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DECISION SUPPORT MODEL FOR PERISHABLE ITEMS IMPACTING RAMP TYPE DEMAND IN A DISCOUNTED RETAIL SUPPLY CHAIN ENVIRONMENT

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Abstract: A single item EOQ model has been developed considering demand as a two parameter ramp type function and deterioration as a Heaviside's function. Both pre and post deterioration discounts are considered where the former helps in maintaining constancy in the demand rate and the latter one boosts the demand of decreased quality items. The starting time periods of pre and post deterioration discount have been determined. The effect of both types of discounts in optimising the profit is examined through numerical illustrations. Sensitivity analysis is also appended to find out the effect of various system parameters. From this study it is observed that it will be more advantageous for management to offer pre deterioration discount in enticing the profit.

Keywords: EOQ Model, Ramp Type Demand, Heaviside's Function, Discounted Selling Price.

MSC: 90B05.

1. INTRODUCTION

Most of the inventory models are explored by considering the demand rate as constant, linearly increasing/decreasing or exponentially increasing/decreasing. But demand of all types of products may not follow these particular patterns over time. Demand for some products increases rapidly as they are introduced in the market, but after certain period of time it becomes constant. The ramp type function is used to represent such type of demand function. The following table gives a glance at research works undertaking different patterns of demand and deterioration.

Table 1: Contribution of authors

Author(s) & Year of Publication	Demand	Deterioration	Price Discount	Pre Deterioration Discount	Post Deterioration Discount	Both Pre & Post Deterioration Discount
Shah et al. [13]	Time dependent	Constant	No	–	–	–
Chatterji & Gothi[3]	Time dependent	Weibull	No	–	–	–
Mishra et al.[7]	Quadratic	Weibull	No	–	–	–
Shah et al. [14]	Quadratic	No	No	–	–	–
Tripathy & Pradhan[17]	Weibull	Time dependent	No	–	–	–
Sujatha & Parvati[16]	Weibull	Time dependent	No	–	–	–
Karmakar& Dutta Chaudhri[6]	Ramp	Constant	No	–	–	–
Aggrawal & Singh[1]	Ramp	Time dependent	No	–	–	–
Skouri et al.[15]	Ramp	Time dependent	No	–	–	–
Arya & Kumar[2]	Ramp	Weibull	No	–	–	–
Giri et al. [4]	Ramp	Weibull	No	–	–	–
Jain & Kumar [5]	Ramp	Weibull	No	–	–	–
Tripathy & Pradhan[19]	Ramp	Weibull	No	–	–	–
Panda et al.[8]	Ramp	Weibull	No	–	–	–
Panda et al. [9]	Ramp	Heaviside's function	No	–	–	–
Panda et al. [10]	Stock dependent	Heaviside's function	No	–	–	–
Sarkar et al. [12]	Constant& Time dependent	No	Yes	No	No	No
Tripathy & Pradhan[18]	Price dependent	No	Yes	No	No	No
Panda et al. [11]	Stock dependent	Heaviside's function	Yes	Yes	Yes	Yes
Present paper	Ramp	Heaviside's function	Yes	Yes	Yes	Yes

The current study focuses on a certain kind of demand pattern which accelerates exponentially as the products are launched in the market, stabilizes with the passage of time, and ultimately declines and becomes asymptotic. Two parameter ramp type function is used to corroborate such type of demand pattern. The inventory deteriorates following a Heaviside's function. Both pre and post deterioration discount are provided, where the former assists in maintaining the constancy in the demand and the latter enhances the demand of decreased quality items. The efficacy of the optimal result is attained by comparing the results obtained in three different scenarios. The sensitivity analysis is conducted to discern the effect of various system parameters in optimising the profit. The concavity of the total profit is also tested graphically.

2. NOTATIONS AND ASSUMPTIONS

2.1. Notations

1. C_0: Set up cost.
2. S: Constant selling price of the product per unit.
3. r_1: Pre deterioration discount per unit.
4. r_2: Post deterioration discount per unit.
5. h: Holding cost per unit per unit time.
6. d: Disposal cost per unit.
7. c: Purchase cost of the product per unit.
8. T_1: The total cycle time.
9. μ : The time period at which the pre deterioration discount is provided.
10. γ: The time period at which the deterioration starts.
11. π: Total profit of the system per unit time.
12. $I(t)$: The inventory level at time t.
13. $I(0) = Q_1$: The initial inventory level is Q_1.

2.2. Assumptions

1. Replenishment rate is infinite.
2. The deterioration rate is assumed as a Heaviside's function.

$$\bar{\theta} = \theta H(t - \gamma).$$

Where t is the time measured from the instant arrivals of a fresh replenishment indicating that the deterioration of the items begins after a time γ from the instant of the arrival in stock. θ is a constant $(0 < \theta < 1)$ and $H(t - \gamma)$ is the well known Heaviside's function defined as

$$H(t-\gamma) = \begin{cases} 1, & \text{if } t \geq \gamma \\ 0, & \text{otherwise.} \end{cases}$$

3. Demand rate is a two parameter ramp type function defined as

$$D(t) = ae^{b\{t-(t-\mu)H(t-\mu)-(t-\gamma)H(t-\gamma)\}}, 0 < \mu < \gamma, a > 0, b > 0,$$

where

$$H(t-\mu) = \begin{cases} 1, & t \geq \mu \\ 0, & t < \mu \end{cases}$$

and

$$H(t-\gamma) = \begin{cases} 1, & t \geq \gamma \\ 0, & t < \gamma. \end{cases}$$

So

$$D(t) = \begin{cases} ae^{bt}, & 0 \leq t < \mu \\ ae^{b\mu}, & \mu \leq t < \gamma \\ ae^{b(\mu+\gamma)}e^{-bt}, & t \geq \gamma. \end{cases}$$

4. $r_1(0 \leq r_1 \leq 1)$ is the percentage pre deterioration discount offer on unit selling price. $\alpha_1 = (1-r_1)^{-n_1}, n_1 \in \mathbb{R}$ is the effect of pre deterioration discount on demand. $r_2(0 \leq r_2 \leq 1)$ is the percentage post deterioration discount offer on unit selling price. $\alpha_2 = (1-r_2)^{-n_2}, n_2 \in \mathbb{R}$ is the effect of post deterioration discount on demand.

3. MATHEMATICAL MODEL AND ANALYSIS

Let Q_1 be the inventory level at the beginning of the cycle. The depletion in the inventory occurs due to demand up to time γ. After time γ, the inventory declines due to demand and deterioration. Ultimately, inventory reaches zero level at time T_1. Before the starting of deterioration i.e., from μ to γ, $r_1\%$ discount on unit selling price of the product is imposed in order to maintain constancy in the demand rate. After starting of deterioration, $r_2\%$ discount on unit selling price is provided to enhance the demand of decreased quality items. This discount is continued for the rest of the replenishment cycle.Then the behavior of the inventory level is governed by the following differential equations

$$\frac{dI(t)}{dt} = -ae^{bt}, \quad 0 \leq t \leq \mu. \tag{1}$$

$$\frac{dI(t)}{dt} = -\alpha_1 ae^{b\mu}, \quad \mu \leq t \leq \gamma. \tag{2}$$

$$\frac{dI(t)}{dt} + \bar{\theta}I(t) = -\alpha_2 ae^{b(\mu+\gamma)}e^{bt}, \quad t \geq \gamma \tag{3}$$

with the initial boundary conditions $I(0) = Q_1$ and $I(T_1) = 0$. For the condition $I(0) = Q_1$, the solution of equation (1) yields

$$I_1(t) = \frac{a}{b}(1 - e^{bt}) + Q_1.$$

At the point $t = \mu$, the inventory level is

$$I_1(\mu) = \frac{a}{b}(1 - e^{b\mu}) + Q_1.$$

With the condition $I_1(\mu) = I_2(\mu)$, solution of equation (2) yields

$$I_2(t) = \alpha_1 a e^{b\mu}(\mu - t) + I_1(\mu).$$

At the point $t = \gamma$, the inventory level is

$$I_2(\gamma) = \alpha_1 a e^{b\mu}(\mu - \gamma) + I_1(\mu). \tag{4}$$

With condition $I_2(\gamma) = I_3(\gamma)$, the solution of equation (3) yields

$$I_3(t) = -\alpha_2 a e^{b(\mu+\gamma)} \frac{e^{-bt}}{(\theta - b)} + I_2(\gamma) + \alpha_2 a \frac{e^{b\mu}}{(\theta - b)} e^{\theta(\gamma - t)}.$$

The boundary condition $I_3(T_1) = 0$ yields

$$I_2(\gamma) = \frac{\alpha_2 a}{(\theta - b)} e^{b\mu} e^{(b-\theta)(\gamma - T_1) - 1}. \tag{5}$$

Equations (4) and (5) generate,

$$I_1(\mu) = I_2(\gamma) - \alpha_1 a e^{b\mu}(\mu - \gamma). \tag{6}$$

So, equation (6) yields

$$Q_1 = I_1(\mu) - \frac{a}{b}(1 - e^{b\mu}).$$

Holding cost and disposal cost of inventories in the cycle is

$$HC + DC = h \int_0^{\mu} I_1(t)dt + h \int_{\mu}^{\gamma} I_2(t)dt + (h + \theta d) \int_{\gamma}^{T_1} I_3(t)dt.$$

Purchase cost of the cycle is given by

$$PC = cQ_1.$$

Total sales revenue in the order cycle is

$$SR = S \int_0^{\mu} D_1(t) + S\alpha_1(1 - r_1) \int_{\mu}^{\gamma} D_2(t)dt + S\alpha_2(1 - r_2) \int_{\gamma}^{T_1} D_3(t)dt.$$

The total profit per unit time of the system is

$$\pi = \frac{1}{T_1}[SR - PC - HC - DC - C_0]. \tag{7}$$

The pre deterioration discount on selling price is to be given in such a way that the discounted selling price is not less than the unit cost of the product i.e., $S(1 - r_1) - c > 0$. Similarly, $S(1 - r_2) - c > 0$. Applying these constraints on the unit total profit function, we have the following maximization problem

$$\begin{aligned} &\text{Maximize} \;\; \pi(\mu, \gamma) \\ &\text{Subject to} \;\; r_1, r_2 < 1 - \frac{c}{S}; \\ &r_1, r_2, \mu, \gamma \geq 0. \end{aligned} \tag{8}$$

The optimum values of μ and γ, which minimize the unit profit, can be obtained by solving the equations

$$\frac{\delta\pi}{\delta\mu} = 0 \; and \; \frac{\delta\pi}{\delta\gamma} = 0. \tag{9}$$

The values satisfy the sufficient conditions

$$\begin{aligned} &\frac{\delta^2\pi}{\delta\mu^2} < 0, \;\; \frac{\delta^2\pi}{\delta\gamma^2} < 0 \\ \text{and} \;\; &\frac{\delta^2\pi}{\delta\mu^2}\frac{\delta^2\pi}{\delta\gamma^2} - \frac{\delta^2\pi}{\delta\mu\delta\gamma} < 0. \end{aligned} \tag{10}$$

3.1. Model for Pre Deterioration Discount

In this case the discount is provided before starting of deterioration. So, there is no post deterioration discount and hence $r_2 = 0$. Thus, the total profit per unit time of the system is

$$\pi = \frac{1}{T_1}[SR - PC - HC - DC - C_0]. \tag{11}$$

The maximization problem in this case is

$$\begin{aligned} &\text{Maximize} \;\; \pi(\mu, \gamma) \\ &\text{Subject to} \;\; r_1 < 1 - \frac{c}{S}; \\ &r_1, \mu, \gamma \geq 0. \end{aligned} \tag{12}$$

The optimum values of μ and γ are obtained by using equation (9). These values satisfy the conditions in equation (10).

3.2. Model for Post Deterioration Discount

In this case the discount is provided only after starting of deterioration. So, there is no pre deterioration discount and hence $r_1 = 0$. Thus, the total profit per unit time of the system is

$$\pi = \frac{1}{T_1}[SR - PC - HC - DC - C_0]. \quad (13)$$

The maximization problem in this case is

$$\begin{aligned} &\text{Maximize } \ \pi(\mu, \gamma) \\ &\text{Subject to } \ r_2 < 1 - \frac{c}{S}; \\ &r_2, \mu, \gamma \geq 0. \end{aligned} \quad (14)$$

The optimum values of μ and γ are obtained by using equation (9). These values satisfy the conditions in the equation (10).

4. NUMERICAL EXAMPLES AND SENSITIVITY ANALYSIS

Example 1.

The values of the system parameters are

$a = 90, b = 0.35, h = 0.3, d = 3, S = 15, C_0 = 80, c = 5, \theta = 0.06, n_1 = n_2 = 2, r_1 = 0.15, r_2 = 0.35, \alpha_1 = 1.18, \alpha_2 = 2.37, T_1 = 3.$

Scenario-I: Both type of discounts

$\mu = 1.45533, \gamma = 1.64047, \pi = 1271.39$ and $Q = 813.936$.

Scenario-II: Only pre deterioration discount

$\mu = 1.57963, \gamma = 2.15897, \pi = 1497.42$ and $Q = 709.205$.

Scenario-III: Only post deterioration discount

$\mu = 1.52388, \gamma = 1.65557, \pi = 1299.6$ and $Q = 820.783$

The following figures represent the concavity of total profit per unit time with respect to the pre and post deterioration discount starting time.

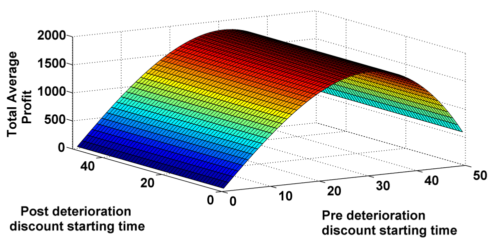

Figure 1: Concavity of total profit per unit time in Scenario-I

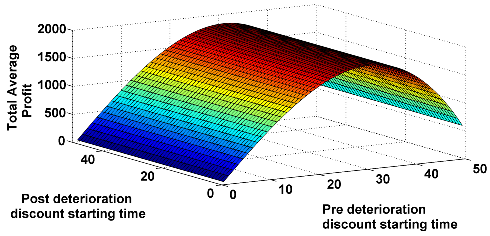

Figure 2: Concavity of total profit per unit time in Scenario-II

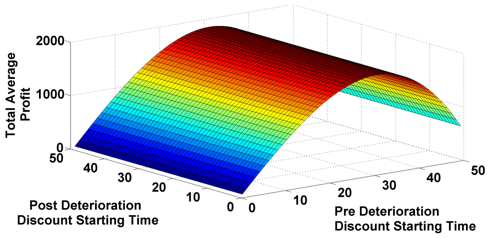

Figure 3: Concavity of total profit per unit time in Scenario-III

Table 2: Sensitivity Analysis for scenario-I

Parameter	% change	μ	γ	π	Q
a	-60 %	1.45385	1.63737	492.419	325.189
	-40 %	1.45467	1.63909	752.074	488.104
	-20 %	1.45509	1.63995	1011.73	651.021
	+20 %	1.45550	1.64082	1531.05	976.855
	+40 %	1.45562	1.64107	1790.71	1139.77
	+60 %	1.45571	1.64125	2050.36	1302.69
h	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	1.56145	1.64359	1344.09	833.572
	+20 %	1.34516	1.64643	1198.68	791.534
	+40 %	–	–	–	–
	+60 %	–	–	–	–
θ	-60 %	1.48213	1.64554	1288.06	818.48
	-40 %	1.47323	1.64376	1282.50	816.98
	-20 %	1.46430	1.64207	1276.95	815.466
	+20 %	1.44632	1.63757	1265.83	812.393
	+40 %	1.43727	1.63757	1260.27	810.834
	+60 %	1.42818	1.63626	1254.72	809.259
b	-60 %	0.483791	0.605963	659.19	463.334
	-40 %	–	–	–	–
	-20 %	1.34171	1.40841	1065.88	699.191
	+20 %	1.52599	1.81826	1494.82	943.113
	+40 %	1.57761	1.96270	1741.41	1077.26
	+60 %	1.62022	2.08580	2015.52	1231.05
d	-60 %	1.47978	1.64650	1282.98	819.957
	-40 %	1.47164	1.64445	1279.13	817.965
	-20 %	1.46349	1.64245	1275.27	815.960
	+20 %	1.44717	1.63853	1267.50	811.900
	+40 %	1.43900	1.63663	1263.60	809.849
	+60 %	1.43083	1.63477	1259.69	807.786
S	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	–	–	–	–
	+20 %	1.71479	1.84181	2222.22	896.801
	+40 %	1.87130	2.05085	3255.55	951.753
	+60 %	1.98213	2.23922	4338.57	990.792
g	-60 %	1.45533	1.64047	1286.81	813.936
	-40 %	1.45533	1.64047	1286.81	813.936
	-20 %	1.45533	1.64047	1286.81	813.936
	+20 %	1.45533	1.64047	1286.81	813.936
	+40 %	1.45533	1.64047	1286.81	813.936
	+60 %	1.45533	1.64047	1286.81	813.936
c	-60 %	2.03732	2.51251	3362.73	1033.07
	-40 %	1.85168	2.14750	2574.73	966.928
	-20 %	1.66749	1.85430	1877.13	893.314
	+20 %	1.15898	1.55313	760.130	723.499
	+40 %	–	–	–	–
	+60 %	–	–	–	–
r_1	-60 %	1.45317	1.66771	1286.23	810.245
	-40 %	1.45331	1.66043	1282.04	811.782
	-20 %	1.45398	1.65143	1277.10	813.057
	+20 %	1.45757	1.62726	1264.87	814.240
	+40 %	1.46094	1.61146	1257.57	813.720
	+60 %	1.46580	1.59267	1249.55	812.044
r_2	-60 %	1.68842	1.89746	1440.56	720.419
	-40 %	1.61966	1.79657	1388.58	740.813
	-20 %	1.54352	1.70968	1333.12	772.239
	+20 %	1.34913	1.59458	1199.77	863.341
	+40 %	1.21717	1.58034	1113.67	914.460
	+60 %	1.04937	1.60969	1007.49	955.504
n_1	-60 %	–	–	–	–
	-40 %	1.49618	1.54416	1236.41	798.480
	-20 %	1.47491	1.59245	1252.38	805.366
	+20 %	1.43748	1.68831	1293.55	824.254
	+40 %	1.42136	1.73607	1319.00	836.384
	+60 %	1.40702	1.78385	1347.89	850.411
n_2	-60 %	1.61948	2.05776	1302.47	761.666
	-40 %	1.54477	1.89697	1266.38	764.048
	-20 %	1.49162	1.76012	1257.08	781.796
	+20 %	1.43283	1.53322	1308.21	860.644
	+40 %	1.42206	1.43480	1368.04	922.803
	+60 %	–	–	–	–
T	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	–	–	–	–
	+20 %	1.69013	2.17887	1405.97	1093.15
	+40 %	1.90527	2.72153	1530.92	1414.47
	+60 %	2.09896	3.26749	1644.56	1776.20

Example 2.

The values of the system parameters are

$a = 90, b = 0.9, h = 0.3, d = 10, S = 17, C_0 = 90, c = 8, \theta = 0.003, n_1 = n_2 = 2, r_1 = 0.20, r_2 = 0.30, \alpha_1 = 1.5625, \alpha_2 = 2.04082, T_1 = 2.8.$

Scenario-I: Both type of discounts
$\mu = 1.32064, \gamma = 1.35691, \pi = 1070.84$ and $Q = 612.8$.
Scenario-II: Only pre deterioration discount
$\mu = 1.40145, \gamma = 1.80495, \pi = 1410.46$ and $Q = 541.645$.
Scenario-III: Only post deterioration discount
$\mu = 1.32151, \gamma = 1.42422, \pi = 1111.3$ and $Q = 613.757$

The following figures represent the concavity of total profit per unit time with respect to the pre and post deterioration discount starting time.

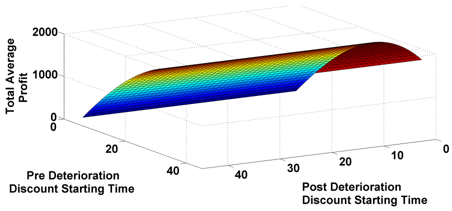

Figure 4: Concavity of total profit per unit time in Scenario-I

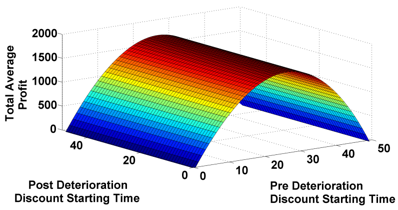

Figure 5: Concavity of total profit per unit time in Scenario-II

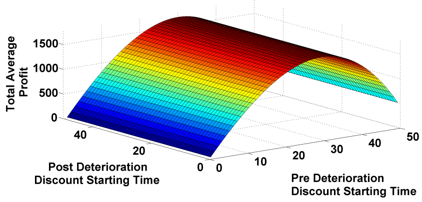

Figure 6: Concavity of total profit per unit time in Scenario-III

Table 3: Sensitivity Analysis for scenario-I

Parameter	% change	μ	γ	π	Q
a	-60 %	1.3185	1.35237	407.944	244.645
	-40 %	1.31969	1.35489	628.91	367.364
	-20 %	1.32028	1.35615	849.876	490.082
	+20 %	1.32088	1.35742	1291.81	735.52
	+40 %	1.32105	1.35778	1512.78	858.239
	+60 %	1.32118	1.35805	1733.75	980.957
h	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	1.36619	1.37255	1106.03	617.925
	+20 %	–	–	–	–
	+40 %	–	–	–	–
	+60 %	–	–	–	–
θ	-60 %	1.33501	1.36421	1079.16	614.748
	-40 %	1.33023	1.36175	1076.39	614.101
	-20 %	1.32544	1.35931	1073.61	613.451
	+20 %	1.31583	1.35453	1068.07	612.146
	+40 %	1.31102	1.35218	1065.07	611.49
	+60 %	1.30619	1.34986	1062.52	610.832
b	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	–	–	–	–
	+20 %	–	–	–	–
	+40 %	–	–	–	–
	+60 %	1.4433	1.77787	1758.36	951.308
d	-60 %	1.33449	1.36355	1077.70	614.909
	-40 %	1.32988	1.36132	1075.42	614.211
	-20 %	1.32526	1.35911	1073.14	613.509
	+20 %	1.31601	1.35472	1068.54	612.086
	+40 %	1.31138	1.35255	1066.24	611.367
	+60 %	1.30674	1.35039	1063.93	610.642
S	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	–	–	–	–
	+20 %	1.48364	1.63597	1909.28	679.435
	+40 %	1.59995	1.88320	2837.22	727.675
	+60 %	1.69408	1.69408	3852.15	763.085
g	-60 %	1.32064	1.35691	1090.13	612.8
	-40 %	1.32064	1.35691	1083.70	612.8
	-20 %	1.32064	1.35691	1077.27	612.8
	+20 %	1.32064	1.35691	1064.42	612.8
	+40 %	1.32064	1.35691	1057.99	612.8
	+60 %	1.32064	1.35691	1051.56	612.8
C	-60 %	1.86019	2.54824	3152.15	820.177
	-40 %	–	–	–	–
	-20 %	1.47324	1.66423	1647.8	685.487
	+20 %	–	–	–	–
	+40 %	–	–	–	–
	+60 %	–	–	–	–
r_1	-60 %	1.30819	1.41578	1104.21	615.629
	-40 %	1.30952	1.40448	1097.30	616.996
	-20 %	1.31321	1.38564	1086.37	616.662
	+20 %	–	–	–	–
	+40 %	–	–	–	–
	+60 %	–	–	–	–
r_2	-60 %	1.55039	1.6084	1338.0	522.055
	-40 %	1.48762	1.51419	1263.62	538.868
	-20 %	1.413311	1.42875	1175.84	568.819
	+20 %	1.19924	1.30743	943.875	669.024
	+40 %	1.03295	1.29605	791.072	728.462
	+60 %	0.795682	1.3514	612.831	765.298
n_1	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	–	–	–	–
	+20 %	1.28864	1.45961	1130.42	641.406
	+40 %	–	–	–	–
	+60 %	–	–	–	–
n_2	-60 %	1.55464	1.89912	1253.51	616.559
	-40 %	–	–	–	–
	-20 %	–	–	–	–
	+20 %	–	–	–	–
	+40 %	–	–	–	–
	+60 %	–	–	–	–
T	-60 %	–	–	–	–
	-40 %	–	–	–	–
	-20 %	–	–	–	–
	+20 %	1.57491	1.80549	1232.82	844.316
	+40 %	1.82407	2.26007	1396.42	1121.92
	+60 %	2.06716	2.71852	1561.82	1449.45

5. DISCUSSIONS

The present paper develops an inventory model for perishable items considering price discount. Here, two types of price discount are considered in three different scenarios. Firstly, both pre and post deterioration discounts are provided. Secondly, only pre deterioration discount, and finally, only post deterioration discount is provided. The efficacy of discounted selling price on optimising the total profit per unit time is studied by stacking up the results obtained in the given scenarios. The results clarify that the maximum profit can be attained in this inventory system only if the pre deterioration discount is provided. The post deterioration discount acquires less profit followed by the case of offering both types of discounts. Furthermore, the sensitivity analysis of the model reveals that the total average profit bumps up for increase in the values of the selling price, total cycle time, and the constants a, b, n_1 and n_2. It declines for increase in the values of disposal cost, deterioration rate, purchase cost, pre and post deterioration discount. The results of sensitivity analysis can act as the guide for managing the aforesaid inventory system.

6. CONCLUSION

Offering of price discount is the way of enticing the customers' preference for the product. It acts as promotional aid for the seller and becomes essential for the short life span products or the products which get deteriorated over time. Most of the business organisations prefer post deterioration discount, but this paper suggests that, under the prevailing circumstances, pre deterioration discount is more beneficial for the decision makers. The management accordingly may embark up on studying the timing and quantity of price discount in pre deterioration period in order to minimise the pre deterioration cost. The model considered here is more suitable for the decoratively perishable items displayed to attract customers.

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