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An Inventory Model for Cubic Deteriorating Items Carry Forward with Weibull Demand and Without Shortages

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Abstract
This paper presents an inventory model for deteriorating items with a uniform replenishment rate with Weibull demand and without shortages. The deterioration rate is a cubic polynomial as a function of time. The purpose of this paper is to minimize the total cost in which deficits are not allowed. A numerical example is presented to illustrate the model. The sensitivity analysis of the optimal solution concerning various parameters is also studied the total optimal average variable inventory cost as the model's actual performance.
Key Words: *Weibull Demand, Cubic Deterioration, Shortages, Deteriorating Items.*

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1. Introduction

In daily life, the deteriorating of goods is a common phenomenon. Most edible matters undergo straight exhaustion during simple storing. Highly volatile liquids such as motor spirit, ethanol, etc., under goes a substantial reduction in a time frame through the course of evaporation. Matters concerning electronic, nuclear, photoelectric, etc., weakens the situation to potentiality and service concerning time. Deterioration is the degradation of value. Covent has thoroughly investigated the inventory models for deteriorating items, and Philip[2] formulated an Economic Order Quantity model. The rate of deterioration of inventory models' two-parameter Weibull distribution shows that the demand rate is constant without inventory shortage. While formulating inventory models, the factor such as demand and deterioration rate cannot be ignored. Kang & Kim[8] studied the price of the deteriorating Inventory since it is the most important factor of demand and production level at the firm, decided the basis price. Covert and Philip[2] moved over Ghare and Schrader's invariable declination rate to a two-attribute Weibull distribution. Afterward, Shah and Jaiswal[19] expressed and re-confirmed an order level inventory frame with a steady rate of deterioration, respectively.

A lot of flourishing information currently derived by Sana and Chaudhuri[18] attempted the model analytically with power order deterioration. Still, they did not solve the model numerically because of the mathematical complexity of the model Lot of flourishing information currently derived by Chung and Ting[1], Covert and Philip[2]. Sahoo et al.[17] have also established an EOQ model with constant deterioration and price-dependent demand. Later, Sachan[13] elaborated the model on deficits. Hollier and Mak[12], Hariga and Benkherouf[10], Wee[5,6] have also established their pattern considering the exponential order. Earlier, Goyal and Giri[14] have put forward an exceptional study on the current drift in framing declination storage of the goods like vegetables, fruits, etc., whose declination rate gets augmented with time. Share and Schrader[11] have primarily exercised the model of deterioration chased by Covert and Philip[2]. They devised a model with an inconsistent Rate of declination with two-factor Weibull distributions, which has further been comprehended by Philip[3], considering an inconsistent declination rate of three-factor Weibull distributions. Seldom in some storage units, the higher the waiting time is, the lesser the retreat rate would be and vice-versa.

Consequently, all through the deficiency phase, the retreat rate is inconsistent and reliant on the waiting time for the subsequent refilling. Chang and Dye[4] have established an Economic Order Quantity from accepting deficit. Newly, Ouyang, Wu, and Cheng[9] have devised an 'Economic Order Quantity' stock account for declination matters in which order utility is exponentially declining and moderately retreat. Dye[4] proposed an Economic Order Quantity model for perishable items with Weibull distributed deterioration. He assumed that the demand rate is a power-form function of time. Sana and Chaudhuri[18] developed a stock-review inventory model for perishable items with uniform replenishment and stock-dependent demand. The deterioration function per unit time is a quadratic function of time. Mishra and Singh[7] developed an Economic Order Quantity Model with Power-Form Stock-Dependent Demand and Cubic Deterioration. In the recent paper, Sahoo, Paul & kumar[15] have emphasized upon inventory model possessing two warehouses inventory model has been developed with exponentially diminishing order rate with limited suspension price including salvages. In another paper, Sahoo, Paul & kalam[16] established An Economic Order Quantity structure for declining matter with cubic order and inconsistent declining rate. The deficit has been accepted and moderately retreated. The Principal significance of the model is to establish an optimal frame.

This model for cubic deteriorating items is developed in which demand rate is Weibull function and without shortages. The total article has been organized into various important sections, including introduction, fundamental assumptions, notations, Mathematical Model, Numerical Analysis, Sensitivity Analysis, and Conclusion.

2. Assumptions and Notations

The following assumption and notations have been considered in this inventory model:

Hypotheses (Assumptions):

The following hypotheses are prepared to initiate the representation.

- The demand function D(I) is taken to be a Weibull function of inventory level I(t) at any time t as $D(I) = \alpha\beta t^{\beta-1}, \alpha > 0, \beta > 1$.
- The replenishment occurs instantaneously at an infinite, but the replenishment size is finite.
- Lead time is zero.
- The deteriorating rate, $\theta(t)$, is a cubic function of time. Here $\theta(t) = a + bt + ct^2 + dt^3$,where *a,b,c,* and d are real numbers, $d \neq 0$
  Where a = initial deterioration
  b = initial rate of change of deterioration.
  c= acceleration of deterioration
  d= 'rate of change of acceleration of deterioration.
  The items undergo decay at $\theta(t).I(t)$ at any time t.
- Shortages are not allowed.
- The time horizon is infinite.
- Holding cost and set-up cost per inventory cycle, both are constant.
- The procurement cost per unit item is constant.

Notations

The following data have been admitted in establishing the representation.

- $I(t)$ =The inventory level at time$t$.
- I_1 =Intial and Terminal inventory level.
- I_2 =Pick of the inventory level.
- R =Finite replenishment rate.
- C_s =Set up the cost per cycle.
- C_h =Holding cost per unit time.
- C_p = Procurement cost per unit time.
- t_1 =Pick off time per inventory level.
- T & TAC =The length of a cycle and Total average cost, respectively.

3. Mathematical Formulation

The inventory level at different instants of time is shown in fig.1.

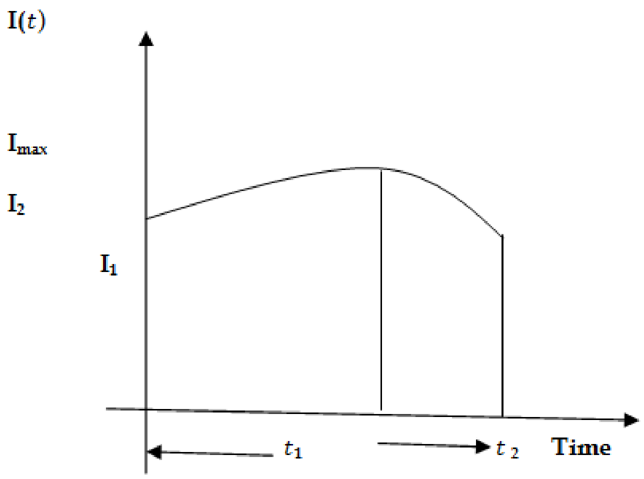

Figure1. Graphical presentation of inventory system

The inventory cycle time encompasses two segments, i.e. [0, t_1] and [t_1, T]. Uniform replenishment rate starts with inventory t_1 and continues up to time t=t_1.The 'Inventory' piles up during [0,t_1], after meeting demands in the market. The 'inventory level' at t=t_1 is I_2.The storage space is limited. It can store a maximum (I_{max}) units. Again the' inventory level' gradually reaches I_1 at time t=T. The instantaneous states of the' inventory level' I (t) at any time to are governed by the following system of differential equations.

$$\theta(t) = a + bt + ct^2 + dt^3, where a, b, c, d \in R and d \neq 0$$

$$\theta'(t) = b + 2ct + 3dt^2$$

$$\theta''(t) = 2c + 6dt$$

$$\theta'''(t) = 6d$$

Where a= initial deterioration
b = initial rate of change of deterioration
c = acceleration of deterioration
d = rate of change of acceleration of the deterioration.

$$\frac{dI(t)}{dt} = R - \propto \beta t^{\beta-1} - \theta(t).I(t), 0 \leq t"t_1 \quad (1)$$

$$with I(0) = I_1 and I(t_1) = I_2$$

$$\frac{dI(t)}{dt} = - \propto \beta t^{\beta-1} - \theta(t).I(t), t_1 \leq t "T \quad (2)$$

With $I(T) = I_1$

We prefer to work I (t) = I

$$\theta(t) = \theta$$

$$\theta'(t) = \theta'$$

$$\theta''(t) = \theta''$$

$$\theta'''(t) = \theta'''$$

Solving the above equations using Taylor's series expansion

Now equation (1) reduces to the following equations.

$$\frac{dI}{dt} = R - \propto \beta t^{\beta-1} - \theta.I$$

$$\frac{d^2I}{dt^2} = -\alpha\beta(\beta-1)t^{\beta-2} + \propto \beta\theta t^{\beta-1} - (\theta' - \theta^2)I - \theta R$$

$$\frac{d^3I}{dt^3} = -\alpha\beta(\beta-1)(\beta-2)t^{\beta-3} + \propto \beta(\beta-1)\theta t^{\beta-2} + \propto \beta\theta^2 t^{\beta-1} - (\theta'' - \theta\theta' - \theta^3)I - \theta^2 R$$

$$\frac{d^4I}{dt^4} = -\alpha\beta(\beta-1)(\beta-2)(\beta-3)t^{\beta-4} + \alpha\beta(\beta-1)(\beta-2)\theta t^{\beta-3} + \alpha\beta(\beta-1)(\theta' + \theta^2)t^{\beta-2} + \alpha\beta(\theta\theta' + \theta'' - \theta^3)t^{\beta-1} + (\theta\theta' + 2\theta\theta'' + 2\theta^2\theta' - \theta''' - \theta^4)I - (\theta'' + \theta\theta' - \theta^3)R$$

Applying initial condition at t=0, $I(0) = I_1$, $\theta(0) = a$, $\theta'(0) = b$, $\theta''(0) = 2c$, $\theta'''(0) = 6d$

$$\frac{dI}{dt}]_{t=0} = R - aI_1 = f_1(I_1)$$

$$\frac{d^2I}{dt^2}]_{t=0} = -(b - a^2)I_1 - aR = f_2(I_1)$$

$$\frac{d^3I}{dt^3}]_{t=0} = -(2c - ab - a^3)I_1 - a^2R = f_3(I_1)$$

$$\frac{d^4I}{dt^4}]_{t=0} = (ab + 4ac + 2a^2b - 6d - a^4)I_1 - (2c + ab - a^3)R = f_4(I_1)$$

$$I(t) = I(0) + [\frac{dI}{dt}]_{t=0}.t + [\frac{d^2I}{dt^2}]_{t=0}.\frac{t^2}{2} + + [\frac{d^3I}{dt^3}]_{t=0}.\frac{t^3}{6} + + [\frac{d^4I}{dt^4}]_{t=0}.\frac{t^4}{24}$$

$$= I_1 + tf_1(I_1) + \frac{t^2}{2}f_2(I_1) + \frac{t^3}{6}f_3(I_1) + \frac{t^4}{24}f_4(I_1) \quad , 0 \le t \le t_1 (3)$$

Again from equation (2), we get

$$\frac{dI(t)}{dt} = -\propto \beta t^{\beta-1} - \theta(t).I(t)$$

It can be written as

$$\frac{dI}{dt} = -\propto \beta t^{\beta-1} - \theta.I$$

$$\frac{d^2I}{dt^2} = -\alpha\beta(\beta-1)t^{\beta-2} + \propto \beta\theta t^{\beta-1} - (\theta' - \theta^2)I$$

$$\frac{d^3I}{dt^3} = -\alpha\beta(\beta-1)(\beta-2)t^{\beta-3} + \propto \beta(\beta-1)\theta t^{\beta-2} + \propto \beta(2\theta' - \theta^2)t^{\beta-1} + (3\theta\theta' - \theta'' - \theta^3)I$$

$$\frac{d^4I}{dt^4} = -\alpha\beta(\beta-1)(\beta-2)(\beta-3)t^{\beta-4} + \propto \beta(\beta-1)(\beta-2)\theta t^{\beta-3} + \propto \beta(\beta-1)(3\theta' - \theta^2)t^{\beta-2} + \propto \beta(3\theta'' - 5\theta\theta' + \theta^3)t^{\beta-1} + (3\theta'^2 + 4\theta\theta'' - \theta''' - 6\theta^2\theta' + \theta^4)I$$

At $t = t_1$

$$I(t_1) = I_2$$

$$\theta(t_1) = a + bt_1 + ct_1{}^2 + dt_1{}^3$$

$$\theta'(t_1) = b + 2ct_1 + 3dt_1{}^2$$

$$\theta''(t_1) = 2c + 6dt_1$$

$$\theta'''(t_1) = 6d$$

$$\frac{dI}{dt}\Big]_{t=t_1} = -\alpha\beta t_1^{\beta-1} - (a + bt_1 + ct_1^2 + dt_1^3)I_2 = f_1(I_2)$$

$$\frac{d^2I}{dt^2}\Big]_{t=t_1} = -\alpha\beta(\beta-1)t_1^{\beta-2} + \alpha\beta(a + bt_1 + ct_1^2 + dt_1^3)t_1^{\beta-1} - [(b-a^2) + (2c-2ab)t_1 + (3d-2ac-b^2)t_1^2 - (2bc+2ad)t_1^3 - (2bd+c^2)t_1^4 - 2cdt_1^5 - d^2t_1^6]I_2 = f_2(I_2)$$

$$\frac{d^3I}{dt^3}\Big]_{t=t_1} = -\alpha\beta(\beta-1)(\beta-2)t_1^{\beta-3} + \alpha\beta(\beta-1)(a + bt_1 + ct_1^2 + dt_1^3)t_1^{\beta-2} +$$

$$\alpha\beta\left\{\begin{matrix}(2b-a^2) + (4c-2ab)t_1 \\ +(6d-2ac-b^2)t_1^2 - (2bc+2ad)t_1^3 \\ -(2bd+c^2)t_1^4 - 2cdt_1^5 - d^2t_1^6\end{matrix}\right\}t_1^{\beta-1}$$

$$+\left[\begin{matrix}(3ab-a^3-2c) + (6ac-3a^2b+3b^2-6d)t_1 + (9ad-3a^2c-3ab^2+9bc)t_1^2 \\ +(-6abc-3a^2d+6bd+b^2c-b^3)t_1^3 + (-6abd-3ac^2-3b^2c+15cd)t_1^4 \\ +(-6acd-3b^2d-3bc^2+9d^2)t_1^5 + (-6bcd-3ad^2-c^3)t_1^6 \\ +(-3bd^2-3c^2d)t_1^7 - 3cd^2t_1^8 - d^3t_1^9]\, I_2\end{matrix}\right]$$

$$= f_3(I_2)$$

$$\frac{d^4I}{dt^4}\Big]_{t=t_1} = -\alpha\beta(\beta-1)(\beta-2)(\beta-3)t_1^{\beta-4} + \alpha\beta(\beta-1)(\beta-2)(a + bt_1 + ct_1^2 + dt_1^3)t_1^{\beta-3}$$

$$+\alpha\beta(\beta-1)\left[\begin{matrix}(3b-a^2) + (6c-2ab)t_1 + (9d-2ac-b^2)t_1^2 \\ +(-2bc-2ad)t_1^3 + (-2bd-c^2)t_1^4 - 2cdt_1^5 - d^2t_1^6\end{matrix}\right]t_1^{\beta-2}$$

$$+\alpha\beta\left[\begin{matrix}(6c-5ab+a^3) + (18d-10ac-5b^2+3a^2b)t_1 \\ +(-15ad-15bc+3a^2c+3ab^2)t_1^2 + (-20bd-10c^2+6abc+3a^2d+b^3)t_1^3 \\ +(-25cd+6abd+3ac^2+3b^2c)t_1^4 + (-15d^2+6acd+3b^2d+3bc^2)t_1^5 \\ +(6bcd+3ad^2+c^3)t_1^6 + (3bd^2+3c^2d)t_1^7 + 3cd^2t_1^8 + d^3t_1^9\end{matrix}\right]t_1^{\beta-1}$$

$$+\left[\begin{matrix}(3b^2+8ac-6d-6a^2b+a^4) + (20bc+24ad-12ab^2-12a^2c+4a^3b)t_1 \\ +(42bd+20c^2-36abc-18a^2d-6b^3+4a^3c+6a^2b^2)t_1^2 \\ +(68cd-48abd-24b^2c-24ac^2+12a^2bc+4a^3d+4ab^3)t_1^3 \\ +(51d^2-60acd-30b^2d-30bc^2+12a^2bd+12ab^2c+6a^2c^2+b^3)t_1^4 \\ +(-72bcd-36ad^2-12c^3+12a^2cd+12ab^2d+12abc^2+4b^3c)t_1^5 \\ +(-42bd^2-42c^2d+24abcd+6a^2d^2+4ac^3+6b^2c^2+4b^3d)t_1^6 \\ +(-48cd^2+12abd^2+12ac^2d+12b^2cd+4bc^3)t_1^7 \\ +(-18d^3+12acd^2+12bc^2d+6b^2d^2+c^4)t_1^8 \\ +(12bcd^2+4ad^3+4c^3d)t_1^9 + (4bd^3+6c^2d^2)t_1^{10} + 4cd^3t_1^{11} + d^4t_1^{12}\end{matrix}\right]I_2$$

$$= f_4(I_2)$$

The total Inventory in the cycle

$$\int_0^T I(t)dt = \int_0^{t_1} I(t)dt + \int_{t_1}^T I(t)dt = I_1 t_1 + f_1(I_1)\frac{t_1^2}{2} + f_2(I_1)\frac{t_1^3}{6} f_3(I_1)\frac{t_1^4}{24} + f_4(I_1)\frac{t_1^5}{120}$$

$$+ I_2(T-t_1) + f_1(I_2)\frac{(T-t_1)^2}{2} + f_2(I_2)\frac{(T-t_1)^3}{6} + f_3(I_2)\frac{(T-t_1)^4}{24} + f_4(I_2)\frac{(T-t_1)^5}{120}$$

Total invested during each inventory cycle is given by

$$TC(T) = C_h\{\int_0^{t_1} I(t)dt + \int_{t_1}^T I(t)dt\} + C_s + C_p R t_1$$

$$= C_h \left\{ \begin{array}{c} I_1 t_1 + f_1(I_1)\frac{t_1^2}{2} + f_2(I_1)\frac{t_1^3}{6} f_3(I_1)\frac{t_1^4}{24} + f_4(I_1)\frac{t_1^5}{120} \\ + I_2(T-t_1) + f_1(I_2)\frac{(T-t_1)^2}{2} + f_2(I_2)\frac{(T-t_1)^3}{6} + f_3(I_2)\frac{(T-t_1)^4}{24} + f_4(I_2)\frac{(T-t_1)^5}{120} \end{array} \right\}$$

$$+ C_s + C_p R\, t_1.$$

Therefore the total average cost is

$$TAC(T) = \frac{1}{T}[C_h\{\int_0^{t_1} I(t)dt + \int_{t_1}^T I(t)dt\} + C_s + C_p R t_1]$$

$$= \frac{1}{T}\left[\begin{array}{c} C_h \left\{ \begin{array}{c} I_1 t_1 + f_1(I_1)\frac{t_1^2}{2} + f_2(I_1)\frac{t_1^3}{6} f_3(I_1)\frac{t_1^4}{24} + f_4(I_1)\frac{t_1^5}{120} \\ + I_2(T-t_1) + f_1(I_2)\frac{(T-t_1)^2}{2} + f_2(I_2)\frac{(T-t_1)^3}{6} + f_3(I_2)\frac{(T-t_1)^4}{24} + f_4(I_2)\frac{(T-t_1)^5}{120} \end{array} \right\} \\ + C_s + C_p R\, t_1 \end{array} \right]$$

Now we optimize TAC (T), for $\boldsymbol{I_1} \geq \boldsymbol{0}, \boldsymbol{R} > \propto \beta \boldsymbol{t}^{\boldsymbol{\beta}-\mathbf{1}} a\boldsymbol{I_1}$,$\boldsymbol{I_2} > \boldsymbol{I_1}$ and $\boldsymbol{I_2} \leq \boldsymbol{I_1}$

The optimal value of 'T' for the minimum total average cost is the solution of the non-linear equation in T

i.e. $\frac{d}{dt}(TAC) = 0$ provided that this obtained value of T satisfies the condition

$[\frac{d^2}{dt^2}(TAC)]_{t=T} > 0$

When T^*nnis the optimal value of T.

The above-constrained optimization problem can be solved using an iterative method when the values of the parameters are prescribed. Hence this objective is fulfilled using **MATHEMATICA12.0,** which returns us the optimal T and the Total optimal average cost (TAC) of the system.

4. Numerical Illustration

Example1:

In this section, we provided a numerical example to illustrate the above theory. Considering an inventory system with the following parameter values in proper units and the Numerical example implemented by MATHEMATICA 12.0. $\boldsymbol{\alpha = 2, \beta = 2, a = 0.08, b = 0.06, c = 0.04, d = 0.02, I_1 = 1500, I_2 = 2000, C_s = 2500, C_h = 7, C_p = 2, , t_1 = 2, R = 300}$.The total average cost *TAC**=15.2531 and the optimal value of *T**=0.9234.

Table 1: Effect of change in various parameters of example 1.

Changing parameter	% Change in the Parameter	*T**	*TAC**	% Change in *TAC**
C_h	50	0.87532	15.5621	2.026
	25	0.97321	14.2395	-6.645
	10	0.98342	12.5345	-17.823
	-10	0.99324	12.1543	-20.316
	-25	1.45462	11.9364	-21.745
	-50	2.32152	10.2135	-33.040
C_s	50	0.91783	21.7314	42.472
	25	0.93252	20.5075	34.448
	10	0.95276	17.4632	14.490
	-10	0.97673	14.7645	-3.203
	-25	0.98351	12.4164	-18.598
	-50	1.28427	10.3172	-32.360
C_p	50	0.87306	15.2544	0.009
	25	0.95732	15.3615	0.711
	10	0.98453	15.5437	1.905
	-10	0.99564	15.6528	2.620
	-25	1.32164	15.8774	4.093
	-50	2.52316	16.3543	7.220
I_1	50	0.95995	23.8113	56.108
	25	0.97132	19.3272	26.710
	10	0.98342	14.2112	-6.831
	-10	0.99352	9.11545	-40.239
	-25	0.99602	7.35461	-51.783
	-50	1.56743	5.37869	-64.737
I_2	50	1.32529	11.7554	-22.931
	25	0.99315	13.1624	-13.707
	10	0.95347	15.4657	1.394
	-10	0.91645	17.3659	13.852
	-25	0.87216	20.9985	37.667

	-50	0.83129	27.6683	81.395
R	50	0.9775	18.3484	20.293
	25	0.9874	18.4125	20.713
	10	0.99435	18.8595	23.644
	-10	1.00763	19.2883	26.455
	-25	1.10721	21.4986	40.946
	-50	1.24327	24.2534	59.007
t_1	50	0.8573	15.5504	1.949
	25	0.83912	15.5636	2.036
	10	0.82146	15.5832	2.164
	-10	0.81124	15.8313	3.791
	-25	0.80243	15.8946	4.206
	-50	0.78287	15.9647	

5. Sensitivity Analysis

We now study the effect of changes of values of the parameters $\boldsymbol{a}, \boldsymbol{b}, \boldsymbol{c}, \boldsymbol{d}, \boldsymbol{\alpha}, \boldsymbol{\beta}, \boldsymbol{t_1}, \boldsymbol{C_h}, \boldsymbol{C_s}, \boldsymbol{C_p}, \boldsymbol{R}, \boldsymbol{I_1}, \boldsymbol{I_2}$ on the optimal total cost. The 'Sensitivity analysis' is performed by changing each parameter by +50%,+25%,+10%,-10%,-25%,-50% taking a parameter at a time and keeping the remaining parameters unchanged.

The investigation has been based upon the previous numerical demonstration, and the consequences have appeared in table 1. The comment underneath has to be experienced.

a) *T** increases while *TAC** decreases with the decrease in the value of the parameter $\boldsymbol{C_h}$. The obtained result shows that *T** is moderately sensitive to change in C_h and *TAC** is highly sensitive to change in C_h.
b) *T** increases while *TAC** decreases with the decrease in the value of the parameter C_s. The obtained result shows that *T** is low sensitivity to Ch and TAC* change* is highly sensitive to C_h.
c) *T** increases while *TAC** increases with the decrease in the value of the parameter C_p. The obtained result shows that *T**is low sensitivity to Cp change,and *TAC** is moderately susceptible to change in C_p.
d) *T** increases while *TAC** decreases with the decrease in parameter I_1. The obtained result shows that *T** is low sensitive to change in I_1, and *TAC** is highly sensitive to change in I_1.
e) *T** decreases while *TAC** increases with the value of the parameter I_2. The obtained result shows that *T** is low sensitive to change in I_2 and *TAC** is highly sensitive to change in I_2.
f) *T**increases while *TAC** increases with the decrease in the value of the parameter *R*. The obtained result shows that *T** is low sensitivity to R, and TAC* change is susceptible to *R*.
g) *T** decreases while *TAC** increases with the reduction of the parameter t_1.The obtained result shows that *T*&TAC** are moderately sensitive to change in t_1.

6. Conclusion

This study has developed an inventory model for the cubic deterioration rate for fruits, vegetables, milk, sweets, and radioactive substances. The supermarket retailer faces this difficulty during trading products whose importance goes down with each passing moment. The demand rate is assumed Weibull function of time. The pattern in which the essential independent factors influencing the total average cost has also been projected through the sensitivity analysis column within this model. This very model can be highly appreciable for the industries in which the demand rate depends upon the time. This study aims to find out the total optimal average variable inventory cost at optimal inventory level, which is the total sum of the set-up cost, carrying charge, and procurement costs of inventory items.

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