., $0 < N < t_p < M < T$

The retailer must have to pay the charge to the products that are not sold after credit period. Therefore, the interest charge is

$$IC_2 = C_{op}I_c\int_M^T I_2(t)dt$$

Here, The interest earned during interval $[0, M]$ is

$$IE_2 = PI_e\left(\int_0^{t_p}\left(\alpha + \beta I_1(t)\right)P^{-\eta}tdt + \int_{t_p}^{M}\left(\alpha + \beta I_2(t)\right)P^{-\eta}tdt\right)$$

The entire revenue function is

$$TP_2 = \frac{1}{T}\left(SR - OC - PC - HC - DC - PIC + IE_2 - IC_2\right) \tag{16}$$

Here, the problem is

$$Maximize\ TP = \begin{cases} TP_{11},\ if\ 0 < M < N < t_p < T \\ TP_{12},\ if\ 0 < t_p < M < N < T \\ TP_{13},\ if\ 0 < t_p < T < M < N \\ TP_2,\ if\ 0 < N < t_p < M < T \end{cases} \tag{17}$$

The ultimate aim is to evaluate the entire revenue function related to is to calculate the production period, vending worth, conservation investment cost.

5. Computational Algorithm:

The ambition is to exploit profit level. To solve problem, model uses a classical optimization algorithm. The algorithm is defined as follows:

Step 1. Initially, consign some values to different variables.

Step 2. Calculate the derivative of equation (17), of all profit functions that vary according to the credit policies with respect to vending worth, preservation technology investment, and production period. That stands,

$$\frac{\partial TP}{\partial t_p}=0, \frac{\partial TP}{\partial \mu}=0, \frac{\partial TP}{\partial P}=0 \tag{18}$$

equation (18) yields the value of decision variables that are being used in equation (17) to calculate the extreme revenue price.

6. Numerical example and Sensitivity analysis

Example 1: Consider α =5000, β =0.2, γ =0.03, θ =0.2, h =\$1.5/unit/year, A =\$200/order, $P_r=100$, C_d =\$20/unit, C_{np} =\$20/unit, C_{op} =\$6.5/unit, $\eta=1.5$, I_e =0.10, I_c =0.15, $k=0.7$, M = 0.0822, N= 0.164.

Using these numerical values, the decision variables are $P=$ \$82.77/unit, $\mu=$ 0.307, t_p =0.226 years, $T=$ 3.221 years, and $TP=$ \$299.82/ year. Figure 1 represents the convex nature of profit function with respect to decision variables selling price, preservation investment cost and production time. Next, we compare two level trade credit cases in Table 2, for given inventory system.

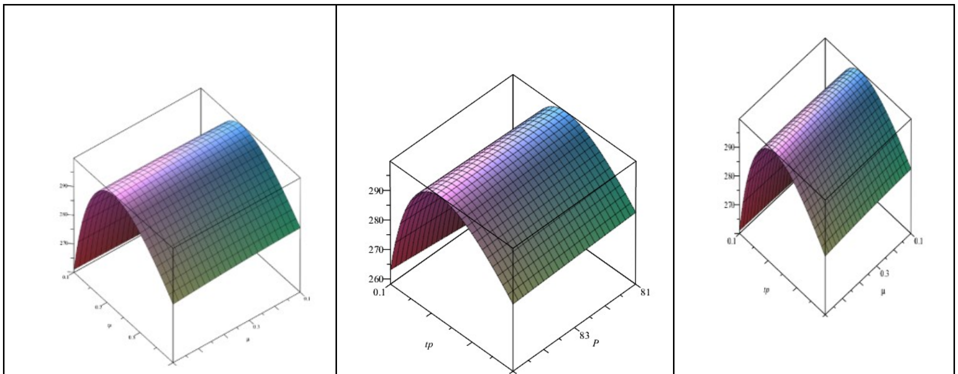

Chart amid μ and P	Chart amid t_p and P	Chart amid t_p and μ

Figure 1. Concavity of objective function

Table 2. Shows the possible cases, when the relation between credit period varies.

P (Selling price)	μ (Preservation investment cost)	t_p (Production time)	T (Cycle time)	TP (Total profit)
		$case1.0 < M < N < t_p < T$		
82.77	0.307	0.226	3.221	299.82
		$case2.0 < t_p < M < N < T$		
81.01	0.264	0.195	2.725	293.03
		$case3.0 < t_p < T < M < N$		
57.57	0.030	0.186	1.495	378.75
		$case4.0 < N < t_p < M < T$		
78.15	0.237	0.237	3.104	307.27

The sensitivity analysis is performed for case 1. A sensitivity of inventory parameters is performed by varying a particular inventory parameter by -10%,10%,20%, -20%, keeping other variables constant.

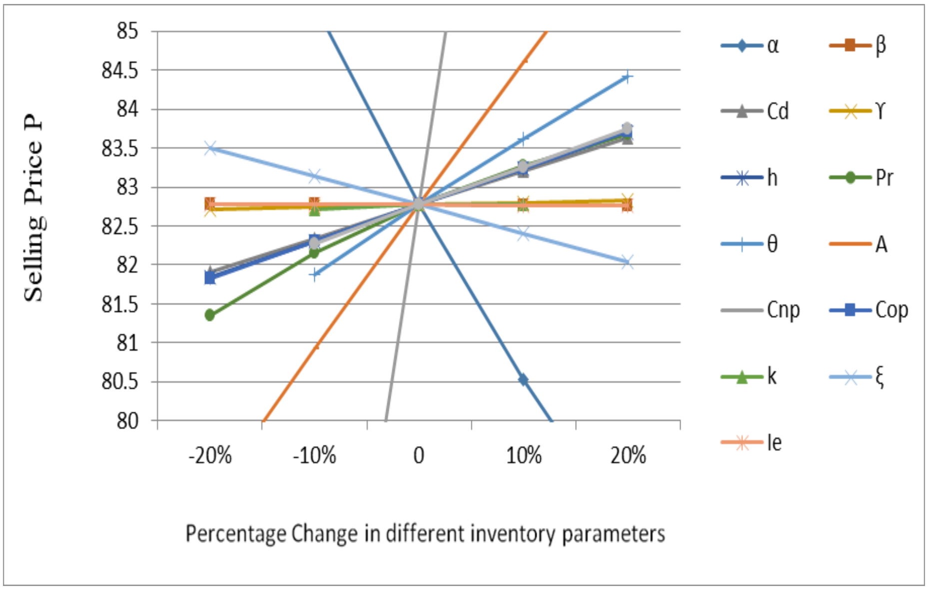

Figure 2. Change in selling price related to inventory parameters.

The purpose in Figure 2 is to exploit the entire revenue function. By an upsurge in deterioration charge, the vending worth increases. Moreover, higher deterioration cost reduces the damage rate which in turn decreases preservation cost. The increase in C_d will have a negative impact on profit function.

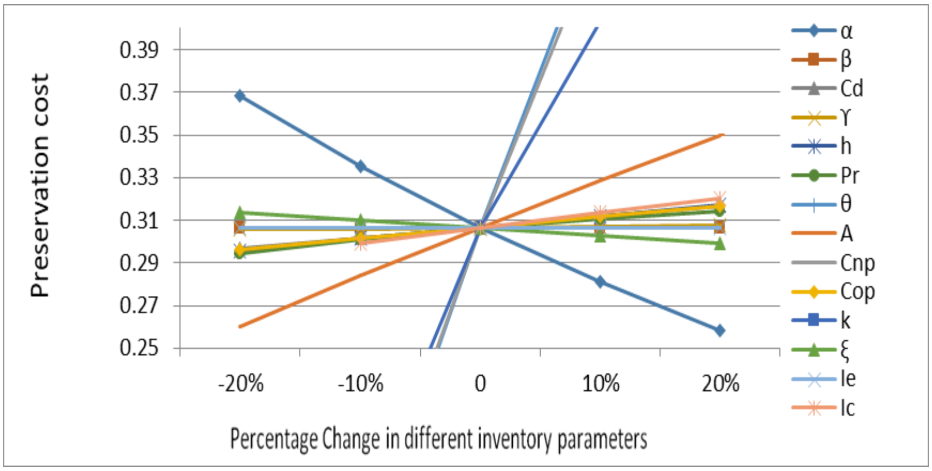

Figure 3. Change in preservation cost related to inventory parameters.

It is depicted from the Figure 3 that a large ordering cost, especially when the manufacturing rate is high, will have a negative effect. The company may introduce some inventory policy to overcome the loss that occurs due to high setup cost. The model uses a credit policy where the delay in payment is permissible up to a certain time. Commonly, the demand for perishable products declines thru period. To avoid a loss that occurs due to damage and spoilage, preservation cost is one of the crucial strategies. An increase in preservation investment cost results in a decrease in profit level. The increase is not advisable.

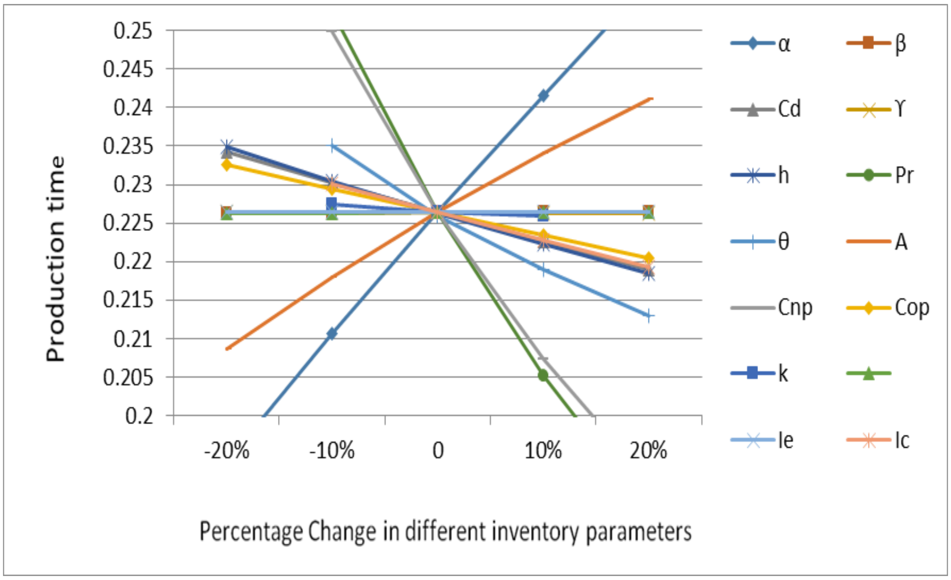

Figure 4. Change in production time related to inventory parameters.

From Figure 4 it is advised that the company may boost the sale by introducing overtime production techniques. The firm will not face shortages and the products are available whenever needed.

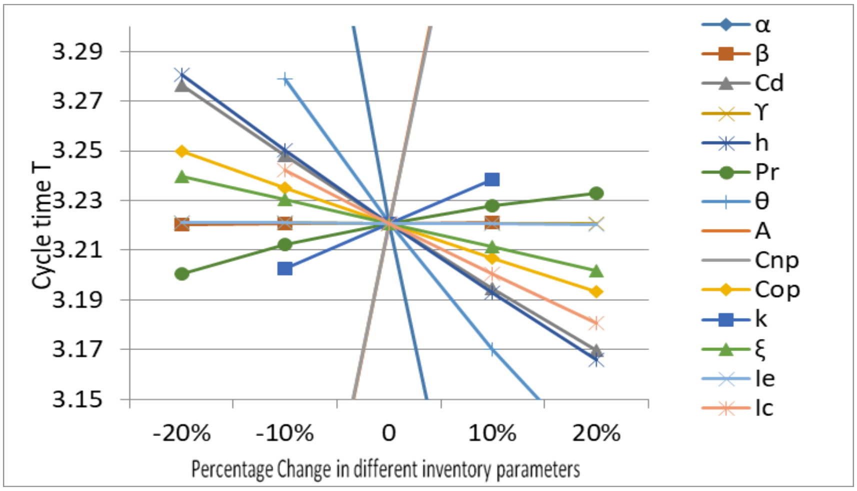

Figure 5. Change in cycle time related to inventory parameters.

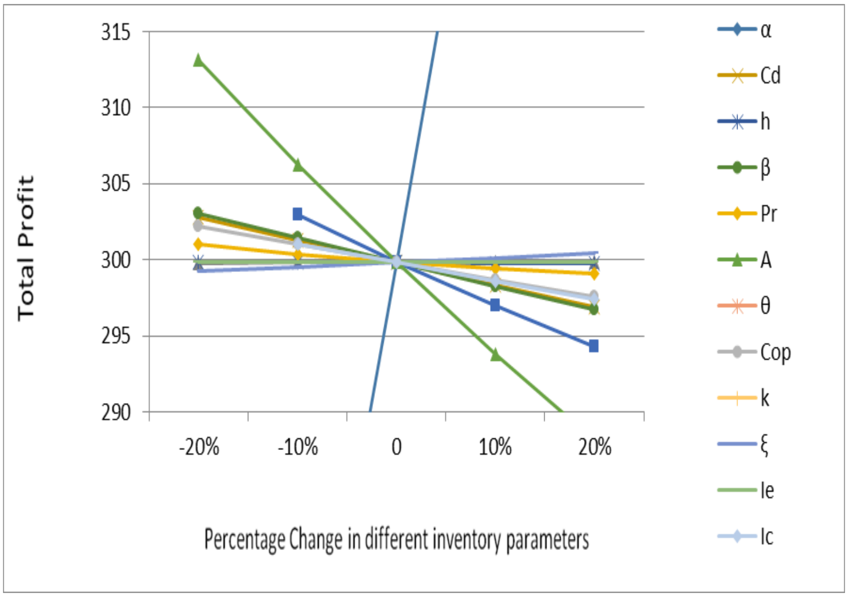

Figure 6. Change in total profit related to inventory parameters.

Figure 5 and Figure 6 suggest that the system is temperately delicate to k and P_r. The increase in the cost function is not advisable as it tends to decrease the profit level. The entire revenue function is exceedingly delicate toward the scale demand i.e., α as large volumes provide choices and quality to the customers. It is observed that with an increase in credit periods, cycle time increases. The stock sensitive demand helps manufacturers to fluctuate profit amounts and reflects product requirements in the market as well. An increase in deterioration rate tends to reduce cycle time, which ensure that one should order less in case to avoid damage rate. To cure the damage, the company requires more money for preservation technology. The total profit decreases.

7. Conclusion

In this paper, the model evaluates overall profit revenue considering the overtime production rate for perishable products. The demand rate is a function of vending worth and stock and selling price taking conservation technology assets to decrease the degree of decline. The model also provides some managerial insights related to key parameters and the problem is solved using classical optimization methods. The goal is to exploit the entire revenue function associated with vending worth, preservation technology investment and production period. To compete with the modern world, the model takes into account credit periods. The revenue parameter is exceedingly sensitive to scale demand. The preservation technology investment will have a positive impact on the deterioration rate and is negatively related to profit function. The overtime production helps to fulfill the demand on time.

Most of the researchers who study overtime production model consider demand rate to be a constant function but in reality it depends on certain factors such as price, time and stock. This work addresses the different research questions. What is the effect of deterioration on retailer's profit? Because of the overtime production process, the company needs to invest more during production time to neglect the situation of stock out. Trade credit policy is being used along with the preservation investment to maximize the profit value.

The model can apply to the problems, dealing with perishable products under permissible overtime production, credit periods and preservation investment to control decay rate. The model has some limitations as the problem is solved for constant rate of deterioration due to the complexity of the problem whereas deterioration rate changes with time. The article can further be extended assuming ramp-type demand or introducing advertisement policy. Additionally, one may incorporate multiple products and multiple buyers under allowable shortages.

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