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Optimization of a Green Inventory System for Deteriorating Items with Price Based Demand Considering Preservation Technology and Carbon Tax Policy

R Vinodini[1], **W Ritha**[1]*

1 PG and Research Department of Mathematics, Holy Cross College (Autonomous), Affiliated to Bharathidasan University, Tiruchirapalli-620002, Tamil Nadu, India

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* **Corresponding author**.

ritha_prakash@yahoo.co.in

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Abstract

Objectives: The importance of preservation technology in this inventory model including imperfect quality items is reducing the carbon emission and wastages, maximizing the total profit and sustainable environment. **Method:** Introducing green concept into this model to reduce environmental pollution and protect the natural resources from the manmade disasters. Inventory models are generally developed for reducing the total cost. In this study, using preservation technology to extend validity period of the manufactured products avoid wastages. The differential equations and differentiation method is used for solving a numerical example. **Findings:** The derivations of the inventory level, optimum order quantity, ordering cost, purchasing cost, holding cost, shortage cost, lost sale cost, cyclic capital cost, transportation cost, preservation technology cost, sales revenue, and green technology investment profit are constructed. The developed model is illustrated with an example. The selling price of the products is $142.5/unit, the replenishment time per cycle is 1.5 month, the total profit of the manufacturing process using preservation technology is $2596, and the amount of carbon emission from the manufacturing industry is 38.9kg/month. **Novelty:** The integration of green concepts into inventory management through preservation technology intended to reduce losses and wastages while enhancing profitability.

Keywords: Green Inventory system; Deteriorating items; Price based demand; Preservation technology and Carbon tax policy

1 Introduction

In a real life situation, the concern towards the environmental sustainability and economic efficiency are increasing. Climate change, global warming and carbon emissions are present environment issues that affect its sustainability. The concept of environmental sustainability becomes more popular among the researchers. This research is about the Optimization of a Green Inventory system for deteriorating items with price based demand considering preservation technology and carbon tax policy. In present scenario, handling the deteriorating items and carbon emission are becoming major issues among the industries. The researchers are incorporating the new technology called preservation technology to extend the manufactured product's validity period. Using these technologies can sort out the problems of industries. The carbon tax policy says, if the carbon emission exceeds the limitation of the Government norms the respective industry has to pay the penalty amount to the Government. If it does not exceed, then the Government returns the amount to the respective industry. Finally, the research paper derived as a mathematical model, and it is examined by an example.

In research world, previously many authors have done research in the field of green technology and preservation technology. The optimal replenishment policy and preservation technology investment for a non-instantaneous deteriorating item are created with under the assumption of stock-dependent demand[(1)]. The paper explained an application of preservation technology in inventory control system with price dependent demand and partial backlogging[(2)]. A model preservation technology investment for an inventory system with variable deterioration rate under expiration dates and price sensitive demand[(3)]. A green inventory model is created with the effect of carbon taxation[(4)]. A sustainable deteriorating inventory model is developed with backorder and controllable carbon emission by using green technology[(5)]. The preservation technology investment, trade credit and partial backordering model for a non-instantaneous is created for deteriorating items[(6)]. A sustainable production-inventory model with imperfect quality under preservation technology and quality improvement investment[(7)]. And the research article created the inventory model for deteriorating items with price sensitive investment in preservation technology[(8)]. Sustainable production-inventory system for perishables under dynamic fuel pricing and preservation technology investment[(9)]. The existing research work[(10)] explains about the products with expiry date and price reliant demand under carbon tax policy. The Green Inventory Model becomes more popular and more effective technology to preserve the environment for future generation. This model is for Model for deteriorating items with a validity period and price based demand while incorporating preservation technology under carbon tax policy.

2 Methodology

2.1 Notations

To develop the proposed model, the following notations and assumptions are used.

T Cycle length (months)

p Retailing price ($/unit), with p>c Constant parameters

O_c Ordering cost ($/order)

e Purchase cost ($/unit)

h Holding cost ($/unit/unit time)

u Expiration date (months)

z_0 Initial deterioration rate (unit/month)

$x(t)$ Deterioration rate at time t (unit/month), $0 \leq x(t) \leq 1$

$I(t)$ Inventory level at time $t \in$ [0,T]

Q Order Quantity in a cycle (units)

$D(p)$ Price-dependent demand (units)

C_c Carbon charge ($/kg)

a Fixed emission factor for shipping (kg/month)

b Variable emission factor for shipping (kg/month)

h Fixed emission factor for inventory holding (kg/month)

l Variable emission factor for inventory holding (kg/month)

A_1 Fixed shipment cost ($/unit)

A_2 Variable shipment cost ($/unit)

PT Preservation Technology cost ($/unit)

σ Emissions per deteriorated item (kg/unit)

A Total average inventory

S Number of deteriorated items

C Carbon emission from inventory holding, transporting and deterioration

β Fraction of per unit profit, $0 < \beta < 1$

$z(p, \beta)$ rate of deterioration

TC Total cost

2.2 Assumptions

1. Demand rate is price based and is defined as

   (a)

   $$D(p) = m - np, p > 0 \tag{1}$$

   (b) Here $m > 0$ is a measuring factor and $0 > n > 1$ is a price elasticity coefficient and both are positive constants.

2. The deteriorating items are degrading continuously overtime and cannot be sold when time is approaching the validity period. Rate of deterioration depends on the validity period and which is calculated as follows:

   (a)

   $$x(t) = \frac{1}{1 + u - t}, 0 \leq t \leq T \leq u \tag{2}$$

   (b) When $t \to 0$ the deterioration rate is minimum.
   (c) When $t \to u$ the deterioration rate is maximum. Which means all the products deteriorate at its validity period.

3. Replenishment is instantaneous and lead time is zero.
4. No replacement, repair or salvage value of deteriorating items during $[0, T]$.
5. Transporting cost for transporting Q units in $TC = A_1 + A_2 Q$, where A_1 is fixed shipment cost, A_2 is variable shipment cost and both are positive known constants.
6. Carbon emissions happens because of transporting, holding the inventory and from the deteriorating items.
7. Carbon emission for transporting Q units is $a + bQ$, where a is a fixed emission and b is a variable emission for transportation.
8. Carbon emission for holding Q units $k + lA$, where k is a fixed emission factor and l is a variable emission factor for holding.
9. Carbon emission from the deteriorating items and σ are the emissions per deteriorating item.
10. Preservation technology investment reduces the rate of deterioration with function $z(p, \beta) = z_0 e^{-(p-c)^2 \beta}$, $0 < \beta < 1, p > 0$ and $z(p, o) = z_0$ and $p > c$.
11. The retailing price is greater than the purchasing cost per unit $p > c$.

2.3 Mathematical Model

The cycle begins at time t = 0 with inventory Q and then gradually depletes to zero at t = T. During [0, T], the inventory is gradually depleted to zero at time T due to the combined effect of demand and deterioration and cannot be sold when time is approaching to the maximum lifetime m. $*$ denotes multiplication. The inventory differential equation $I(t)$ at time t in [0, T] is,

$$x(t)=\frac{1}{1+u\ -t},0\leq t\leq T\leq u \tag{2}$$

$$\frac{dI(t)}{dt}=-(m-np)-x(t)I(t),\qquad 0\leq t\leq T\leq u \tag{3}$$

Where $x(t)=\frac{1}{1+u\ -t},0\leq t\leq T\leq u$

Using the boundary condition $I(T)=0$

$$I(t)=(m-np)(1+u\ -t)\log\left(\frac{1+u\ -t}{1+u\ -T}\right)\qquad 0\leq t\leq T\leq m \tag{4}$$

The order quantity Q is,

$$Q=I(0)=(m-np)(1+u)\log\left(\frac{1+u}{1+u\ -T}\right) \tag{5}$$

Total average inventory is,

A = $\int_0^T I(t)dt$

$$A=(m-np)\left[\frac{(1+u)^2}{2}\log\left(\frac{1+u}{1+u\ -T}\right)+\frac{T^2}{4}-\frac{(1+u)T}{2}\right] \tag{6}$$

Number of deteriorated items is,

$$\begin{aligned} S &= Q-(D*T)\\ S &= \left[\left((m-np)(1+u)\log\left(\frac{1+u}{1+u\ -T}\right)\right)-((m-np)T)\right] \end{aligned} \tag{7}$$

The carbon emission from inventory holding, transporting and deterioration is,

$$C=a+bQ+k+lA+S$$

$$C=\left\{\begin{aligned} &a+b(m-np)(1+u)\log\left(\frac{1+u}{1+u\ -T}\right)+k\\ &+l(m-np)\left[\frac{(1+u)^2}{2}\log\left(\frac{1+u}{1+u\ -T}\right)+\frac{T^2}{4}-\frac{(1+u)T}{2}\right]\\ &+\sigma^*\left[\left((m-np)(1+u)\log\left(\frac{1+u}{1+u\ -T}\right)\right)-((m-np)T)\right] \end{aligned}\right\} \tag{8}$$

The total profit of the inventory system is given by,

The total profit = "sales revenue – [ordering cost + purchase cost + transportation cost + holding cost + preservation technology cost + tax cost]"

The various components of the total profit equation are calculated as follows:

$$\text{Sales revenue is } SR=p*(m-np)T \tag{9}$$

Ordering cost:

Frequently the retailer orders the new products with an ordering cost is

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

Purchase cost:

Purchasing cost depends on the order quantity purchased during the cycle and cost of ordering items per unit. The purchase cost is,

$$P = c * Q = c\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right) \tag{11}$$

Transportation cost:

The products are transported to the retailer, thus the retailer incurs a transportation cost. The quantity of the products and distance are different for different retailers and the fixed cost also charged along with variable transportation cost.

$$\begin{aligned} TC &= A_1 + A_2 Q \\ TC &= A_1 + A_2\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right) \end{aligned} \tag{12}$$

Holding cost:

Proper storage of deteriorating items is required to control its deterioration. The retailer incurs the inventory holding cost for the maintenance of products is stock. The holding cost is,

$$H = h * A = h\left\{(m-np)\left[\frac{(1+u)^2}{2}\log\left(\frac{1+u}{1+u-T}\right) + \frac{T^2}{4} - \frac{(1+u)T}{2}\right]\right\} \tag{13}$$

Preservation technology cost:

The cost of preservation technology refers to the expenses spent for preserving the manufactured products for a long time without affecting the product's quality. This technology used to avoid wastages and loss.

$$PT = \frac{(p-c)}{T} Q$$

$$PT = \frac{(p-c)}{T}\beta\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right) \tag{14}$$

Carbon emission cost under tax:

Carbon emission occurs because of transportation, inventory holding and deterioration items in the environment. A carbon tax is imposed on carbon emission in a form of carbon pricing. So, keep checking and controlling the amount of carbon emission. The carbon emission cost under emission tax policy is given by,

Tax cost $= C_c * (c)$

$$\text{Tax cost } = C_c{}^* \left\{ \begin{aligned} & a + b(m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right) + k \\ & + l(m-np)\left[\frac{(1+u)^2}{2}\log\left(\frac{1+u}{1+u-T}\right) + \frac{T^2}{4} - \frac{(1+u)T}{2}\right] \\ & + \sigma^* \left[\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right) - ((m-np)T)\right] \end{aligned} \right\} \tag{15}$$

Using the **equations (9) to (15)** the total profit unit time is,

$$TP(p,T)=\frac{1}{T}\left[\begin{array}{l} p(m-np)T-O_c-c\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right) \\ -A_1-A_2\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right) \\ -h(m-np)\left\{(m-np)\left[\frac{(1+u)^2}{2}\log\left(\frac{1+u}{1+u-T}\right)+\frac{T^2}{4}-\frac{(1+u)T}{2}\right]\right\} \\ a+b(m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)+k \\ +l(m-np)\left[\frac{(1+u)^2}{2}\log\left(\frac{1+u}{1+u-T}\right)+\frac{T^2}{4}-\frac{(1+u)T}{2}\right] \\ -\frac{(p-c)}{T}\beta\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right) \\ +\sigma^*\left[\left((m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\right)-((m-np)T)\right] \end{array}\right] \tag{16}$$

$$TP(p,T)=\frac{1}{T}\left[\begin{array}{l} p(m-np)T-O_c-A_1-\left\{\begin{array}{l}\left(A_2+c+C_cb+\frac{p-c}{T}\beta+C_c\right) \\ (m-np)(1+u)\log\left(\frac{1+u}{1+u-T}\right)\end{array}\right\} \\ \left\{(h+C_cl)\left((m-np)\left[\frac{(1+u)^2}{2}\log\left(\frac{1+u}{1+u-T}\right)+\frac{T^2}{4}-\frac{(1+u)T}{2}\right]\right)\right\} \\ +C_c\sigma T(m-np)-C_c(b+k) \end{array}\right] \tag{17}$$

2.3.1. Optimality

The total profit function of two variables p and T. In order to establish optimality the following necessary and sufficient conditions must be satisfied.

$\frac{\partial TP(p,T)}{\partial p}=0$ and $\frac{\partial TP(p,T)}{\partial T}=0$

$$\frac{\partial TP(p,T)}{\partial p}=-2np+m-nC_c\sigma+\frac{1}{T}\left\{\begin{array}{l}\left[n(1+u)\log\left(\frac{1+u}{1+u-T}\right)(c+A_2+C_cb+C_c\sigma)\right] \\ -\left[n(-lC_c-h)\left(\frac{T^2}{4}-\frac{(1+u)T}{2}\right)+\left(\frac{(1+u)^2\log\left(\frac{1+u}{1+u-T}\right)}{2}\right)\right] \\ -\frac{\beta}{T^2}\left[(1+u)\log\left(\frac{1+u}{1+u-T}\right)(m+nc-2np)\right]\end{array}\right\} \tag{17}$$

Solving the **equation (17)** get the expression of p^*,

$$p^*=-2n+m-nC_c\sigma+\frac{1}{T}\left\{\begin{array}{l}\left[n(1+u)\log\left(\frac{1+u}{1+u-T}\right)(c+A_2+C_cb+C_c\sigma)\right] \\ -\left[n(-lC_c-h)\left(\frac{T^2}{4}-\frac{(1+u)T}{2}\right)+\left(\frac{(1+u)^2\log\left(\frac{1+u}{1+u-T}\right)}{2}\right)\right] \\ -\frac{\beta}{T^2}\left[(1+u)\log\left(\frac{1+u}{1+u-T}\right)(m+nc-2n)\right]\end{array}\right\} \tag{18}$$

$$\frac{\partial TP(p,T)}{\partial T}=\left[\begin{array}{l} -\frac{1}{T^2}\left\{\begin{array}{l}(-lC_c-h)(m-np)\left(\frac{T^2}{4}-\frac{(1+u)T}{2}\right)+\left(\frac{(1+u)^2\log\left(\frac{1+u}{1+u-T}\right)}{2}\right)+C_c(m-np)\sigma T\\ +p(m-np)T+(1+u)(m-np)(A_2-C_cb-C_c\sigma-c)\log\left(\frac{1+u}{1+u-T}\right)\\ -A_1-C_c(b+k)-O_c\end{array}\right\}\\ +\frac{1}{T}\left\{\begin{array}{l}(-lC_c-h)(m-np)\left(\frac{T}{2}+\frac{(1+u)^2}{2(1+u-T)}-\frac{(1+u)}{2}\right)\\ +\frac{(1+u)(m-np)(A_2-C_cb-C_c\sigma-c)}{(1+m-T)}\\ +C_c(m-np)\sigma+p(m-np)\end{array}\right\}\end{array}\right] \tag{19}$$

Solving the above equations, get the optimal solution of p and T. Substitute the value of parameters in respective equation, get the optimal value of p and T.

2.4 Numerical Example

Consider the following parameters to illustrate the proposed model:

m 90

n 0.7

c $12/unit

h $1/unit/month

u 2 months

O_c $20/order

A_1 $8/unit

A_2 $0.1/unit

z_0 0.2

a 20kg/month

b 0.1kg/month

k 15kg/month

l 0.1kg/month

σ 0.2kg/unit

C_c $3/kg

Substitute the above values in the respective equations get the value of selling price, replenishment time per cycle and total profit amount. And also get the amount of carbon emissions emitted by the manufacturing industry.

3 Result and discussion

The results of this study demonstrate that integration of green inventory system with preservation technology can significantly enhance operational sustainability while maintaining inventory quality and reducing environmental impacts. A key observation is that preservation technology plays a critical role in supporting the objectives of green inventory systems. Minimizing deterioration and waste, preservation technologies strengthen the effectiveness of sustainable inventory management practices. The relationship between green inventory systems and preservation technology highlights the importance of adopting an integrated approach to sustainability The optimal replenishment policy and preservation technology investment for a non-instantaneous deteriorating item are created with under the assumption of stock-dependent demand[1]. The paper explained an application of preservation technology in inventory control system with price dependent demand and partial backlogging[2]. A model preservation technology investment for an inventory system with variable deterioration rate under expiration dates and price sensitive demand[3]. A green inventory model is created with the effect of carbon taxation[4]. A sustainable deteriorating inventory model is developed with backorder and controllable carbon emission by using green technology[5]. The preservation technology investment, trade credit and partial backordering model for a non-instantaneous is created for deteriorating items[6]. A sustainable production-inventory model with imperfect quality under preservation technology and quality improvement investment[7]. And the research article created the inventory model for deteriorating items with price sensitive investment in preservation technology[8]. Sustainable production-inventory system for perishables under dynamic fuel pricing and preservation technology investment[9]. The existing research work[10] explains about the products with expiry date and price reliant demand under carbon tax policy. The Green Inventory Model becomes more popular and more effective technology to preserve the environment for future generation. This model is for Model for deteriorating items with a validity period and price based demand while incorporating preservation technology under carbon tax policy. In the present research work, selling price of the products is $142.5/unit, the replenishment time per cycle is 1.5 month, the total profit of the manufacturing process using preservation technology is $2596, and the amount of carbon emission from the manufacturing industry is 38.9kg/month. The existing research paper sustainable inventory model for perishable products is developed with expiration date and price reliant demand under carbon tax policy has the total profit as $2095.479, the selling price is $72.475/unit and the replenishment cycle time is 1.128 month. The total profit and the selling price are increased due to the increasing the validity period while incorporating the preservation technology. The cycle time variation is negligible and carbon emission also reduced while using the green technology.

4 Conclusion

This study has developed a sustainable inventory model for perishable products with expiration date and price reliant demand under carbon tax policy which has the total profit as $2095.479, the selling price as $72.475/unit and the replenishment cycle time as 1.128 month. This research work concludes that using preservation technology into the mathematical model is to maximize the profit and sustainability of environment and minimize the wastages and loss. In present scenario, the consumers are very conscious about their health and environment. They show less interest in the products which has the short validity period. Customers expect more validity period for the products. Incorporating the preservation technology is to preserve the finished goods for a longer time. Preservation technology plays a vital role in extending the shelf life, safety and quality of products especially in food and healthcare sectors. As technology continues to evolve, modern preservation methods are becoming more efficient, sustainable and environmental friendly. The extension of validity period for the products leads to avoid wastages.

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