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Analytical Study of Deterministic Inventory Model with Consideration of Biquadratic Demand Rate and Weibull Distribution as Deterioration Rate

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***Abstract*-This work investigates an inventory model for decomposing items or products with a biquadratic demand over time and uses Weibull distribution as deterioration rate. Shortages are permissible in the model. It also demonstrates that the biquadratic demand function is convex and provides the best solution. The convexity of this model is demonstrated via a three-dimensional graphical representation. To double-check the model, an illustration is made. The ideal solution has been subjected to a sensitivity analysis concerning main parameters, and the results have been presented.**

Keywords: **Deterioration, Biquadratic demand, Shortages, Total inventory cost, Weibull distribution.**

INTRODUCTION

Inventory is defined as the stock of items kept on hand to ensure a trade or business's efficient and smooth operation. It also contributes to the company's growth. Manufacturers, schools, farms, hospitals, and higher education institutions all rely on it. Both merchants and wholesalers must keep their inventory of things or products at a minimum. It is made up of several diverging conditions that can be turned into models. These circumstances could include deterministic demand, demand changes over time, degradation, and soforth.

The mathematical model is distributed into two kinds, i.e., Deterministic and Stochastic models. Deterministic and stochastic mathematical models are the two types of models available. The demand rate is constant in the Deterministic model. In inventory, demand is quite crucial. The demand rate was expected to remain constant in the basic inventory model. However, this isn't always possible.

For many inventory products, like fashionable items, dairy goods, electric items, fruits and vegetables, and so on, the hypothesis of not changing demand rate is not appropriate; the demand rate may be dependent on time, stock, and on price. Fruits, vegetables, medications, dairy products, and other items have a finite shelf life. They deteriorate over time. Items or things that deteriorate are referred to as degrading items. The inventory system is plagued by issues caused by the deterioration of items or products.

The change in demand rate could also be linear, i.e., demand might increase or decrease linearly with time. We employ a linear polynomial as a demand function for linear demand. It should occasionally be a significant change in demand, i.e., demand is rapidly increasing with relevance time. A biquadratic polynomial demand function can be utilized to achieve this increment. Biquadratic demand can help you reduce inventory costs and grow your business.

S.K. Ghosh and K.S. Chaudhuri (2004) created an order-level inventory model for a decaying item with by taking deterioration rate as Weibull distribution. An inventory mathematical model for degrading products with exponentially deteriorating demand was proposed by Liang- Yuh Ouyang, Kun-Shan WU, and Mei-Chuan CHENG (2005). In 2008, Ajanta Roy created a mathematical model for decaying items in which demand was depends on price. He'd also added a time-based holding cost. The case in which degrading rate follows Weibull distributions, C. K. Tripathy* and U. Mishra (2010) devised a listing model. A list model for decaying products was presented by R. Amutha and Dr. E. Chandrasekaran (2012). Demand was supposed to be a straight line in this model. The cost of holding is calculated as a linear function of time. Dr. Ravish Kumar Yadav and Ms. PratibhaYadav(2013) demonstrate the production model with assumption of cubic demand rate. R. Venkateswarlu and R. Mohan (2014) created a list model for deteriorating products constructed on the hypothesis that demand is a quadratic function of time. This concept was created to lower total inventory costs (TIC). Garima Sharma and Bhawna Vyas (2018) suggested a inventory model for decaying products with a Weibull distribution. Demand is measured to be a one degree function of time, with shortages permitted and partially backlogged. Ganesh Kumar, Sunita, and Ramesh Inaniyan (2020) proposed a listing model with a time-dependent demand rate employing various factors. It is supposed that the demand rate is a three degree polynomial of your time.

The demand rate is treated as a biquadratic polynomial of time in this paper, and the deterioration rate fluctuates with time. The cost of the order is believed to be constant and does not fluctuate over time. This model's convexity is checked using a three-dimensional graphical representation. To validate the model, an illustration is also created. The ideal solution has been subjected to a sensitivity analysis concerning essential factors, and the results are displayed.

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NORMS AND REPRESENTATIONS

The mathematical model is explained using the norms and representations listed below.

Norms

a, b, c, d, and e are constant.

The demand rate $f(t)$ at time t is supposed as $f(t) = \mathrm{a} + \mathrm{bt} + \mathrm{ct}^2 + \mathrm{dt}^3 + et^4$;a, b, c, d, e is constant.

Replenishment takes place.

Shortages are permitted.

$\theta(t) = \alpha\beta t^{\beta-1}$Denotes the deterioration rate.

Representations

C_{SC}	Shortage cost per unit per unit time.
C_{OC}	Ordering cost per order.
C_{DC}	Deterioration cost.
C_{HC}	Holding Cost.
W	The maximum inventory level for each ordering cycle.
S	Shortage level for each cycle.
Q	The order quantity ($Q = W + s$).
$Q(t)$	Inventory level at time t.
t_1	Time at which shortages start.
T	The total length of each ordering cycle.
TC	Total inventory cost over the period (0, T).
α	Scale Parameter
β	Shape Parameter

MATHEMATICAL FORMULATION

The graph below (Figure 1) shows how inventory changes over time. The ideal order quantity, Q, and the total optimal inventory cost, TC, are shown in this diagram.

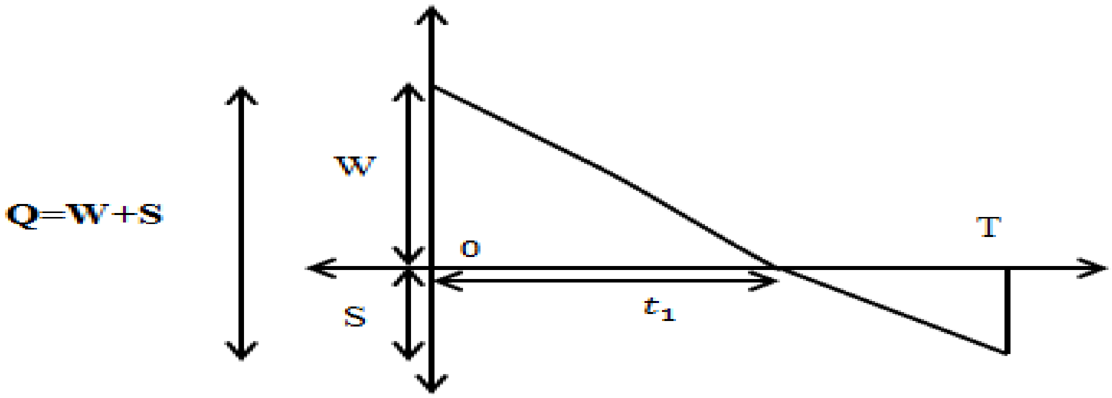

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Figure 1: Inventory level (Q) vs time

At t=0, the inventory level extents it's extreme, and refillinitiates. Following that, the inventory level lowers over the time range [0, t] until falling to zero at t=t_1. Further, at $t = t_1$ shortages occur during the time interval $[t_1, T]$.
Now till the shortages are allowed at interval $[0, t_1]$, the differential equation is given by:

$$\frac{dQ_1(t)}{dt} + \alpha\beta t^{\beta-1}Q_1(t) = -(a + bt + ct^2 + dt^3 + et^4); 0 \le t \le t_1 \quad (1)$$

And during the interval $[t_1, T]$, the shortage occurs, so the differential equation is given by:-

$$\frac{dQ_2(t)}{dt} = -(a + bt + ct^2 + dt^3 + et^4); t_1 \le t \le T \quad (2)$$

With the boundary conditions: t=0, Q(0)=W
T=t_1; Q(t_1)=0
T=T; Q(T)=S
Now, by solving the above equations (1), we get:

$$Q_1(t) = \Big[a(t_1 - t) + \frac{b}{2}(t_1^2 - t^2) + \frac{c}{3}(t_1^3 - t^3) + \frac{d}{4}(t_1^4 - t^4) + \frac{e}{5}(t_1^5 - t^5) + \frac{a\alpha}{\beta+1}\left(t_1^{\beta+1} - t^{\beta+1}\right) + \frac{b\alpha}{\beta+2}\left(t_1^{\beta+2} - t^{\beta+2}\right) + \frac{c\alpha}{\beta+3}\left(t_1^{\beta+3} - t^{\beta+3}\right) + \frac{d\alpha}{\beta+4}\left(t_1^{\beta+4} - t^{\beta+4}\right) + \frac{e\alpha}{\beta+5}\left(t_1^{\beta+5} - t^{\beta+5}\right) - \Big(a\alpha\left(t_1 t^{\beta} - t^{\beta+1}\right) + \frac{b\alpha}{2}\left(t_1^2 t^{\beta} - t^{\beta+2}\right) + \frac{c\alpha}{3}\left(t_1^3 t^{\beta} - t^{\beta+3}\right) + \frac{d\alpha}{4}\left(t_1^4 t^{\beta} - t^{\beta+4}\right) + \frac{e\alpha}{5}\left(t_1^5 t^{\beta} - t^{\beta+5}\right) + \frac{a\alpha^2}{\beta+1}\left(t_1^{\beta+1} t^{\beta} - t^{2\beta+1}\right) + \frac{b\alpha^2}{\beta+2}\left(t_1^{\beta+2} t^{\beta} - t^{2\beta+2}\right) + \frac{c\alpha^2}{\beta+3}\left(t_1^{\beta+3} t^{\beta} - t^{2\beta+3}\right) + \frac{d\alpha^2}{\beta+4}\left(t_1^{\beta+4} t^{\beta} - t^{2\beta+4}\right) + \frac{e\alpha^2}{\beta+5}\left(t_1^{\beta+5} t^{\beta} - t^{2\beta+5}\right)\Big)\Big]$$

By solving equation (2), we get:

$$Q_2(t) = a(t_1 - t) + \frac{b}{2}(t_1^2 - t^2) + \frac{c}{3}(t_1^3 - t^3) + \frac{d}{4}(t_1^4 - t^4) + \frac{e}{5}(t_1^5 - t^5) \quad (4)$$

(3)

Now, at t=0, the maximum inventory level for each cycle is given by:
Q(0)=W, t=0

$$W = Q_1(0) = at_1 + \frac{bt_1^2}{2} + \frac{ct_1^3}{3} + \frac{dt_1^4}{4} + \frac{et_1^5}{5} + \frac{a\alpha t_1{}^{\beta+1}}{\beta+1} + \frac{b\alpha t_1{}^{\beta+2}}{\beta+2} + \frac{c\alpha t_1{}^{\beta+3}}{\beta+3} + \frac{d\alpha t_1{}^{\beta+4}}{\beta+4} + \frac{e\alpha t_1{}^{\beta+5}}{\beta+5}$$

And at t=T, the maximum amount of cubic demand per cycle is given by:
t=T, Q_2(t)= -S

$$S = -\left(a(t_1 - T) + \frac{b}{2}(t_1^2 - T^2) + \frac{c}{3}(t_1^3 - T^3) + \frac{d}{4}(t_1^4 - T^4) + \frac{e}{5}(t_1^5 - T^5)\right)$$

Now, the order quantity per cycle is:

$$Q = W + S = at_1 + \frac{bt_1^2}{2} + \frac{ct_1^3}{3} + \frac{dt_1^4}{4} + \frac{et_1^5}{5} + \frac{a\alpha t_1{}^{\beta+1}}{\beta+1} + \frac{b\alpha t_1{}^{\beta+2}}{\beta+2} + \frac{c\alpha t_1{}^{\beta+3}}{\beta+3} + \frac{d\alpha t_1{}^{\beta+4}}{\beta+4} + \frac{e\alpha t_1{}^{\beta+5}}{\beta+5} - \left(a(t_1 - T) + \frac{b}{2}(t_1^2 - T^2) + \frac{c}{3}(t_1^3 - T^3) + \frac{d}{4}(t_1^4 - T^4) + \frac{e}{5}(t_1^5 - T^5)\right) \quad (5)$$

Holding cost per unit per unit time is given by:

$$\text{Holding Cost per cycle} = C_{HC} \int_0^{t_1} Q_1(t)dt$$

$$\text{Holding Cost per cycle} = C_{HC}\left(\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4} + \frac{dt_1^5}{5} + \frac{et_1^6}{6} + \frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)} + \frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)} + \frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)} + \frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)} + \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)} + \frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)} + \frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)} + \frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)} + \frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\right) \quad (6)$$

Shortages cost per unit per unit time is given by:

$$\text{Shortage Cost per cycle} = (-)\, C_{SC} \int_{t_1}^{T} Q_2(t)$$

$$\text{Shortage Cost per cycle} = -C_{SC}\left[a\left(t_1T - \frac{T^2}{2} - \frac{t_1^2}{2}\right) + b\left(\frac{t_1^2T}{2} - \frac{T^3}{6} - \frac{t_1^3}{3}\right) + c\left(\frac{t_1^3T}{3} - \frac{T^4}{12} - \frac{t_1^4}{4}\right) + d\left(\frac{t_1^4T}{4} - \frac{T^5}{20} - \frac{t_1^5}{5}\right) + e\left(\frac{t_1^5T}{5} - \frac{T^6}{30} - \frac{t_1^6}{6}\right)\right] \quad (7)$$

Ordering cost per order is given by:

$$\text{Ordering cost per order} = C_{OC} \quad (8)$$

Now, the deteriorating cost is given by:

$$\text{Cost due to Deterioration} = C_{DC}\left[W - \int_0^{t_1} Q(t)dt\right] \quad (9)$$

$$\text{Cost due to Deterioration} = C_{DC}\left[\frac{a\alpha t_1{}^{\beta+1}}{\beta+1} + \frac{b\alpha t_1{}^{\beta+2}}{\beta+2} + \frac{c\alpha t_1{}^{\beta+3}}{\beta+3} + \frac{d\alpha t_1{}^{\beta+4}}{\beta+4} + \frac{e\alpha t_1{}^{\beta+5}}{\beta+5}\right]$$

Therefore, the total cost per unit time per unit cycle is given by:

$$TC = \frac{1}{T}(\text{Holding Cost per cycle} + \text{Shortage Cost per cycle} + \text{Ordering cost per cycle} + \text{Cost due to Deterioration})$$

$$TC = \frac{1}{T}\Bigg\{C_{HC}\left[\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4} + \frac{dt_1^5}{5} + \frac{et_1^6}{6} + \frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)} + \frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)} + \frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)} + \frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)} + \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)} + \frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)} + \frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)} + \frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)} + \frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\right] + C_{SC}\left[a\left(t_1T - \frac{T^2}{2} - \frac{t_1^2}{2}\right) + b\left(\frac{t_1^2T}{2} - \frac{T^3}{6} - \frac{t_1^3}{3}\right) + c\left(\frac{t_1^3T}{3} - \frac{T^4}{12} - \frac{t_1^4}{4}\right) + d\left(\frac{t_1^4T}{4} - \frac{T^5}{20} - \frac{t_1^5}{5}\right) + e\left(\frac{t_1^5T}{5} - \frac{T^6}{30} - \frac{t_1^6}{6}\right)\right] + C_{OC} + C_{DC}\left[\frac{a\alpha t_1{}^{\beta+1}}{\beta+1} + \frac{b\alpha t_1{}^{\beta+2}}{\beta+2} + \frac{c\alpha t_1{}^{\beta+3}}{\beta+3} + \frac{d\alpha t_1{}^{\beta+4}}{\beta+4} + \frac{e\alpha t_1{}^{\beta+5}}{\beta+5}\right]\Bigg\}$$

This is the essential condition to minimize the total cost of inventory.

(10)

$$\frac{d(TC)}{dT} = -\frac{1}{T^2}\Big\{C_{HC}\Big[\frac{at_1^2}{2}+\frac{bt_1^3}{3}+\frac{ct_1^4}{4}+\frac{dt_1^5}{5}+\frac{et_1^6}{6}+\frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)}+\frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)}+\frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)}+\frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)}+\frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)}+\frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)}+\frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)}+\frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)}+\frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)}+\frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\Big]-C_{SC}\Big[a\Big(t_1 T-\frac{T^2}{2}-t_1\Big)+b\Big(\frac{t_1^2 T}{2}-\frac{T^3}{6}-\frac{t_1^3}{3}\Big)+c\Big(\frac{t_1^3 T}{3}-\frac{T^4}{12}-\frac{t_1^4}{4}\Big)+d\Big(\frac{t_1^4 T}{4}-\frac{T^5}{20}-\frac{t_1^5}{5}\Big)+e\Big(\frac{t_1^5 T}{5}-\frac{T^6}{30}-\frac{t_1^6}{6}\Big)\Big]+C_{OC}+C_{DC}\Big[\frac{a\alpha t_1{}^{\beta+1}}{\beta+1}+\frac{b\alpha t_1{}^{\beta+2}}{\beta+2}+\frac{c\alpha t_1{}^{\beta+3}}{\beta+3}+\frac{d\alpha t_1{}^{\beta+4}}{\beta+4}+\frac{e\alpha t_1{}^{\beta+5}}{\beta+5}\Big]\Big\}-\frac{1}{T}\Big\{C_{SC}\Big[a(t-T)+b\Big(\frac{t^2}{2}-\frac{T^2}{2}\Big)+c\Big(\frac{t^3}{3}-\frac{T^3}{3}\Big)+d\Big(\frac{t^4}{4}-\frac{T^4}{4}\Big)+e\Big(\frac{t^5}{5}-\frac{T^5}{5}\Big)\Big]\Big\}$$

$$\frac{d(TC)}{dt_1} = \frac{1}{T}\Big\{C_{HC}\Big[at_1^1+bt_1^2+ct_1^3+dt_1^4+et_1^5+\frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)t_1}+\frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)t_1}+\frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)t_1}+\frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)t_1}+\frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)t_1} \quad \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)t_1}-\frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)t_1}-\frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)t_1}-\frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)t_1}-\frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)t_1}\Big]-C_{SC}[a(T-t_1)+b(t_1 T-)+(t_1^2 T-t_1^3)+d(t_1^3 T-t_1^4)]+e(t_1^4 T-t_1^5)+C_{DC}\Big[\frac{a\alpha t_1{}^{\beta+1}}{t_1}+\frac{b\alpha t_1{}^{\beta+2}}{t_1}+\frac{c\alpha t_1{}^{\beta+3}}{t_1}+\frac{d\alpha t_1{}^{\beta+4}}{t_1}+\frac{e\alpha t_1{}^{\beta+5}}{t_1}\Big]\Big\} \quad (11)$$

We get the optimal values of t_1 and T by solving equations (11) & (12) by using MAPLE 15. (12)

NUMERICAL ILLUSTRATION:

Now check the optimality of the model with the help of numerical illustration and solve the illustration with the help of Maple 15.

To explain the model numerically, assume the following parameters of the inventory system are:

$$a = 10, b = 4, c = 4, d = 3, e = 1, C_{HC} = 4, C_{SC} = 15, C_{OC} = 100, C_{DC} = 10, \alpha = .1, \beta = .5$$

Under the above-given parameters, by using Maple 15 get the optimal shortage value t_1 =1.225416367per unit time and the optimal length of the ordering cycle is T=1.556794252unit time. The total inventory cost is TC=175.8805538

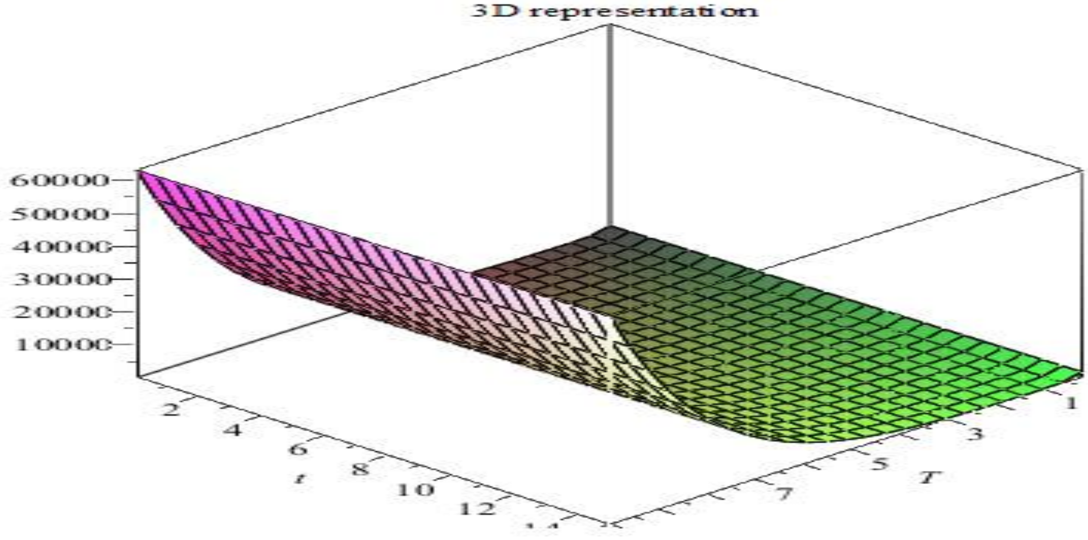

Figure 2: 3-Dimensional Graphical representation of TC of Inventory Model

SENSITIVITY ANALYSIS:

Here we study the effect of changes in the model parameters such that $w, x, y, z, C_{HS}, C_{CS}, C_{OC}, C_{DC}$, *and* θ.The outcome is given in the below table:

Parameter	% change	Change in			
		T	t_1	Q	TC

a	+20%	1.597550880	1.274069415	38.65517092	191.0561533
	+10%	1.577020782	1.249544947	35.93667087	183.5041291
	-10%	1.536952465	1.201815947	30.76197504	168.1885975
	-20%	1.517572654	1.178879348	28.30655892	160.4316979
b	+20%	1.501613821	1.1657930267	33.76754921	184.8439132
	+10%	1.547535314	1.215376063	33.38182725	176.9737570
	-10%	1.566115698	1.235561412	33.22434121	174.7736631
	-20%	1.575497192	1.245809515	33.13863488	173.6528493
c	+20%	1.528959210	1.196022110	33.03043667	178.0645596
	+10%	1.542674188	1.210490325	33.16683238	176.9878185
	-10%	1.571334524	1.240819200	33.44581050	174.7411413
	-20%	1.586310430	1.256718385	33.58806381	173.5678444
d	+20%	1.526796435	1.194217408	32.78385029	177.6603799
	+10%	1.541413981	1.209419932	33.03742838	176.7882722
	-10%	1.573012877	1.242286339	33.58908200	174.9340470
	-20%	1.590156715	1.260121373	33.89038569	173.9451283
e	+20%	1.542119986	1.210344266	32.99034601	176.5766696
	+10%	1.549331526	1.217754036	33.14480758	176.2328373
	-10%	1.564526134	1.233349296	33.47240987	175.5193374
	-20%	1.572547158	1.241572870	33.64654472	175.1486597
C_{HC}	+20%	1.478935859	1.087793616	29.71354209	182.4678092
	+10%	1.516649579	1.155467050	31.40682950	179.4165153
	-10%	1.600268496	1.298720922	35.47812836	171.7806808
	-20%	1.648207744	1.376665133	38.02178127	167.0135514
C_{SC}	+20%	1.6977757911	1.336163687	35.31614974	211.3422656
	+10%	1.580273789	1.283477927	34.52577782	181.9466968
	-10%	1.534580303	1.161692901	32.16839210	169.2916272
	-20%	1.514488320	1.091000064	31.14478206	162.1126338
C_{OC}	+20%	1.606659144	1.272009196	35.67659780	188.5209740
	+10%	1.582670774	1.249773287	34.51793138	182.2505081
	-10%	1.528600436	1.198397191	32.02679388	169.3991252
	-20%	1.497465938	1.167911761	30.66474128	162.7908682
C_{DC}	+20%	1.540301098	1.195608340	32.50905016	177.9193268
	+10%	1.548539670	1.210541511	32.90458989	176.9121422
	-10%	1.568123016	1.234881290	33.50519686	174.9101307
	-20%	1.573381075	1.255036810	34.12420314	173.7427724
α	+20%	1.538769470	1.192968937	32.74139579	178.0435188
	+10%	1.547731256	1.209159250	33.02324656	176.9785494
	-10%	1.565973304	1.241760817	33.58816307	174.7484009
	-20%	1.575283583	1.258213049	33.87221786	173.5808745
β	+20%	1.550507595	1.216311169	32.96001308	175.7267000
	+10%	1.553592004	1.220780829	33.12893369	175.8025768
	-10%	1.560122293	1.230228829	33.48980946	175.9606847
	-20%	1.563585054	1.235230629	33.68299989	176.0430154

a, b, TC, and Q will increase or decreasewith an increase or decrease, respectively.
With the increase in c, d, e, TC increase, and Q decrease.
If C_{DC} (Deterioration Cost) andC_{HC} (Holding Cost) increases, TCincreases, and Q willdecrease.
If C_{SC} (Shortage Cost), C_{OC} (Ordering Cost) increases, Q and TC willincrease.
If α increases, Q decrease, and TC l increase.
If βincreases, Q and TC alsoincrease.
On the basis of supposition of biquadratic demand and Weibull distribution as deterioration function different cases are arise:
CASE1: Study of Model in case of biquadratic demand and Weibull distribution with variable Holding Cost
In this case we find out the Total Inventory Cost and verify with the help of numerical illustration

$$HC = \int_0^{t_1} (A + Bt)\, Q_1(t)dt$$

With the help of equation (3), we get

$$HC = \int_0^{t_1} (A+Bt)\Bigg[a(t_1 - t) + \frac{b}{2}(t_1^2 - t^2) + \frac{c}{3}(t_1^3 - t^3) + \frac{d}{4}(t_1^4 - t^4) + \frac{e}{5}(t_1^5 - t^5) + \frac{a\alpha}{\beta+1}\left(t_1^{\beta+1} - t^{\beta+1}\right)$$
$$+ \frac{b\alpha}{\beta+2}\left(t_1^{\beta+2} - t^{\beta+2}\right) + \frac{c\alpha}{\beta+3}\left(t_1^{\beta+3} - t^{\beta+3}\right) + \frac{d\alpha}{\beta+4}\left(t_1^{\beta+4} - t^{\beta+4}\right) + \frac{e\alpha}{\beta+5}\left(t_1^{\beta+5} - t^{\beta+5}\right)$$
$$- \Bigg(a\alpha\left(t_1 t^{\beta} - t^{\beta+1}\right) + \frac{b\alpha}{2}\left(t_1^2 t^{\beta} - t^{\beta+2}\right) + \frac{c\alpha}{3}\left(t_1^3 t^{\beta} - t^{\beta+3}\right) + \frac{d\alpha}{4}\left(t_1^4 t^{\beta} - t^{\beta+4}\right) + \frac{e\alpha}{5}\left(t_1^5 t^{\beta} - t^{\beta+5}\right)$$
$$+ \frac{a\alpha^2}{\beta+1}\left(t_1^{\beta+1} t^{\beta} - t^{2\beta+1}\right) + \frac{b\alpha^2}{\beta+2}\left(t_1^{\beta+2} t^{\beta} - t^{2\beta+2}\right) + \frac{c\alpha^2}{\beta+3}\left(t_1^{\beta+3} t^{\beta} - t^{2\beta+3}\right)$$
$$+ \frac{d\alpha^2}{\beta+4}\left(t_1^{\beta+4} t^{\beta} - t^{2\beta+4}\right) + \frac{e\alpha^2}{\beta+5}\left(t_1^{\beta+5} t^{\beta} - t^{2\beta+5}\right)\Bigg)\Bigg] dt$$

$$HC = A\Bigg(\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4} + \frac{dt_1^5}{5} + \frac{et_1^6}{6} + \frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)} + \frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)}$$
$$+ \frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)} + \frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)} + \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)} + \frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)}$$
$$+ \frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)} + \frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)} + \frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\Bigg)$$
$$+ B\Bigg(\frac{at_1^3}{6} + \frac{bt_1^4}{8} + \frac{ct_1^5}{10} + \frac{dt_1^6}{12} + \frac{et_1^7}{14} + \frac{a\alpha t_1^{\beta+3}}{(\beta+3)(\beta+2)} + \frac{b\alpha t_1^{\beta+4}}{(\beta+2)(\beta+4)} + \frac{c\alpha t_1^{\beta+5}}{(\beta+2)(\beta+5)}$$
$$+ \frac{d\alpha t_1^{\beta+6}}{(\beta+2)(\beta+6)} + \frac{e\alpha t_1^{\beta+7}}{(\beta+2)(\beta+7)} + \frac{a\alpha^2 t_1^{2\beta+3}}{(\beta+2)(2\beta+3)} + \frac{b\alpha^2 t_1^{2\beta+4}}{(\beta+2)(2\beta+4)}$$
$$+ \frac{c\alpha^2 t_1^{2\beta+5}}{(\beta+2)(2\beta+5)} + \frac{d\alpha^2 t_1^{2\beta+6}}{(\beta+2)(2\beta+6)} + \frac{e\alpha^2 t_1^{2\beta+7}}{(\beta+2)(2\beta+7)}\Bigg)$$

$$TC = \frac{1}{T}(HC + SC + OC + DC)$$

$$TC = \frac{1}{T}\Bigg\{A\Bigg(\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4} + \frac{dt_1^5}{5} + \frac{et_1^6}{6} + \frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)} + \frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)}$$
$$+ \frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)} + \frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)} + \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)} + \frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)}$$
$$+ \frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)} + \frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)} + \frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\Bigg)$$
$$+ B\Bigg(\frac{at_1^3}{6} + \frac{bt_1^4}{8} + \frac{ct_1^5}{10} + \frac{dt_1^6}{12} + \frac{et_1^7}{14} + \frac{a\alpha t_1^{\beta+3}}{(\beta+3)(\beta+2)} + \frac{b\alpha t_1^{\beta+4}}{(\beta+2)(\beta+4)} + \frac{c\alpha t_1^{\beta+5}}{(\beta+2)(\beta+5)}$$
$$+ \frac{d\alpha t_1^{\beta+6}}{(\beta+2)(\beta+6)} + \frac{e\alpha t_1^{\beta+7}}{(\beta+2)(\beta+7)} + \frac{a\alpha^2 t_1^{2\beta+3}}{(\beta+2)(2\beta+3)} + \frac{b\alpha^2 t_1^{2\beta+4}}{(\beta+2)(2\beta+4)}$$
$$+ \frac{c\alpha^2 t_1^{2\beta+5}}{(\beta+2)(2\beta+5)} + \frac{d\alpha^2 t_1^{2\beta+6}}{(\beta+2)(2\beta+6)} + \frac{e\alpha^2 t_1^{2\beta+7}}{(\beta+2)(2\beta+7)}\Bigg) + C_{SC}\Bigg[a\left(t_1 T - \frac{T^2}{2} - \frac{t_1^2}{2}\right)$$
$$+ b\left(\frac{t_1^2 T}{2} - \frac{T^3}{6} - \frac{t_1^3}{3}\right) + c\left(\frac{t_1^3 T}{3} - \frac{T^4}{12} - \frac{t_1^4}{4}\right) + d\left(\frac{t_1^4 T}{4} - \frac{T^5}{20} - \frac{t_1^5}{5}\right) + e\left(\frac{t_1^5 T}{5} - \frac{T^6}{30} - \frac{t_1^6}{6}\right)\Bigg]$$
$$+ C_{DC}\left[\frac{a\theta t_1^3}{6} + \frac{b\theta t_1^4}{8} + \frac{c\theta t_1^5}{10} + \frac{d\theta t_1^6}{12} + \frac{e\theta t_1^7}{14}\right] + C_{OC}\Bigg\}$$

This is the essential condition to minimize the total cost of inventory.

$$\frac{d(TC)}{dT}=-\frac{1}{T^2}\Bigg\{A\Bigg(\frac{at_1^2}{2}+\frac{bt_1^3}{3}+\frac{ct_1^4}{4}+\frac{dt_1^5}{5}+\frac{et_1^6}{6}+\frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)}+\frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)}+\frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)}$$
$$+\frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)}+\frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)}+\frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)}+\frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)}$$
$$+\frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)}+\frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)}+\frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\Bigg)$$
$$+B\Bigg(\frac{at_1^3}{6}+\frac{bt_1^4}{8}+\frac{ct_1^5}{10}+\frac{dt_1^6}{12}+\frac{et_1^7}{14}+\frac{a\alpha t_1^{\beta+3}}{(\beta+3)(\beta+2)}+\frac{b\alpha t_1^{\beta+4}}{(\beta+2)(\beta+4)}+\frac{c\alpha t_1^{\beta+5}}{(\beta+2)(\beta+5)}$$
$$+\frac{d\alpha t_1^{\beta+6}}{(\beta+2)(\beta+6)}+\frac{e\alpha t_1^{\beta+7}}{(\beta+2)(\beta+7)}+\frac{a\alpha^2 t_1^{2\beta+3}}{(\beta+2)(2\beta+3)}+\frac{b\alpha^2 t_1^{2\beta+4}}{(\beta+2)(2\beta+4)}$$
$$+\frac{c\alpha^2 t_1^{2\beta+5}}{(\beta+2)(2\beta+5)}+\frac{d\alpha^2 t_1^{2\beta+6}}{(\beta+2)(2\beta+6)}+\frac{e\alpha^2 t_1^{2\beta+7}}{(\beta+2)(2\beta+7)}\Bigg)+C_{SC}\Bigg[a\left(t_1T-\frac{T^2}{2}-\frac{t_1^2}{2}\right)$$
$$+b\left(\frac{t_1^2T}{2}-\frac{T^3}{6}-\frac{t_1^3}{3}\right)+c\left(\frac{t_1^3T}{3}-\frac{T^4}{12}-\frac{t_1^4}{4}\right)+d\left(\frac{t_1^4T}{4}-\frac{T^5}{20}-\frac{t_1^5}{5}\right)+e\left(\frac{t_1^5T}{5}-\frac{T^6}{30}-\frac{t_1^6}{6}\right)\Bigg]$$
$$+C_{DC}\left[\frac{a\theta t_1^3}{6}+\frac{b\theta t_1^4}{8}+\frac{c\theta t_1^5}{10}+\frac{d\theta t_1^6}{12}+\frac{e\theta t_1^7}{14}\right]+C_{OC}\Bigg\}$$
$$-\frac{1}{T}\left[C_{SC}\left(a(t_1-T)+b\left(\frac{t_1^2}{2}-\frac{T^2}{2}\right)+c\left(\frac{t_1^3}{3}-\frac{T^3}{3}\right)+d\left(\frac{t_1^4}{4}-\frac{T^4}{4}\right)+e\left(\frac{t_1^5}{5}-\frac{T^5}{5}\right)\right)\right]$$

$$\frac{d(TC)}{dt_1}=\frac{1}{T}\Bigg\{\Bigg(A\alpha t_1+3\left(\frac{Ab}{3}+\frac{Ba}{6}\right)t_1^2+4\left(\frac{Ac}{4}+\frac{Bb}{8}\right)t_1^3+5\left(\frac{Ad}{5}+\frac{Bc}{10}\right)t_1^4+6\left(\frac{Ae}{6}+\frac{Bd}{12}\right)t_1^5+\frac{Bet_1^6}{2}$$
$$+\frac{Aa\alpha\beta t_1^{\beta+2}}{(\beta+1)t_1}+\frac{1}{t_1}\left(\frac{Ab}{(\beta+1)}+\frac{Ba}{2\beta+4}\right)\alpha\beta t_1^{\beta+3}+\frac{1}{t_1}\left(\frac{Ac}{(\beta+1)}+\frac{Bb}{2\beta+4}\right)\alpha\beta t_1^{\beta+4}$$
$$+\frac{1}{t_1}\left(\frac{Ad}{(\beta+1)}+\frac{Bc}{2\beta+4}\right)\alpha\beta t_1^{\beta+5}+\frac{1}{t_1}\left(\frac{Ae}{(\beta+1)}+\frac{Bd}{2\beta+4}\right)\alpha\beta t_1^{\beta+6}+\frac{Be\alpha\beta t_1^{\beta+7}}{2(\beta+2)t_1}-\frac{Aa\alpha^2 t_1^{2\beta+2}}{(\beta+1)t_1}$$
$$-\frac{1}{t_1}\left(\frac{Ab}{(\beta+1)}+\frac{Ba}{\beta+2}\right)\alpha^2 t_1^{2\beta+3}-\frac{1}{t_1}\left(\frac{Ac}{(\beta+1)}+\frac{Bb}{\beta+2}\right)\alpha^2 t_1^{2\beta+4}$$
$$-\frac{1}{t_1}\left(\frac{Ad}{(\beta+1)}+\frac{Bc}{\beta+2}\right)\alpha^2 t_1^{2\beta+5}-\frac{1}{t_1}\left(\frac{Ae}{(\beta+1)}+\frac{Bd}{\beta+2}\right)\alpha^2 t_1^{2\beta+6}-\frac{Be\alpha^2 t_1^{2\beta+2}}{(\beta+1)t_1}\Bigg)$$
$$-C_{SC}[a(T-t_1)+b(t_1T-t_1^2)+(t_1^2T-t_1^3)+d(t_1^3T-t_1^4)]+e(t_1^4T-t_1^5)$$
$$+C_{DC}\left[\frac{a\alpha t_1^{\beta+1}}{t_1}+\frac{b\alpha t_1^{\beta+2}}{t_1}+\frac{c\alpha t_1^{\beta+3}}{t_1}+\frac{d\alpha t_1^{\beta+4}}{t_1}+\frac{e\alpha t_1^{\beta+5}}{t_1}\right]\Bigg\}$$

NUMERICAL ILLUSTRATION:

Now check the optimality of the model with the help of numerical illustration and solve the illustration with the help of Maple 15.

To explain the model numerically, assume the following parameters of the inventory system are:

$$a=10, b=4, c=4, d=3, e=1, C_{SC}=15, C_{OC}=100, C_{DC}=10, \alpha=0.1, \beta=0.5, A=1, B=1$$

Under the above-given parameters, by using Maple 15 get the optimal shortage value t_1 = 1.691902646per unit time and the optimal length of the ordering cycle is T=1.855814734unit time. The total inventory cost is TC=138.7049825

CASE 2: Study of Model in case of biquadratic demand and Weibull distribution with Variable Ordering Cost

$$OC = \frac{C_{OC}}{T}$$

$$TC = \frac{1}{T}\left(C_{HC}\left(\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4} + \frac{dt_1^5}{5} + \frac{et_1^6}{6} + \frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)} + \frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)} + \frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)} + \frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)} + \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)} + \frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)} + \frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)} + \frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)} + \frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\right) - C_{SC}\left[a\left(t_1T - \frac{T^2}{2} - \frac{t_1^2}{2}\right) + b\left(\frac{t_1^2T}{2} - \frac{T^3}{6} - \frac{t_1^3}{3}\right) + c\left(\frac{t_1^3T}{3} - \frac{T^4}{12} - \frac{t_1^4}{4}\right) + d\left(\frac{t_1^4T}{4} - \frac{T^5}{20} - \frac{t_1^5}{5}\right) + e\left(\frac{t_1^5T}{5} - \frac{T^6}{30} - \frac{t_1^6}{6}\right)\right] + \frac{C_{OC}}{T} + C_{DC}\left[\frac{a\alpha {t_1}^{\beta+1}}{\beta+1} + \frac{b\alpha {t_1}^{\beta+2}}{\beta+2} + \frac{c\alpha {t_1}^{\beta+3}}{\beta+3} + \frac{d\alpha {t_1}^{\beta+4}}{\beta+4} + \frac{e\alpha {t_1}^{\beta+5}}{\beta+5}\right]\right)$$

This is the essential condition to minimize the total cost of inventory.

$$\frac{d(TC)}{dT} = -\frac{1}{T^2}\left\{C_{HC}\left[\frac{at_1^2}{2} + \frac{bt_1^3}{3} + \frac{ct_1^4}{4} + \frac{dt_1^5}{5} + \frac{et_1^6}{6} + \frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)(\beta+2)} + \frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)(\beta+3)} + \frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)(\beta+4)} + \frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)(\beta+5)} + \frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)(\beta+6)} + \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)(2\beta+2)} + \frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)(2\beta+3)} + \frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)(2\beta+4)} + \frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)(2\beta+5)} + \frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)(2\beta+6)}\right] - C_{SC}\left[a\left(t_1T - \frac{T^2}{2} - t_1\right) + b\left(\frac{t_1^2T}{2} - \frac{T^3}{6} - \frac{t_1^3}{3}\right) + c\left(\frac{t_1^3T}{3} - \frac{T^4}{12} - \frac{t_1^4}{4}\right) + d\left(\frac{t_1^4T}{4} - \frac{T^5}{20} - \frac{t_1^5}{5}\right) + e\left(\frac{t_1^5T}{5} - \frac{T^6}{30} - \frac{t_1^6}{6}\right)\right] + \frac{C_{OC}}{T} + C_{DC}\left[\frac{a\alpha {t_1}^{\beta+1}}{\beta+1} + \frac{b\alpha {t_1}^{\beta+2}}{\beta+2} + \frac{c\alpha {t_1}^{\beta+3}}{\beta+3} + \frac{d\alpha {t_1}^{\beta+4}}{\beta+4} + \frac{e\alpha {t_1}^{\beta+5}}{\beta+5}\right]\right\} - \frac{1}{T}\left\{C_{SC}\left[a(t-T) + b\left(\frac{t^2}{2} - \frac{T^2}{2}\right) + c\left(\frac{t^3}{3} - \frac{T^3}{3}\right) + d\left(\frac{t^4}{4} - \frac{T^4}{4}\right) + e\left(\frac{t^5}{5} - \frac{T^5}{5}\right)\right] + \frac{C_{OC}}{T^2}\right\}$$

$$\frac{d(TC)}{dt_1} = \frac{1}{T}\left\{C_{HC}\left(at_1^1 + bt_1^2 + ct_1^3 + dt_1^4 + et_1^5 + \frac{a\alpha\beta t_1^{\beta+2}}{(\beta+1)t_1} + \frac{b\alpha\beta t_1^{\beta+3}}{(\beta+1)t_1} + \frac{c\alpha\beta t_1^{\beta+4}}{(\beta+1)t_1} + \frac{d\alpha\beta t_1^{\beta+5}}{(\beta+1)t_1} + \frac{e\alpha\beta t_1^{\beta+6}}{(\beta+1)t_1} - \frac{a\alpha^2 t_1^{2\beta+2}}{(\beta+1)t_1} - \frac{b\alpha^2 t_1^{2\beta+3}}{(\beta+1)t_1} - \frac{c\alpha^2 t_1^{2\beta+4}}{(\beta+1)t_1} - \frac{d\alpha^2 t_1^{2\beta+5}}{(\beta+1)t_1} - \frac{e\alpha^2 t_1^{2\beta+6}}{(\beta+1)t_1}\right) - C_{SC}[a(T - t_1) + b(t_1T - t_1^2) + (t_1^2T - t_1^3) + d(t_1^3T - t_1^4)] + e(t_1^4T - t_1^5) + C_{DC}\left[\frac{a\alpha {t_1}^{\beta+1}}{t_1} + \frac{b\alpha {t_1}^{\beta+2}}{t_1} + \frac{c\alpha {t_1}^{\beta+3}}{t_1} + \frac{d\alpha {t_1}^{\beta+4}}{t_1} + \frac{e\alpha {t_1}^{\beta+5}}{t_1}\right]\right\}$$

NUMERICAL ILLUSTRATION

Now check the optimality of the model with the help of numerical illustration and solve the illustration with the help of Maple 15.

To explain the model numerically, assume the following parameters of the inventory system are:

$$a = 10, b = 4, c = 4, d = 3, e = 1, C_{HC} = 4, C_{SC} = 15, C_{OC} = 100, C_{DC} = 10, \alpha = 0.1, \beta = 0.5$$

Under the above-given parameters, by using Maple 15 get the optimal shortage value t_1 = 1.280008147 per unit time and the optimal length of the ordering cycle is T=1.615370973unit time. The total inventory cost is TC=152.5636318

CONCLUSION

The sensitivity analysis found that in the case of biquadratic demand (a function of time), the model predicts that the rate of deterioration will alter over time. It can be shown that parameters a and b are directly proportional to TC and Q, whereas the parameters c, d, e, C_{HC}, and C_{DC} are inversely proportional to Q. It also demonstrates that this technique can be used to determine the total inventory cost. This also shows that Total Inventory Cost minimizes in case of variable holding cost. Finally, a graphical depiction is used to verify the model. The obtained findings determine the model's stability. This model can be expanded or replaced with a different demand rate.

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