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Deterministic EOQ Models for Non-Linear Time Induced Demand and Different Holding Cost Functions

R.P.Tripathi, *D.Singh and *Surbhi Aneja
Department of mathematics, Graphic Era University, Dehradun (UK) India
tripathi_rp0231@rediffmail.com
*Department of mathematics, SGRR (P. G) College, Dehradun (UK) India
doon.dinesh@gmail.com
*Department of mathematics, SGRR (P. G) College, Dehradun (UK) India
surbhianejajgd@gmail.com

ABSTRACT

This paper presents an Economic order quantity (EOQ) model for deteriorating items. The demand rate is non-linear function of time. In this paper two models have been derived for different holding costs **(i).** The holding cost is linear function of the on hand inventory level and **(ii).** A non-linear function of time for which the item is kept in the stock. Optimization is done for both the models and numerical examples are presented to check the feasibility of the optimal solutions. Sensitivity analysis is also presented with respect to the various parameters used in the numerical example.

Indexing terms/Keywords

Deterioration; inventory; non-linear holding cost; EOQ Model

Academic Discipline And Sub-Disciplines

Mathematics (Operations Research)

SUBJECT CLASSIFICATION

90B05

TYPE (METHOD/APPROACH)

Theoretical approach

INTRODUCTION

Controlling and managing the inventory is among the biggest concern for any business regardless of its level. This concern leads the researchers to make inventory models for the better management of inventory. But while dealing with the real life problems it is not possible to consider all the factors affecting the depletion of inventory. Yet researchers have been able to consider most of the phenomenon like deterioration, demand rate etc.

As most of the physical goods undergo deterioration due to spoilage and many other factors. Most of the eatables that are available in market use preservatives. So they cannot be use after a definite time. So deterioration is an important factor to consider while developing an inventory model. Balkhi and Benkherouf (2004) developed an inventory model for deteriorating items with stock dependent and time varying demand rates. Lee and Dye (2012) established inventory model for deteriorating items under stock dependent demand rate and controllable deterioration rate. Arinadav and Herbon (2013) presented optimal inventory policy for a perishable item with demand function sensitive to price and time. Chang et al. (2010) presented optimal replenishment for non-instantaneous deteriorating items with stock-dependent demand. Giri and Chaudhari have developed many inventory models for the deteriorating items. Moon and Giri (2005) developed Economic order quantity models for ameliorating or deteriorating items under inflation and time discounting. Giri, Chaudhari and Goswami (1996) presented an inventory model for deteriorating items with stock-dependent demand rate. Giri and Chaudhari (1998) established deterministic model of perishable inventory with stock dependent demand rate and non-linear holding cost.

Most of the inventory models have been developed with constant holding cost. But this is not a realistic case. Weiss (1982) has taken no-linear holding cost in his paper. Goh (1994) also presented EOQ model with general demand and holding cost functions. Muhlemann and Valris (1980) have also taken variable holding cost rate in formulating the EOQ model. Singh, Tripathi and Mishra (2013) developed inventory model with deteriorating items and time-dependent holding cost. Tripathi and singh (2015) presented an inventory model with stock-dependent demand and different holding cost function. Other studies that have been done in this area can be marked for Alfares (2007), Pando (2013), Tripathi (2015) and Roy (2008).

In real life it is observed that the demand rate is often influenced by the amount of on-hand inventory. Soni and Shah(2008) presented a mathematical model to formulate optimal ordering policies for retailer when demand is partially constant and partially stock-dependent and the supplier offer progressive permissible delay to settle the account. Silver and Peterson (1982) established an inventory model in which retail level is directly propotional to the amount of inventory displayed. Gupta and Vrat (1986) established EOQ model for demand rate is a function of initial stock level.

In this paper the main aim is to find optimal cycle time which minimizes the total relevant cost. The rest of the paper is organized as follows. Assumptions and notations are given in section 2 followed by mathematical formulation. Numerical examples are discussed in section 4. In section 5 we provide sensitivity analysis, Conclusions and future research directions have been marked in the last section 6.

2 ASSUMPTIONS AND NOTATIONS

Following assumptions are made throughout the manuscript

1. The demand is a function of power of time.
2. Shortages are not allowed.
3. The deterioration rate is constant i.e. $0 < \Theta < 1$.
4. The replenishment is instantaneous.
5. The lead time is negligible.

In addition the following notations are used in the whole manuscript-

$q(t)$ - Inventory level at time t

$D_1 t^{\beta}$ - Demand rate

D_1 - Scale parameter, $D_1 > 0$

β - Shape parameter, $0 < \beta < 1$

θ - Deterioration rate, $0 < \theta < 1$

h - Holding cost per unit item per unit time

HC - Holding cost during the cycle

DC – Deterioration cost per cycle

Q - Order quantity in one cycle

TCU - Total relevant inventory cost

K - The cost of placing an order

C_1 - Cost per unit item

3. MATHEMATICAL MODEL

At the initial level of cycle time T the inventory level is Q which is depleted during the cycle time T due to constant rate of deterioration and time dependent demand rate and becomes zero at the end of cycle time T.

The differential equation describing the changes in the inventory level $q(t)$ over the period ($0 \le t \le T$) is given by:

$$\frac{dq(t)}{dt} + \theta q(t) = -D_1 t^{\beta}; 0 \le t \le T, \quad (1)$$

With the boundary condition $q(0) = Q$ and $q(T) = 0$.

Solving (1) and neglecting higher powers of θ we get

$$q(t) = D_1\left[\frac{1}{\beta+1}\left(T^{\beta+1} - t^{\beta+1}\right) - \theta\left\{T^{\beta+1}\left(\frac{t}{\beta+1} - \frac{T}{\beta+2}\right) - t^{\beta+2}\left(\frac{1}{\beta+1} - \frac{1}{\beta+2}\right)\right\}\right.$$

$$+\frac{\theta^2}{2}\left\{T^{\beta+1}\left(\frac{t^2}{\beta+1}-\frac{2tT}{\beta+2}+\frac{T^2}{\beta+3}\right)-t^{\beta+3}\left(\frac{1}{\beta+2}-\frac{2}{\beta+2}+\frac{1}{\beta+3}\right)\right\}\Bigg] \quad (2)$$

The order quantity for one cycle is

$$Q=D_1T^{\beta+1}\left(\frac{1}{\beta+1}+\frac{\theta T}{\beta+2}+\frac{1}{2}\frac{\theta^2T^2}{\beta+3}\right) \quad (3)$$

3.1. <u>Model A:</u> In this model, the holding cost is taken to be the linear function of on- hand inventory level $q(t)$.

Therefore, the holding cost is

$$HC=\int_0^T hq(t)\,dt \quad (4)$$

Substituting (2) in (4) gives

$$HC=D_1h\int_0^T q(t)dt=D_1hT^{\beta+2}\left(\frac{1}{\beta+2}+\frac{1}{2}\frac{\theta T}{\beta+3}+\frac{1}{6}\frac{\theta^2T^2}{\beta+4}\right) \quad (5)$$

The deterioration cost is given by

$$DC=C_1\left(Q-\int_0^T D_1t^{\beta}dt\right) \quad (6)$$

Using (3) in (6), we have

Deterioration cost is

$$DC=D_1C_1\theta T^{\beta+2}\left(\frac{1}{\beta+2}+\frac{\theta}{2}\frac{T}{\beta+3}\right) \quad (7)$$

The total relevant cost per unit time is given by

$$TCU=\frac{K+HC+DC}{T} \quad (8)$$

$$TCU=\frac{K}{T}+D_1hT^{\beta+1}\left(\frac{1}{\beta+2}+\frac{\theta}{2}\frac{T}{\beta+3}+\frac{\theta^2}{6}\frac{T^2}{\beta+4}\right)+D_1C_1\theta T^{\beta+1}\left(\frac{1}{\beta+2}+\frac{\theta}{2}\frac{T}{\beta+3}\right) \quad (9)$$

In this paper our main concern is to find the optimal order quantity Q^*, which minimizes the total relevant cost TCU of the inventory model.

The necessary condition for the TCU to be minimum is

$$\frac{d}{dT}(TCU)=0$$

Which give

$$T\left[\frac{d}{dT}(HC)+\frac{d}{dT}(DC)\right]=(K+HC+DC) \quad (10)$$

Substituting the value of HC and DC from equation (5) and (7), the above equation reduces to

$$D_1 hT^{\beta+1}\left\{1+\left(\frac{\theta}{2}-\frac{1}{\beta+2}\right)T+\left(\frac{\theta^2}{6}-\frac{\theta}{2(\beta+3)}\right)T^2-\frac{\theta^2}{6}\frac{T^3}{(\beta+4)}\right\}$$
$$+D_1 C_1 T^{\beta+1}\left\{1+\left(\frac{\theta}{2}-\frac{1}{\beta+2}\right)T-\frac{\theta}{2}\frac{T^2}{(\beta+3)}\right\}=K \quad (11)$$

From the above expression we can calculate the value of T^*, that can be used to calculate the value of Q^* by substituting in (3), which minimizes the total relevant cost TCU of the inventory system, provided $\frac{d^2(TCU)}{dT^2}>0$.

The second derivative of (9) w.r.t T is given by

$$\frac{d^2(TCU)}{dT^2}=\frac{2K}{T^3}+D_1\frac{\beta(\beta+1)}{(\beta+2)}(h+C_1\theta)T^{\beta-1}+D_1\frac{\theta}{2}\frac{(\beta+1)(\beta+2)}{(\beta+3)}(h+C_1\theta)T^{\beta}$$
$$+D_1 h\frac{\theta^2}{6}\frac{(\beta+2)(\beta+3)}{(\beta+4)}T^{\beta+1} \quad (12)$$

It can be seen from (12) that $\frac{d^2(TCU)}{dT^2}>0$, which shows that TCU gives minimum value at $T=T^*$($T=T^*$ obtained on solving (11) for T)

The Following figure shows the existence of global minima for TCU of Model A.

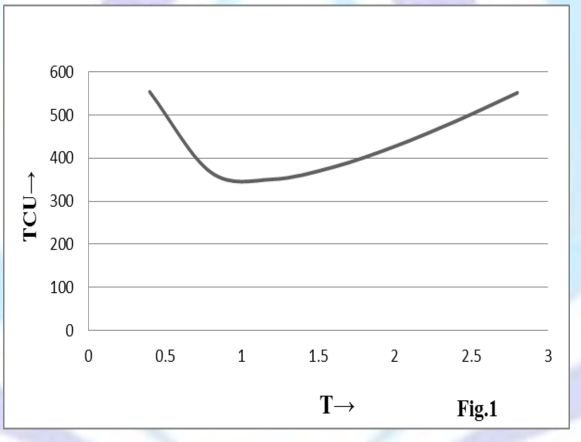

Fig.1

3.2. Model B: Non-linear time dependent holding cost

In this model holding cost is non-linear function of time ($0\le t\le T$).

$$\frac{d}{dt}(HC)=ht^{\gamma};\gamma>1 \quad (13)$$

The holding cost per order will be

$$HC=\int_0^T ht^{\gamma}dt \quad (14)$$

Holding cost is

$$HC=\frac{h}{\gamma+1}T^{\gamma+1} \quad (15)$$

There is no change for the deterioration cost for model B, So the expression for the Total relevant cost for Model **B** is

$$TCU = \left[\frac{K}{T} + \frac{h}{\gamma+1} T^{\gamma} + D_1 C_1 \theta \frac{T^{\beta+1}}{\beta+2} + D_1 C_1 \frac{\theta^2}{2} \frac{T^{\beta+2}}{\beta+3} \right] \quad (16)$$

Differentiating (14) w.r.to cycle time T and equating it to zero, we will get the expression

$$hT^{\gamma}\left(1+\frac{T}{\gamma+1}\right)+D_1C_1\theta T^{\beta+1}\left(1+\left(\frac{\theta}{2}-\frac{1}{\beta+2}\right)T-\frac{\theta}{2}\frac{T^2}{\beta+3}\right)=K \quad (17)$$

Differentiating (14) w.r.to cycle time T, twice yields

$$\frac{d^2(TCU)}{dT^2}=\frac{2K}{T^3}+\frac{h\gamma(\gamma-1)T^{\gamma-2}}{(\gamma+1)}+D_1C_1\theta\frac{\beta(\beta+1)}{(\beta+2)}T^{\beta-1}$$

$$+D_1C_1\frac{\theta^2}{2}\frac{(\beta+1)(\beta+2)}{(\beta+3)}T^{\beta} \quad (18)$$

By putting various values of the parameters, we will be able to find the value of T^* and Q^* (Optimal value of T and Q) numerically. To minimize the Total relevant cost TCU, cycle time T and order quantity Q, the following condition should be satisfied – $\left[\frac{d^2(TCU)}{dT^2}>0\right]$.

The Following figure shows the existence of global minima for TCU of Model B.

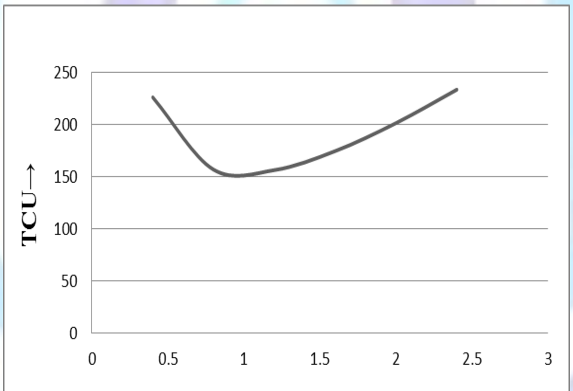

Fig.2

4. NUMERICAL EXAMPLE

Following data is used in their appropriate units to get the optimal values for the inventory system. To obtain the minimum value further calculation is required.

Example 1 (for model A): $D_1=100, K=200, \beta=0.1, \theta=0.05, h=1.6, C_1=30$ in appropriate units.

T^* =1.47552, Q^* = 144.983, TCU^* =367.711.

Example 2(for model B): $D_1=100, K=80, \beta=0.1, \theta=0.05, h=1.6, C_1=30, \gamma=3$ in appropriate units.

T^* =0.90269, Q^* = 83.1766, TCU^* =153.715.

5. SENSITIVITY ANALYSIS

The sensitivity analysis has been performed here based on above example 1, changing one parameter at a time and keeping all other parameters constant.

Table A: Effect of various parameters on (Q^*, T^*, TCU^*) for Model A, based on example 1

Table A_1:

	β				
	0.1	0.3	0.5	0.7	0.9
Q^*	144.983	92.3545	72.312	60.3774	51.6637
T^*	1.47552	1.12315	1.03793	0.99684	0.97376
TCU^*	367.711	337.908	326.259	316.923	308.871

Table A_2:

	θ				
	0.05	0.07	0.09	0.11	0.13
Q^*	144.983	92.3497	74.2853	62.9485	54.8156
T^*	1.47552	0.981586	0.803949	0.690398	0.607905
TCU^*	367.711	380.423	413.81	448.939	484.559

Table A_3:

	h				
	1.6	2.4	3.2	4	4.8
Q^*	144.983	144.983	144.983	144.983	144.983
T^*	1.47552	0.913974	0.689397	0.557234	0.469189
TCU^*	367.711	389.664	440.514	497.874	557.807

Table A_4:

	D1				
	100	200	300	400	500
Q^*	144.983	90.3897	84.3657	81.813	80.3852
T^*	1.47552	0.523183	0.341371	0.256094	0.206
TCU^*	367.711	528.337	722.432	913.496	1101.15

Table A_5:

	K				
	200	180	160	140	120
Q^*	144.983	144.983	144.983	144.983	144.983
T^*	1.47552	1.12685	0.931743	0.77704	0.643474
TCU^*	367.711	331.316	310.463	293.498	278.374

Table A_6:

	C1				
	30	50	70	90	110
Q^*	144.983	144.983	144.983	144.983	144.983
T^*	1.47552	0.875405	0.691098	0.581034	0.505061
TCU^*	367.711	399.63	453.043	505.647	556.842

Table B: Effect of various parameters on (Q^*, T^*, TCU^*) for Model B, based on example 2

Table B_1:

	β				
	0.2	0.4	0.6	0.8	1.0
Q^*	72.173	58.0348	48.6981	41.9346	36.7847
T^*	0.86967	0.847034	0.84183	0.842539	0.845702
TCU^*	150.776	144.969	139.736	135.156	131.166

Table B_2:

	θ				
	0.07	0.09	0.11	0.13	0.15
Q^*	46.1342	33.0685	25.8989	21.3167	18.1232
T^*	0.530272	0.392118	0.314112	0.263197	0.227109
TCU^*	201.319	250.503	299.176	347.229	394.704

Table B_3:

	h				
	2.4	3.2	4	4.8	5.6
Q^*	83.1766	83.1766	83.1766	83.1766	83.1766
T^*	0.885522	0.870894	0.858105	0.846717	0.836437
TCU^*	154.183	154.646	155.1	155.546	155.982

Table B_4:

	D1				
	200	300	400	500	600
Q^*	58.1871	54.4326	52.8203	51.9144	51.3316
T^*	0.351988	0.229814	0.172393	0.138656	0.11634
TCU^*	272.866	390.79	505.493	617.706	727.929

Table B_5:

	K				
	70	60	50	40	30
Q^*	83.1766	83.1766	83.1766	83.1766	83.1766
T^*	0.706808	0.567926	0.452919	0.35162	0.259128
TCU^*	148.526	144.424	140.549	136.534	132.022

Table B6:

	C_1				
	50	70	90	110	130
Q^*	83.1766	83.1766	83.1766	83.1766	83.1766
T^*	0.432361	0.29815	0.22981	0.187881	0.159369
TCU^*	232.741	312.582	390.79	467.567	543.144

The results of table A can be summed up as follows-

(i). From the table A_1 it is relevant that as the value of scale parameter β increases optimal order quantity Q^* decreases and so the optimal cycle time T^* and Total relevant cost TCU^*.

(ii). From table A_2 it is clear that the increasing effect of deterioration rate θ increases TCU* but decreases Q^* and T^*.

(iii). Table A_3 shows the variation in the value of Q^*, T^* and TCU^* with respect to the per unit holding cost h. There is no change in optimal order quantity corresponding to unit holding cost h. Whereas increment in the value of h decreases the optimal cycle time T* and increase in the total relevant cost TCU^*.

(iv). Table A_4 indicates that the increment in the scale parameter D_1 results the decrement Q* and T^* but increment in TCU^*.

(v). From Table A_5, we see that a significant decrease in the unit ordering cost K leaves no change in Q^* but produces a significant decrease in T* and TCU^*.

(vi). Table A_6 shows that as the value of per unit item cost C_1 increases, TCU^* increases and T^* decreases, whereas no change is seen in Q^*.

The results of Table B summarized in the following points:

(i). Increase of shape parameter β causes significant decrease in Q^* and TCU^*.But there is insignificant change in $T^*$with respect to increase in β.

(ii). Increase of unit holding cost h cause insignificant changes in T^* and TCU^* change for Q^*.So the change of h will cause insignificant change in T^*, Q^* and TCU^*.

(iii). Increase of Θ causes significant increase in TCU^*, decrease in T^* and Q^*.So the positive change in Θ will lead positive change in $TCU^*$and negative change in T^* and Q^*.

(iv). Positive change in scale parameter D_1 and C_1 causes significant positive change in TCU^* and negative change in T^* but increase in D_1 causes decrease in Q^* whereas increase in C_1 does not alter the Q^*.

6. CONCLUSION AND FUTURE RESEARCH

In this paper, we have developed inventory models with non-linear time dependent demand. Holding cost rate is taken as quantity dependent for model A and non-linear time-dependent for model B. This type of assumption is valid with time retailers which sells products like green vegetables, breads and seasonal fruits, whose quality decreases with time due to direct spoilage or physical decay. The time-dependent holding cost is realistic assumption because to arrange greater storage facilities to cease spoilage and to keep the freshness of the commodities in the stock cannot let the holding cost constant.

Mathematical models have been developed for two different situations. Sensitivity analysis with respect to variation of different parameters revealed significant changes in T^*, Q^* and TCU^*.

From managerial point of view, we can conclude the sensitivity of the parameters for T^*, Q^* and TCU^* in the following table-

For model A:

(1). Positive change of Θ and D_1 results in positive change in TCU^* but yields negative change in $T^*$and Q^*.

(2). Change in h and C_1 leads positive change in TCU^*, negative change in T^* and insignificant change in Q^*.

(3). Change in β result negative change in T^*, Q^* and TCU^*.

(4). Negative change in K leads negative change in T^*, TCU^* and leads no change in Q^*.

For model B:

(1). Positive change of Θ and D_1 results in positive change in TCU^* but yields negative change in $T^*$and Q^*.

(2). Change in h and C_1 leads positive change in TCU^*, negative change in T^* and insignificant change in Q^*.

(3). Change in β result negative change in $T^*$and TCU^*, positive change in Q^*.

(4). Negative change in K leads negative change in T^*, TCU^* and leads no change in Q^*.

The model discussed in this paper may be generalized to allow for shortages. We may also extend the present model for exponential demand as well as inflation dependent demand.

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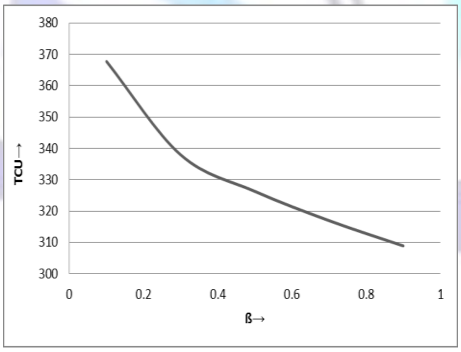
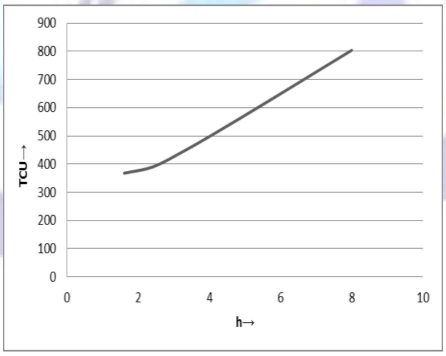
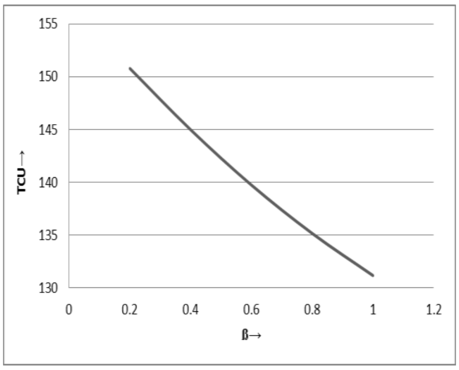
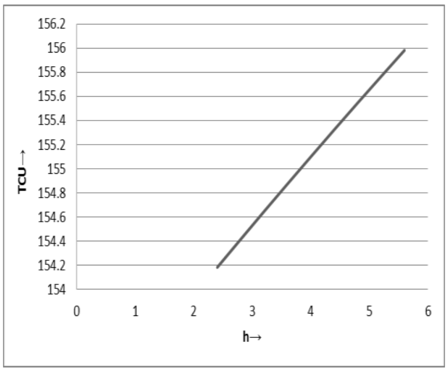
Graphs for model A





Graphs for model B





The above figures show variation of TCU with different parameters used for model A and B.

Author' biography with Photo

R.P.Tripathi is Professor and Head of Department of Mathematics at Graphic Era University, Dehradun (Uttarakhand) INDIA. He obtained his Ph.D degree in Mathematics and master degree in Mathematics from DDU Gorakhpur University (UP) INDIA. His research interests include operations research, modeling and simulation, economics and information system, graph theory and Finsler Geometry. He presented his research at several national and international conferences, and attended workshops on C++, finite element methods, MATLAB. His articles appeared in the Journal of Springer, Inderscience, Tamkang Journal of Mathematics, Taiwan, Republic of China, International Journal of Operations Research, Taylor and Francis and many other reputed journals. He also published several books for engineering students. He has been teaching courses at Graphic Era University, Dehradun Uttarakhand (INDIA) .He is reviewer of European Journal of Operational Research, International Journal of Production Research, Springer and many other reputed journals.

Dinesh Singh is Head of Department of Mathematics at SGRRPG College, Dehradun (Uttarakhand) INDIA. He obtained his Ph.D degree in Mathematics and master degree in Mathematics form DDU Gorakhpur University (UP) INDIA. His research interests include operations research and Summability. He presented his research at several national and international conferences. He also organized a conference. His articles appeared in Inderscience and many other reputed journals.

Surbhi Aneja is research scholar at H.N.B Garhwal University, Srinagar Garhwal (Uttarakhand) INDIA. She obtained her master degree in Mathematics from H.N.B Garhwal University, Srinagar Garhwal (Uttarakhand) INDIA. Her research interests include operations research, modeling and simulation and Inventory control. She has communicated two papers for publication in other journals.

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