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An Inflation Effect on Deteriorating Production Inventory Model with Price and Stock Dependent Demand

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ABSTRACT

This paper presents two production inventory models for deteriorating items with price and stock-dependent demand that take inflation into account. We formulated the corresponding problem as a nonlinearly constrained optimization problem and solved it using the Generalized Reduced Gradient Method. A set of numerical examples have been considered to illustrate the models, and the significant features of the results are discussed. On the basis of these examples, we have compared the two models. Sensitivity analyses have been conducted taking one parameter at a time while keeping the other parameters the same.

Keywords: Production Inventory; Inflation; deteriorating; price and stock-dependent demand

AMS Mathematics Subject Classification (2020): 90B05

1. Introduction

Production inventory models have been developed under the assumption that the life time of an item is infinite while it is in storage. But in real system, demand rate, price, inflation, deterioration rate is always in dynamic state. This assumption is not always true due to the effect of deterioration in the preservation of commonly used physical goods like wheat, paddy or any other type of food grains, vegetables, fruits, drugs, pharmaceuticals, etc. Due to highly completion in marketing policies and conditions such as the price variations and the advertisement of an item change its demand pattern amongst the public. The selling price of an item is one of the decisive factors in selecting an item for use. It is commonly observed that lower selling price causes increase in demand whereas higher selling price has the reverse effect. Ghare and Schrader [6] first developed an inventory model for exponentially decaying inventory. Mondal et al. [14] derived an inventory model for deteriorating items and stock-dependent consumption rate. Padmanabhan, et al. [17] worked on an EOQ models for perishable items under stock-dependent selling rate. Datta, et al. [4] assumed an inventory system with stock-dependent, price-sensitive demand rate. Sana et al. [20] proposed a production inventory model for a deteriorating item with trended demand and shortages and in the same year Sana developed a model on a volume flexible production policy for deteriorating item with stock-dependent demand rate. Teng, et al. [22] studied an Economic production quantity models for deteriorating items with price-and stock-dependent demand. Taleizadeh et al. [23] considered an economic order quantity model with partial backordering and a special sale price. Kawale, et al. [11] developed an EPQ model using Weibull deterioration for deterioration item with time varying holding cost. Hsieh et al[7] worked on a production-inventory model incorporating the effect of preservation technology investment when demand is fluctuating with time. Pal et al. [18] proposed an inventory model of price and stock dependent demand rate with deterioration under inflation and delay in payment. Bhunia et al. (2016) investigation of two-warehouse inventory problems in interval environment under inflation via particle swarm optimization. Hossen et al. [15] developed an Inventory Model with Price and Time Dependent Demand with Fuzzy Valued Inventory Costs Under Inflation. Mishra et al. [24] investigated an inventory model under price and stock dependent demand for controllable deterioration rate with shortages and preservation technology investment. Other important factors which have been widely accepted by the researchers to have crucial impact on the inventory policy decisions are inflation and time value of money. So inflation plays important role in the inventory system and decision making. At present, it is impossible to ignore the effects of inflation on the inventory system. Buzacott [1] developed the first EOQ model taking inflationary effects into account. Misra [13] investigated inventory systems under the effects of inflation. Bierman and Thomas [3] suggested the inventory decision policy under inflationary conditions. Hou KL [6] proposed an Inventory model for deteriorating items with stock- dependent consumption rate and shortage under inflation and time discounting. Kl et al. [8] developed an EOQ model for deteriorating items with price-and stock-dependent selling rates under inflation and time value of money. Lo St et al. [12] derived an integrated production- inventory model with imperfect production processes and Weibull distribution deterioration under inflation. Hossen [9] proposed an inventory model for deteriorating item price dependent demand under inflation. Wang et al. [25] offered inventory models with a joint dynamic pricing, advertising and production model with inventory level dependent goodwill. Mohammad Anwar Hossen [16] discussed the impact of inflation and advertisement dependent demand in an inventory system. In this work, presented two production inventory models for deteriorating items with price and stock dependent demand that take inflation into account. We formulated the corresponding problem as a nonlinear constrained optimization problem and solved it using the Generalized Reduced Gradient Method. A set of numerical examples have been considered to illustrate the models and the significant features of the results are discussed. On the basis of these examples, we have compared the two models. Sensitivity analyses have been conducted taking one parameter at a time, while keeping the other parameters the same.

2. Assumptions

The following assumptions and notations are used to develop the proposed model:

(i) Continuous and overtime production system is considered.

(ii) Inflation effect of the system.

(iii) The demand rate $D(p,q)$ is dependent on selling price (p) of an item and stock of goods. It is denoted by $D(p,q) = a - bp + cq(t),\ a,b,c > 0$

(iv) The deteriorated units ware neither repaired nor refunded.

(v) The inventory system involves only one item and one stocking point and the

inventory planning horizon is infinite.
(vi) Replenishments are instantaneous and lead time is constant.
(vii) Shortages are not allowed.

3. Notations

$q(t)$	Inventory level at time t	$D(p,q)$	Price and stock dependent demand
P_o	Continuous production rate per unit time	θ	Deterioration rate ($0<\theta<<1$)
R	Highest shortage level	t_1	Time at which the stock level reaches to maximum
C_o	Replenishment cost per order	p	Selling price per unit of item
C_p	Purchasing cost per unit	C_h	Holding cost per unit per unit time
$D(t)$	Time dependent demand	T	Time at which the stock level reaches to zero
r	Inflation rate	Z	The average cost of the system without inflation effect
Z_1	The average cost of the system with inflation effect		

4. Production inventory model without inflation effect

In this case, we have developed an EPQ model in which the production rate is partially constant and partially depends on inventory level as well as demand of an item. In this situation, we cannot consider any inflation effect of the production system.

The demand rate is dependent on the price and stock of goods, i.e.

$D(p,q)=a-bp+cq(t)$ where $a,b,c>0$. The production rate is

$P(t)=P_o+\{-\gamma q(t)+\delta D(q)\}$ where $P_o,\delta>0$ and $0\le\gamma\le 1$.

Here P_o is the continuous production rate and $\{-\gamma q(t)+\delta D(q)\}$ is the overtime production rate at time *t*.

In this manufacturing system, the production cycle starts at *t=0* and production continue up to $t = t_1$ when the stock level reaches to the maximum. There after production stops at $t = t_1$ and inventory level gradually depletes to zero at the end of the production cycle $t = T$ due to deterioration and customers demand.

Then the inventory system can be described by the following differential equations:

$$\frac{dq(t)}{dt} + \theta q(t) = P(t) - D\left(p, q\right), \qquad 0 \le t \le t_1 \tag{1}$$

$$\frac{dq(t)}{dt} + \theta q(t) = -D(p, q), \qquad t_1 \le t \le T \tag{2}$$

with the boundary conditions

$$q\left(t\right) = 0 \text{ at } t = 0 \text{ and } t = T. \tag{3}$$

Also $q\left(t\right)$ is continuous at $t = t_1$. From equation (1) We get

$$\frac{dq(t)}{dt} + \theta\, q(t) = P(t) - D(p, q)$$

$$\Rightarrow \frac{dq(t)}{dt} + \theta\, q(t) = P_\circ + \left\{-\gamma\, q(t) + \delta\, D(p, q)\right\} - D(p, q)$$

$$\Rightarrow \frac{dq(t)}{dt} + \left\{\theta + \gamma - \beta(\delta - 1)\right\} q(t) = P_\circ + (a - bp)(\delta - 1)$$

$$\frac{dq(t)}{dt} + \lambda\, q(t) = \mu \quad \text{where,} \quad \begin{aligned} &\lambda = \theta + \gamma - \beta(\delta - 1) \textit{ and} \\ &\mu = P_\circ + (a - bp)(\delta - 1) \end{aligned}$$

$$\Rightarrow \frac{d}{dt}\left\{e^{\lambda t} q(t)\right\} = \mu\, e^{\lambda t}$$

$\Rightarrow q(t) = \dfrac{\mu}{\lambda} + C\, e^{-\lambda t}$, Using the conditions (3), we get $C = -\dfrac{\mu}{\lambda}$

Then, the solutions of the differential equations (1) are given by

$$q(t) = \mu(1 - e^{-\lambda t}) / \lambda, \qquad 0 \le t \le t_1 \tag{4}$$

And from equation (2) we get

$$\frac{dq(t)}{dt} + \theta\, q(t) = -D(p,q)$$

$$\Rightarrow \frac{dq(t)}{dt} + \theta\, q(t) = -(a-bp) - \beta\, q(t)$$

$$\Rightarrow \frac{dq(t)}{dt} + (\theta+\beta)\, q(t) = -\alpha \text{ Where } \alpha = (a-bp)$$

$$\Rightarrow \frac{d}{dt}\left\{e^{(\theta+\beta)} q(t)\right\} = -\alpha\, e^{(\theta+\beta)t}$$

$$\Rightarrow q(t) = -\frac{\alpha}{(\theta+\beta)} + C_1\, e^{-(\theta+\beta)t} \quad \Rightarrow C_1 = \frac{\alpha}{(\theta+\beta)} e^{(\theta+\beta)T}$$

$$q(t) = \alpha\left\{e^{(\theta+\beta)(T-t)} - 1\right\}/(\theta+\beta) \qquad t_1 \le t \le T \tag{5}$$

Using continuity condition we have

$$\mu(1-e^{-\lambda t_1})/\lambda = \alpha\left\{e^{(\theta+\beta)(T-t_1)} - 1\right\}/(\theta+\beta) \tag{6}$$

Now the total inventory holding cost for the entire cycle is given by

$$C_{hol} = C_h\left\{\int_0^{t_1} q(t)\,dt + \int_{t_1}^{T} q(t)dt\right\} \tag{7}$$

$$= C_h\left\{\int_0^{t_1} \frac{\mu}{\lambda}(1-e^{\lambda t})dt + \int_{t_1}^{T} \frac{\alpha}{(\theta+\beta)}\left(e^{(\theta+\beta)(T-t)} - 1\right)\right\}$$

$$= C_h\left\{\frac{\mu}{\lambda^2}(\lambda t_1 - e^{\lambda t_1} + 1) - \frac{\alpha\, e^{(\theta+\beta)T}}{(\theta+\beta)^2}\left(e^{-(\theta+\beta)T} - e^{-(\theta+\beta)t_1}\right) - \frac{\alpha}{\theta+\beta}(T-t_1)\right\}$$

Production cost of the system is given by

$$PC = C_p P_o t_1 + C_o \int_0^{t_1} \left\{-\gamma q(t) + \delta D(p,q)\right\} dt \tag{8}$$

$$= C_p P_\circ t_1 + C_\circ \int_0^{t_1} \left\{ -\gamma \cdot \frac{\mu}{\lambda}(1-e^{\lambda t}) + \delta(a - bp + \beta q(t)) \right\} dt$$

$$= C_p P_\circ t_1 + C_\circ \int_0^{t_1} \{\delta(a-bp) + \frac{\mu}{\lambda}(\beta\delta - \gamma)\} dt + C_\circ \frac{\mu}{\lambda}(\gamma - \delta\beta) \int_0^{t_1} e^{\lambda t} dt$$

$$= C_p P_\circ t_1 + C_\circ t_1 \left\{ \delta(a-bp) + \frac{\mu}{\lambda}(\beta\delta - \gamma) \right\} + C_\circ \frac{\mu}{\lambda^2}(\gamma - \beta\delta)(e^{\lambda t_1} - 1)$$

Total amount of item deteriorated during time period $[0, T]$ is given by

$$CD = C_p \left[\int_0^{t_1} \theta q(t) dt + \int_{t_1}^{T} \theta q(t) dt \right] \tag{9}$$

$$= C_p \left\{ \int_0^{t_1} \frac{\theta\mu}{\lambda}(1-e^{\lambda t}) dt + \int_{t_1}^{T} \frac{\theta\alpha}{(\theta+\beta)} \left(e^{(\theta+\beta)(T-t)} - 1 \right) \right\}$$

$$= C_p \left\{ \frac{\theta\mu}{\lambda^2}(\lambda t_1 - e^{\lambda t_1} + 1) - \frac{\alpha\, \theta e^{(\theta+\beta)T}}{(\theta+\beta)^2} \left(e^{-(\theta+\beta)T} - e^{-(\theta+\beta)t_1} \right) - \frac{\theta\alpha}{\theta+\beta}(T - t_1) \right\}$$

Hence, in this case, the average cost $Z(t_1, T)$ is given by

$$Z(t_1, T) = \frac{X}{T} \tag{10}$$

where X= <*setup cost*> + <*production cost*> + <*inventory holding cost*>

+ <*deterioration cost*> $= C_4 + C_{hol} + PC + CD$

5. Production inventory model with inflation effect

In this section, we have discussed an EPQ model in which the production rate is partially constant and partially depends on inventory level as well as demand of an item. In this situation, we have been considered an inflation effect of the production system.

The demand rate dependent of price and stock of goods i.e., $D(p,q) = a - bp + \beta q(t)$ where $a, b, \beta > 0$.

The production rate is $P(t) = P_\circ + \{-\gamma q(t) + \delta\, D(p,q)\}$ where $P_o, \delta > 0$ and $0 \le \gamma \le 1$.

Here P_o is the continuous production rate and $\{-\gamma q(t)+\delta D(q)\}$ is the overtime production rate at time *t*.

In this manufacturing system, the production cycle starts at *t=0* and production continue up to $t=t_1$ when the stock level reaches to the maximum. There after production stops at $t=t_1$ and inventory level gradually depletes to zero at the end of the production cycle $t=T$ due to deterioration and customers demand. Pictorial representation of the inventory system is shown in **Fig-1:**

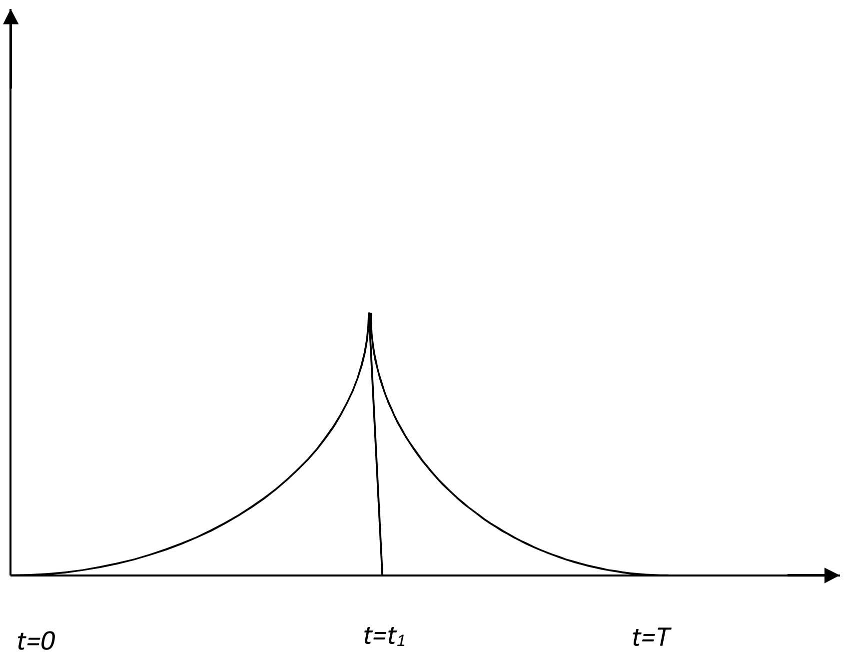

Fig-1: Pictorial representation of a production inventory model

Then the inventory system can be described by the following differential equations:

$$\frac{dq(t)}{dt}+\theta q(t)=P(t)-D\left(p,q\right), \quad 0\le t\le t_1 \tag{11}$$

$$\frac{dq(t)}{dt}+\theta q(t)=-D(p,q), \quad t_1\le t\le T \tag{12}$$

with the boundary conditions $q(t)=0$ at $t=0$ and $t=T$. (13)

Also $q(t)$ is continuous at $t=t_1$.

From equation (11) we get $\dfrac{dq(t)}{dt}+\theta\, q(t)=P(t)-D(p,q)$

$$\Rightarrow \frac{dq(t)}{dt}+\theta\, q(t)=P_{\circ}+\{-\gamma q(t)+\delta D(p,q)\}-D(p,q)$$

$$\Rightarrow \frac{dq(t)}{dt}+\{\theta+\gamma-\beta(\delta-1)\}q(t)=P_{\circ}+(a-bp)(\delta-1)$$

$$\Rightarrow \frac{dq(t)}{dt}+\lambda\, q(t)=\mu \quad \text{Where,} \quad \begin{array}{l}\lambda=\theta+\gamma-\beta(\delta-1)\ and\\ \mu=P_{\circ}+(a-bp)(\delta-1)\end{array}$$

$$\Rightarrow \frac{d}{dt}\{e^{\lambda t}q(t)\}=\mu\, e^{\lambda t}$$

$\Rightarrow q(t)=\dfrac{\mu}{\lambda}+C\, e^{-\lambda t}$, Using the conditions (13), we get $C=-\dfrac{\mu}{\lambda}$

Then, the solutions of the differential equations (11) is given by

$$q(t)=\mu(1-e^{\lambda t})/\lambda, \qquad 0\le t\le t_1 \tag{14}$$

And from equation (12) we get

$$\frac{dq(t)}{dt}+\theta\, q(t)=-D(p,q)$$

$$\Rightarrow \frac{dq(t)}{dt}+\theta\, q(t)=-(a-bp)-\beta\, q(t)$$

$$\Rightarrow \frac{dq(t)}{dt}+(\theta+\beta)\, q(t)=-\alpha \quad \text{Where } \alpha=(a-bp)$$

$$\Rightarrow \frac{d}{dt}\{e^{(\theta+\beta)}q(t)\}=-\alpha\, e^{(\theta+\beta)t}$$

$$\Rightarrow q(t)=-\frac{\alpha}{(\theta+\beta)}+C_1\, e^{-(\theta+\beta)t} \Rightarrow C_1=\frac{\alpha}{(\theta+\beta)}e^{(\theta+\beta)T}$$

$$q(t)=\alpha\left\{e^{(\theta+\beta)(T-t)}-1\right\}/(\theta+\beta) \qquad t_1\le t\le T \tag{15}$$

Using continuity condition we have

$$\mu(1-e^{-\lambda t_1})/\lambda=\alpha\left\{e^{(\theta+\beta)(T-t_1)}-1\right\}/(\theta+\beta) \tag{16}$$

Now the total inventory holding cost for the entire cycle is given by

$$C_{hol}=C_h\left\{\int_0^{t_1}e^{-rt}q(t)\,dt+\int_{t_1}^{T}e^{-rt}q(t)dt\right\} \tag{17}$$

$$=C_h\left\{\int_0^{t_1}\frac{\mu}{\lambda}e^{-rt}(1-e^{\lambda t})dt+\int_{t_1}^{T}\frac{\alpha}{(\theta+\beta)}e^{-rt}\left(e^{(\theta+\beta)(T-t)}-1\right)\right\}$$

$$=C_h\left\{\begin{array}{l}\frac{\mu}{\lambda}(e^{-rt_1}-1)-\frac{\mu}{\lambda(\lambda-r)}\left(e^{(\lambda-r)t_1}-1\right)-\frac{\alpha e^{(\theta+\beta)T}}{(\theta+\beta)(r+\theta+\beta)}(e^{-(r+\theta+\beta)T}-e^{-(r+\theta+\beta)t_1})+\\ \frac{\alpha}{r(\theta+\beta)}(e^{-rT}-e^{-rt_1})\end{array}\right\}$$

Production cost of the system is given by

$$PC=C_pP_o t_1e^{-rt_1}+C_o\int_0^{t_1}e^{-rt}\left\{-\gamma q(t)+\delta D(p,q)\right\}dt \tag{18}$$

$$=C_pP_\circ t_1e^{-rt_1}+C_\circ\int_0^{t_1}e^{-rt}\left\{-\gamma\cdot\frac{\mu}{\lambda}(1-e^{\lambda t)})+\delta(a-bp+\beta q(t))\right\}dt$$

$$=C_pP_\circ t_1e^{-rt_1}+\frac{C\circ}{r}\left\{\delta(a-bp)+\frac{\mu}{\lambda}(\beta\delta-\gamma)\right\}(e^{-rt_1}-1)+\frac{C\circ}{(\lambda-r)}\frac{\mu}{\lambda}(\gamma-\beta\delta)(e^{(\lambda-r)t_1}-1)$$

Total amount of item deteriorated during time period $[0,T]$ is given by

$$CD=C_p\left[\int_0^{t_1}e^{-rt}\theta q(t)dt+\int_{t_1}^{T}e^{-rt}\theta q(t)dt\right] \tag{19}$$

$$=C_p\left\{\int_0^{t_1}\frac{\theta\mu}{\lambda}e^{-rt}(1-e^{\lambda t})dt+\int_{t_1}^{T}\frac{\theta\alpha}{(\theta+\beta)}e^{-rt}\left(e^{(\theta+\beta)(T-t)}-1\right)\right\}$$

$$=C_p\begin{cases}\dfrac{\theta\mu}{\lambda r}(1-e^{-rt_1})-\dfrac{\theta\mu}{\lambda(\lambda-r)}(e^{(\lambda-r)t_1}-1)+\dfrac{\theta\alpha e^{(\theta+\beta)T}}{(\theta+\beta)(r+\theta+\beta)}\left(e^{-(\theta+r+\beta)t_1}-e^{-(\theta+r+\beta)T}\right)+\\ \dfrac{\alpha\theta}{(\theta+\beta)r}\left(e^{-rT}-e^{-rt_1}\right)\end{cases}$$

Hence, in this case, the average cost $Z_1\left(t_1,T\right)$ is given by

$$Z_1\left(t_1,T\right)=\frac{X}{T} \tag{20}$$

where X= *<setup cost>* + *<production cost>* + *<inventory holding cost>* + *<deterioration cost>* $=C_4e^{-rT}+C_{hol}+PC+CD$

6. Numerical example

To illustrate the above models, a set of numerical examples with the following data has been considered. The values of parameters of different examples have been shown in **Table 1**.

Table 1: Values of parameters of different examples

Parameters	Example-1	Example-2	Example-3	Example-4
C_4	\$100	\$200.00	\$250.00	\$350.00
C_h	\$.25	\$1.50	\$1.50	\$1.25
C_p	\$2.00	\$3.00	\$5.00	\$4.5
C_o	\$2.50	\$3.5	\$7.00	\$7.00
p	\$4.00	\$6.00	\$10.00	\$10.5
θ	\$0.10	\$0.15	\$0.10	\$0.12
a	45.00	50.00	55.00	60.00
b	0.50	0.40	0.60	0.7
γ	0.03	0.03	0.03	0.03
β	0.25	0.25	0.25	0.25
r	0.05	0.05	0.05	0.05
δ	0.30	0.30	0.30	0.30

P_o	\$75	\$80	\$85	\$90

According to the solution procedure, the optimal solution has been obtained with the help of LINGO software. The optimum values of t_1 and T, along with maximum average cost are displayed in **Table 2**.

Table 2: Optimal solution of the inventory model

EPQ model without inflation effect				***EPQ model with inflation effect***			***Additional cost due to inflation effect***
Example	t_1	T	Z	t_1	T	Z_1	Z_1-Z
1	1.1661	2.0147	99.135	1.1021	1.9427	191.888	92.753
2	1.1921	1.9999	204.169	1.1455	1.9311	355.241	151.072
3	1.0262	1.7876	283.448	0.9532	1.6751	557.964	274.516
4	1.3000	2.2016	324.009	1.2344	2.1045	590.773	266.764

7. Sensitivity analysis

For the given example-1 mentioned earlier, sensitivity analysis has been performed to study the effect of changes (under or over estimation) of different parameters like demand, deterioration and inventory cost parameters. This analysis has been carried out by changing (increasing and decreasing) the parameters from – 20% to + 20%, taken one or more parameters at a time making the other parameters at their more parameters at a time and making the other parameters at their original values. The results of this analysis are shown in **Table 3**.

Table 3: Sensitivity analysis with respect to different parameters of EPQ model with inflation effect

Parameter	% changes of parameters	% changes in Z^*	% changes in	
			t_1^*	T^*
	– 20	-0.53	1.18	.02

C_h	– 10	-0.26	0.58	0.51
	10	0.26	-0.58	-0.51
	20	0.52	-1.14	-1.01
P_o	– 20	-8.09	48.61	4.44
	– 10	-3.53	18.95	9.30
	10	2.84	-13.39	-6.38
	20	5.18	-23.45	-11.05
C_p	– 20	-12.84	12.59	0.97
	– 10	-6.36	5.77	5.07
	10	6.25	-4.97	-4.41
	20	12.41	-9.31	-8.29
C_4	– 20	-5.20	-12.98	11.61
	– 10	-2.51	-6.41	-5.69
	10	2.36	6.26	5.50
	20	4.60	12.43	10.84
a	– 20	-10.23	-17.82	2.11
	– 10	-4.86	-9.29	-1.54
	10	4.39	10.40	2.60
	20	8.32	22.21	6.43
b	– 20	0.41	0.87	.19
	– 10	0.21	0.43	0.09
	10	-0.21	-0.44	-0.09
	20	-0.41	-0.87	-0.50
r	– 20	1.22	-2.37	2.10
	– 10	0.61	-1.21	-1.07

	10	-0.61	1.25	1.10
	20	-1.23	2.55	2.25
	– 20	0.39	0.87	.19
	– 10	0.21	0.43	0.09
p	10	-0.21	-0.44	-0.09
	20	-0.41	-0.87	-0.18

8. Concluding remarks

Two deterministic inventory models are presented here for deteriorating items with variable demand inflation effects. We formulated the corresponding problem as a nonlinear constrained optimization problem and solved it using the Generalized Reduced Gradient Method. A set of numerical examples have been considered to illustrate the models and the significant features of the results are discussed. On the basis of these examples, we have compared the two models. Sensitivity analyses have been conducted taking one parameter at a time, while keeping the other parameters the same. In this study, we compared the results of an inventory system with and without an inflation effect. The cost of inventory management is rising rapidly due to inflation. The proposed models are also applicable to problems where the selling prices of items as well as the advertisement of items affect demand. This policy is applicable to fashionable goods, two-level and single-level credit policy approaches.

For further research, one can extend the proposed models in several ways. In addition, these models can be extended for other types of variable demand based on displayed stock levels, time and other factors. On the other hand, these can also be generalized by considering two-level credit policies. These models can be used in fuzzy and interval environments as well.

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