OPTIMIZATION OF AN INVENTORY MODEL FOR DETERIORATING ITEMS ASSUMING DETERIORATION DURING CARRYING WITH TWO-WAREHOUSE FACILITY

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Abstract

A common topic in the context of its application in today's business contexts is inventory modelling and management. It is well-known that deterioration has a big impact on inventory management. One of the most frequent supply chain concerns is the deterioration of items during transit from a supplier's storehouse to a retailer's storehouse. In light of this, a two-level supply chain inventory model for decaying goods is developed with two warehouse (storehouse) facilities for retailers, namely Owned Warehouse (OW) and Rented Warehouse (RW), assuming deterioration both during carrying from a supplier's storehouse to a retailer's storehouses and in the retailer's storehouses themselves. Also, we are assuming the selling price and time sensitive demand. We are developed this model under inflation. Shortages are not allowed. The main objective of this study is to determine the optimal ordering policy in order to maximizes the retailer's profit per unit of time. The applicability of our suggested model is investigated using a numerical example and with the support of MATLAB programming software (version: R2021b). Sensitivity analysis is used to examine the effects of changing the values of system parameters. Graphical representations are also shown in this paper.

Keywords: Two-warehouse, Demand based on timing and selling price, Inflation, Deterioration during carrying and Optimization.

1. Introduction and literature survey

Design and production operations plays an important role in supply chain inventory management. Two-warehouse inventory management is a useful for optimising discrete item design and production operations. It enables producers to customise their manufacturing and distribution processes based on unique product quality, demand patterns, and lead times, resulting in increased operational efficiency and customer satisfaction. Deterioration is a key factor in both deterministic and probabilistic inventory models of the classical type. Profit changes anti-proportionally to the decline rate, meaning that if the deterioration rate rises, the retailer's profit falls, and if the deterioration rate falls, the retailer's profit rises. In the current analysis of an inventory model, the rate of deterioration cannot be disregarded. Deterioration is defined as the loss of the initial product's marginal values as well as damage, decay, disappearance, obsolescence and harm to utility. Poswal, P., et al. [47] and Mahata, S. and Debnath, B.K. [51] are also constructing an inventory model based on certain novel assumptions. Kumar, A., et al. [49], Kumar, K., et al. [50], Kundu, T. and Islam, S. [52], Yusuf T.I., et al. [53] and Kumar, P., et al. [54] have also implemented optimisation approaches in various domains.

Inventory management is essential for preventing waste, maintaining product quality, and guaranteeing timely component delivery in the mechanical and electrical industries when it comes to perishable or deteriorating products. Here are a few specific applications for deteriorating goods in these industries: Temperature-controlled storage, management of humidity, First In First Out (FIFO), tracking of expiration dates, real-time monitoring, frequent quality checks, appropriate packaging, cooperation with suppliers, shortened storage durations, customised storage solutions, emergency response plan, waste reduction techniques, and continuous improvement. A study on the application of manufacturing in the Malaysian electrical and electronics industries was conducted by Wong, Y.C., et al. [55]. Basdere, B., et al. [56] Electronic and electrical product disassembly factories to recover resources in material and product cycles. Colledani, M., et al. [57] Manufacturing system design and management for superior product quality. Yusuf T., et al. [53] studied about analysis of the parameters relating to manufacturing flexibility and efficient performance.

Several kinds of realistic assumptions are taken into account when developing this work. Deterioration during carrying is one such sensible supposition. A portion of the entire order spoils during carrying for a variety of causes. Long distances travelled by the carrying vehicle (such kind of justification is appropriate for medicine, blood, radioactive elements, vaccine, fruits, vegetables, etc.), weather conditions while carrying (such kind of justification is appropriate for sugar, salt, vegetables, fruit, fish, meat, eggs, etc.), carelessness while loading and unloading (such kind of justification is the primary cause of an untrained labour force, and such kind of justification is appropriate for any kind of product), etc. are some possible reasons. A lot of study has already been done in inventory control and inventory management systems that take deterioration into consideration as a crucial factor. Many researchers in the past, including Ghare and Schrader [1] and Aggrawal and Jaggi [5], accepted that once things are received, they begin to deteriorate. The analyses of the development of the deteriorating inventory literature were given by some researchers, including Bakker et al. [12] and Yadav et al. [10].

Another significant factor related to an inventory system is the item's demand. One of the modelling community's major concerns has been it. In order to reflect practical scenarios, a variety of inventory models have been built and explored over time for various item types, taking into account various demand patterns. The demand is influenced by a wide range of variables, including quality, stock, various promotional deals, service quality, etc. One of these crucial factors that greatly influences customer's demand is selling price. The majority of the products are evidently price dependent. Some goods are extremely sensitive, while others are not. As a consequence, when an item's selling price increases, demand for that item declines, and when it decreases, demand for that item increases. Demand obviously declines as the selling price rises. On the other hand, a cheap selling price for some goods might make consumers wonder about their freshness and quality. The demand is also influenced by time. According to some researchers, demand can be a time- based function, while others contend that a quadratic function of time would be more suitable. The market demand in the earlier instance varies dramatically over time, while the market demand in the later case changes gradually over time. In especially for products like vegetables, fruits, sweets, etc., these situations rarely correspond to actual market scenarios. Thus, it appears that a demand function with a linear time dependence is more accurate and a better representation of the changing market needs over time. (An in-depth analysis of the time-dependent linear demand rate pattern is provided in [45]). A large number of inventory management models are informed by the realistic feature that are lower selling prices result in higher sales for many decaying products. Mondal et al. [7] established a selling price-dependent inventory model based on customer's demand. You [8] optimized the product's selling price to maximize the average profit of a manufacturing company. Maihami and Kamalabadi [11] investigated the impact of time and selling price on customer demands in an inventory system. Sarkar et al. [17] considered price and time- based demand in their manufacturing inventory system under reliability and inflation. Manna et al. [29] conducted additional research on the impact of advertising and selling price on the rate of demand in a manufacturing inventory model. In the past few years, Kumar et al. [36], Yadav et al. [32], Yadav and Swami [33], Aditi and Jaggi [37], Gautam et al. [34] and Yadav and Swami [26] are used price sensitive demand or time sensitive demand in their research.

Another crucial factor of an inventory system is inflation. The total price of products and services rises as a result of inflation over time. When prices rise overall, each unit of currency may purchase fewer products and services. Therefore, inflation denotes a decline in the buying power of money, or a loss of real value in the internal medium of exchange and unit of account of the economy. In 1975, Buzacott [2] constructed the first Economic Order Quantity (EOQ) model that took inflationary effects into account, and it was at this time that he first introduced inventory models with inflation. The inventory model with inflation is then suggested by Harold and Thomas [4]. In the past few years, Inventory models Kausar et al. [38], Tiwari et al. [25], Yadav et al. [23], Yadav and Swami [27] and the Yadav et al. [24] have been proposed in an inflationary context.

Another crucial component of inventory management is deciding where to store the goods. The development of traditional inventory models took into account only one storage facility with infinite capacity. Typically, this storing space is referred to as an owned warehouse. (OW). In actual market situations, however, a merchant may choose to buy more goods than his storage capacity at once due to a price reduction offered for bulk purchases, a high reordering cost, high demand for a product, or seasonal products. Consequently, a second storage space is leased in order to store extra items. The owned warehouse (i.e., OW) is nearby and is known as the rented warehouse (i.e., RW), which we typically presume to have unlimited capacity. Typically, the carrying cost in RW is greater than that in OW. So, in order to lower inventory expenses, RW items are released first, followed by OW items. The two-warehouse inventory approach was first presented by Hartley [3]. A two-storage stock model for degradation goods with time-sensitive demand was then put forth by Bhunia and Maiti [6]. Yang [9] provided some consideration to the two-storage model with incomplete backlogs for deteriorating products and a constant demand rate under inflation. In the recent few years, Swati et al. [13], Chaman and Singh [14], Yadav et al. [21], Hatibaruah and Saha [46], Yadav and Swami [30], Nath and Sen [39], Yadav et al. [43], Vandana and Das [44] and Aarya, D.D., et al. [48] are developed inventory models under two storage facility.

Table 1: *The comparison of our current work with previously published work*

Source	Demand	Deterioration	Warehouses	Preservation Technology	Inflation	Deterioration during carrying
Ghiami et al. [15]	Stock dependent	Yes	Single	No	No	No
Rizwanullah et al. [35]	Stock dependent	Yes	Two	No	Yes	No
Tayal et al. [16]	Selling price & time dependent	Yes	Single	Yes	Yes	No
Tiwari et al. [41]	Constant	Yes	Two	No	No	No
Saha and Chakrabarti [28]	Stock and advertisement dependent	Yes	Single	No	No	No
Momeni et al. [31]	Stock and selling price dependent	Yes	Single	No	No	No
Mahata and Debnath [42]	Selling price dependent	Yes	Single	Yes	No	Yes
Bhunia et al. [19]	Time, selling price and advertisement dependent	Yes	Two	No	No	No
Palanivel et al. [20]	Stock dependent	Yes	Two	No	Yes	No
Jiangtao et al. [18]	Stock dependent	Yes	Single	No	No	No
Huang et al. [40]	Selling price & stock dependent	Yes	Single	No	Yes	No
Akhtar et al. [45]	Selling price & time dependent	Yes	Single	No	No	No
Present paper	Selling price & time dependent	Yes	Two	No	Yes	Yes

2. Presumptions and notations

2.1. Presumptions

The following presumptions were used in the formulation of the mathematical model.

1. We know that selling price and time have an impact on market demand. As a result of this finding, we share Akhtar, et al. [45] and Aarya, D.D., et al. [48] view that demand is a function of both time and selling price-dependent.
2. Demand rate function is $f(p,t) = a - bp + ct$, where $a, b, c > 0$ are constants.
3. We consider the deterioration during carrying same as Mahata and Debnath [42].
4. We are assuming constant rate of deterioration, which is $\theta(0 < \theta << 1)$ in supplier's storehouse and $\gamma(0 < \gamma << 1)$ in retailer's storehouses..
5. Planning horizon is infinite.
6. There is no lead time.
7. In retailer's storehouses, OW capacity is limited but RW capacity is deemed boundless same as Vandana and Das [44] and Aarya, D.D., et al. [48].
8. We are assuming constant holding cost in both the storehouses.
9. Both the time and the expense of transportation are insignificant.
10. We consider the inflation for developed this model same as Palanivel et al. [20] and Huang et al. [40].
11. There is no item replacement or repair.
12. Stock out are not allowed.

2.2. Notations

Table 2 is provided a description of the notations utilised for the constructed mathematical model.

Table 2: *Notations*

Notation	Units	Description
a	Constant	Coefficient of demand function
b	Constant	Coefficient of demand function
c	Constant	Coefficient of demand function
θ	Constant	Rate of deterioration during carrying.
γ	Constant	Rate of deterioration in retailer's warehouses.
Q	Units	The quantity of orders made each cycle
M	Units	Deteriorating items quantity due to carrying
W	Units	Retailer's Owned Warehouse capacity
$S - W$	Units	Retailer's Rented Warehouse
t_1	Weeks	The stock arrived in retailer's warehouses at this time.
$I(t)$	Units	Inventory level at time t.
h	\$/Unit	Holding cost per unit..
β	\$/Units	Deterioration cost per unit.
r	Constants	Inflation rate.
α	\$/Units	Cost of purchasing per unit.
$TAIPF$	\$/Cycle	The total average inventory profit function

Table 3: *Decision-makingparameters*

Notation	Units	Description
p	\$/Units	Selling price of each product, where $p > \alpha$.
T	Weeks	Length of the cycle..

3. Mathematical Model Formulation

In the starting, Q units of deteriorating goods were ordered by the retailer from supplier. Thus, Q represents the inventory quantity at time zero. The inventory level steadily drops M at the time $t = t_1$ due to the deterioration rate θ while during carrying from the supplier's storehouse to retailer's storehouses (i.e., RW and OW). At the time interval $t \in [t_1, t_2]$, the joint impact of deterioration and demand decreases the inventory/stock level in RW of the retailer's storehouse to drop until it reaches zero. Also, at the time interval $t \in [t_1, t_2]$, only the effect of deterioration decreases the inventory level in OW of the retailer's storehouse. Again, at the time interval $t \in [t_2, T]$, the joint impact of deterioration and demand decreases the inventory/stock level in OW of the retailer's storehouse to drop until it reaches zero (See fig.1).

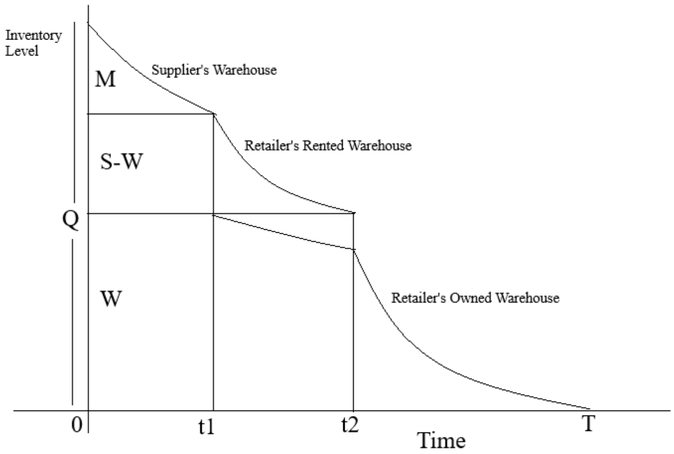

Figure 1: *A graphical representation of a deteriorated inventory model with two warehouses*

The stock level at $t = 0$ to $t = T$ is characterised in the differential equations as follows:

$$\frac{dI_1(t)}{dt} + \theta I_1(t) = -f(p,t); \quad t \in [0, t_1] \tag{1}$$

with the boundary conditions (B.C.) $I_1(t_1) = S$ and $I_1(0) = Q$.

$$\frac{dI_2(t)}{dt} + \gamma I_2(t) = -f(p,t); \quad t \in [t_1, t_2] \tag{2}$$

with the boundary conditions (B.C.) $I_2(t_2) = 0$ and $I_2(t_1) = S - W$.

$$\frac{dI_3(t)}{dt} + \gamma I_3(t) = 0; \quad t \in [t_1, t_2] \tag{3}$$

with the boundary conditions (B.C.) $I_3(t_1) = W$.

$$\frac{dI_4(t)}{dt} + \gamma I_4(t) = -f(p,t); \quad t \in [t_2, T] \tag{4}$$

with the boundary conditions (B.C.) $I_4(T) = 0$.

The equations (5), (6), (7) and (8) are the solutions of equations (1), (2), (3) and (4), respectively:

$$I_1(t) = \frac{1}{\theta^2}\left[c + \theta^2 e^{(t_1-t)\theta}\left(S + \frac{(a-bp+ct_1)}{\theta} - \frac{c}{\theta^2}\right)\right] - \frac{(a-bp+ct)}{\theta} \tag{5}$$

$$I_2(t) = \frac{1}{\gamma^2}\left[c + \gamma^2 e^{(t_2-t)\gamma}\left(\frac{(a-bp+ct_2)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct)}{\gamma} \tag{6}$$

$$I_3(t) = We^{(t_1-t)\gamma} \tag{7}$$

$$I_4(t) = \frac{1}{\gamma^2}\left[c + \gamma^2 e^{(T-t)\gamma}\left(\frac{(a-bp+cT)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct)}{\gamma} \tag{8}$$

From the equations (7) and (8), using the continuity at $t = t_2$, we get

$$W = e^{(t_2-t_1)\gamma}\left\{\frac{1}{\gamma^2}\left[c + \gamma^2 e^{(T-t_2)\gamma}\left(\frac{(a-bp+cT)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct_2)}{\gamma}\right\} \tag{9}$$

From the equations (7) and (9), we get

$$I_3(t) = e^{(t_2-t_1)\gamma}\left\{\frac{1}{\gamma^2}\left[c + \gamma^2 e^{(T-t_2)\gamma}\left(\frac{(a-bp+cT)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct_2)}{\gamma}\right\}e^{(t_1-t)\gamma} \tag{10}$$

Using $I_2(t) = S - W$ in equation (6), we get

$$S = W + \frac{1}{\gamma^2}\left[c + \gamma^2 e^{(t_2-t_1)\gamma}\left(\frac{(a-bp+ct_2)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct_1)}{\gamma} \tag{11}$$

From the equations (9) and (11), we get

$$S = e^{(t_2-t_1)\gamma}\left\{\frac{1}{\gamma^2}\left[c + \gamma^2 e^{(T-t_2)\gamma}\left(\frac{(a-bp+cT)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct_2)}{\gamma}\right\} + \frac{1}{\gamma^2}\left[c + \gamma^2 e^{(t_2-t_1)\gamma}\left(\frac{(a-bp+ct_2)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct_1)}{\gamma} \tag{12}$$

Using $I_1(0) = Q$ in equation (5), we get

$$Q = \frac{1}{\theta^2}\left[c + \theta^2 e^{t_1\theta}\left(S + \frac{(a-bp+ct_1)}{\theta} - \frac{c}{\theta^2}\right)\right] - \frac{(a-bp)}{\theta} \tag{13}$$

Since $M = Q - S$, So from equations (12) and (13), we get

$$M = \frac{1}{\theta^2}\left[c + \theta^2 e^{t_1\theta}\left(S + \frac{(a-bp+ct_1)}{\theta} - \frac{c}{\theta^2}\right)\right] - \frac{(a-bp)}{\theta} - \left\{e^{(t_2-t_1)\gamma}\left\{\frac{1}{\gamma^2}\left[c + \gamma^2 e^{(T-t_2)\gamma}\left(\frac{(a-bp+cT)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct_2)}{\gamma}\right\} + \frac{1}{\gamma^2}\left[c + \gamma^2 e^{(t_2-t_1)\gamma}\left(\frac{(a-bp+ct_2)}{\gamma} - \frac{c}{\gamma^2}\right)\right] - \frac{(a-bp+ct_1)}{\gamma}\right\} \tag{14}$$

Next, we compute the associated costs and profit as follows:

1. **The Ordering cost:**

$$OC = A \tag{15}$$

2. **The Holding cost:**

$$HC = h\left[\int_{t_1}^{t_2} I_2(t)e^{-rt}dt + \int_{t_1}^{t_2} I_3(t)e^{-rt}dt + \int_{t_2}^{T} I_4(t)e^{-rt}dt\right]$$

$$HC = \Bigg\{ h \Bigg\{ \frac{1}{\gamma} \Bigg[c \Bigg(\frac{(1+rT)}{r^2 e^{rT}} - \frac{(1+rt_2)}{r^2 e^{rt_2}} \Bigg) \Bigg] + \frac{a}{r\gamma} \Bigg(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}} \Bigg) - \frac{c}{r\gamma^2} \Bigg(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}} \Bigg)$$
$$- \Bigg(\frac{a e^{T\gamma} e^{-T(r+\gamma)} - a e^{T\gamma} e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)} \Bigg) + e^{T\gamma} \Bigg(\frac{c e^{-T(r+\gamma)} - c e^{-t_2(r+\gamma)}}{\gamma^2 (r+\gamma)} \Bigg)$$
$$- \Bigg(\frac{pb e^{-rT} - pb e^{-rt_2}}{r\gamma} \Bigg) + \frac{bp e^{\gamma T}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) - \frac{T c e^{\gamma T}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) \Bigg\}$$
$$- h \Bigg\{ \frac{1}{\gamma} \Bigg[c \Bigg(\frac{(1+rt_1)}{r^2 e^{rt_1}} - \frac{(1+rt_2)}{r^2 e^{rt_2}} \Bigg) \Bigg] + \frac{a}{r\gamma} \Bigg(\frac{1}{e^{rt_1}} - \frac{1}{e^{rt_2}} \Bigg) - \frac{c}{r\gamma^2} \Bigg(\frac{1}{e^{rt_1}} - \frac{1}{e^{rt_2}} \Bigg)$$
$$- \Bigg(\frac{a e^{t_2\gamma} e^{-t_1(r+\gamma)} - a e^{t_2\gamma} e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)} \Bigg) + e^{t_2\gamma} \Bigg(\frac{c e^{-t_1(r+\gamma)} - c e^{-t_2(r+\gamma)}}{\gamma^2 (r+\gamma)} \Bigg)$$
$$- \Bigg(\frac{pb e^{-rt_1} - pb e^{-rt_2}}{r\gamma} \Bigg) + \frac{bp e^{\gamma t_2}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{t_1(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) - \frac{t_2 c e^{\gamma t_2}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{t_1(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) \Bigg\}$$
$$+ \frac{h}{\gamma^2 (r+\gamma)} \Bigg[\Bigg(\frac{1}{e^{t_2(r+\gamma)}} - \frac{1}{e^{t_1(r+\gamma)}} \Bigg) \Bigg(c(e^{T\gamma} - e^{t_2\gamma}) - a\gamma(e^{T\gamma} - e^{t_2\gamma})$$
$$+ bp\gamma(e^{T\gamma} - e^{t_2\gamma}) + (c\gamma t_2 e^{t_2\gamma} - Tc\gamma e^{T\gamma}) \Bigg) \Bigg] \Bigg\} \quad (16)$$

3. **The Deterioration cost:**

$$DC = \gamma\beta \Bigg[\int_{t_1}^{t_2} I_2(t) e^{-rt} dt + \int_{t_1}^{t_2} I_3(t) e^{-rt} dt + \int_{t_2}^{T} I_4(t) e^{-rt} dt \Bigg]$$

$$DC = \Bigg\{ \gamma\beta \Bigg\{ \frac{1}{\gamma} \Bigg[c \Bigg(\frac{(1+rT)}{r^2 e^{rT}} - \frac{(1+rt_2)}{r^2 e^{rt_2}} \Bigg) \Bigg] + \frac{a}{r\gamma} \Bigg(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}} \Bigg) - \frac{c}{r\gamma^2} \Bigg(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}} \Bigg)$$
$$- \Bigg(\frac{a e^{T\gamma} e^{-T(r+\gamma)} - a e^{T\gamma} e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)} \Bigg) + e^{T\gamma} \Bigg(\frac{c e^{-T(r+\gamma)} - c e^{-t_2(r+\gamma)}}{\gamma^2 (r+\gamma)} \Bigg)$$
$$- \Bigg(\frac{pb e^{-rT} - pb e^{-rt_2}}{r\gamma} \Bigg) + \frac{bp e^{\gamma T}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) - \frac{T c e^{\gamma T}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) \Bigg\}$$
$$- \gamma\beta \Bigg\{ \frac{1}{\gamma} \Bigg[c \Bigg(\frac{(1+rt_1)}{r^2 e^{rt_1}} - \frac{(1+rt_2)}{r^2 e^{rt_2}} \Bigg) \Bigg] + \frac{a}{r\gamma} \Bigg(\frac{1}{e^{rt_1}} - \frac{1}{e^{rt_2}} \Bigg) - \frac{c}{r\gamma^2} \Bigg(\frac{1}{e^{rt_1}} - \frac{1}{e^{rt_2}} \Bigg)$$
$$- \Bigg(\frac{a e^{t_2\gamma} e^{-t_1(r+\gamma)} - a e^{t_2\gamma} e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)} \Bigg) + e^{t_2\gamma} \Bigg(\frac{c e^{-t_1(r+\gamma)} - c e^{-t_2(r+\gamma)}}{\gamma^2 (r+\gamma)} \Bigg)$$
$$- \Bigg(\frac{pb e^{-rt_1} - pb e^{-rt_2}}{r\gamma} \Bigg) + \frac{bp e^{\gamma t_2}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{t_1(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) - \frac{t_2 c e^{\gamma t_2}}{\gamma(r+\gamma)} \Bigg(\frac{1}{e^{t_1(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}} \Bigg) \Bigg\}$$
$$+ \frac{\beta}{\gamma^2 (r+\gamma)} \Bigg[\Bigg(\frac{1}{e^{t_2(r+\gamma)}} - \frac{1}{e^{t_1(r+\gamma)}} \Bigg) \Bigg(c(e^{T\gamma} - e^{t_2\gamma}) - a\gamma(e^{T\gamma} - e^{t_2\gamma})$$
$$+ bp\gamma(e^{T\gamma} - e^{t_2\gamma}) + (c\gamma t_2 e^{t_2\gamma} - Tc\gamma e^{T\gamma}) \Bigg) \Bigg] \Bigg\} \quad (17)$$

4. **The Purchasing cost:**

$$PC = \alpha \cdot Q = \alpha \cdot \frac{1}{\theta^2} \Bigg[c + \theta^2 e^{t_1\theta} \Bigg(S + \frac{(a - bp + ct_1)}{\theta} - \frac{c}{\theta^2} \Bigg) \Bigg] - \frac{(a - bp)}{\theta} \quad (18)$$

5. **The Sales Revenue:**

$$SR = p \int_{t_1}^{T} f(p,t) dt = \frac{p(2a + Tc - 2bp + ct_1)(T - t_1)}{2} \quad (19)$$

Thus, we compute the total profit per unit time by the following equation:

$$TAIPF(p,T) = \frac{1}{T}[SR - OC - HC - DC - PC]$$

$$\begin{aligned}
TAIPF(p,T) = \frac{1}{T}\Bigg\{ & \frac{p(2a+Tc-2bp+ct_1)(T-t_1)}{2} - A \\
& - \Bigg\{(h+\gamma\beta)\Bigg\{\frac{1}{\gamma}\left[c\left(\frac{(1+rT)}{r^2e^{rT}} - \frac{(1+rt_2)}{r^2e^{rt_2}}\right)\right] + \frac{a}{r\gamma}\left(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}}\right) - \frac{c}{r\gamma^2}\left(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}}\right) \\
& - \left(\frac{ae^{T\gamma}e^{-T(r+\gamma)} - ae^{T\gamma}e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)}\right) + e^{T\gamma}\left(\frac{ce^{-T(r+\gamma)} - ce^{-t_2(r+\gamma)}}{\gamma^2(r+\gamma)}\right) \\
& - \left(\frac{pbe^{-rT} - pbe^{-rt_2}}{r\gamma}\right) + \frac{bpe^{\gamma T}}{\gamma(r+\gamma)}\left(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right) - \frac{Tce^{\gamma T}}{\gamma(r+\gamma)}\left(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right)\Bigg\} \\
& - (h+\gamma\beta)\Bigg\{\frac{1}{\gamma}\left[c\left(\frac{(1+rt_1)}{r^2e^{rt_1}} - \frac{(1+rt_2)}{r^2e^{rt_2}}\right)\right] + \frac{a}{r\gamma}\left(\frac{1}{e^{rt_1}} - \frac{1}{e^{rt_2}}\right) - \frac{c}{r\gamma^2}\left(\frac{1}{e^{rt_1}} - \frac{1}{e^{rt_2}}\right) \\
& - \left(\frac{ae^{t_2\gamma}e^{-t_1(r+\gamma)} - ae^{t_2\gamma}e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)}\right) + e^{t_2\gamma}\left(\frac{ce^{-t_1(r+\gamma)} - ce^{-t_2(r+\gamma)}}{\gamma^2(r+\gamma)}\right) \\
& - \left(\frac{pbe^{-rt_1} - pbe^{-rt_2}}{r\gamma}\right) + \frac{bpe^{\gamma t_2}}{\gamma(r+\gamma)}\left(\frac{1}{e^{t_1(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right) - \frac{t_2ce^{\gamma t_2}}{\gamma(r+\gamma)}\left(\frac{1}{e^{t_1(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right)\Bigg\} \\
& + \frac{h+\beta}{\gamma^2(r+\gamma)}\Bigg[\left(\frac{1}{e^{t_2(r+\gamma)}} - \frac{1}{e^{t_1(r+\gamma)}}\right)\Bigg(c(e^{T\gamma} - e^{t_2\gamma}) - a\gamma(e^{T\gamma} - e^{t_2\gamma}) \\
& + bp\gamma(e^{T\gamma} - e^{t_2\gamma}) + (c\gamma t_2e^{t_2\gamma} - Tc\gamma e^{T\gamma})\Bigg)\Bigg]\Bigg\} \\
& - \alpha\cdot\frac{1}{\theta^2}\left[c + \theta^2e^{t_1\theta}\left(S + \frac{(a-bp+ct_1)}{\theta} - \frac{c}{\theta^2}\right)\right] - \frac{(a-bp)}{\theta}\Bigg\}
\end{aligned} \tag{20}$$

Let $t_1 = kt_2,\ 0 < k < 1$, then we get equation (21) from equation (20).

$$\begin{aligned}
TAIPF(p,T) = \frac{1}{T}\Bigg\{ & \frac{p(2a+Tc-2bp+ckt_2)(T-kt_2)}{2} - A - \Bigg\{(h+\gamma\beta)\Bigg\{\frac{1}{\gamma}\left[c\left(\frac{(1+rT)}{r^2e^{rT}} - \frac{(1+rt_2)}{r^2e^{rt_2}}\right)\right] \\
& + \frac{a}{r\gamma}\left(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}}\right) - \frac{c}{r\gamma^2}\left(\frac{1}{e^{rT}} - \frac{1}{e^{rt_2}}\right) - \left(\frac{ae^{T\gamma}e^{-T(r+\gamma)} - ae^{T\gamma}e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)}\right) + e^{T\gamma}\left(\frac{ce^{-T(r+\gamma)} - ce^{-t_2(r+\gamma)}}{\gamma^2(r+\gamma)}\right) \\
& - \left(\frac{pbe^{-rT} - pbe^{-rt_2}}{r\gamma}\right) + \frac{bpe^{\gamma T}}{\gamma(r+\gamma)}\left(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right) - \frac{Tce^{\gamma T}}{\gamma(r+\gamma)}\left(\frac{1}{e^{T(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right)\Bigg\} \\
& - (h+\gamma\beta)\Bigg\{\frac{1}{\gamma}\left[c\left(\frac{(1+rkt_2)}{r^2e^{rkt_2}} - \frac{(1+rt_2)}{r^2e^{rt_2}}\right)\right] + \frac{a}{r\gamma}\left(\frac{1}{e^{rkt_2}} - \frac{1}{e^{rt_2}}\right) - \frac{c}{r\gamma^2}\left(\frac{1}{e^{rkt_2}} - \frac{1}{e^{rt_2}}\right) \\
& - \left(\frac{ae^{t_2\gamma}e^{-kt_2(r+\gamma)} - ae^{t_2\gamma}e^{-t_2(r+\gamma)}}{\gamma(r+\gamma)}\right) + e^{t_2\gamma}\left(\frac{ce^{-kt_2(r+\gamma)} - ce^{-t_2(r+\gamma)}}{\gamma^2(r+\gamma)}\right) - \left(\frac{pbe^{-rkt_2} - pbe^{-rt_2}}{r\gamma}\right) \\
& + \frac{bpe^{\gamma t_2}}{\gamma(r+\gamma)}\left(\frac{1}{e^{kt_2(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right) - \frac{t_2ce^{\gamma t_2}}{\gamma(r+\gamma)}\left(\frac{1}{e^{kt_2(r+\gamma)}} - \frac{1}{e^{t_2(r+\gamma)}}\right)\Bigg\} \\
& + \frac{h+\beta}{\gamma^2(r+\gamma)}\Bigg[\left(\frac{1}{e^{t_2(r+\gamma)}} - \frac{1}{e^{kt_2(r+\gamma)}}\right)\Bigg(c(e^{T\gamma} - e^{t_2\gamma}) - a\gamma(e^{T\gamma} - e^{t_2\gamma}) \\
& + bp\gamma(e^{T\gamma} - e^{t_2\gamma}) + (c\gamma t_2e^{t_2\gamma} - Tc\gamma e^{T\gamma})\Bigg)\Bigg]\Bigg\} - \alpha\cdot\frac{1}{\theta^2}\left[c + \theta^2e^{kt_2\theta}\left(S + \frac{(a-bp+ckt_2)}{\theta} - \frac{c}{\theta^2}\right)\right] - \frac{(a-bp)}{\theta}\Bigg\}
\end{aligned} \tag{21}$$

4. Solution procedure

In this section, we explore the concavity of the objective function. Tiwari et al. [22] is also used the following technique for optimization in their research article. The necessary criteria must be satisfied in order to attain a maximum total profit:

$$\frac{\partial TAIPF(p,T)}{\partial p} = 0, \quad \frac{\partial TAIPF(p,T)}{\partial T} = 0 \tag{22}$$

Two equations are derived from equation (22). The optimal values of p and T (namely, p^* and T^*) are determined by solving these two equations, which include two unknown variables, p and T , the subsequent sufficient conditions are also satisfied by it.

The conditions as mention below that must be satisfied in order to maximize $TAIPF(p,T)$ using the hessian matrix HM, a matrix of 2^{nd} order partial derivatives:

$$\mathcal{H} = \begin{bmatrix} \frac{\partial^2 TAIPF(p,T)}{\partial p^2} & \frac{\partial^2 TAIPF(p,T)}{\partial p \partial T} \\ \frac{\partial^2 TAIPF(p,T)}{\partial T \partial p} & \frac{\partial^2 TAIPF(p,T)}{\partial T^2} \end{bmatrix},$$

$$D_{11} = \frac{\partial^2 TAIPF(p,T)}{\partial p^2} < 0, \quad D_{22} = det(HM) > 0.$$

Here, D_{11} and D_{22} are the minors of the hessian matrix HM. Figure 2 displays the whole solution strategy for our proposed model, which was derived using MATLAB software (version: R2021b).

5. Numerical illustration

To maximize the total average profit function $TAIPF(p,T)$, the present model seeks to identify the p and T optimal values. Since $TAIPF(p,T)$ generated in equation (21) is to find the best values for the decision variables p and T, it is extremely difficult to calculate a complex function analytically. The model is solved with the help of the following algorithm.

5.1. Algorithm

1. Fix the values of the parameters $a, b, c, \theta, t_2, \gamma, S, \alpha, \beta, h, r, A, k$.
2. Build the function $TAIPF(p,T)$ given by equation (21).
3. Maximize $TAIPF(p,T)$ subject to the constraints $0 < t_1 < t_2 < T$ and $0 < \alpha < p$.
4. Calculate the optimum values p^*, T^*, t_1^*, Q^* and $TAIPF^*$.

5.2. Example

A numerical example is given in this section to show how the model works. The following parameters values are used as input:

$$a = 75,\ b = 1.5,\ c = 2.1,\ \theta = 0.46,\ t_2 = 4.0\ weeks,\ \gamma = 0.44,\ S = 900\ units,$$

$$\alpha = \$1.1/unit,\ \beta = \$1.8/unit,\ h = \$3.6/unit,\ r = 0.85,\ A = \$110,\ k = 0.55.$$

The optimal solution obtained is as below:

$$p^* = \$32.4827/unit,\ T^* = 10.6011\ weeks,\ t_1^* = 2.2000\ weeks,$$

$$Q^* = 2586.3\ units,\ TAIPF^* = \$550.0893/cycle.$$

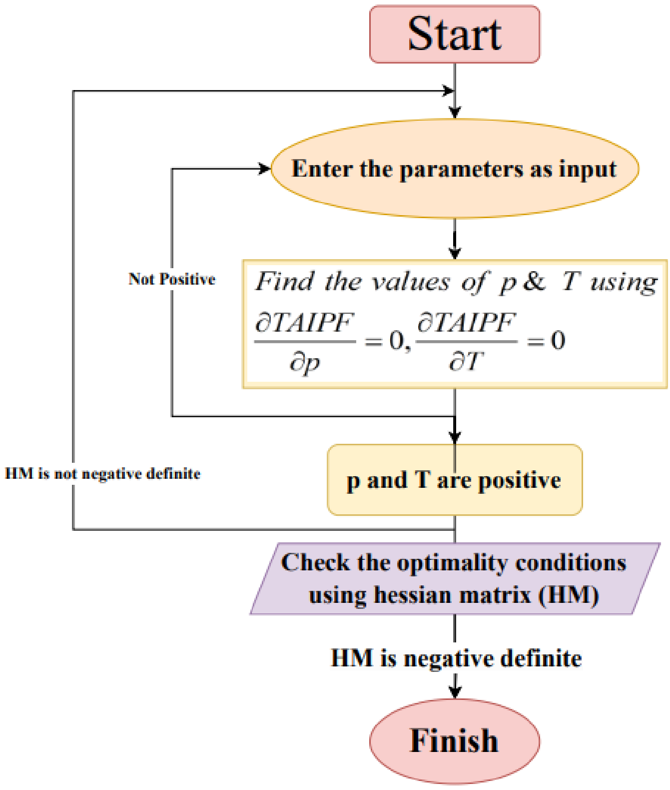

Figure 2: *A flowchart depicting our established model solving process.*

6. Sensitivity analysis

Sensitivity analysis is used in this part to investigate how changes in the parameter's values affect the optimum values. In order to do these studies, one parameter was changed by ±5% and ±10% at a time while remaining at its original value for the other parameters. The following table 3 is demonstrate the outcomes of the sensitivity analysis.

Table 4: *Sensitivity analysis with respect to above example*

Parameters	% Change	% change in optimal value				
		p^*	T^*	t_1^*	Q^*	$TAIPF^*$
a	-10%	29.9669	10.5885	2.2000	2572.1	400.1475
	-5%	31.2235	10.5938	2.2000	2579.2	473.2606
	+5%	33.7443	10.6103	2.2000	2593.3	630.6352
	+10%	35.0079	10.6211	2.2000	2600.4	714.9006
b	-10%	35.9273	10.7299	2.2000	2587.1	664.1233
	-5%	34.1133	10.6628	2.2000	2586.7	603.9984
	+5%	31.0093	10.5443	2.2000	2585.8	501.4878
	+10%	29.6713	10.4918	2.2000	2585.4	457.4537
c	-10%	31.9951	10.5684	2.2000	2588.0	523.7440
	-5%	32.2385	10.5847	2.2000	2587.1	536.8524
	+5%	32.7277	10.6176	2.2000	2585.4	563.4554
	+10%	32.9733	10.6341	2.2000	2584.5	576.9513

Table 5: *Sensitivity analysis with respect to above example (Continue)*

Parameters	% Change	% change in optimal value p^*	T^*	t_1^*	Q^*	$TAIPF^*$
θ	-10%	32.3843	10.5333	2.2000	2342.1	575.5644
	-5%	32.4326	10.5667	2.2000	2461.1	563.1258
	+5%	32.5348	10.6366	2.2000	2717.9	536.4270
	+10%	32.5889	10.6731	2.2000	2856.2	522.1102
t_2	-10%	32.2278	9.9178	1.9800	2331.5	542.8833
	-5%	32.3541	10.2592	2.0900	2455.7	546.6066
	+5%	32.6138	10.9435	2.3100	2723.6	553.3205
	+10%	553.3205	11.2863	2.4200	2868.0	556.2894
γ	-10%	32.7035	11.4222	2.2000	2585.0	606.0342
	-5%	32.5851	10.9900	2.2000	2585.7	577.2419
	+5%	32.3940	10.2492	2.2000	2586.8	524.3797
	+10%	32.3168	9.9289	2.2000	2587.2	499.9510
α	-10%	32.3676	10.5285	2.2000	2586.9	577.0201
	-5%	32.4255	10.5652	2.2000	2586.6	563.5307
	+5%	32.5394	10.6363	2.2000	2585.9	536.6945
	+10%	32.5955	10.6708	2.2000	2585.6	523.3453
β	-10%	32.4765	10.6361	2.2000	2586.3	553.6050
	-5%	32.4796	10.6185	2.2000	2586.3	551.8408
	+5%	32.4859	10.5839	2.2000	2586.2	548.3502
	+10%	32.4891	10.5668	2.2000	2586.2	546.6234
h	-10%	32.4551	10.7659	2.2000	2586.4	566.4975
	-5%	32.4687	10.6816	2.2000	2586.3	558.1543
	+5%	32.4973	10.5241	2.2000	2586.2	542.2818
	+10%	32.5122	10.4503	2.2000	2586.1	534.7136
r	-10%	32.5857	10.1147	2.2000	2585.7	499.6508
	-5%	32.5293	10.3579	2.2000	2586.0	525.3019
	+5%	32.4454	10.8445	2.2000	2586.5	574.0624
	+10%	32.4164	11.0879	2.2000	2586.6	597.2693
A	-10%	32.4794	10.5985	2.2000	2586.3	551.1270
	-5%	32.4811	10.5998	2.2000	2586.3	550.6081
	+5%	32.4844	10.6025	2.2000	2586.3	549.5705
	+10%	32.4861	10.6038	2.2000	2586.2	549.0518
k	-10%	32.2278	9.9178	1.9800	2331.5	542.8833
	-5%	32.3541	10.2592	2.0900	2455.7	546.6066
	+5%	32.6138	10.9435	2.3100	2723.6	553.3205
	+10%	32.7473	11.2863	2.4200	2868.0	556.2894

Following are a few insights drawn from the sensitivity analysis's observations.

1. If we increase in a, then the total average inventory profit $TAIPF$ is increases, because demand is increases. Simultaneously selling price, total cycle length T and total quantity Q are increases (See figure 7).
2. If we increase in b , then the total average inventory profit $TAIPF$ is decreases, because demand is decreases. Simultaneously selling price, total cycle length T and total quantity Q

are decreases.

3. If we increase in c , then the total average inventory profit $TAIPF$ is increases, because demand is increases. Simultaneously selling price and total cycle length T are increases, and total quantity Q is decreases.

4. If we increase in θ (deterioration during carrying), then the total average inventory profit $TAIPF$ is decreases, because the associated cost is increases. Simultaneously selling price, total cycle length T and total quantity Q are increases (See figure 4).

5. If we increase in γ, then the total average inventory profit $TAIPF$ is decreases, because the deterioration in retailer's warehouses are increases, so that associated inventory cost is increases. Simultaneously selling price, total cycle length T are decreases, and total quantity Q is increases.

6. If we increase in r, then the total average inventory profit $TAIPF$ is increases, because selling price will be decreases, so that demand will be increases. If demand will be increase, then the total average inventory profit is increases. Simultaneously the total cycle length T and total quantity Q are increases.

7. If we increase in α, β and h , then the total average inventory profit $TAIPF$ is decreases, because associated inventory costs are increases. Simultaneously, selling price p is increases and the total quantity Q is decreases.

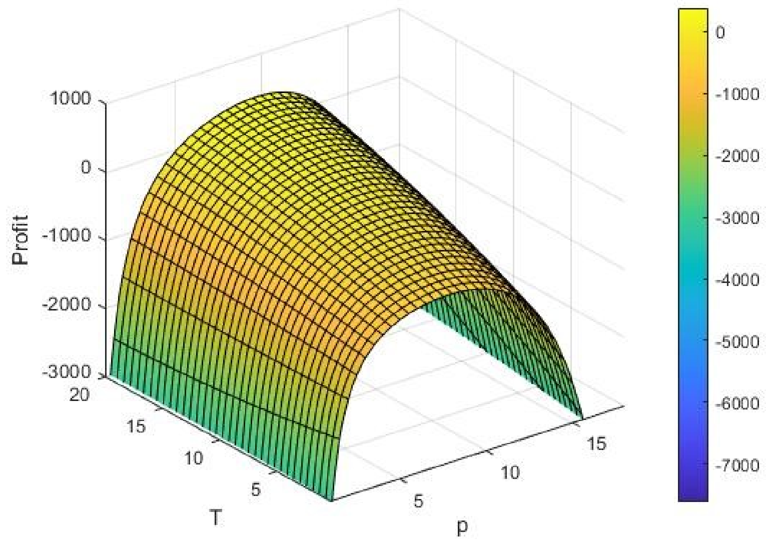

Figure 3: *Concavity of $TAIPF(p, T)$ with respect to p and T*

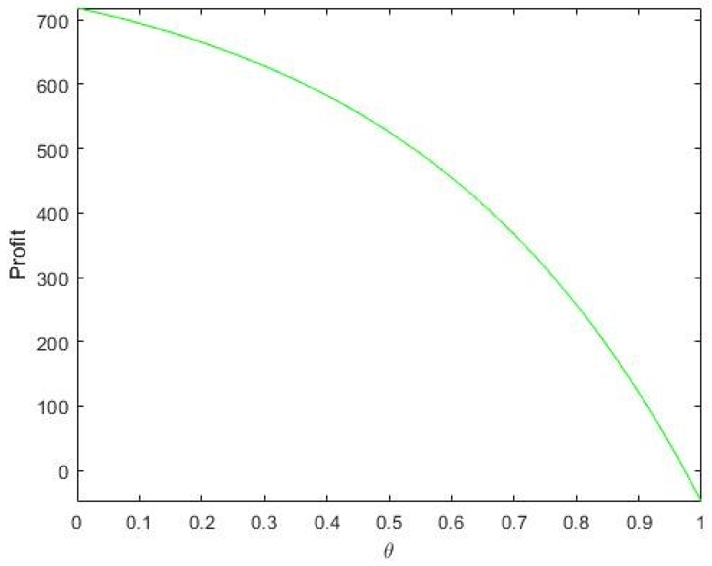

Figure 4: *Variation between Profit vs. Deterioration during carrying* (θ)

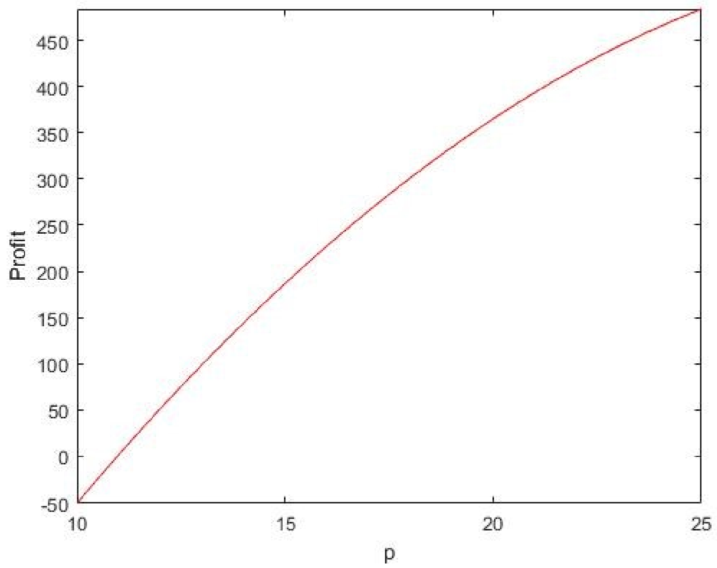

Figure 5: *Variation between Profit vs. Selling price* (p)

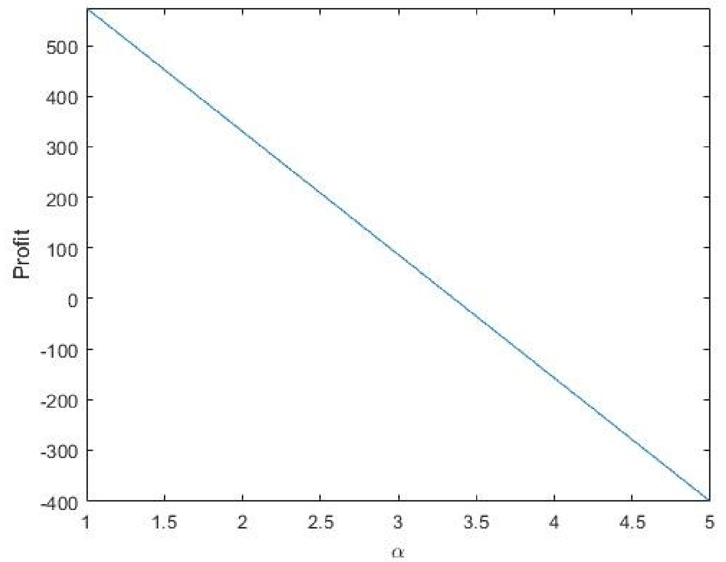

Figure 6: *Variation between Profit vs. Purchasing cost* (α)

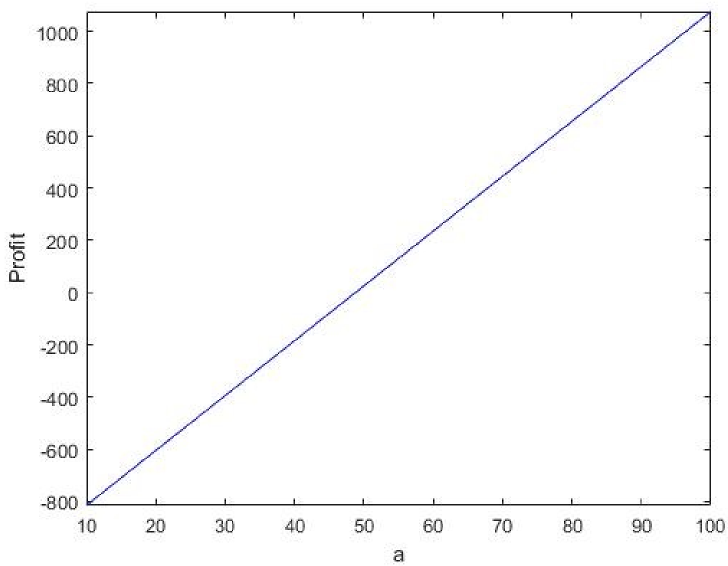

Figure 7: *Variation between Profit vs. Constant part of demand function* (a)

7. Conclusion and future directions

In this study, the carrying of decaying goods from the supplier™s storehouse to the retailer™s storehouses and deterioration in the retailer™s storehouses with time and selling price incumbent demand under inflation have both been addressed in a two-level supply chain inventory model. We are presuming that retailers have two warehouses, named as OW and RW. We are taking a steady rate of decline into account. In such a scenario, shortages are not permitted. This study aims to find the optimal selling price and cycle length by implementing an algorithm that maximizes the total average inventory profit per unit of time. Considering deterioration during carrying is the most important part of this article. Many researchers have not yet taken into account that part of this article. Finally, the applicability of the proposed model is demonstrated

with a numerical example and pictorial representation. A sensitivity analysis of important parameters is provided with the help of MATLAB software (version: R2021b).
The proposed model can also be modified to take into consideration different types of variable demands. It is also possible to recommend future research, such as investigating payment policies and preservation technologies.

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