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Effects on Inventory Model in Time Deteriorate Rate with Variable Cost

Garima Khare[1], Garima Sharma[2]

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Abstract: This paper anticipates showing the optimistic a reflection of an inventory model employing quadratic demand, scarcity allows, and time-dependent with varying degradation rate with ordering and storage cost. The impact of such criteria on the total cost of the inventory will be evaluated. The conceptual frameworks are then illustrated by numerical examples, and sensitivity analysis of the key variables affecting the appropriate solution is also performed.

Keywords: *Inventory Model, Degradation rate, Demand, Shortages, Time-Dependent Holding and variable Ordering Cost.*

1. Introduction

Mathematical principles have been industrialized in recent years for a variety of real-life problems, mostly for controlling inventory. The organization's next biggest concern is deciding when and in what quantities to order so that the overall cost associated with the inventory structure will be as low as possible. The inventory system analysis is commonly accepted without taking into account the consequences of deterioration in the inventory system. Deterioration is defined as damage, decay, aridity, fading, and so forth. Foods such as fruits, vegetables, fish, meat, photographic film, battery packs, tissue samples, and series of images are examples of delicate items. Many academics have studied the inventory problem with limited or infinite production rates using various production rates and different types of demand. Typically, quatern demand types are expected in inventory models: (a) constant demand, (b) time-dependent demand, (c) probabilistic demand, and (d) securities demand. Using the deterioration of possessions, the inventory for worsening goods was initially deliberate in 1952 by Whitin [1]. Between 1968 to 1985, Emmons, Azoury and Miller expanded the approach [2],[3]. Two-parameter variable degradation rate Covert and Philip's 1973 Weibull distribution contains a time-quadratic demand rate, inventory shortages, and a time-dependent holding cost [4]. Goswami, A., & Chaudhuri, K. S. considered linear demand in their inventory model in 1991 [5]. Gupta and Gerchak reported in 1995 the simultaneous selection of product durability and order quantity for things that degrade over time [6]. In 1999, Chang and Dye published a thorough analysis of literature in decline. They claimed to have created a model of inventories for degrading items with some backlog[7]. It was projected by Uttam Kumar Khedelkar, Diwahar Shukla, and Raghovendra Pratap Singh Chandel that a logarithmic inventory model would have a deficit of degrading items. Ghosh and Chaudhuri and Khara and Chaudhuri afterwards recognized their models with quadratic time-varying order between 2004 and 2006 [8].

Vinod Kumar et al. built a partial backlog inventory model for degrading products with time-dependent demand and time-varying holding costs in 2013 [9]. Ajanta Roy developed a model for decaying products with price-dependent order and time-varying holding costs in 2008 [10].

In 2014, Bhanu Priya and Trailokyanath Singh proposed a model for exponentially falling demand and time-varying holding costs [11]. Mohan and R. Venkateswarlu devised a model for quadratic order with time-dependent deterioration without shortages and salvage value in 2017 [12]. In 2018, Kavitha Priya and K. Senbagam developed a model for time-dependent deteriorating products with quadratic time-varying demand and partial backlog [13].

[1] *Research Scholar, Department of Mathematics, Mody University of Science and technology, Lakshmangarh, Rajasthan, India*
[2] *Assistant Professor, Department of Mathematics, Mody University of Science and technology, Lakshmangarh, Rajasthan, India*

We expanded on the research done by Suman and Garima Sharma on the inventory model for a time-dependent decaying items and varying storage cost [14].

This study examined inventory models for degrading goods with time-dependent quadratic demand and variable holding and ordering costs. Here, we assume that the inventory model's deterioration rate is dependent on time. Numerical examples are utilized to perform this sensitivity analysis.

2. Assumptions and Notations

This mathematical model is described by using the following assumptions and notations. Assumptions are,

(i). The degradation rate $f(t)$ at times it is assumed as $f(t) = v_1 + v_2 t + v_3 t^2$; v_1, v_2, and v_3 are constants.
(ii). Replenishment occurs.
(iii). Shortages are allowed.
(iv). $\theta(t) = \theta t$ is the degradation rate.
(v). Holding cost and ordering cost both are variable.
(vi). Here cost of Holding varies with time. i.e. $P_H = \alpha + \beta t$, where $\alpha > 0, \beta > 0$.
(vii). Here Ordering cost is $P_o = q^{\gamma - 1}$ where $q > 0,\ \gamma > 0$.

Notations are

- P_S = Shortage Cost per unit time.
- P_o = Ordering cost per order.
- P_D = Deterioration cost.
- W =The maximum inventory level for ever cycle of ordering.
- S = The maximum amount of inventory.
- Q = The order quantity $(Q = W + S)$.
- $I(t)$ = Level of inventory at time t.
- t_1 = he moment a shortage begins.
- T =Total length of each ordering cycle.
- TIC =Inventory total cost per order period $(0, T)$.
- α = Holding cost parameter.
- β = Holding cost parameter.

3. Model Formulation:

The replenishment of a decaying commodity with shortages and variable holding and ordering costs is assumed in this work. We note the optimal order quantity, Q, and the total optimal inventory cost.

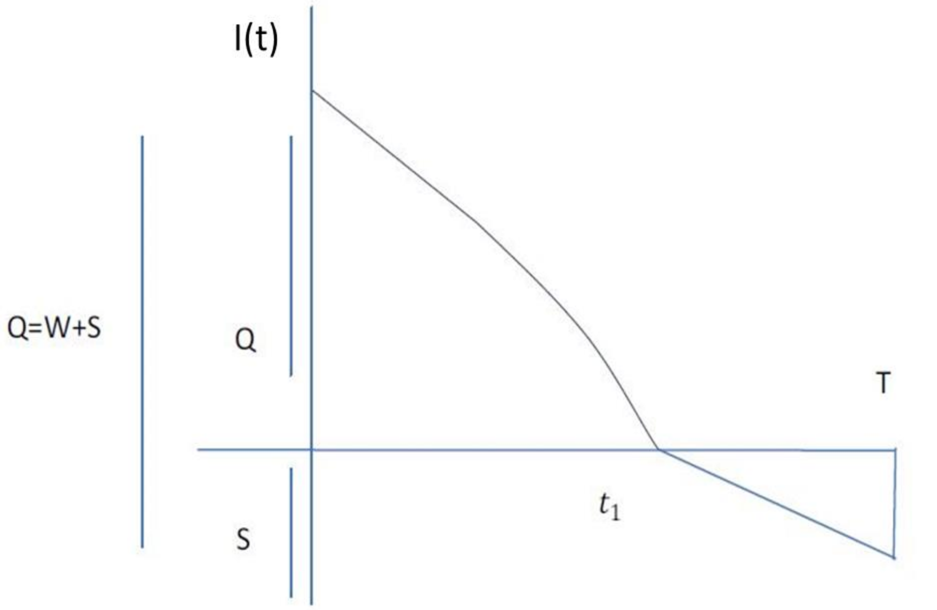

Figure1- Inventory level I(t) vs time

The inventory level maximum at $t = 0$, and replenishment is complete, i.e., W. In this interval $[0, t_1]$, the demand and deterioration of items in the inventory level decline linearly and then decrease to zero over time $t = t_1$. Further, at $t1$, shortages occur during the time interval $[t_1, T]$, and at the time $t = T$ reaches the maximum inventory level, i.e., S. The below graph (figure 1) represents the inventory behaviour at any time. Now till the shortages are allowed at interval $[0, t_1]$, the differential equation is given by

$$\frac{dI_1(t)}{dt} + \theta t I(t) = -(v_1 + v_2 t + v_3 t^2);\ 0 \le t \le t_1 \quad (1)$$

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

$$\frac{dI_1(t)}{dt} == -(v_1 + v_2 t + v_3 t^2);\ t_1 \le t \le T \quad (2)$$

With the boundary conditions: $t = 0, I(0) = W$,

$t = t_1; I(t_1) = 0$

$t = T;\ I(T) = S$

Now by solving equation (1), we get,

$$I(t_1) = v_1(t_1 - t) + \frac{v_2}{2}({t_1}^2 - t^2) + \frac{v_3}{3}({t_1}^3 - t^3) + \frac{v_1\theta}{6}({t_1}^3 - t^3) + \frac{v_2\theta}{8}({t_1}^4 - t^4) + \frac{v_3\theta}{10}({t_1}^5 - t^5) - \frac{v_1\theta}{2}({t_1}^2 t_1 - t^3) - \frac{v_2\theta}{4}(t^2{t_1}^2 - t^4) - \frac{v_3\theta}{6}\left(t^2{t_1}^3 - t^5\right) - \frac{v_1\theta^2}{12}(t^2{t_1}^3 - t^5) - \frac{v_2\theta^2}{16}(t^2{t_1}^4 - t^6) - \frac{v_3\theta^2}{20}\left(t^2{t_1}^5 - t^7\right) \quad (3)$$

By solving equation (2), we get:

$$I(t_2) = v_1(t_1 - t) + \frac{v_2}{2}({t_1}^2 - t^2) + \frac{v_3}{3}({t_1}^3 - t^3) \quad (4)$$

Now, at $t = 0$ the maximum inventory level for each cycle is given by

$I(0) = W, t = 0$

$$W = I_1(0) = v_1 t_1 + \frac{v_2}{2}{t_1}^2 + \frac{v_3}{3}{t_1}^3 + \frac{v_1\theta}{6}{t_1}^3 + \frac{v_2\theta}{8}{t_1}^4 + \frac{v_3\theta}{10}{t_1}^5$$

And at $t = T$ the maximum amount of quadratic demand per cycle is given by

$t = T, I_2(t) = -S$

$$S = -v_1(t_1 - T) - \frac{v_2}{2}({t_1}^2 - T^2) - \frac{v_3}{3}({t_1}^3 - T^3)$$

Now, the order quantity per cycle is,

$$Q = W + S = v_1 t_1 + \frac{v_2}{2}{t_1}^2 + \frac{v_3}{3}{t_1}^3 + \frac{v_1\theta}{6}{t_1}^3 + \frac{v_2\theta}{8}{t_1}^4 + \frac{v_3\theta}{10}{t_1}^5 - v_1(t_1 - T) - \frac{v_2}{2}({t_1}^2 - T^2) - \frac{v_3}{3}({t_1}^3 - T^3) \quad (5)$$

Holding cost per unit time is given by,

$$HC = \int_0^{t_1} (\alpha + \beta t) I_1(t)$$

$$HC = \frac{1}{2}\alpha v_1 t_1^2 + \left(\frac{1}{3}\alpha v_2 + \frac{1}{6}\beta v_1\right) t_1^3 + \left[\alpha\left(\frac{1}{4}v_3 + \frac{1}{12}v_1\theta\right) + \frac{1}{8}\beta v_2\right] t_1^4 + \left[\frac{1}{15}\alpha v_2\theta + \beta\left(\frac{1}{10}v_3 + \frac{1}{40}v_1\theta\right)\right] t_1^5 + \left[\alpha\left(\frac{1}{18}v_3\theta - \frac{1}{72}v_1\theta^2\right) + \frac{1}{48}\beta v_2\theta\right] t_1^6 + \left[\beta\left(\frac{1}{56}v_3\theta - \frac{1}{112}v_1\theta^2\right) - \frac{1}{84}\alpha v_2\theta^2\right] t_1^7 - \left(\frac{1}{96}\alpha v_3\theta^2 + \frac{1}{128}\beta v_2\theta^2\right) t_1^8 - \frac{1}{144}\beta v_3\theta^2 t_1^9 \quad (6)$$

Ordering cost per order is given by:

$$OC = P_o = q^{\gamma-1} \quad (7)$$

Now, the deteriorating cost is given by,

$$D = P_D\left[W - \int_0^{t_1} f(t)dt\right]$$

$$DC = P_D\left[\frac{v_1\theta t_1^3}{6} + \frac{v_2\theta t_1^4}{8} + \frac{v_3\theta t_1^5}{10}\right] \quad (8)$$

Shortages cost per unit time is given by

$$SC = -P_S\int_{t_1}^{T} I_2(t)$$

$$SC = -P_S\left[v_1\left(t_1T - \frac{T^2}{2} - \frac{t_1^2}{2}\right) + v_2\left(\frac{t_1^2T}{2} - \frac{T^3}{6} - \frac{t_1^3}{3}\right) + v_3\left(\frac{t_1^3T}{3} - \frac{T^4}{12} - \frac{t_1^4}{4}\right)\right] \quad (9)$$

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

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

$$= \frac{1}{T}\Big[\frac{1}{2}\alpha v_1 t_1^2 + \left(\frac{1}{3}\alpha v_2 + \frac{1}{6}\beta v_1\right) t_1^3 + \left\{\alpha\left(\frac{1}{4}v_3 + \frac{1}{12}v_1\theta\right) + \frac{1}{8}\beta v_2\right\} t_1^4 + \left\{\frac{1}{15}\alpha v_2\theta + \beta\left(\frac{1}{10}v_3 + \frac{1}{40}v_1\theta\right)\right\} t_1^5 + \left\{\alpha\left(\frac{1}{18}v_3\theta - \frac{1}{72}v_1\theta^2\right) + \frac{1}{48}\beta v_2\theta\right\} t_1^6 + \left\{\beta\left(\frac{1}{56}v_3\theta - \frac{1}{112}v_1\theta^2\right) - \frac{1}{84}\alpha v_2\theta^2\right\} t_1^7 - \left(\frac{1}{96}\alpha v_3\theta^2 + \frac{1}{128}\beta v_2\theta^2\right) t_1^8 - \frac{1}{144}\beta v_3\theta^2 t_1^9 - P_S\left\{v_1\left(t_1T - \frac{1}{2}T^2 - \frac{1}{2}t_1\right) + v_2\left(\frac{1}{2}t_1^2T - \frac{1}{6}T^3 - \frac{1}{3}t_1^3\right) + v_3\left(\frac{1}{3}t_1^3T - \frac{1}{12}T^4 - \frac{1}{4}t_1^4\right)\right\} + q^{\gamma-1} + P_D\left(\frac{1}{6}v_1\theta t_1^3 + \frac{1}{8}v_2\theta t_1^4 + \frac{1}{10}v_3\theta t_1^5\right)\Big] \quad (10)$$

The model's goal is to identify the appropriate values of t_1 and T to reduce the average total cost per unit of time, or TIC. For the optimal value, we have to get a partial derivative of t_1 and T and equating to zero.

$$\frac{d(TIC)}{dT} = -\frac{1}{T^2}\Big[\frac{1}{2}\alpha v_1 t_1^2 + \left(\frac{1}{3}\alpha v_2 + \frac{1}{6}\beta v_1\right) t_1^3 + \left\{\alpha\left(\frac{1}{4}v_3 + \frac{1}{12}v_1\theta\right) + \frac{1}{8}\beta v_2\right\} t_1^4 + \left\{\frac{1}{15}\alpha v_2\theta + \beta\left(\frac{1}{10}v_3 + \frac{1}{40}v_1\theta\right)\right\} t_1^5 + \left\{\alpha\left(\frac{1}{18}v_3\theta - \frac{1}{72}v_1\theta^2\right) + \frac{1}{48}\beta v_2\theta\right\} t_1^6 + \left\{\beta\left(\frac{1}{56}v_3\theta - \frac{1}{112}v_1\theta^2\right) - \frac{1}{84}\alpha v_2\theta^2\right\} t_1^7 -$$

$$\left(\frac{1}{96}\alpha v_3\theta^2 + \frac{1}{128}\beta v_2\theta^2\right) t_1^8 - \frac{1}{144}\beta v_3\theta^2 t_1^9 - P_S\left\{v_1\left(t_1T - \frac{1}{2}T^2 - \frac{1}{2}t_1\right) + v_2\left(\frac{1}{2}t_1^2T - \frac{1}{6}T^3 - \frac{1}{3}t_1^3\right) + v_3\left(\frac{1}{3}t_1^3T - \frac{1}{12}T^4 - \frac{1}{4}t_1^4\right)\right\} + q^{\gamma-1} + P_D\left(\frac{1}{6}v_1\theta t_1^3 + \frac{1}{8}v_2\theta t_1^4 + \frac{1}{10}v_3\theta t_1^5\right)\Bigg] - \frac{P_S\left\{v_1(t_1-T)+v_2\left(\frac{1}{2}t_1^2-T^2\right)+v_3\left(\frac{1}{3}t_1^3-\frac{1}{3}T^3\right)\right\}}{T} \qquad (11)$$

$$\frac{d(TIC)}{dt_1} = \frac{1}{T}\Bigg[\alpha v_1 t_1 + 3\left(\frac{1}{3}\alpha v_2 + \frac{1}{6}\beta v_1\right)t_1^2 + 4\left\{\alpha\left(\frac{1}{4}v_3 + \frac{1}{12}v_1\theta\right) + \frac{1}{8}\beta v_2\right\}t_1^3 + 5\left\{\frac{1}{15}\alpha v_2\theta + \beta\left(\frac{1}{10}v_3 + \frac{1}{40}v_1\theta\right)\right\}t_1^4 + 6\left\{\alpha\left(\frac{1}{18}v_3\theta - \frac{1}{72}v_1\theta^2\right) + \frac{1}{48}\beta v_2\theta\right\}t_1^5 + 7\left\{\beta\left(\frac{1}{56}v_3\theta - \frac{1}{112}v_1\theta^2\right) - \frac{1}{84}\alpha v_2\theta^2\right\}t_1^6 - 8\left(\frac{1}{96}\alpha v_3\theta^2 + \frac{1}{128}\beta v_2\theta^2\right)t_1^7 - \frac{1}{16}\beta v_3\theta^2 - P_S\left\{v_1\left(T - \frac{1}{2}\right) + v_2(t_1T - t_1^2) + v_3(t_1^2T - t_1^3)\right\} + P_D\left\{\frac{v_1\theta t_1^2}{2} + \frac{v_2\theta t_1^3}{2} + \frac{v_3\theta t_1^4}{2}\right\}\Bigg] \qquad (12)$$

We get the optimal value of t_1 and T by solving the equation (11) and (12) by using MAPLE18.

4. Numerical Example

Consideration has been given to a hypothetical system with the following values for various parameters.

$$v_1 = 9.75, v_2 = 20.5, v_3 = 15, P_S = 2.5, q = 100, \gamma = 1.5, P_D = 3.5, \theta = .05, \alpha = 5, \beta = 21$$

We have solved this example with the help of MAPLE 18 to determine the optimal shortage value, $t_1 = 0.09069410610$ per unit time, and the optimal length of the ordering cycle is $T = 0.6470855900$ unit time. The total inventory cost is $TIC = 27.45847895$.

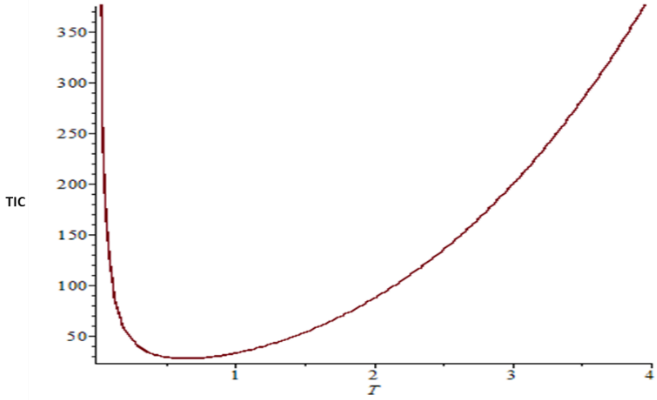

Figure. 2 Total inventory cost TIC vs time

This graph shows the convexity of a model.

5. Sensitive Analysis(11)

Sensitivity analysis was performed on the previously described numerical example to investigate the effect of underestimation of several parameters such as demand, deterioration, shortage cost, ordering cost, and holding cost variable with optimizing system profit. This analysis was carried out by adjusting (raising or decreasing) one parameter at a time (from -20% to +20%) while leaving the other parameters same. Table 1 displays the findings of these analyses.

Table 1. Sensitive analysis concerning different parameters.

Parameter	% Change	Change In			
		T	t1	Q	TIC
v_1	20	0.625460186	0.07657923461	12.55113863	28.98189467
	10	0.63622875	0.083500042	12.26036461	28.22597883
	-10	0.658090313	0.9826521477	11.63567151	26.67521197
	-20	0.669073425	0.106169879	11.30495962	25.88804321
v_2	20	0.627170592	0.086367182	12.18655848	28.12361684
	10	0.637061465	0.088517627	12.06994531	27.78804326
	-10	0.65831982	0.093130251	11.83236455	27.10109313
	-20	0.669775875	0.095611475	11.71121906	26.74899016
v_3	20	0.639108593	0.087439552	11.98438491	27.62351909
	10	0.643027488	0.08904798	11.97014839	27.54175821
	-10	0.65129301	0.092380937	11.94125438	27.37360663
	-20	0.655660994	0.094111799	11.68793502	27.29026483
Ps	20	0.608303585	0.08916683	10.84932966	29.68454199
	10	0.626665133	0.090315522	11.36580885	28.59414814
	-10	0.67019711	0.090337536	12.64356604	26.26958499

	-20	0.696851427	0.089235413	13.4637492	25.01692887
	20	0.670555169	0.100754208	12.65441971	28.90700788
	10	0.659326987	0.096014192	12.31740734	28.20566992
	-10	0.633608106	0.084633232	11.56453143	26.65712922
Q	-20	0.618584398	0.077592956	11.13686518	25.79060852
	20	0.64707448	0.090663794	11.95544387	27.45855435
	10	0.647080034	0.090678946	11.95560659	27.45851667
	-10	0.64709115	0.090709275	11.95593233	27.45844122
P_D	-20	0.647098303	0.090728791	11.95614193	27.45839269
	20	0.641361939	0.074237312	11.78870942	27.51580767
	10	0.6440081	0.081870883	11.86578084	27.49010288
	-10	0.650657405	0.100870724	12.060692	27.41920124
α	-20	0.654783833	0.11255633	12.18255051	27.37000541
	20	0.645839687	0.087283403	11.91929245	27.46701027
	10	0.646441455	0.088933631	11.93690292	27.46287066
	-10	0.647777531	0.092578462	11.97605474	27.45380648
β	-20	0.648523776	0.094602915	11.99795374	27.44881953
	20	0.64718405	0.090221021	12.01612077	27.57097031
	10	0.647190347	0.090237812	12.01611377	27.57092972
	-10	0.647202954	0.090271427	12.01609977	27.57084854
θ	-20	0.647206739	0.09028152	12.01638775	27.57080789
	20	0.99604474	0.206465451	24.82239525	55.81859546
	10	0.781682243	0.142310829	16.27286634	36.65761794
	-10	19.89630708	8.986119045	48921.68713	97722.95364
γ	-20	19.89629918	8.986119078	48921.63702	97722.82799

- With an increase or decrease in v_1 and v_2, TIC increases or decreases, respectively, and Q varies.
- If v_3 and P_D Increases or decreases, TIC and Q have the same value(minor changes).
- If P_S (shortage cost) increases or decreases, TIC increases or decreases, respectively.
- If q (Ordering variable) decreases, TIC decreases.
- If holding parameters α and β, there are no TIC and Q changes.
- γ is highly sensitive. If γ increases, TIC and Q increase, but when γ decreases TIC and Q exceedingly increase.
- TIC and Q do not vary much with an increase and decrease in θ.

6. Conclusion

We developed an inventory model with quadratic demand, shortfall permits, and time-dependent deterioration rate with variable holding and ordering cost in the proposed model. We also demonstrated that the optimal solution is derived from the minimized objective cost function, which is jointly convex. A numerical example and sensitivity analysis for parameters are also provided to evaluate the solution technique. The acquired results stipulate the firmness of the model. The above model is very thoughtful in the case of time-dependent demand and holding cost, and variable ordering cost. This model further can be expanded for partial backlogging.

7. Application

To ensure the existence of a distinct point of minimum, the cost function's convexity condition is established. It is used to keep track of the inventory of various non-immediately perishable commodities like food, electronics, and fashion accessories. We may expand the demand function to include stochastic changing demand patterns or demand rates that depend on stock. The model could also be developed to incorporate more realistic elements like quantity discounts, tolerable expense delays, time value of money, a finite replenishment rate, inflation, and probabilistic demand.

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BIOGRAPHY

Garima Khare was born in Indore, India. She received her graduate degree from Devi Ahilya Vishwavidyalaya Indore. She received her post-graduate and M.Phil. degree from Vikram University, Ujjain in 2006 and 2007 respectively. Currently, she is a research scholar at School of Liberal Arts and Sciences, Mody University of Science and Technology, Sikar. She has presented 2 papers at international conferences and 01 Book Chapter in IPP.

Garima Sharma working as an Assistant Professor in the School of Liberal Arts and Sciences, Mody University of Science and Technology, Sikar. She was awarded a Ph.D. from Banasthali Vidyapith, Newai in the area of Inventory models. She has around 16 years of teaching experience. Her areas of interest include Inventory Models, Queuing Theory, Linear Programming Problems, and Numerical Analysis. 2 students are pursuing Ph.D. and supervised dissertation for 5 Postgraduate and 7 under graduate students. She has published 14 national and international journals/ conferences. She got patent 01(IOT Intelligent Waste Management System) and 01 is in pipeline.