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# Production Inventory Model for Multi-Item Perishable Goods with Price and Stock-Dependent Demand Under Trade Credit Policy

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## ABSTRACT

**According to the law of demand, price and demand are inversely related. With the increase in price, the demand for an item decreases and vice versa. It is observed that the demand for an item is also influenced by the instantaneous stock level. In this paper, an attempt is made to develop a price and lot-size policy for perishable goods in the case of multi-item, whose demand has been considered to be dependent upon price as well as the stock level, and the goods are of a deteriorating nature. The deteriorating item loses its economic value with time. A mathematical model has been formulated to minimize total supply chain cost under trade credit policy. Illustrative numerical problems and further sensitivity analysis have been carried out. The results obtained show that model behaviour is justified for real-life experiences. It has been observed that the total supply chain cost for all three items increases gradually with the increase in the rate of deterioration. The cycle time, credit period, and lot size decrease with the increase in the deterioration rate. The production inventory model with trade credit financing can be useful for the supply chain managers to reduce supply chain cost and increase supply chain surplus.**

**Keywords:** *deterioration, inventory, price sensitivity, trade credit policy, supply chain*

## 1. INTRODUCTION

The deteriorating items, such as fruits, vegetables, dairy products, chemicals, drugs, and packaged food items, degrade with time. With its degrading quality, its economic value also decreases. So, retailers and suppliers have to optimize their inventory to minimize the loss incurred due to deterioration and simultaneously maximize their sales. Thus, deterioration phenomena of perishable goods have a direct impact on the managerial decision. Hwang and Shinn (1997) derived a joint pricing and lot-sizing problem for the exponentially deteriorating product for price-sensitive demand. Cenk Caliskan (2020) also considered an inventory model with exponential deterioration. Sarkar and Sarkar (2013) assumed a time-varying deterioration rate in their inventory model to determine the optimal cycle length of each item to minimize total cost. Liu *et al.,* (2021) also considered a time-varying deterioration rate for a two-echelon supply chain model. While Chowdhury and Ghosh (2022) assumed the deterioration rate to be constant throughout the life of the product. Jolai *et al.,* (2006) considered a variable deterioration rate in their inventory model and assumed deterioration to follow the Weibull distribution. They also took into consideration inflation and the time value of money in their model. Duary *et al.,* (2021) also considered the Weibull distribution for deterioration. Whereas Sindhuja and Arathi (2022) proposed the Pareto distribution for deterioration. Qin *et al.,* (2014), in the pricing and lot-sizing problem, assumed that the quality of the item and physical quantity deteriorate simultaneously. Therefore, they considered demand as a function of the quality of the product, selling price and stock on display. Soni (2013) proposed a model for single-item non-instantaneous deteriorating goods for price and stock-sensitive demand. In a non-instantaneous deteriorating item, degradation of quality occurs after a certain period. Taleizadeh *et al.,* (2015), Shaikh *et al.,* (2022) developed a Vendor Managed Inventory (VMI) (Seifbarghy and Gilkalayeh, 2017) system with deteriorating items. Amiri *et al.,* (2020) developed a model for determining optimal sales of perishable products in which they considered the product with an expiry date instead of continuous deterioration. Vahdani (2022) developed an integrated lot-sizing and economic disposal model for perishable goods with a predetermined lifetime. Mishra and Mishra (2008) considered the EOQ model for a deteriorating item under a perfectly competitive market that encompasses the idea of minimum deterioration or waste for economic efficiency. Reza Maihami *et al.,* (2019) considered the probabilistic model for deterioration in which they assumed that the deterioration of retailers' inventory follows a uniform distribution, the manufacturer's inventory follows a triangular distribution, and distributors' inventory follows a beta distribution.

Demand can be formulated as a constant (Aggarwal and Aneja, 2016) or a function of price (Dye and Yang, 2016), stock level displayed (Chung *et al.,*, 2013), time, and credit period (Guchhait *et al.,*, 2014), etc. Demand dependent on price is termed as price sensitivity demand, which means the extent to which the sale of a particular item is affected due to fluctuation in the price of items. Some authors have considered demand as either a function of price or stock level, while others have taken a combination of two or more parameters. Demand has been formulated as a linear function of selling price by Bhunia and Shaikh (2015). Chakraborty *et al.,* (2015) and Chung *et al.,* (2013) have taken demand as a deterministic linear function of the instantaneous stock level. Zang *et al.,* (2015) and Halim *et al.,* (2021) formulated demand as a function of price and stock, while Guchhait *et al.,* (2014) considered demand as a combined function of stock level, selling price and credit period. Shaikh *et al.,* (2020) considered a ramp-type demand with a preservation facility for a deteriorating item. Pal *et al.,* (2006) considered demand dependent on the frequency of advertisement along with its dependency on stock level, while Khan et al (2020) considered demand dependent on the selling price and frequency of advertisement. Rahman *et al.,* (2022) formulated the EOQ model for perishable item in which they considered time-demand dependent. Limi *et al.,* (2024) considered the quadratic demand function, while Sebatjane (2024) considered demand dependent on the circularity index.

In the current scenario, suppliers are providing the flexibility of delayed payment to retailers. The supplier provides goods to the retailer without immediate payment and gives him a time duration, typically 30 to 90 days, to pay back the supplier. This is known as trade credit or short-term financing. Suppliers' intention to give sufficient time to pay back is to boost their product sales and increase revenue. This helps small buyers in maintaining cash flow and operational liquidity. During the credit period, the supplier may charge minimum interest or may not charge for a specific time duration (Abadi *et al.,*, 2025). The credit financing is highly beneficial and effective for small and medium enterprises (SMEs) that may have a limited budget for maintaining inventory, especially in developing countries. As per a report published in 2024 by the Director General of Foreign Trade, Ministry of Commerce and Industry, India, that 28% of exports in 2023 were supported by credit financing (DGFT, Ministry of Commerce and Industry, India, 2024). Abadi *et al.,* (2025) also found that it is widely practised in various industries and is useful in maintaining a smooth supply chain. There are one-way credit facility and two-way credit facility. In a two-way credit facility, the retailer also gives the facility of delayed payment to its customers. There are some authors, such as Wu *et al.,* (2014), Guchhait *et al.,* (2014), Cárdenas-Barrón (2020), and Yang (2023), who have considered trade credit facilities or delayed payment systems in their models. Simultaneously, there is an increase in default risk for the manufacturer if the retailer is unable to pay back. So, the supplier has to determine the optimal credit period, and thus, it becomes an important strategy to increase revenue. Hwang and Shinn (1997) considered one level of credit policy in their model, in which, only suppliers provide delayed credit facility to the retailer, while few others such as Wu *et al.,* (2014), Guchhait *et al.,* (2014) in their work, considered two levels of credit financing in which supplier provide delayed credit facility to the retailer and retailer in turn also provide credit period to its consumers.

A lot of research work has been done on the single item inventory model for deteriorating items in the past by researchers such as Bhunia and Shaikh (2015), Qin *et al.,* (2014), Chang *et al.,* (2010). Very few authors such as Chakraborty *et al.,* (2015), Bhattacharya (2005) have proposed a multi-item inventory model for deteriorating goods. A summary of the literature covered related to this topic is listed in Table 1.

From the literature, it was found that authors have focused mainly on the single-item inventory model for deteriorating goods. There hasn't been much work on multi-item inventory problems, especially for deteriorating goods, except for a few such as Chakraborty *et al.,* (2015). Here, it is an attempt to formulate a production inventory model (Karim and Nakade, 2019) under trade credit financing for a multi-item whose demand depends upon price and instantaneous stock level. The joint optimization of the total supply chain cost by the retailer and supplier has been considered. Chakraborty *et al.,* (2015) have considered the demand as a function of instantaneous stock level, but the demand for deteriorating goods such as dairy products and food items will be impacted by not only stock level but also price. In order to capture the more realistic demand, the current work has been attempted, where the demand has been taken as a function of both price and instantaneous stock level, which will improve the work of Chakraborty *et al.,* (2015), and it is also expected to improve the solution. The paper is structured as follows. Section 2 provides notations and assumptions used in the paper, and in Section 3, a mathematical model is proposed. Section 4 discusses the application of an example, a numerical problem on the model and Sections 5 and 6 discuss the results of sensitivity analysis and conclusion, respectively.

# 2. ASSUMPTIONS AND NOTATIONS

From the literature, it was found that authors have focused mainly on the single-item inventory model for deteriorating goods. There hasn't been much work on multi-item inventory problems, especially for deteriorating goods, except for a few such as Chakraborty *et al.,* (2015). Here, it is an attempt to formulate a production inventory model (Karim and Nakade, 2019) under trade credit financing for a multi-item whose demand depends upon price and instantaneous stock level. The joint optimization of the total supply chain cost by the retailer

## *2.1 Assumptions*

The assumptions considered in this paper is the same as in the work of Chakraborty *et al.,* (2015), except for the demand, which is price and stock dependent. They are as follows:

(i) The model is formulated for multi-item deteriorating goods, a single supplier and a single retailer for a finite horizon. The supplier itself produces goods and supplies on retailer demand.

(ii) The demand has been assumed as a function of price and the level of stock displayed.

(iii) The shortage is not allowed in this model.

(iv) The deterioration rate is constant, and deterioration starts when the item reaches the retailer's inventory warehouse.

(v) The supplier offers a delayed payment facility to the retailer. The retailer gets the flexibility to clear the payment due by period (Mi), which is always less than the cycle time (Ti) (i.e., Mi ≤ Ti).

(vi) Interest is levied by the supplier for the remaining stock after Mi period.

(i) The unit production cost is governed by $F_i(PR_i) = R_i + \frac{G_i}{PR_i} + K_i PR_i^{\gamma_i}$, where $R_i$, $G_i$, $K_i$ and $\gamma_i$ are positive real numbers.

(ii) Transportation cost depends on the number of goods purchased by the retailer, which is given by equation $TC_i = TC_i^0 + TC_i^1 Q_i$, where $TC_i^1 > 0$.

(vii) Procurement cost depends on the credit period as $c_i = c_i^0 + c_i^1 e^{M_i}$, where $c_i^1 > 0$

**Table 1** Summary of Related Literature Review

| Author | Year | Price sensitivity | Stock Dependency | Deterioration considered | Trade credit policy | Multi-item |
|---|---|---|---|---|---|---|
| Abadi *et al.,* | 2025 | | | | Yes | |
| Amiri *et al.,* | 2020 | Yes | | Yes | | |
| Bhunia and Shaikh | 2015 | Yes | | Yes | Yes | |
| Bhattacharya, D.K | 2005 | | Yes | Yes | | Yes |
| Cárdenas-Barrón | 2020 | | Yes | Yes | Yes | |
| Cenk Caliskan | 2020 | | | Yes | | |
| Chakraborty *et al.,* | 2015 | | Yes | Yes | Yes | Yes |
| Chang *et al.,* | 2010 | | | Yes | Yes | |
| Chowdhury and Ghosh | 2022 | | | Yes | | |
| Chen *et al.,* | 2019 | Yes | Yes | Yes | | |
| Chung and Barron | 2013 | | Yes | Yes | Yes | |
| Dye and Yang | 2016 | Yes | | Yes | | |
| Dye and Hseih | 2011 | Yes | Yes | Yes | | |
| Guchhait *et al.,* | 2014 | Yes | Yes | Yes | Yes | |
| Halim *et al.,* | 2021 | Yes | Yes | Yes | | |
| Hendalianpour, A. | 2020 | Yes | | Yes | | |
| Hwang and Shinn | 1997 | Yes | Yes | Yes | Yes | |
| Jolai *et al.,* | 2006 | | Yes | Yes | | |
| Khan *et al.,* | 2020 | Yea | | Yes | Yes | |
| Limi *et al.,* | 2024 | | | Yes | | |
| Lu *et al.,* | 2021 | Yes | | Yes | | |
| Maihami and Kamalabadi | 2012 | Yes | | Yes | Yes | |
| Mishra *et al.,* | 2019 | Yes | Yes | Yes | Yes | |
| Mishra and Mishra | 2008 | | Yes | Yes | | |
| Pal *et al.,* | 2006 | Yes | Yes | Yes | | |
| Qin *et al.,* | 2014 | Yes | Yes | Yes | | |
| Rahman *et al.,* | 2021 | | | Yes | | |
| Sarkar and Sarkar | 2013 | | Yes | Yes | | |
| Sebatjane, M | 2024 | | | Yes | | |
| Shaikh *et al.,* | 2019 | | | Yes | Yes | |
| Shaikh *et al.,* | 2020 | | | Yes | Yes | |
| Shaikh *et al.,* | 2022 | | | Yes | Yes | |
| Soni H. N. | 2013 | Yes | Yes | Yes | Yes | |
| Taleizade *et al.,* | 2015 | Yes | | Yes | | |
| Tiwari *et al.,* | 2018 | Yes | | Yes | Yes | |
| Tiwari *et al.,* | 2018 | Yes | Yes | Yes | | |
| Vahdani *et al.,* | 2022 | | | Yes | | |
| Wu *et al.,* | 2014 | | | Yes | Yes | |
| Yang H. | 2023 | | | Yes | Yes | |
| Zhang *et al.,* | 2015 | Yes | Yes | Yes | | |
| This Paper | -- | Yes | Yes | Yes | Yes | Yes |

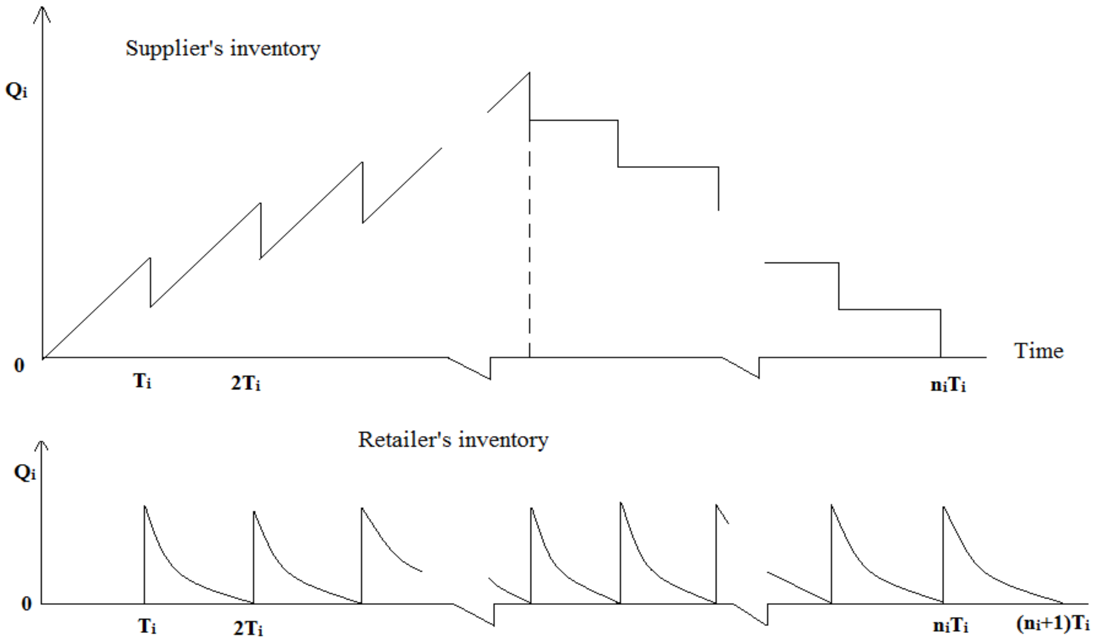


**Figure 1** Inventory Cycle of Supplier and Retailer

### 2.2 *Notations*

For convenience, all notations are also the same as those taken in the work of Chakraborty *et al.,* (2015), which are as follows:

i ith item
$n_i$ the number of order fulfilment of retailer for the ith item.
$P_i^r$ selling price of the ith item offered by the retailer
$A_i$ ordering cost per order for the ith item for the retailer
$\theta_i$ rate of deterioration of the ith item for retailer inventory
$T_i$ replenishment time interval for the ith item of the retailer
$M_i$ credit period for the ith item, offered by the supplier to the retailer
$c_i$ procurement cost for the ith item for the retailer
$h_i^r$ holding cost rate for ith item for retailer
$h_i^s$ holding cost rate for the ith item for the supplier
$I_i^d$ rate of interest for ith item for revenue deposited by the retailer
$I_i^c$ rate of interest to be paid to the supplier for the item remaining from Mi to Ti for ith item
$I_i^s$ rate of interest for supplier opportunity loss due to payment delay for ith item
$PR_i$ rate of production for ith item at the supplier
$TC_i$ Transportation cost of supplier for ith item
$S_i$ setup cost of supplier for ith item
$w_i^r$ per unit storage area for ith item at retailer
$w_i^s$ per unit storage area for ith item at supplier
$D_i(t)$ rate of demand which is equal to $\alpha_i(P_i^r) + \beta_i q_i(t)$, $\alpha_i > 0, \beta_i > 0$
$Q_i$ initial quantity of the ith item procured by the retailer for a cycle
W Total storage area of the supplier and the retailer
B Total budget of the supplier and retailer

## 3. MATHEMATICAL MODEL FORMULATION

In this model, the manufacturer and supplier are the same and produce the ith item at the rate PRi. The retailer orders the Qi amount in each cycle from the supplier. The supplier fulfils the retailer's order for cycle time Ti and gives the flexibility to clear payment by Mi. The retailer fulfils the demand of his customer and earns interest on the revenue collected, and pays back the supplier at the end of the credit period. At the end of the cycle, the retailer again orders Qi items from the supplier for another cycle. This continues up to time niTi, and at time (ni+1)Ti, inventory reaches zero. The inventory cycle of the supplier and retailer is shown in Figure 1.

### 3.1 *Retailer's Inventory*

Retailer's inventory decreases due to the combined effect of deterioration and demand, and inventory at any given point in time t can be computed by the following differential equation.

The differential equation for inventory level $q_i(t)$ for ith item for each cycle is given by:

$$\frac{dq_i(t)}{dt} + \theta_i q_i(t) = -\left(\alpha_i(P_i^r) + \beta_i q_i(t)\right) \tag{1}$$

With boundary condition:

$$q_i(0) = Q_i\ ; \qquad q_i(T_i) = 0 \tag{2}$$

Solving equation (1) with boundary condition (2)

$$q_i(t) = \frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)(T_i-t)} - 1\right). \tag{3}$$

$$Q_i = \frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)T_i} - 1\right). \tag{4}$$

Retailer average ordering cost for ith item is given by:

$$ROC_i = \frac{A_i}{T_i} \tag{5}$$

Retailer average holding cost for ith item is given by:

$$RHC_i = \frac{c_i h_i^r}{T_i}\int_0^{T_i} q_i(t)dt = \frac{c_i h_i^r}{T_i}\int_0^{T_i}\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)(T_i-t)}-1\right)dt = \frac{\alpha_i(P_i^r)c_i h_i^r}{(\theta_i+\beta_i)T_i}\left[\frac{1}{(\theta_i+\beta_i)}\left(e^{(\theta_i+\beta_i)(T_i-t)}-1\right) - T_i\right] \quad (6)$$

Retailer average deterioration cost for ith items is given by:

$$RDC_i = \frac{c_i}{T_i}\left[Q_i - \int_0^{T_i} D_i(t)dt\right] = \frac{c_i}{T_i}\left[Q_i - \int_0^{T_i}\left(\alpha_i(P_i^r)+\beta_i q_i(t)\right)dt\right] = \frac{c_i}{T_i}\left[\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)T_i}-1\right) - \alpha_i(P_i^r)T_i + \frac{\alpha_i(P_i^r)\beta_i}{(\theta_i+\beta_i)^2}\left\{1-e^{(\theta_i+\beta_i)T_i}\right\} + \frac{\alpha_i(P_i^r)\beta_i T_i}{\theta_i+\beta_i}\right] \quad (7)$$

Retailer average interest charged for ith item is given by:

$$RIC_i = \frac{c_i I_i^c}{T_i}\int_{M_i}^{T_i} q_i(t)dt = \frac{c_i I_i^c}{T_i}\int_{M_i}^{T_i}\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)(T_i-t)}-1\right)dt = \frac{c_i I_i^c}{T_i}\frac{\alpha_i(P_i^r)}{(\theta_i+\beta_i)}\left[\frac{1}{\theta_i+\beta_i}\left\{e^{(\theta_i+\beta_i)(T_i-t)}-1\right\} - T_i + M_i\right] \quad (8)$$

Retailer average interest earned for ith item is given by:

$$RIE_i = \frac{P_i^r I_i^d}{T_i}\int_0^{T_i} D_i(t)(T_i-t)dt = \frac{P_i^r I_i^d}{T_i}\int_0^{T_i}\left(\alpha_i(P_i^r)+\beta_i q_i(t)\right)(T_i-t)dt = \frac{P_i^r I_i^d \alpha_i(P_i^r)}{T_i}\left[\frac{T_i^2}{2} - \frac{\beta_i T_i^2}{2(\theta_i+\beta_i)} + \frac{\beta_i}{(\theta_i+\beta_i)}\left\{\frac{T_i e^{(\theta_i+\beta_i)T_i}}{(\theta_i+\beta_i)} - \frac{1}{(\theta_i+\beta_i)^2}\left(e^{(\theta_i+\beta_i)(T_i-t)}-1\right)\right\}\right]. \quad (9)$$

Retailer average total cost for ith item is given by:

$$TR = \sum_{i=0}^{m} TR_i = \sum_{i=0}^{m}(ROC_i + RHC_i + RDC_i + RIC_i - RIE_i). \quad (10)$$

### 3.2 Supplier's Inventory

The supplier starts production at time t =0, and its inventory also starts building up. The production continues for a certain time, and its inventory also increases up to this time. Since Qi is supplied in each cycle Ti, inventory decreases, and eventually, it will come to zero at the time niTi, when the retailer receives the last order.

Supplier average inventory cost for ith item is given by:

$$SIC_i = \frac{h_i^s}{n_i T_i}\left[n_i Q_i - \frac{1}{2}n_i Q_i\frac{n_i Q_i}{P_i} - Q_i\{T_i + 2T_i + \cdots + (n-1)T_i\}\right] = \frac{h_i^s Q_i}{2}\left[(n+1) - \frac{n_i Q_i}{PR_i T_i}\right]. \quad (11)$$

Supplier average setup cost for ith item is given by:

$$SSC_i = \frac{S_i}{n_i T_i} \quad (12)$$

Supplier average production cost for ith item is given by:

$$SPC_i = \frac{F(PR_i)Q_i}{T_i} = \frac{F(PR_i)}{T_i}\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)T_i}-1\right). \quad (13)$$

Supplier average opportunity interest loss for ith item is given by:

$$SOIL_i = \frac{I_i^s c_i M_i Q_i}{T_i} = \frac{I_i^s c_i M_i}{T_i}\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)T_i}-1\right). \quad (14)$$

Supplier average transportation cost for ith item is given by:

$$STC_i = \frac{TC_i}{T_i} = \frac{TC_i^0 + TC_i^1\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)T_i}-1\right)}{T_i}. \quad (15)$$

Supplier average total cost is given by:

$$TS = \sum_{i=0}^{m} TS_i = \sum_{i=0}^{m}(SIC_i + SSC_i + SPC_i + SOIL_i + STC_i). \quad (16)$$

### 3.3 Total Supply Chain Cost

Total supply chain cost can be computed by adding the retailer's average total cost and the supplier's average total cost for the ith item is given by:

$$TSC(T_i, M_i) = \sum_{i=0}^{m}(TR_i + TS_i). \quad (17)$$

### 3.4 Objective Function

Here, the objective is to minimize total supply chain cost (TSC) with space constraint and budget constraint. Here, the optimum cycle time and credit period are to be found in such a way that TSC is minimized. TSC is given by equation (17). The model has constraints for budget and space. The objective function has been expressed by equation (18). The space constraint and the budget constraint have been expressed by equations (19) and (20), respectively.

$$\textit{Minimize } TSC(T_i, M_i) \quad (18)$$

$$\text{s.t}: \sum_{i=0}^{m}(w_i^r + w_i^s)\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)T_i}-1\right) \le W \quad (19)$$

$$\sum_{i=0}^{m} F(PR_i)PR_i + c_i\frac{\alpha_i(P_i^r)}{\theta_i+\beta_i}\left(e^{(\theta_i+\beta_i)T_i}-1\right) \le B. \quad (20)$$

## 4. ILLUSTRATIVE NUMERICAL PROBLEM

Data for the numerical example has been shown in Table 2. Data for numerical illustration has been taken from the case study discussed in the work of Chakraborty *et al.,* (2015), except for the value of the parameter of demand. Here, the expression for price-sensitive demand, $\alpha_i(P_i^r) = 200 - 4P_i^r$, and the value of $\beta_1$ is taken from the work of Dye and Hseih (2011). This numerical can be assumed for a manufacturer which produces some items with deteriorating in nature, such as dairy products or some ready-made food items, such as cooked food, canned food, soups, etc., and supplies them to the retail stores. Using the same case study of Chakraborty *et al.,* (2015), but with a different demand function, will not affect the model, but it will give a more realistic picture of demand and a better solution. The demand for the above-mentioned examples of goods will be affected by the price as well as the displayed stock level at stores. The high stock level will indicate the freshness of the item and attract demand, and a lower stock level will indicate old product and hence reduce demand, but if the price is lowered, that will again attract the customer to take benefit of the reduced price, ultimately impacting demand. Hence, demand can be impacted by both price and stock level.

**Table 2** Data for Illustrative Numerical

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $A_1$ | $A_2$ | $A_3$ | $P_1^r$ | $P_2^r$ | $P_3^r$ | $I_1^d$ | $I_2^d$ | $I_3^d$ |
| 130 | 140 | 160 | 30 | 20 | 25 | 0.05 | 0.03 | 0.03 |
| $c_1^0$ | $c_2^0$ | $c_3^0$ | $h_1^r$ | $h_2^r$ | $h_3^r$ | $I_1^c$ | $I_2^c$ | $I_3^c$ |
| 25 | 35 | 40 | 0.6 | 0.5 | 0.5 | 0.07 | 0.06 | 0.05 |
| $c_1^1$ | $c_2^1$ | $c_3^1$ | $h_1^s$ | $h_2^s$ | $h_3^s$ | $I_1^s$ | $I_2^s$ | $I_3^s$ |
| 0.8 | 0.7 | 0.9 | 6 | 5 | 7 | 0.04 | 0.04 | 0.03 |
| $\Theta_1$ | $\Theta_2$ | $\Theta_3$ | $\gamma_1$ | $\gamma_2$ | $\gamma_3$ | $\beta_1$ | $\beta_2$ | $\beta_3$ |
| 0.05 | 0.10 | 0.15 | 0.0006 | 0.0005 | 0.0007 | 0.1 | 0.2 | 0.3 |
| $PR_1$ | $PR_2$ | $PR_3$ | G1 | G2 | G3 | R1 | R2 | R3 |
| 1500 | 1300 | 1250 | 60 | 70 | 55 | 15 | 18 | 20 |
| S1 | S2 | S3 | K1 | K2 | K3 | $w_1^r$ | $w_2^r$ | $w_3^r$ |
| 3000 | 3500 | 3300 | 5 | 3 | 4 | 5 | 6 | 7 |
| $TC_1^0$ | $TC_2^0$ | $TC_3^0$ | $TC_1^1$ | $TC_2^1$ | $TC_3^1$ | $w_1^s$ | $w_2^s$ | $w_3^s$ |
| 150 | 160 | 155 | 0.04 | 0.02 | 0.03 | 15 | 16 | 17 |
| B | W | | | | | | | |
| 98000 | 6000 | | | | | | | |

**Table 3** Optimal Result of Model

| Item | $n_i$ | $C_i$ | $M_i$ | $T_i$ | $Q_i$ | $TR_i$ | $TS_i$ | $TSC_i$ | TSC |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 25.94 | 0.1647 | 0.5000 | 41.54 | 591.43 | 5344.25 | 5935.68 | 21656.37 |
| 2 | 3 | 35.77 | 0.0949 | 0.3333 | 42.07 | 873.85 | 7048.22 | 7922.08 | |
| 3 | 3 | 41.00 | 0.1094 | 0.3333 | 35.96 | 949.85 | 6848.77 | 7798.62 | |

### 4.1 *Solution of Numerical*

The numerical example was considered and solved using the above input data with the help of optimization software LINGO 17.0. The results obtained are shown in Table 3.

### 4.2 *Solution of Numerical*

Sensitivity analysis of the model is performed for different values of deterioration rate for all three items. The results obtained are shown in Table 4, and the change in total supply chain cost, cycle time, credit period and lot-size with respect to the change in deterioration rate are shown in Figures 2, 3, 4 and 5, respectively.

## 5. RESULT DISCUSSION

The mathematical model was solved with the help of a numerical example, as shown in Section 4. The input data and solution are shown in Table 2 and Table 3, respectively. The results corresponding to all three items for the number of orders, cycle time, credit period, lot size and minimum total supply chain cost have been obtained. In order to check the robustness of the model, a sensitivity analysis has been performed by changing the rate of deterioration. The results for the same have been shown in Table 4 and Figures 2, 3, 4 and 5. It can be observed that the nature of the results is consistent and does not change abruptly with the gradual change of deterioration rate. It can also be seen from the table and these figures that how the total supply chain cost and other parameters are behaving with the change in the rate of deterioration. It can be observed from Table 4 and Figure 2 that the total supply chain cost for all three items increases gradually with the increase in the rate of deterioration. With a higher rate of deterioration, the cost of deterioration will increase, and due to this, the total cost of the supply chain will increase. Change in cycle time and credit period with respect to an increase in deterioration rate has been depicted in Figures 3 and 4, respectively. It can be observed that the cycle time decreases with the increase in the deterioration rate. Since cycle time is decreasing, the credit period should also decrease, and the same can be seen in Figure 4 and Table 4. Figure 5 depicts the change in lot size with the increase in the deterioration rate. It is obvious that due to the higher rate of deterioration, the retailer, in order to have minimum loss of items, it will order a smaller quantity for a short duration but it will increase the number of orders, and the same can also be seen reflecting in the results shown in Table 4. The above result can be practically experienced since the higher rate of deterioration will force the retailer to order a lower quantity; consequently, it will have a lower cycle time and credit period.

This inventory model with trade credit financing can be useful for managers who are looking to improve the financial performance of the organisation and the supply chain. This model will also help in deciding the optimum lot size of such goods that degrade with time and lose their economic value. The results from sensitivity analysis can be helpful in making decisions related to optimum credit period, inventory size and deciding possible action in different scenarios. The different goods will have different rates of deterioration. The sensitivity analysis of supply chain cost, cycle time, credit period and quantity with respect to deterioration rate shows how the decision can vary for different goods which have different rates of deterioration. The managers can find this model and analysis useful when they need to make tradeoffs among various parameters and minimize the cost of the supply chain.

## 6. CONCLUSION

In this paper, an attempt is made to optimize total supply chain cost for a deteriorating multi-item production-inventory model under a trade credit policy. The demand function here considered is an additive function of price and stock level. As the level of stock displayed affects the demand for an item, price also plays an important role in controlling demand. So, demand can have a better picture if

**Table 4** Optimal Result for Different Value of Deterioration Rate

| Increase in Deterioration rate | Item | $n_i$ | $C_i$ | $M_i$ | $T_i$ | $Q_i$ | $TSC_i$ | $TSC$ |
|---|---|---|---|---|---|---|---|---|
| +0.05 | 1 | 2 | 25.94 | 0.1606 | 0.5000 | 42.07 | 5991.44 | 21843.00 |
| | 2 | 3 | 35.77 | 0.0934 | 0.3333 | 42.43 | 7987.76 | |
| | 3 | 3 | 41.00 | 0.1076 | 0.3333 | 36.27 | 7863.81 | |
| +0.10 | 1 | 2 | 25.94 | 0.1565 | 0.5000 | 42.61 | 6048.12 | 22032.00 |
| | 2 | 3 | 35.77 | 0.0920 | 0.3333 | 42.79 | 8054.17 | |
| | 3 | 3 | 41.00 | 0.1058 | 0.3333 | 36.58 | 7929.71 | |
| +0.15 | 1 | 2 | 25.93 | 0.1526 | 0.5000 | 43.16 | 6105.75 | 22223.41 |
| | 2 | 3 | 35.77 | 0.0906 | 0.3333 | 43.16 | 8121.33 | |
| | 3 | 3 | 41.00 | 0.1040 | 0.3333 | 36.90 | 7996.33 | |
| +0.20 | 1 | 2 | 25.93 | 0.1487 | 0.5000 | 43.71 | 6164.34 | 22417.26 |
| | 2 | 3 | 35.77 | 0.0892 | 0.3333 | 43.53 | 8189.23 | |
| | 3 | 3 | 41.00 | 0.1023 | 0.3333 | 37.22 | 8063.69 | |
| +0.25 | 1 | 3 | 25.89 | 0.1122 | 0.3333 | 28.53 | 6213.42 | 22603.11 |
| | 2 | 3 | 35.76 | 0.0878 | 0.3333 | 43.90 | 8257.90 | |
| | 3 | 3 | 41.00 | 0.1006 | 0.3333 | 37.54 | 8131.79 | |
| +0.30 | 1 | 3 | 25.89 | 0.1104 | 0.3333 | 28.77 | 6250.98 | 22766.78 |
| | 2 | 3 | 35.76 | 0.0864 | 0.3333 | 44.28 | 8327.33 | |
| | 3 | 4 | 40.98 | 0.0805 | 0.2500 | 27.50 | 8188.48 | |
| +0.35 | 1 | 3 | 25.89 | 0.1086 | 0.3333 | 29.02 | 6288.95 | 22908.23 |
| | 2 | 4 | 35.75 | 0.0686 | 0.2500 | 32.58 | 8381.20 | |
| | 3 | 4 | 40.97 | 0.0795 | 0.2500 | 27.68 | 8238.08 | |
| +0.40 | 1 | 3 | 25.89 | 0.1068 | 0.3333 | 29.27 | 6327.34 | 23047.45 |
| | 2 | 4 | 35.75 | 0.0678 | 0.2500 | 32.79 | 8432.00 | |
| | 3 | 4 | 40.97 | 0.0786 | 0.2500 | 27.85 | 8288.10 | |
| +0.45 | 1 | 3 | 25.89 | 0.1051 | 0.3333 | 29.52 | 6366.17 | 23187.94 |
| | 2 | 4 | 35.75 | 0.0670 | 0.2500 | 33.00 | 8483.23 | |
| | 3 | 4 | 40.97 | 0.0776 | 0.2500 | 28.04 | 8338.54 | |
| +0.50 | 1 | 3 | 25.89 | 0.1034 | 0.3333 | 29.78 | 6405.42 | 23329.72 |
| | 2 | 4 | 35.75 | 0.0662 | 0.2500 | 33.21 | 8534.90 | |
| | 3 | 4 | 40.97 | 0.0766 | 0.2500 | 28.22 | 8389.40 | |

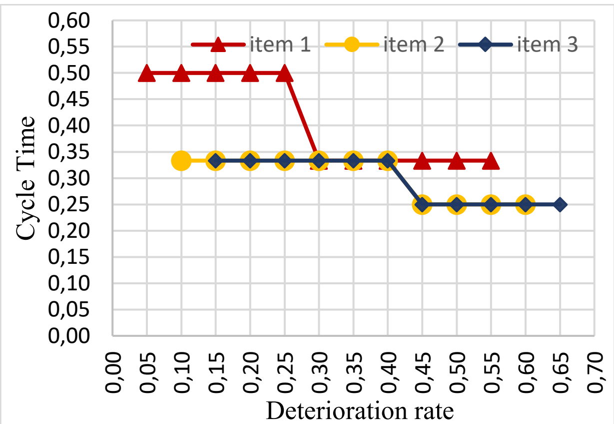


**Figure 2** TSC with Respect to Change in Deterioration Rate

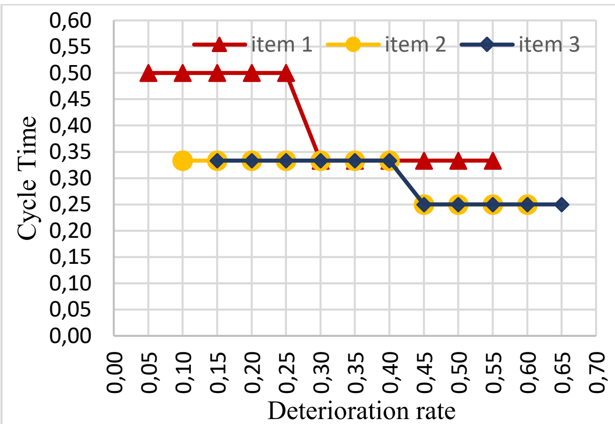


**Figure 3** Cycle Time with Respect to Change in Deterioration Rate

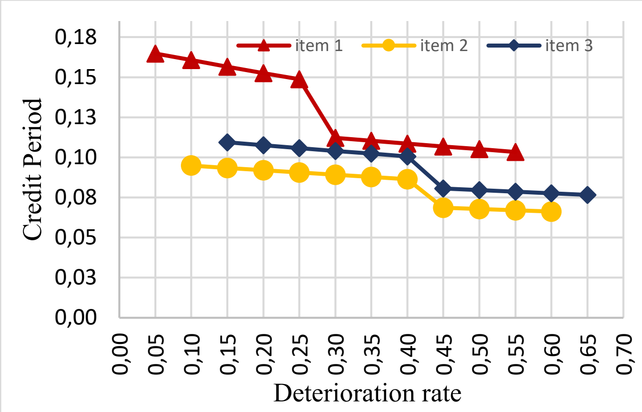


**Figure 4** Credit Period with Respect to Change in Deterioration Rate

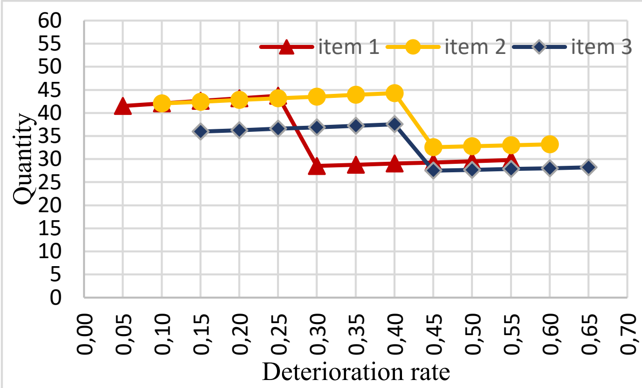


**Figure 5** Quantity with Respect to Change in Deterioration Rate

it is taken as a function of both. A trade credit facility was also considered in the model, in which the supplier offers a delayed payment condition. The model thus formulated for minimizing total supply chain cost and optimising other model parameters was validated with a numerical example. The sensitivity analysis was also performed by changing the rate of deterioration to show the robustness of the model and also to understand how the total cost, cycle time, lot size, credit period, etc., are changing. It can be noticed from Table 4 and Figures 2, 3, 4 and 5, how the supply chain cost and other model parameters are affected by the increasing rate of deterioration. A retail manager can utilize this model to optimize their lot size and ordering frequency depending upon the nature of the products and its perishability. This can help him in minimizing supply chain costs and thus maximizing profit. This model can be implemented where a supplier and retailer work together to optimize their supply chain and minimize cost for some perishable goods. The demand considered in this model is price and stock-dependent, which will provide retailers with a better approximation for the demand. In the case, where suppliers provide a credit facility to the retailer, they can use this model to find out what could be the optimum period for which they can delay their loan amount to the retailer. The trade credit facility is beneficial for both the supplier and retailer since it can lessen the financial burden on the retailer, and on the other hand, it will boost sales by providing a good stock level at retail. Further, this model can be extended for a variable rate of deterioration and including some factor like the influence of inflation. This model can also be formulated for the multi-retailer and the multi-supplier.

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