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A TWO WAREHOUSE INVENTORY MODEL FOR MULTIVARIATE DEMAND WITH INVESTMENT IN GREEN TECHNOLOGY

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ABSTRACT

In today's emerging issues, the level of carbon emission is increasing daily in the world. By using green technology, carbon dioxide emissions can be lessened. Green technology is a technology aimed at reducing the impact of humans on the environment. Inflation is the most critical factor in today's business situation. A two warehouse has to be considered to store the stocks of goods where the holding cost of the items to store them is perceived to increase with time. This paper deals with retailing business, which has multivariate demand with all factors mentioned above. We consider two warehouse management systems. A numerical illustration is carried out by using the software MATHEMATICA12.0. A sensitivity analysis has been performed to see how different parameters affect the total cost.

Keywords: Inflation, Multivariate demand, Deterioration, Green technology, Two Warehouse.

1. INTRODUCTION

In the 21st century, governments and citizens cannot assume that social issues like pollution, dwindling resources, and climate change will be ignored for the sake of future generations. The government can play a central role in building a green future, community by community, through policies, research, education, incentives, and forward-looking relationships with industry. We now have better chances of success than ever before. The dawn of a new era of "green technology" (also known as "clean technology") promises a healthier planet and new opportunities for businesses that can sustain it. Similar to the early years of the information technology revolution, this sector also has excitement. A non-profit organization called Green Technology is devoted to informing government efforts toward sustainability, providing a platform for speakers from the public and private sectors to exchange ideas.

Inflation is measured by the consumer price index, which is the change in the cost to the average consumer of acquiring a basket of goods and services that may be fixed or changed periodically, as in yearly cycles. India's inflation rate for 2020 was 6.62%, to 2.9% increase from 2019.

Almost all industries have two warehouse facilities. For displaying items, one warehouse is located at the marketplace, while the other is far from where most of the stock is stored. In addition, storage space plays an important role in a variety of aspects. The problem of inventory management in two warehouses has been studied extensively in literature. The two-warehouse problem was first studied by Hartley (1976). Sarma (1987) introduced the concept of limited storage capacity of owned warehouses (OW). Additionally, Kumari, Singh, and Kumar (2008) and Singh, Rathore, and Saxena (2014b) have studied the two-warehouse problem for deteriorating items.

Furthermore, most retailing industries cannot sustain constant demand. Several factors, including the selling price, stock level, and time, can influence the demand rate for a specific item, especially for textile products.

2. LITERATURE REVIEW

Green technologies have significantly impacted the communities of the areas that have implemented them. Providing biogas plants to rural households has empowered communities and increased their productivity. Distributing solar lanterns has also made a significant impact on rural communities. People have benefited from it not only by using it for themselves but also by trading it. Villagers in Rajasthan are taught eco-friendly tools such as solar cookers and mud refrigerators using initiatives such as the barefoot college. The villagers themselves build water storage and rainwater harvesting techniques. They do not rely on outside help. The villages have seen a significant rise in their standard of living. Kelle and Silver's (1989) article was the first to investigate an optimal forecasting system that could be used to forecast products that organizations could potentially reuse. Many recent types of research have studied green technology. Toptal et al. (2014) developed a joint decision inventory model through the different carbon emission policies. Zheng and Yang (2015) developed an integrated model with investment in green technology. Datta (2017) introduced a model with investment in green technology. This paper develops a production inventory model with a carbon tax policy. Bhattacharyya and Sanna (2019) developed a production inventory model with eco-friendly manufacturing under probabilistic demand. Recently Hasan et al. (2021) developed an optimizing inventory model with the investment in technology under different carbon emission technology.

Demand plays one of the critical roles for any business or industry. In today's situation, constant demand is not realistic. During the pandemic, the vaccine demand rapidly increased in the Ist and second waves of covid-19. Also, the demand for sanitizer and masks increased daily during the pandemic. So, the demand must depend upon many factors. Singh and Diksha (2009) proposed an integrated inventory model for deteriorating items with supplier and buyer cooperation having multivariate demand. Palanivel and Uthayakumar (2013) investigated the effect of inflation and the time value of money on the non- instantaneous decaying EOQ model with price and advertisement-sensitive demand rate under inflation. Padiyar et al. (2021) developed an inventory model for deteriorating items with price-sensitive demand under a fuzzy environment.

The concept of two warehouses is firstly introduced by Hartley (1976). Many researchers work in many in this direction. Yang (2004) introduced a two-warehouse inventory model with constant demand and shortages under inflation. Yang (2006) extended the model of Yang (2004) to include partial backlogs and then compared two warehouse models using the minimum cost approach. Maiti et al. (2006) developed a two-warehouse inventory system where both warehouses are rented. One rented warehouse is located near the marketplace, and another rented warehouse is a little away from the marketplace. They considered the effect of inflation under a random planning horizon. The first study on inflation is given by Buzacott (1975). They derived the EOQ model with inflation on costs. Recently, Kumar and Rajput (2016) analyzed the impact of inflation on the probabilistic inventory control model with shortages. Tiwari et al. (2016) investigated a two-warehouse inventory model for deteriorating items. They studied the effect of inflation on the optimal model. This model allows shortages and partial backlogging. Panda et al. (2018) studied a two-warehouse optimal model of decaying products having variable demand and shortages with a permissible delay approach. In this paper, we developed a two-warehouse inventory model. Demand is considered multivariate and depends upon selling price, stock level, and time. An investment in green technology is considered under the effect of inflation. This paper deals with any retailing business with more stock, but there is little storage facility to store the stocks. So, in this case, they can hire a warehouse on a rental basis.

3. ASSUMPTION AND NOTATIONS

3.1 ASSUMPTION

1. Demand is multivariate which is depends upon; selling price, stock and time.
  $D (P, I(t), t) = a-b p+ c I(t)+dt$
Where a. b, c, d > 0
2. Deterioration is taken into account
3. Inflation is taken into consideration.
4. Investment is green technology is taken in account.
5. Lead time is zero.
6. Replenishment rate is infinite.
7. The own warehouse storage capacity is W and rented warehouse storage capacity is Q_1+W.

3.2 NOTATIONS

O Ordering cost per order
$I_R(t)$ = Rented warehouse inventory level
$I_O(t)$ = Own warehouse inventory level
θ_o = Rate of deterioration in own ware houses

W = Capacity of own warehouse
Q_1 = Capacity of rented warehouse
TC = Total inventory cost
H_R = Holding cost for rented warehouse
H_O = Holding cost for own ware house
D_R = Deterioration cost for own ware house
G = Investment in green technology
r = Rate of inflation

4. MATHEMATICAL MODELING

This proposed model approached for a retailing business which has two warehouse inventory system. In this model we developed a two-warehouse inventory model. In which the demand for product is depends upon the multivariate factors, like selling price, stock and time.
The governing differential equation describing the inventory level is given by

$$\frac{dI_R(t)}{dt} = -D(P, I(t), t) - \theta_R I_R(t) \quad 0 \le t \le t_1 \qquad (1)$$

$$\frac{dI_O(t)}{dt} = -\theta_O I_R(t) \quad 0 \le t \le t_1 \qquad (2)$$

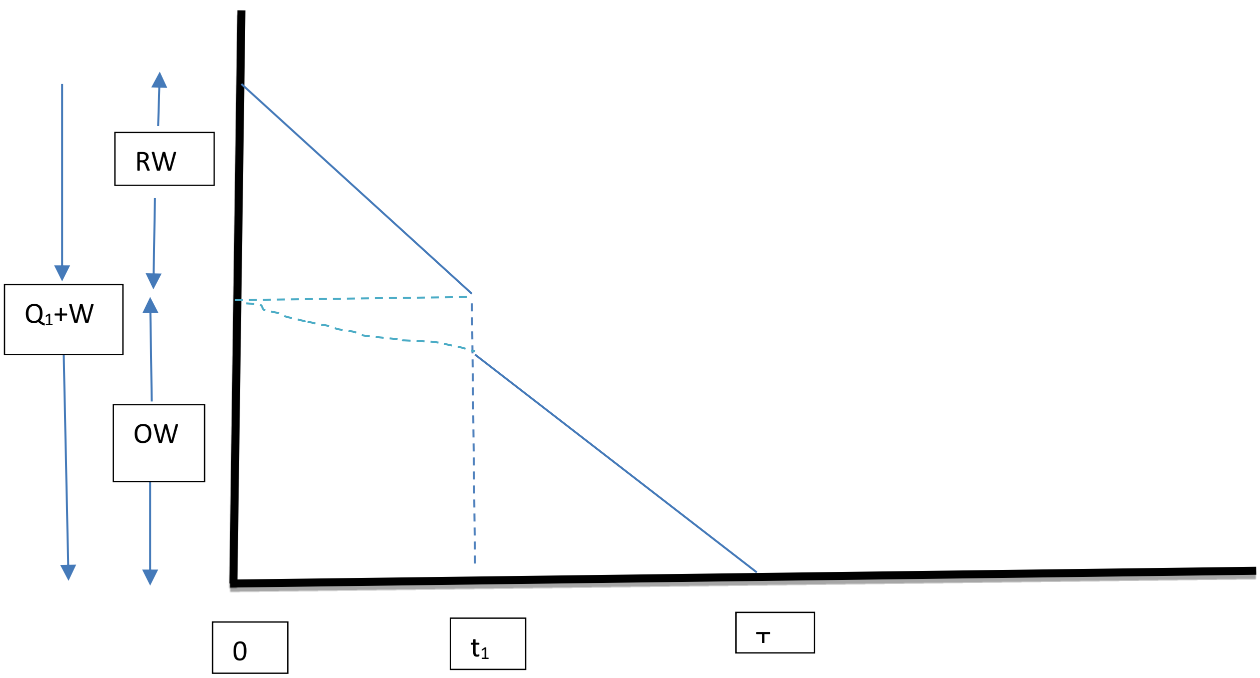

Figure 1: Graphical representation of behavior of different inventory level.

$$\frac{dI_O(t)}{dt} = -D(P, I(t), t) - \theta_O I_O(t) \quad t_1 \le t \le T \qquad (3)$$

With boundary condition $I_R(0) = Q_1$, $I_O(0) = W$
$I_R(t_1) = 0$, $I_O(t_1) = W_O$, $I_O(T) = 0$
Solution of Equation (1) with boundary condition

$$I_R(t) = \frac{(a-bP)}{(c+\theta_R)}\left[-1 + e^{(c+\theta_R)(t_1-t)}\right] - d\left[\frac{t(c+\theta_R)-1}{(c+\theta_R)^2}\right] + d[(c+\theta_R)t_1 - 1]e^{(c+\theta_R)(t_1-t)} \qquad (4)$$

At t=0 $I_R(0) = Q_1$

$$Q_1 = \frac{(a-bP)}{(c+\theta_R)}\left[-1+e^{(c+\theta_R)t_1}\right] + d\left[\frac{1}{(c+\theta_R)^2}\right] + d[(c+\theta_R)t_1 - 1]e^{(c+\theta_R)t_1} \quad (5)$$

Solution of Equation (2) with boundary condition

$$I_O(t) = W_O e^{\theta_O(t_1-t)} \quad (6)$$

Solution of Equation (3) with boundary condition

$$I_O(t) = \frac{(a-bP)}{(c+\theta_O)}\left[e^{(c+\theta_O)(T-t)} - 1\right] - d\left[\frac{t(c+\theta_O)-1}{(c+\theta_O)^2}\right] + d\left[\frac{[(c+\theta_O)T-1]e^{(c+\theta_O)(T-t)}}{(c+\theta_O)^2}\right] \quad (7)$$

At $t = t_1$

$$W_O = \frac{(a-bP)}{(c+\theta_O)}\left[e^{(c+\theta_O)(T-t)} - 1\right] - d[t_1(\theta_O+c)-1] + d[\theta_O+c)T-1]e^{(c+\theta_O)(T-t_1)} \quad (8)$$

Inventory Costs:

(1) Ordering cost = O

(2) Holding cost $=H_R\int_0^{t_1} e^{-rt} I_R(t)\,dt + H_o\int_0^T e^{-rt} I_o(t)\,dt$

Holding cost $= H_R\Big[\frac{(a-bP)}{(c+\theta_R)}\Big[\Big[\frac{(1c-e^{(c+\theta_R-r)t_1}}{r} + \frac{e^{(c+\theta_R)t_1}-1}{r}\Big] + \frac{d}{(c+\theta_R)}\left[\frac{(1-rt_1)e^{-rt_1}}{r^2} - \frac{1}{r^2}\right] + \frac{d}{(c+\theta_R)^2}\left[\frac{e^{-rt_1}-1}{r}\right] + d\left[\frac{[(c+\theta_R)t_1-1]}{(c+\theta_R)^2}\left[\frac{-e^{-rt_1}}{(\theta_R+c+r)}\right]\right]\Big] + H_O\Big[\frac{W_O}{(\theta_O+r)}[1-e^{-rt_1}] + \frac{(a-bP)}{(c+\theta_O)}\left[\frac{-e^{-rT}}{(\theta_O+c+r)} - T + \frac{e^{(\theta_O+c)T}e^{-(\theta_O+c+r)t_1}}{(\theta_O+c+r)} - t_1\right] - \frac{d}{(c+\theta_R)^2}\left[[(1-rT)e^{-rT} - (1-rt_1)e^{-rt_1}] + \frac{e^{-rT}}{r} - \frac{e^{-rt_1}}{r}\right] + d\,\frac{[(\theta_O+c)T-1]}{(\theta_O+c)^2}\left[\frac{-e^{-rT}}{(\theta_O+c+r)} + \frac{e^{(\theta_O+c)T}e^{-(\theta_O+c+r)t_1}}{(\theta_O+c+r)}\right]\Big]$

(3) **Deterioration cost** $= H_R\theta_R\int_0^{t_1} e^{-rt} I_R(t)dt + H_o\theta_0\int_0^T e^{-rt} I_o(t)dt$

Deterioration cost $=D_R\theta_R\Big[\frac{(a-bP)}{(c+\theta_R)}\left[\left[\frac{(1-e^{(c+\theta_R-r)t_1}}{r}\right] + \left[\frac{e^{(c+\theta_R)t_1}-1}{r}\right]\right] + \frac{d}{(c+\theta_R)}\left[\frac{(1-rt_1)e^{-rt_1}}{r^2} - \frac{1}{r^2}\right] + \frac{d}{(c+\theta_R)^2}\left[\frac{e^{-rt_1}-1}{r}\right] + d\left[\frac{[(c+\theta_R)t_1-1]}{(c+\theta_R)^2}\left[\frac{-e^{-rt_1}}{(\theta_R+c+r)}\right]\right]\Big] + H_O\theta_O\Big[\frac{W_O}{(\theta_O+r)}[1-e^{-rt_1}] + \frac{(a-bP)}{(c+\theta_O)}\left[\frac{-e^{-rT}}{(\theta_O+c+r)} - T + \frac{e^{(\theta_O+c)T}e^{-(\theta_O+c+r)t_1}}{(\theta_O+c+r)} - t_1\right] - \frac{d}{(c+\theta_O)^2}\left[\frac{(\theta_O+c)}{r^2}[(1-rT)e^{-rT} - (1-rt_1)e^{-rt_1}] + \frac{e^{-rT}}{r} - \frac{e^{-rt_1}}{r}\right] + \frac{d[(\theta_O+c)T-1]}{(\theta_O+c)^2}\left[\frac{-e^{-rT}}{(\theta_O+c+r)} + \frac{e^{(\theta_O+c)T}e^{-(\theta_O+c+r)t_1}}{(\theta_O+c+r)}\right]\Big]$

(4) **Green Technology investment** = GT

So, the total cost

TC = $\frac{1}{T}$[Ordering cost + Holding cost + Deterioration cost + Green Technology cost]

$=\frac{1}{T}\Big[O + (H_R + D_R\theta_R)\left[\frac{(a-bP)}{(c+\theta_R)}\left[\frac{(1-e^{(c+\theta_R-r)t_1}}{r} + \frac{e^{(c+\theta_R)t_1}-1}{r}\right] + \frac{e^{(c+\theta_R)t_1}-1}{r}\right] + \frac{d}{(c+\theta_R)}\left[\frac{(1-rt_1)e^{-rt_1}-1}{r^2}\right] + \frac{d}{(c+\theta_R)^2}\left[\left[\frac{e^{-rt_1}-1}{r}\right] + d\Big[\frac{[(c+\theta_R)t_1-1]}{(c+\theta_R)^2}\left[\frac{-e^{-rt_1}}{(\theta_R+c+r)}\right] + (H_O + \theta_O D_R)\left[\frac{W_O}{(\theta_O+r)}[1-e^{-rt_1}] + \frac{(a-bP)}{(c+\theta_O)}\left[\frac{-e^{-rT}}{(\theta_O+c+r)} - T + \frac{e^{(\theta_O+c)T}e^{-(\theta_O+c+r)t_1}}{(\theta_O+c+r)} - t_1\right] - \frac{d}{(c+\theta_O)^2}\left[\frac{(\theta_O+c)}{r^2}[(1-rT)e^{-rT} - (1-rt_1)e^{-rt_1}] + \frac{e^{-rT}}{r} - \frac{e^{-rt_1}}{r}\right] + d\,\frac{[(\theta_O+c)T-1]}{(\theta_O+c)^2}\left[\frac{-e^{-rT}}{(\theta_O+c+r)} + \frac{e^{(\theta_O+c)T}e^{-(\theta_O+c+r)t_1}}{(\theta_O+c+r)}\right]\right] + GT\Big]$

5. NUMERICAL RESULTS

All the parameters are taken into appropriate units.

O = 100, a = 150, b=.02, $H_R = 11$, $\theta_R = 0.6$, $D_R = 2$,c=5, r=0.5, d=2, $H_O = 8$, $\theta_O = 0.4$, $D_O = 2$, G=10

We get Total cost = 941.281 \$, p= 3527.28 Rs/item, $t_1 = 0.2469$, $T = 0.311025$

6. CONVEXITY

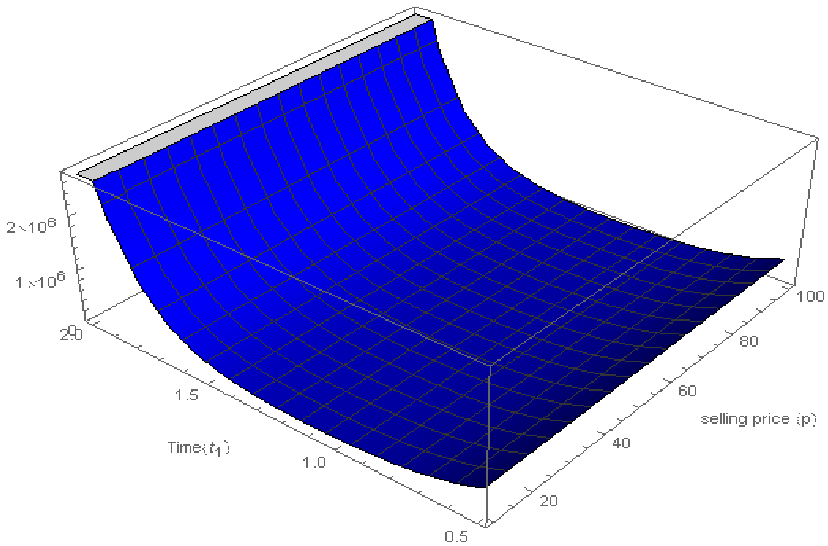

Figure 2: Convexity between selling price (p) , t_1 and total cost

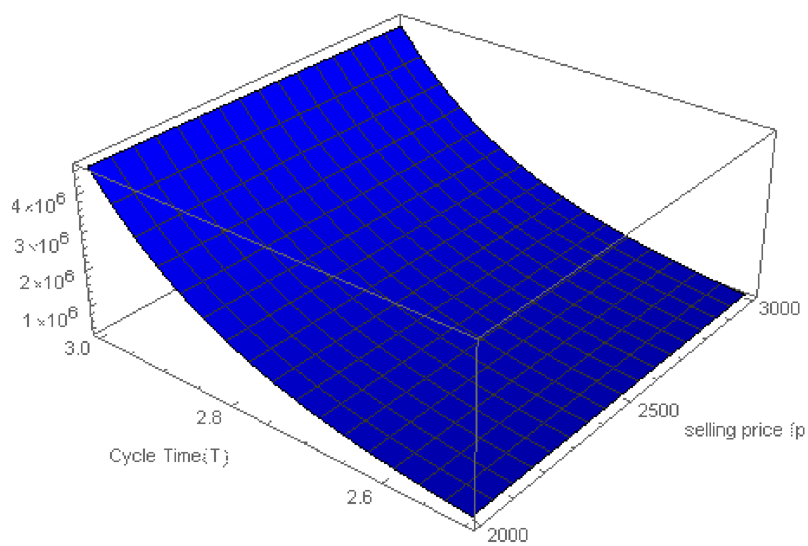

Figure 3: convexity between selling price, total cycle lenth and total cos

7. SENSITIVITY ANALYSIS

Table 1 : Sensitivity Analysis

Parameters	% change	Min	P	t_1	T
r	+5%	1149.58	2296.79	0.235954	0.030012
	+10%	1481.45	903.467	0.227621	0.291049
	+15%	859.119	3998.460	0.250955	0.323220
	-5%	1541.47	550.207	0.227341	0.285592
	-10%	1632.46	71.9059	0.225841	0.281902
	-15%	1388.13	1245.85	0.231573	0.286216
θ_O	+5%	1424.94	985.233	0.226682	0.28882
	+10%	1540.22	209.269	0.221161	0.28382
	+15%	1534.48	60.0728	0.218579	0.282427
	-5%	1664.72	162.454	0.227675	0.285437
	-10%	1571.17	812.015	0.232894	0.289377
	-15%	281.316	6485.83	0.331562	0.358762
θ_R	+5%	1597.67	318.36	0.225044	0.285307
	+10%	1512.44	769.655	0.226092	0.28748
	+15%	1500.58	854.521	0.225601	0.287688
	-5%	1604.02	230.33	0.226457	0.285438
	-10%	1294.15	1753.79	0.234798	0.294966
	-15%	1550.41	443.371	0.229135	0.287135
a	+5%	1116.3	3052.09	0.239208	0.301989
	+10%	1360.01	2225.41	0.231374	0.292446
	+15%	1552.02	1643.82	0.226761	0.286658
	-5%	1398.64	908.53	0.230335	0.291178
	-10%	1260.40	1218.52	0.234254	0.295997
	-15%	1008.21	2078.76	0.243713	0.307304
b	+5%	790.364	4045.22	0.255821	0.320907
	+10%	950.278	3167.21	0.246481	0.310504
	+15%	970.632	2944.07	0.245476	0.309349
	-5%	1041.48	3202.24	0.242241	0.305582
	-10%	960.114	3818.31	0.245991	0.309941
	-15%	1552.88	605.279	0.226743	0.286635

8. GRAPHICAL REPRESENTATION OF SENSITIVITY ANALYSIS.

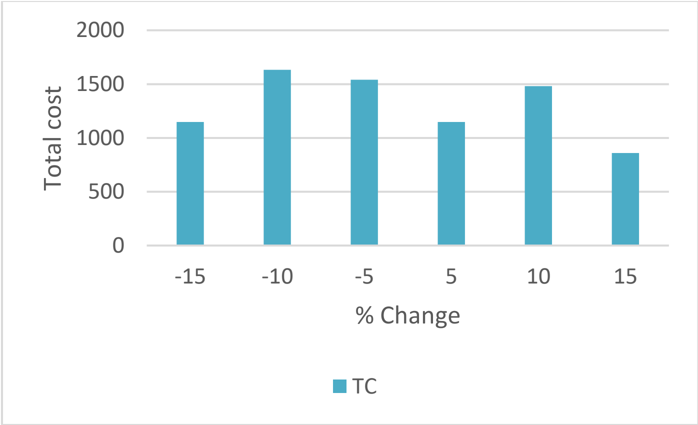

Figure 4: Graphical representation of sensitivity analysis with respect to inflation rate ‘r’

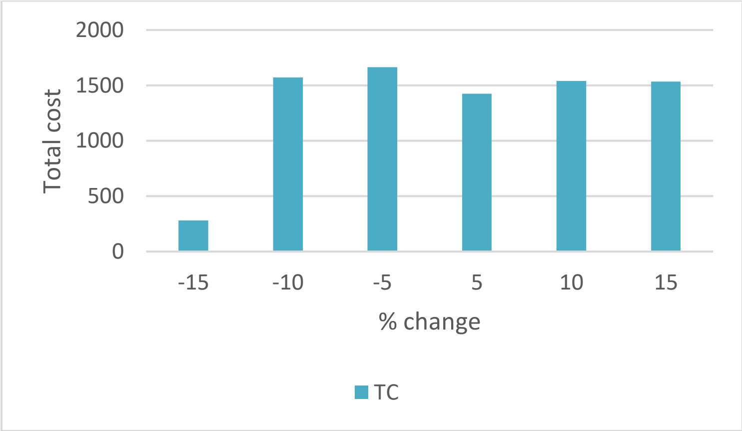

Figure 5: Graphical representation of change in total cost and θ_O

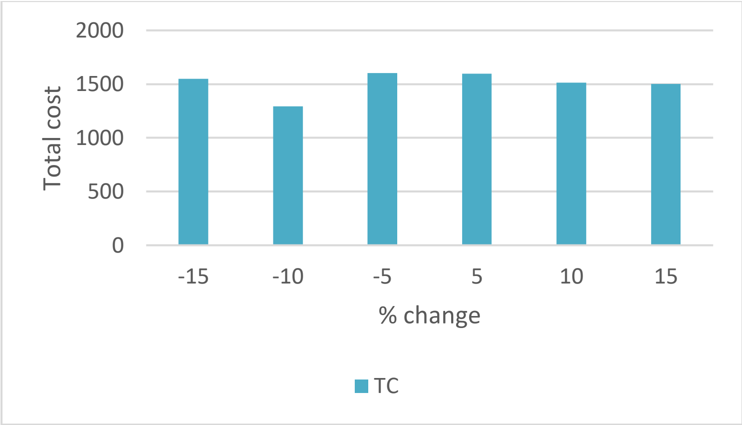

Figure 6: Graphical representation of change in total cost and $'\theta_R'$

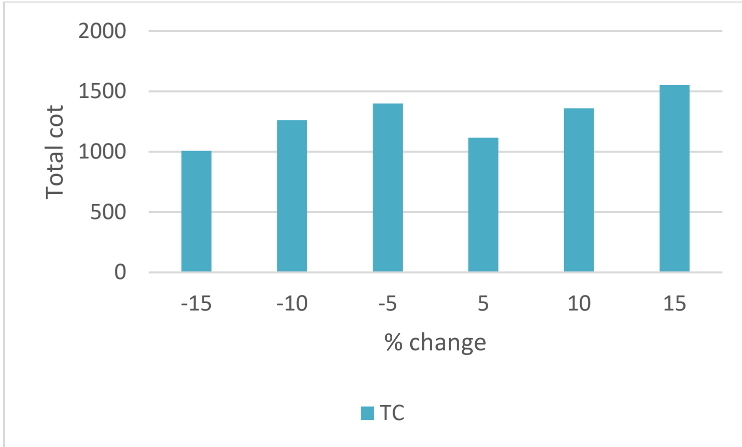

Figure 7: Graphical representation of change in total cost and 'a'

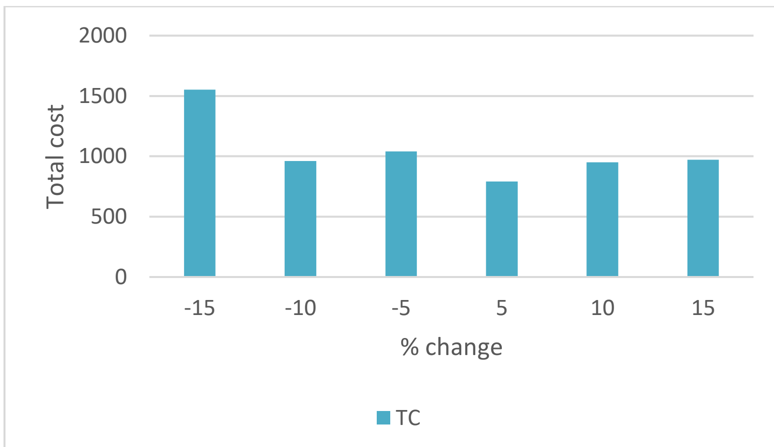

Figure 8: Graphical representation of change in total cost and 'b'

9. OBSERVATIONS

- On increases the percent change in inflation from -15% to -10% the total cost increases and on increases in the inflation from +5% to +10% the total cost increases. But it shows the negative impact when it increases from -10% to -5% and +10% to +15%.
- On increases the deterioration rate in own warehouse from -15% to -5% and +5% to +15% the total cost is increase.
- On increases in the deterioration rate in rented warehouse the total cost is decreases when it changes from -15% to -10% and total cost is increases when it changes from -10% to +5%.
- On increases the percent change in demand shape parameter 'a' from -15% to -5% the total cost increases and on increases in the demand shape parameter from +5% to +15% the total cost increases.
- On increases in the price elasticity parameter 'b' the total cost is increases from -10% to -5% to +15%. But it shows the abnormality when it changes from -15%to -10%.
- It is recommended that parameter changes be conducted carefully. Due to the complexity of the problem, the analytical results may lead to some infeasible solutions.

10. CONCLUSION

In this paper we developed a mathematical model with multivariate demand for deterioration with the effect of inflation. A two-warehouse facility is taken in this study. From the sensitivity analysis we conclude that the total cost is minimum when the price elasticity coefficient is minimum. The total cost is minimum when the demand shape parameter is minimum. This paper can be extended when demand is taken probabilistic. Also, this paper can be extended in uncertain environment and investment in different carbon regulations policies.

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