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Anima Bag
Department of Statistics, Rama Devi Women's University, Bhubaneswar, Odisha, India

Nalini Prava Behera
Department of Statistics, Udayanath (Auto.) College of Science & Technology, Adaspur, Cuttack, Odisha, India

Corresponding Author:
Anima Bag
Department of Statistics, Rama Devi Women's University, Bhubaneswar, Odisha, India

An integrated vendor-buyer supply chain model with inflation induced demand under conditional delivery

Anima Bag and Nalini Prava Behera

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Abstract
The present study proposes an integrated vendor-buyer supply chain framework for perishable products, incorporating inflation-induced demand that is further influenced by advertisement frequency. To capture realistic market conditions, the model introduces a trade credit policy with conditional delivery, aiming to maximize the overall profitability of the system. The vendor and buyer are assumed to establish a long-term collaborative relationship to enhance sustainability and efficiency within the supply chain. The optimal policies are derived with the objective of maximizing total system profit. An empirical investigation is conducted, complemented by a sensitivity analysis to evaluate the robustness of the proposed model under varying parameter settings. The findings provide valuable insights for inventory managers in determining profit-maximizing strategies in integrated systems, particularly under inflationary conditions where demand significantly impacts cost structures. The model is especially relevant for industries handling luxury goods, fashion products, electrical equipment, and manufacturing devices, where profit optimization under dynamic market forces is crucial.

Keywords: Integrated supply chain, vendor, perishable product, inflation, conditional delivery

Introduction

An integrated vendor-buyer supply chain represents a coordinated framework involving the vendor, retailer and customer, collectively striving to achieve operational efficiency and sustainability. To ensure long-term profitability and seamless functioning of business operations, vendors and buyers typically prefer to engage in sustained collaborative arrangements. The seminal work of Goyal (1976) [7] pioneered this domain by introducing the optimization of the total cost in an integrated supply chain environment. Banerjee (1986) [4] extended this perspective by proposing ordering policies that enhanced joint profitability for both parties. Subsequently, Goyal and Gunasekaran (1995) [14] advanced the framework by incorporating deteriorating items within the inventory system. Huang (2004) [12] introduced the concept of unreliability in a single-vendor, single-buyer production-inventory setting and formulated the corresponding optimal policy. Hoque (2009) [9] also investigated a similar production-inventory model with the objective of deriving viable system solutions. Further contributions include Tayal *et al*. (2016) [24], who integrated credit-period considerations into the vendor-buyer inventory model, and Mishra & Talati (2017) [22], who enriched the framework by incorporating both advertising frequency and quantity discount policies.

Collaboration, whether within a supply chain structure or in broader inter-firm contexts, is widely acknowledged as a key enabler of enhanced performance outcomes. A considerable body of literature has explored integrated inventory models encompassing two or more supply chain partners. Foundational studies in this domain was carried by Banerjee (1986) [4]. Goyal and Gupta (1989) [15] provided an influential review of integrated inventory modeling efforts, while Aderohunmu *et al*. (1995) [2] examined Just-In-Time (JIT) applications within such systems. Lu *et al*. (1995) [20] extended the scope by addressing inventory models involving a single vendor and multiple buyers. Hill (1997) [8] and Viswanathan (1998) [28] examined replenishment policies under scenarios of equal and unequal lot sizing, respectively. Goyal and

Nebebe (2000) proposed a modular cost-reduction inventory framework, later extended by Wu and Ouyang (2003) [30], who explicitly accounted for shortages in the system. further refined the algorithm proposed by Wu and Ouyang, thereby contributing to its practical applicability. The following decade witnessed intensified research in integrated modeling. Hsu and Hsu (2012, 2013) [10, 11] emphasized the significance of planned backorders, while Khanna *et al*. (2016) [19] extended their work by embedding trade-credit policies within the modeling framework. The relevance of collaboration has also been validated through industrial practices. In recent years, the focus has shifted toward sustainability-oriented integrated models. Gautam and Khanna (2018) [13] developed an integrated inventory model that addressed imperfect production processes, setup cost reduction, and carbon emissions. Wang *et al*. (2019) [29] analyzed supply chain systems in which suppliers provide environmental friendly products to sustainability-conscious consumers. Manna *et al*. (2021) [21] proposed a single-manufacturer; multi-retailer framework that incorporated a realistic pre-payment mechanism, whereas Rout *et al*. (2021) [23] addressed the issue of vehicle routing in sustainable integrated supply chains.

In the contemporary global economy, inflation serves as a critical factor that diminishes the purchasing power of money. Many nations face persistent inflationary pressures that directly affect consumer demand patterns for various goods and services. Rising inflation not only reduces the real value of savings but also encourages greater expenditure on non-essential or luxury items, thereby altering market demand structures. Hence, overlooking the implications of inflation would present an incomplete and ethically questionable assessment of economic dynamics. Buzacott (1975) [5] first discussed EOQ model with inflationary effect subject to different pricing policies. Chang *et al*. discussed the effect of inflation on the inventory model for deteriorating items in consideration with partial backlogging. Other researchers like Jaggi *et al*. (2006) [17], Chern *et al*. (2008) [6], Jaggi *et al*. (2016) [18], Thangam and Uthayakumar (2010) [25] contribute their valuable efforts in developing the inventory models under inflationary effect. Bag *et al*. (2017) [3], Tripathy &Bag (2018) [26], Tripathy & Behera (2019) [27] are some authors who contribute their valuable efforts in developing the inventory models.

Despite these significant contributions, existing literature continues to exhibit notable gaps. Most studies have predominantly emphasized either cost optimization or sustainability in isolation without adequately addressing the simultaneous impact of multiple real-world factors such as product deterioration, environmental considerations, credit policies, and consumer-driven demand variability. Furthermore, only limited attempts have been made to integrate advanced coordination mechanisms that can balance profitability with sustainability imperatives. This gap necessitates the development of more comprehensive and realistic integrated vendor-buyer models that jointly account for economic, operational, and environmental dimensions. The present study aims to bridge this gap by proposing an improved framework that captures these complexities and offers practical insights for both academia and industry.

The rest of the chapter is developed as follows. Notations and assumptions are placed in the next section. Mathematical formulation with solution procedure is established next. In the third section empirical investigation is carried out. In the fourth section sensitivity analysis is performed with respect to major parameters. The conclusion and future research scope is demonstrated in the last section.

Author	Demand Type	Trade credit	Effect of Inflation
Goyal (1976) [7]	Constant	Absent	Absent
Banerjee (1986) [4]	Constant	Absent	Absent
Goyal & Gupta (1989) [15]	Deterministic	Absent	Absent
Lu (1995) [20]	Constant	Absent	Absent
Wu and Ouyang (2003) [30]	Constant	Absent	Absent
Hsu (2012,2013) [10, 11]	Constant	Absent	Absent
Khanna (2016)	Constant (Continuous)	Present	Absent
Gautam & Khanna (2018) [13]	Constant	Absent	Absent
Gautam *et al.* (2019)	Constant	Absent	Absent
Manna (2021) [21]	Constant	Present	Absent
Present paper	Quadratic	Present	Present

2. Notations and Assumptions

The following notations and assumptions are introduced in the proposed inventory model.

2.1 Notations

- A_0**:** Ordering cost of the inventory by the retailer
- A_1**:** Ordering cost of the inventory by the customer
- m**:** Manufacturing cost per unit item of the inventory
- C_0 **:** Purchase cost per unit item of the inventory by retailer
- s**:** Selling price per unit item of the inventory by the retailer,
- h**:** Holding cost per unit item per annum
- M**:** Credit period offered to the retailer to settle the account (a decision variable)
- $D(t)$**:** Annual demand rate
- $I(t)$**:** Inventory level of the inventory system at any instant of time ‘t’ ($0 \le t \le T$)
- k **:** Deterioration rate of the on hand inventory
- T**:** Optimal cycle time of the inventory system (a decision variable)
- Q_1**:** Manufacturing quantity of the vendor
- Q_2**:** Purchase quantity of the retailer
- N**:** Constant rate of inflation
- $\emptyset_1$**:** Total profit of the vendor per unit time

- $\emptyset_2$**:** Total profit of the retailer per unit time

2.2 Assumptions

1. A single item inventory model is considered here.
2. The inventory system deals with deteriorating items that deteriorate at a constant rate.
3. The lead time is zero or negligible.
4. The shortage is not allowed.
5. The demand rate depends upon the time, inflation and credit period and represented by

$$D(t) = ae^{Nt}\left(1+bt-ct^2\right)M^{\beta} \tag{1}$$

Here $a > 0$ is scale demand, $0 \le b < 1$ is the linear rate of change of demand, $0 \le c < 1$ is the quadratic rate of change of demand and $\beta > 0$ is a constant and N is constant rate of inflation.

6. If longer credit period is given to the buyer, default risk decreases and the rate of default risk for given credit period *M* is considered as

$$F(M) = 1 - M^{\gamma} \text{, where } \gamma > 0 \text{ is a constant} \tag{2}$$

3. Mathematical Model

For vendor

The mathematical model deals with the perishable products which deteriorate with a constant rate *k*. The buyer is offered a credit period with a quadratic demand. With permissible credit period the inventory level at any instant of time '*t*' is represented by the differential equation

$$\frac{dI(t)}{dt} = -aM^{\beta}e^{Nt}\left(1+bt-ct^2\right) - kI(t) \tag{3}$$

The solution of differential equation (3) with initial condition *I (T)* = 0 is given by

(4)

At the beginning, when *t* = 0, the number of units in the inventory system is

$$Q_1 = I(0) = \left(-\frac{1}{(N+k)^3}\right)\left(aM^{\beta}\right)\left[(N+k)^2 - (N+k)b - 2c + \left((N+b)^2\left(cT^2 - Tb - 1\right) - 2(N+b)\left(-\frac{b}{2} + Tc\right) + 2c\right)e^{(N+K)T}.\right] \tag{5}$$

The associated costs of the inventory system per cycle for the supplier are as follows.

Sales revenue after default risk: SR = Selling price*Total demand

$$= s \times \int_0^T D(t)dtM^{\gamma} = s \times \int_0^T ae^{Nt}\left(1+bt-ct^2\right)M^{\beta+\gamma}dt$$

$$= \frac{saM^{\beta+\gamma}}{N}\left[e^{NT}\left(1 + bT - cT^2 - \frac{b}{N} + \frac{2cT}{N} - \frac{2c}{N^2}\right) + \frac{2c}{N^2} + \frac{b}{N} - 1\right] \tag{6}$$

Manufacturing cost (MC) = $me^{Nt}Q$ (7)

Ordering cost (OC) = A_0e^{Nt} (8)

Holding cost (HC) =

$$h\int_0^T I(t)dt = -a\left(\frac{M^{\beta}h}{(N+k)^3}\right)\left[\begin{array}{l}(N+k)^2T + \frac{b}{2}(N+k)^2T^2 - \frac{c}{3}(N+k)^2T^3 + (N+k) - b - \frac{2c}{(N+k)} \\ + \left(c(N+k)T^2 - b(N+k)T - (N+k) + b - 2cT + \frac{2c}{(N+k)}\right)e^{(N+k)T}\end{array}\right] \tag{9}$$

The total profit of the seller per unit time is given by

$\emptyset_1 = (I/T)[SR - MC - OC - HC]$

$$= \frac{s_1 a M^{\beta+\gamma}}{NT}\left[e^{NT}\left(1 + bT - cT^2 - \frac{b}{N} + \frac{2cT}{N} - \frac{2c}{N^2}\right) + \frac{2c}{N^2} + \frac{b}{N} - 1\right]$$

$$-\frac{me^{Nt}Q_1}{T} - \frac{A_0}{T}e^{Nt} + \frac{a}{T}\left(\frac{M^{\beta}h}{(N+k)^3}\right)\left[\begin{array}{l}(N+k)^2T + \frac{b}{2}(N+k)^2T^2 - \frac{c}{3}(N+k)^2T^3 + (N+k) - b - \frac{2c}{(N+k)} \\ +\left(c(N+k)T^2 - b(N+k)T - (N+k) + b - 2cT + \frac{2c}{(N+k)}\right)e^{(N+k)T}\end{array}\right] \quad (10)$$

For Retailer

The retailer does not give credit period to the customer and simultaneously default risk will be absent. The mathematical model deals with the perishable products which deteriorate with a constant rate *k*. The inventory level at any instant of time '*t*' is represented by the differential equation

$$\frac{dI(t)}{dt} = -ae^{Nt}\left(1 + bt - ct^2\right) - kI(t) \quad (11)$$

The solution of differential equation (3) with initial condition *I (T)* = 0 is given by

$$I(t) = -\frac{1}{(N+k)^3}a\left[\begin{array}{l}(N+k)^2(1+bT-cT^2) - (N+k)(b-2ct) - 2c + \\ \left\{(N+k)^2(T^2 - Tb - 1) - 2(N+k)(-\frac{b}{2} + Tc) + 2c)\right\}e^{(N+k)(T-t)}\end{array}\right] \quad (12)$$

At the beginning, when $t = 0$, the number of units in the inventory system is

$$Q_2 = I(0) = \left(-\frac{1}{(N+k)^3}\right)(a)\left[(N+k)^2 - (N+k)b - 2c + \left((N+b)^2\left(cT^2 - Tb - 1\right) - 2(N+b)\left(-\frac{b}{2} + Tc\right) + 2c\right)e^{(N+k)T}.\right] \quad (13)$$

The associated costs of the inventory system per cycle for the supplier are as follows.

Sales revenue: SR = Selling price*Total demand

$$= s \times \int_0^T D(M,T)dt = s \times \int_0^T ae^{Nt}\left(1 + bt - ct^2\right)dt$$

$$= \frac{sa}{N}\left[e^{NT}\left(1 + bT - cT^2 - \frac{b}{N} + \frac{2cT}{N} - \frac{2c}{N^2}\right) + \frac{2c}{N^2} + \frac{b}{N} - 1\right] \quad (14)$$

Purchase cost (PC) = $C_0 e^{Nt} Q_2$ (15)

Ordering cost (OC) = $A_1 e^{Nt}$ (16)

Holding cost (HC) =

$$h\int_0^T I(t)dt = -a\left(\frac{h}{(N+k)^3}\right)\left[\begin{array}{l}(N+k)^2T + \frac{b}{2}(N+k)^2T^2 - \frac{c}{3}(N+k)^2T^3 + (N+k) - b - \frac{2c}{(N+k)} \\ +\left(c(N+k)T^2 - b(N+k)T - (N+k) + b - 2cT + \frac{2c}{(N+k)}\right)e^{(N+k)T}\end{array}\right] \quad (17)$$

The total profit of the seller per unit time is given by

$$\emptyset_2 = \left(\frac{I}{T}\right)[SR - PC - OC - HC]$$

$$= \frac{s_2 a}{NT}\left[e^{NT}\left(1+bT-cT^2-\frac{b}{N}+\frac{2cT}{N}-\frac{2c}{N^2}\right)+\frac{2c}{N^2}+\frac{b}{N}-1\right]$$

$$-\frac{A_1}{T}e^{Nt}-\frac{me^{Nt}Q_2}{T}+\frac{a}{T}\left(\frac{h}{(N+k)^3}\right)\left[\begin{array}{l}(N+k)^2T+\frac{b}{2}(N+k)^2T^2-\frac{c}{3}(N+k)^2T^3+(N+k)-b-\frac{2c}{(N+k)}\\+\left(c(N+k)T^2-b(N+k)T-(N+k)+b-2cT+\frac{2c}{(N+k)}\right)e^{(N+k)T}\end{array}\right] \tag{18}$$

Total Profit of the Integrated Supply Chain model for both vendor and retailer is

$$\emptyset = \emptyset_1 + \emptyset_2$$

$$= \frac{(s_1+s_2)a(1+M^{\beta+\gamma})}{NT}\left[e^{NT}\left(1+bT-cT^2-\frac{b}{N}+\frac{2cT}{N}-\frac{2c}{N^2}\right)+\frac{2c}{N^2}+\frac{b}{N}-1\right]$$

$$-\frac{me^{Nt}Q_1}{T}-\frac{C_0e^{Nt}Q_2}{T}-\frac{(A_0+A_1)}{T}e^{Nt}$$

$$+\frac{a}{T}\left(\frac{h}{(N+k)^3}\right)\left(1+M^{\beta}\right)\left[\begin{array}{l}(N+k)^2T+\frac{b}{2}(N+k)^2T^2-\frac{c}{3}(N+k)^2T^3+(N+k)-b-\frac{2c}{(N+k)}\\+\left(c(N+k)T^2-b(N+k)T-(N+k)+b-2cT+\frac{2c}{(N+k)}\right)e^{(N+k)T}\end{array}\right] \tag{19}$$

The necessary conditions to maximize the total profit of the inventory system and to find the optimal values of credit period and production period are

$$\frac{\partial\phi}{\partial M}=0 \text{ and } \frac{\partial\phi}{\partial T}=0 \tag{20}$$

For concavity of the profit function the following sufficient conditions should be satisfied.

$$\frac{\partial^2\phi}{\partial M^2}<0,\ \frac{\partial^2\phi}{\partial T^2}<0 \text{ and } \left(\frac{\partial^2\phi}{\partial M^2}\right)\left(\frac{\partial^2\phi}{\partial T^2}\right)-\left(\frac{\partial^2\phi}{\partial M\partial T}\right)>0 \tag{21}$$

By solving the pair of equations in equation (20), the optimal values of credit period M and cycle time T can be obtained.
The solutions are determined with the help of MATHEMATICA- 5.1 software and the concavity conditions are also checked.

Solution procedure

- **Step 1:** The parameters in inventory system are assigned with values.
- **Step2:** The simultaneous equations (20) are solved with MATHEMATICA 5.1.
- **Step 3:** The sufficiency conditions for concavity are tested.
- **Step 4:** The total profit of the inventory system is found out by equation (19).

4. Empirical Investigation

Numerical Example-1

Let a=50, □=5, b=0.35, c=0.2, □=4, m=Rs.12/unit, S_1=Rs.2/unit, S_2=Rs.2/unit, h=0.5, A_0=250, A_1=100, k=0.15, N=0.4, C_0=17/unit, Q_1=150 units, Q_2=120 units
Result: M=1.48813, T=5.59204, Total Profit=Rs.68375.7

Numerical Example-2

Let a=55, □=4, b=0.35, c=0.1, □=3, m=Rs.10/unit, S_1=Rs.3/unit,S_2=Rs.2/unit, h=0.6, A_0=300, A_1=150, k=0.15, N=0.5, Q_1=150 units, Q_2=120 units, C_0=18/unit
Result: M=1.79816, T=5.7141, Total Profit=Rs.32893.4

Numerical Example-3

Let a=60, □=4, b=0.35, c=0.1, □=4, m=Rs.13/unit, S_1=Rs.3/unit, S_2=Rs.3/unit, h=0.7, A_0=350, A_1=200, k=0.15, N=0.6, Q_1=150 units, Q_2=120 units, C_0=20/unit
Result: M=0.356839, T=4.56365, Total Profit=Rs.1013.35

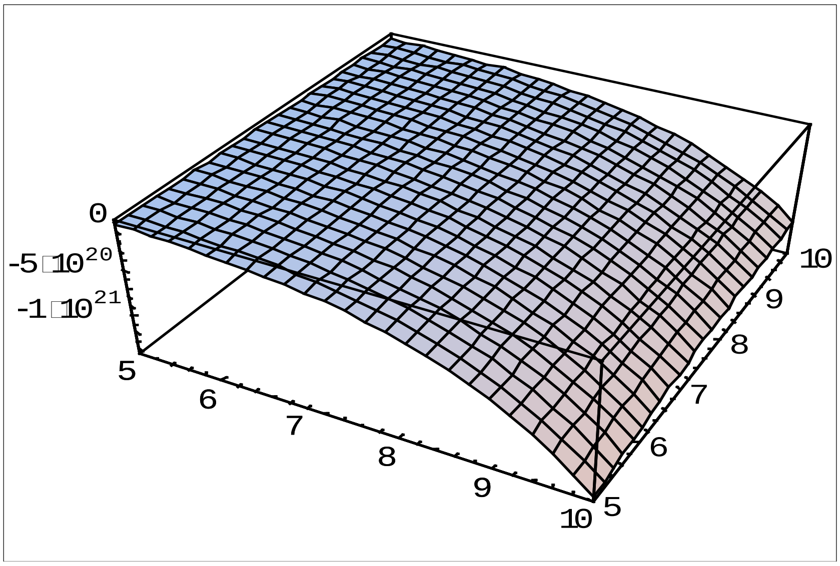

Fig 1: Concavity of total profit (TP) w.r.t. cycle time (T) and credit period(M) (Numerical Example-1**)**

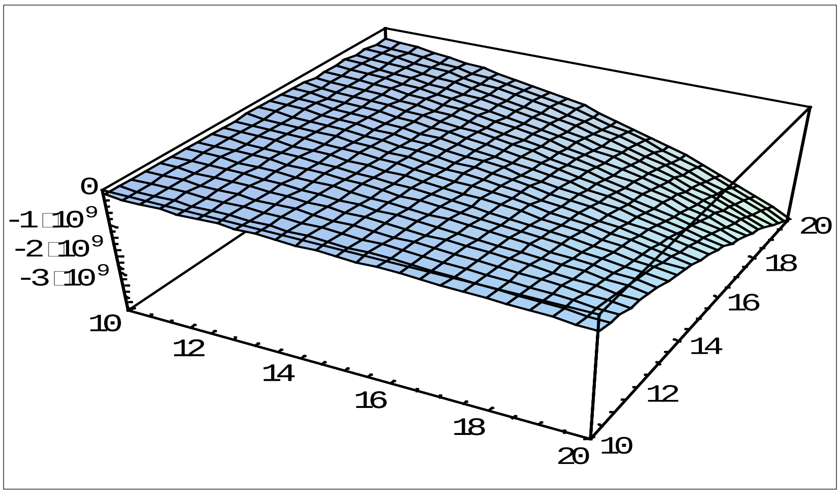

Fig 2: Concavity of total profit (TP) w.r.t. cycle time (T) and credit period(M) (Numerical Example-2)

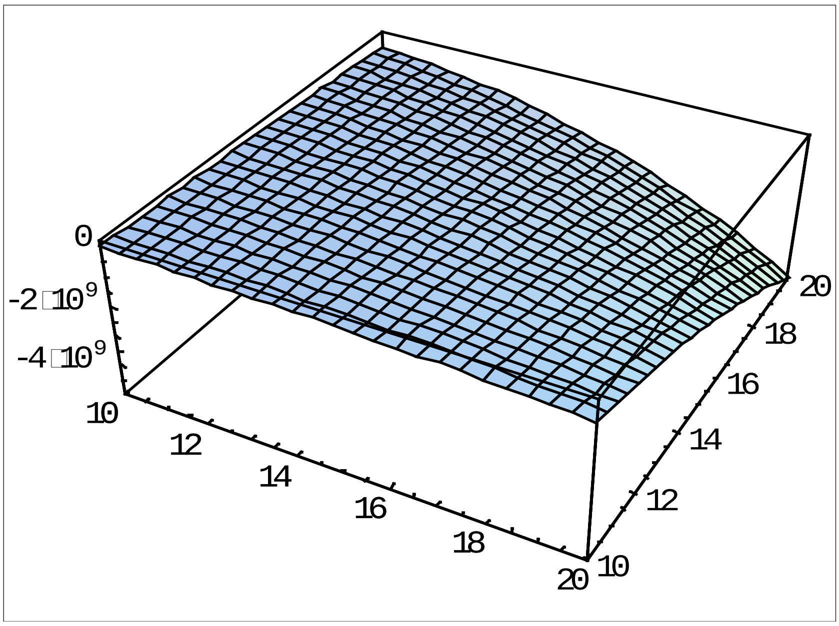

Fig 3: Concavity of total profit (TP) w.r.t. cycle time (T) and credit period(M) (Numerical Example-3)

Sensitivity Analysis

The effect of changes of parameters on the optimal solution are studied. Sensitivity Analysis is performed by changing the parameters by 25% and 50% and taking one parameter at a time, keeping the remaining parameters at their original value.

Table 1: Sensitivity Analysis of Numerical Example-1

Parameter	% Change	M	T	TP
a (50)	-40	1.55242	5.42348	49575
	-20	1.51708	5.51775	59675
	+20	1.46357	5.65321	16041
	+40	1.44222	5.7057	82905
b (0.35)	-40	0.560004	4.61665	3818
	-20	**	4.94452	**
	+20	**	5.00594	**
	+40	1.45661	5.59707	111035
β (5)	-40	0.01045	4.12819	7548
	-20	0.830063	4.93106	8826
	+20	1.74413	6.17934	212524
	+40	1.88511	6.77995	311520
k (0.15)	-40	0.890699	4.94198	20282
	-20	1.24828	5.34275	44817
	+20	**	4.93692	**
	+40	1.98153	6.06336	130926
c (0.10)	-40	**	6.17534	**
	-20	1.14785	5.60202	46308
	+20	1.69578	5.62356	56783
	+40	1.98827	5.72465	69777
m (12)	-40	1.48863	5.59273	68617
	-20	1.48838	5.59239	68496
	+20	1.48788	5.5917	68254
	+40	1.48763	5.59135	68133
s (4)	-40	1.48813	5.59204	50280
	-20	1.48813	5.59204	50280
	+20	1.48813	5.59204	50280
	+40	1.48813	5.59204	50280
h (0.5)	-40	1.93352	5.88833	116717
	-20	1.6736	5.72324	80233
	+20	1.33854	5.47247	45449
	+40	1.03567	5.16498	24545
N (0.4)	-40	1.724	5.91886	26964
	-20	**	4.97489	**
	+20	1.42337	5.50314	59025
	+40	1.37543	5.43805	39408

*Note: **indicates irrelevant results*

Observations

Based on the sensitivity analysis the following managerial insights are obtained.

1. The total profit (TP) is highly sensitive with respect to the parameter a, b, c, β and k. If the mentioned parameter values increases then the total profit increases rapily.
2. The total profit (TP) is moderately sensitive w.r.t the parameter m. It indicates the TP gradually decreases if the given parameter value change.
3. The TP remain static w.r.t the parameter s. it means that if the given parameter value is changed then it is hardly any effect in the TP of the inventory system.
4. The total profit (TP) is highly sensitive with respect to the parameter h and N. If the mentioned parameter values increase then the total profit decreases rapily.

5. Conclusion

A vendor-buyer integrated inventory model for deteriorating items subject to inflation induced demand has been developed in this paper. The cycle time and optimal credit period with consideration to default risk has been found out which maximizes the total profit of the system. In the real market world all the factors considered here are equally important to make decision on implementation of various marketing policies in the inventory system. Sensitivity analysis provides a thorough idea about the impact of several system parameters on the total profit of the system which can help to establish marketing strategies. It is advised to make less production period and allow more credit period for more demand to maximize the total profit. This model can also be extended by considering partial backlogging and shortage. Preservation technology can also be included to reduce deterioration.

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