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EOQ Model with Time Dependent Holding Cost under Trade Credits

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Abstract

In this paper we have developed a deterministic inventory model with constant demand with variable holding cost under Trade Credit. Here we have considered shortages are allowed and the deterioration is assumed as function of time. Suitable numerical example and sensitivity analysis is also carried out at the end.

Keywords: Constant demand, deterioration rate, shortages, time dependent deterioration.

Introduction

Researchers studied deterministic inventory models under Quadratic, linear, exponentially increasing/decreasing demand rate for the products like electronic goods, food stuffs, fashionable clothes etc., and some inventory models studied under price dependent demand considering variable deterioration rate. In business buying inventory with full capital amount is not viable. In developing different types of inventory models, considering permissible under trade credit is also a worth attempt. Researchers developed trade credits in different ways. Here trade credit means that supplier offers the customer (Case 1) a permissible delay in payments, i.e., trade credits to attract customers to increase demand in (Case II) to motivate quick payment and reduce credit expenses. Though many EOQ models proposed under permissible delay in payments we have developed an inventory model with constant demand considering variable holding cost with shortages. In this model deterioration rate is function of time. Hariga developed an inventory model of deteriorating items for time-varying demand also considering shortages[1]. Chakraborti and Choudhuri proposed an EOQ model for deteriorating products of linear trend in demand with shortages in all cycles[2]. Giri and Chaudhuri developed an economic order quantity model for deteriorating items of time varying demand and costs considering shortages[3]. Goyal and Giri studied complete survey of recent trend in deteriorating inventory models[4]. Mondal et. al developed an inventory model of ameliorating products for price dependent demand rate[5]. You studied the inventory system for the products with price and time dependent demands[6].

Ajanta Roy proposed an inventory model for deteriorating items of time varying holding cost with and without shortages in the price dependent demand[7]. Mishra and Singh studied an inventory model for deteriorating items with time dependent demand and partial backlogging[8]. Mishra developed an inventory model with Weibull rate of deterioration and rate of demand is constant with variable holding cost considering shortages and salvage value[9]. Mukesh et al, proposed a deterministic inventory model for deteriorating products with price dependent demand under trade credits[10]. Vikas Sharma and Rekha developed an inventory model for time dependant demand for deteriorating items with Weibull rate of deterioration and shortages[11].

Venkateswarlu and Mohan studied an EOQ model with 2-parameter Weibull deterioration, time dependent quadratic demand and salvage value[12]. Venkateswarlu and Mohan proposed an EOQ model for time varying deterioration and price dependent quadratic demand with salvage value[13]. Mohan and Venkateswarlu developed an EOQ models with variable holding cost and salvage value[14]. Mohan and Venkateswarlu proposed an inventory model for, time Dependent quadratic demand with salvage considering deterioration rate is time dependent[15]. Recently, Mohan and Venkateswarlu developed an inventory model with Quadratic Demand, Variable Holding Cost with Salvage value[16].

In this paper, we developed a model with time-dependent deterioration when the demand rate is constant under trade credits. Shortages are allowed. Time horizon is infinite. The optimal total cost is obtained. The sensitivity analysis is done with numerical example. The robustness of this model by increasing /deceasing of parameters, which gives the objectives from the sensitivity analysis carried out at the end.

Assumptions and notations

The mathematical model is developed on the following assumptions and notations: The demand rate $D(t)$ at time t is assumed to be $D(t) = R_1$, Lead time is zero, Replenishment rate is infinite, $\theta(t) = \theta t$ is the deterioration rate, $0 < \theta < 1$. A, the ordering cost, $h+\alpha t$, $h>0$, $\alpha>0$, the holding cost per unit, C, the cost per unit, $I(t)$ is the inventory level at time t., The order quantity in one cycle is q. C_1 is the shortage cost per unit per order, NDU, The number of deteriorating units per order with one cycle time.

Mathematical Model

The differential equation which governs describes the instantaneous inventory level at time t is given by

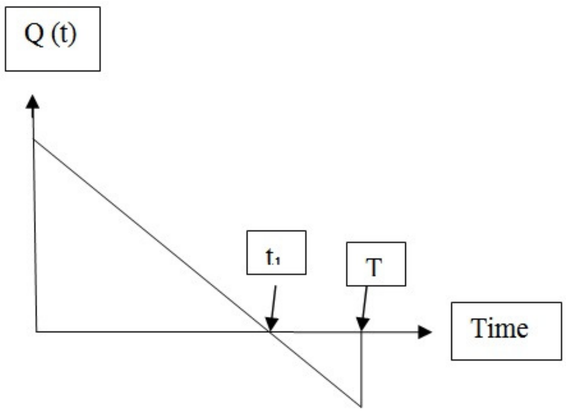

Figure-1
Time - Inventory graph

$$\frac{dQ_1(t)}{dt} + \theta t\, I(t) = -R_1, \qquad 0 \le t \le t_1 \tag{1}$$

$$\frac{dQ_2(t)}{dt} = -R_1, \qquad t_1 \le t \le T \tag{2}$$

With the initial condition $Q_1(t) = Q_2(t) = 0, at\ t = t_1$

Using the initial condition, solution of equation (1) is given by

$$Q_1(t) = -\left\{(R_1 t) + \theta \frac{R_1 t^3}{6} + \theta^2 \frac{R_1 t^5}{40}\right\} e^{-\theta \frac{t^2}{2}}$$

$$+K_1 e^{-\theta \frac{t^2}{2}} = -\left\{(R_1 t) + \theta \frac{R_1 t^3}{6} + \theta^2 \frac{R_1 t^5}{40}\right\}\left(1 - \theta \frac{t^2}{2} + \theta^2 \frac{t^4}{8}\right)$$

$$+ K_1\left(1 - \theta \frac{t^2}{2} + \theta^2 \frac{t^4}{8}\right)$$

Using the condition $Q_1(t_1) = 0$, we get the value of K_1. Substituting the value K_1 in the above equation, we get

$$Q_1(t) = \{R_1(t_1 - t)\} + \theta\left\{\frac{R_1(t_1^3 - t^3)}{6}\right\} + \theta^2\left\{\frac{R_1(t_1^5 - t^5)}{40}\right\} - \theta\left(\frac{R_1(t^2 t_1 - t^3)}{2}\right) - \theta^2\left(\frac{R_1}{12}(t_1^3 t^2 - t^5)\right) + \theta^2\left(\frac{R_1}{8}(t^4 t_1 - t^5)\right) \tag{3}$$

Using $Q_1(0) = Q$, we obtain

$$Q = \left[R_1 t_1 + \theta\left(\frac{R_1 t_1^3}{6}\right) + \theta^2\left(\frac{R_1 t_1^5}{40}\right)\right] \tag{4}$$

The solution of equation (2) using the boundary condition $Q_2(t_1) = 0$ is $Q_2(t) = R_1(t_1 - t)$

Inventory Model with Shortages

The total cost (TC) of the system consists of the following costs:
Ordering cost (OC) = A
Inventory holding cost per cycle

$$(IHC) = \int_0^{t_1} (h + \alpha t) Q_1(t)\, dt \tag{5}$$

$$IHC = hR_1\left[\frac{t_1^2}{2} + \theta\left(\frac{t_1^4}{12}\right) + \theta^2\left(\frac{1}{90} t_1^6\right)\right] + \alpha R_1\left[\frac{t_1^3}{6} + \theta\left(\frac{t_1^5}{4}\right) + \theta^2\left(\frac{t_1^7}{336}\right)\right] \tag{6}$$

The number of units that deteriorated during this cycle time is

$$NDU = Q - \int_0^{t_1} D(t)\, dt, \text{ where } D(t) = R_1 \tag{7}$$

$$NDU = R_1\left[\theta\left(\frac{t_1^3}{6}\right) + \theta^2\left(\frac{t_1^5}{40}\right)\right]$$

Cost due to deterioration =C*D

$$CD = CR_1\left[\theta\left(\frac{t_1^3}{6}\right) + \theta^2\left(\frac{t_1^5}{40}\right)\right] \tag{8}$$

Shortage cost (SC) = $C_1 \int_0^{t_1} Q_2(t)\, dt$

$$SC = \pi\left[R_1\left(\frac{T^2}{2} - t_1 T\right) + \frac{R_1 t_1^2}{2}\right] \tag{9}$$

Since we are considering the inventory system under Trade credits the following two cases arises: Case (i): $M \le t_1$ (Here the payment on or before when inventory reaches to zero)

In case-i, the credit period ended on or before when the inventory level reaches to zero. After due date M, the time horizon for the interest payable is $M \le t \le t_1$ for the inventory which are not sold after the due date.

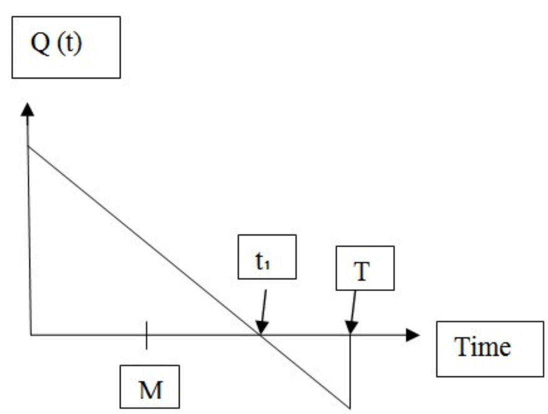

Figure-2
Time inventory graph for case i

Hence

$$IE_{Earn} = CI_E \int_0^{t_1} (t_1 - t)\,dt = CI_E \frac{t_1^2}{2}$$

$$IC_{Char} = CI_c \int_M^{t_1} R_1\,dt = CI_c (t_1 - M)$$

Total Average Cost ($TC(t_1, T)$) is given by

$$TC(t_1,T)_1 = \frac{1}{T}\left(IHC + CD + OC + SC + IC_{Char} - I_{Earn}\right) \tag{10}$$

$$TC(t_1,T)_1 = \frac{1}{T}\left[\begin{array}{l} hR_1\left[\frac{t_1^2}{2} + \theta\left(\frac{t_1^4}{12}\right) + \theta^2\left(\frac{1}{90}t_1^6\right)\right] \\ + \alpha R_1\left[\frac{at_1^3}{6} + \theta\left(\frac{at_1^5}{4}\right) + \theta^2\left(\frac{at_1^7}{336}\right)\right] \\ + CR_1\left[\theta\left(\frac{t_1^3}{6}\right) + \theta^2\left(\frac{t_1^5}{40}\right)\right] + A \\ \pi\left[R_1\left(\frac{T^2}{2} - t_1T\right) + \frac{at_1^2}{2}\right] \\ + CI_c(t_1 - M) - CI_E\frac{t_1^2}{2} \end{array}\right] \tag{11}$$

The necessary condition for minimizing the total cost is

$$\frac{\partial(TC(t_1,T)_1)}{\partial t_1} = 0 \quad and \quad \frac{\partial(TC(t_1,T)_1)}{\partial T} = 0, \text{ i,e.,}$$

$$\frac{\partial(TC(t_1,T)_1)}{\partial t_1} = \frac{1}{T}\left[\begin{array}{l} hR_1\left[t_1 + +\theta\left(\frac{at_1^3}{3}\right) + \theta^2\left(0.0667 * t_1^5\right)\right] \\ + \alpha R_1\left[\frac{t_1^2}{2} + \theta\left(\frac{5t_1^4}{4}\right) + \theta^2\left(\frac{7t_1^6}{336}\right)\right] + \\ \pi R_1\left[(t_1 - T)\right] \\ + CR_1\left[\theta\left(\frac{t_1^2}{2}\right) + \theta^2\left(\frac{t_1^4}{8}\right)\right] + CI_{Char} - CI_{Ear}t_1 \end{array}\right] = 0$$

and

$$\frac{\partial(TC(t_1,T)_1)}{\partial T} = -\frac{1}{T^2}\left[\begin{array}{l} hR_1\left[\frac{t_1^2}{2} + \theta\left(\frac{at_1^4}{12}\right) + \theta^2\left(0.0111\,at_1^6\right)\right] \\ + \alpha R_1\left[\frac{t_1^3}{6} + \theta\left(\frac{t_1^5}{4}\right) + \theta^2\left(\frac{t_1^7}{336}\right)\right] + A \\ \pi R_1\left[\left(\frac{T^2}{2} - t_1T\right) + \frac{at_1^2}{2}\right] \\ + CR_1\left[\theta\left(\frac{t_1^3}{6}\right) + \theta^2\left(\frac{t_1^5}{40}\right)\right] + CI_{Char}(t_1 - M) \\ - CI_{Earn}\frac{t_1^2}{2} \end{array}\right] + \frac{1}{T}\left(\pi\left[R_1(t_1 - T)\right]\right) = 0 \tag{12}$$

Provided

$$\left(\frac{\partial^2(TC(t_1,T)_1)}{\partial t_1^2}\right)\left(\frac{\partial^2(TC(t_1,T)_1)}{\partial T^2}\right) - \left(\frac{\partial^2(TC(t_1,T)_1)}{\partial t_1 \partial T}\right) > 0,$$

where

$$\frac{\partial^2(TC(t_1,T)_1)}{\partial t_1^2} = \frac{1}{T}\left[\begin{array}{l} h\left[R_1 + \theta\left(R_1t_1^2\right) + \theta^2\left(\frac{1}{3}R_1t_1^4\right)\right] \\ + \alpha\left[R_1t_1 + \theta\left(\frac{R_1t_1^3}{2}\right) + \theta^2\left(\frac{42\,at_1^5}{336}\right)\right] + \\ \pi\left[R_1\right] - CI_{Earn} \\ + C\left[\theta\left(R_1t_1\right) + \theta^2\left(\frac{R_1t_1^3}{2}\right)\right] \end{array}\right] \tag{13}$$

$$\frac{\partial^2(TC(t_1,T)_1)}{\partial T^2} = \frac{2}{T^3}\left[\begin{array}{l} h\left[\frac{R_1t_1^2}{2} + \theta\left(\frac{R_1t_1^4}{12}\right) + \theta^2\left(0.0111\,R_1t_1^6\right)\right] \\ + \alpha\left[\frac{R_1t_1^3}{6} + \theta\left(\frac{R_1t_1^5}{40}\right) + \theta^2\left(\frac{R_1t_1^7}{336}\right)\right] + A + \\ \pi\left[R_1\left(\frac{T^2}{2} - t_1T\right) + \frac{R_1t_1^2}{2}\right] + \\ C\left[\theta\left(\frac{R_1t_1^3}{6}\right) + \theta^2\left(\frac{R_1t_1^5}{40}\right)\right] + \\ CI_{Char}(t_1 - M) - CI_{Earn}\frac{t_1^2}{2} \end{array}\right] - \frac{1}{T}C_1\left[R_1\right] + \frac{1}{T^2}\left(C_1R_1(t_1 - T)\right) \tag{14}$$

$$\frac{\partial^2(TC(t_1,T)_1)}{\partial t_1 \partial T} = -\frac{1}{T^2}\left[\begin{array}{l} h\left(R_1t_1 + \theta\left(\frac{R_1t_1^3}{3}\right) + \theta^2\left(0.01116\,R_1t_1^5\right)\right) \\ + \alpha\left[\frac{R_1t_1^2}{2} + \theta\left(\frac{R_1t_1^4}{8}\right) + \theta^2\left(\frac{7R_1t_1^6}{336}\right)\right] \\ + \pi\left[-R_1T + R_1t_1\right] \\ + C\left[\theta\left(\frac{R_1t_1^2}{2}\right) + \theta^2\left(\frac{R_1t_1^4}{8}\right)\right] + CI_{Char} - CI_{Earn}t_1 \end{array}\right] + \frac{1}{T}\pi(-R_1) \tag{15}$$

Case (ii): $M > t_1$ (In this case Interest payable per cycle is zero when $t_1 \le M \le T$)

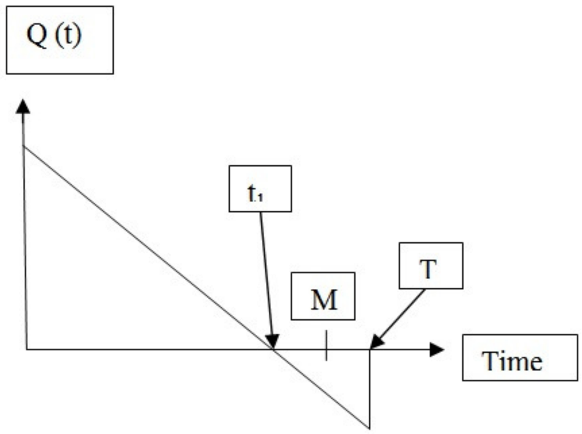

Figure-3
Time inventory graph for case ii

Total Average Cost $(TC(t_1, T)_2)$ is given by $TC(t_1, T)_2 = \frac{1}{T}\left(IHC + CD + OC + SC - IE^1{}_{Earn}\right)$

$$TC(t_1, T)_2 = \frac{1}{T}\begin{bmatrix} hR_1\left[\frac{t_1^2}{2} + \theta\left(\frac{t_1^4}{12}\right) + \theta^2\left(\frac{1}{90}t_1^6\right)\right] \\ + \alpha R_1\left[\frac{t_1^3}{6} + \theta\left(\frac{t_1^5}{4}\right) + \theta^2\left(\frac{t_1^7}{336}\right)\right] \\ + CR_1\left[\theta\left(\frac{t_1^3}{6}\right) + \theta^2\left(\frac{t_1^5}{40}\right)\right] + A \\ \pi\left[R_1\left(\frac{T^2}{2} - t_1 T\right) + \frac{R_1 t_1^2}{2}\right] \\ - CI_{Earn}\left(R_1 M t_1 - \frac{R_1 t_1^2}{2}\right) \end{bmatrix}$$

The necessary condition for minimizing the total cost is

$$\frac{\partial(TC(t_1, T)_2)}{\partial t_1} = 0 \quad and \quad \frac{\partial(TC(t_1, T)_2)}{\partial T} = 0 \text{, i.e,}$$

$$\frac{\partial(TC(t_1, T)_2)}{\partial t_1} = \frac{1}{T}\begin{bmatrix} hR_1\left[t_1 + +\theta\left(\frac{at_1^3}{3}\right) + \theta^2\left(0.0667 * t_1^5\right)\right] \\ + \alpha R_1\left[\frac{t_1^2}{2} + \theta\left(\frac{t_1^4}{8}\right) + \theta^2\left(\frac{7t_1^6}{336}\right)\right] + \\ \pi R_1\left[(t_1 - T)\right] \\ + CR_1\left[\theta\left(\frac{t_1^2}{2}\right) + \theta^2\left(\frac{t_1^4}{8}\right)\right] - CI_{Earn}(R_1 M - R_1 t_1) \end{bmatrix} = 0$$

and

$$\frac{\partial(TC(t_1, T)_2)}{\partial T} = -\frac{1}{T^2}\begin{bmatrix} hR_1\left[\frac{t_1^2}{2} + \theta\left(\frac{t_1^4}{12}\right) + \theta^2\left(0.0111\, t_1^6\right)\right] \\ + \alpha R_1\left[\frac{t_1^3}{6} + \theta\left(\frac{t_1^5}{40}\right) + \theta^2\left(\frac{t_1^7}{336}\right)\right] + A \\ \pi R_1\left[\left(\frac{T^2}{2} - t_1 T\right) + \frac{t_1^2}{2}\right] \\ + CR_1\left[\theta\left(\frac{t_1^3}{6}\right) + \theta^2\left(\frac{t_1^5}{40}\right)\right] - CI_{Earn} R_1\left(Mt_1 - \frac{t_1^2}{2}\right) \end{bmatrix}$$

$$-\frac{1}{T}\left(\pi\left[R_1(t_1 - T)\right]\right) = 0 \tag{16}$$

Provided

$$\left(\frac{\partial^2(TC(t_1, T)_2)}{\partial t_1^2}\right)\left(\frac{\partial^2(TC(t_1, T)_2)}{\partial T^2}\right) - \left(\frac{\partial^2(TC(t_1, T)_2)}{\partial t_1 \partial T}\right) > 0,$$

Numerical Example for case I: By putting proper units of parametric values for, A =80 a = 40, C = 4, M = 0.09 π=0.1 Ie =0.09, θ =0.01, h = 0.9, α = 0.1, C_1= 0.1, α=0.1 Ic=.12, Using MATHCAD Software, the optimal values the inventory system are: t_1= 1.012, T = 6.839, TC = 23.307

Numerical Example for case II: A =80 a = 40, C=4, M = 2 π=0.1 Ie =0.09, θ =0.01, h = 0.9, α = 0.1, C_1= 0.1, α=0.1 Ic=.12

Sensitivity Analysis

We will study the effect of changes made in the values of the parameters θ, A, a, α, C, γ, h and π on the optimal cycle time, total cost and EOQ of these models. We have the following inferences can be made from table-1 and table–2 using case I and II Decrease in the parameters θ , A , a decreases the total optimal system cost. Similarly the increase in these parameters increases the total optimal cost. The effect of these parameters is more pronounced on the total cost of the system.

The effect of the parameter π on the total optimal cost is very significant. The total optimal cost of the system is very significant by considering all variables together decreasing or increasing.

Conclusion

We have developed inventory management model for deteriorating items when the demand rate is assumed to be constant. It is assumed that the deterioration rate is proportional to time. We have solved the model considering shortages .The objectives are discussed in the sensitivity analysis for the various parameters and the sensitivity analysis is calculated in percentile variation rather than actual values from the tables. This model can be extended further incorporating inflation, and using fuzzy concepts.

Table-1

Case 1: $M \le t_1$

Parameter	% change	t_1	T	TC
Θ	-25	0.6917	0.07311	-0.03862
	-10	0.395257	0.029244	-0.02145
	10	-0.29644	-0.02924	0.017162
	25	-0.98814	-0.10235	0.051487
A	-25	-12.253	-13.2768	-13.4423
	-10	-4.64427	-5.07384	-5.15296
	10	4.44664	4.825267	4.899816
	25	10.57312	11.66837	11.85481
A	-25	13.73518	15.30926	-13.3093
	-10	4.841897	5.35166	-5.09718
	10	-4.1502	-4.62056	4.844038
	25	-9.58498	-10.4694	11.71751
A	-25	1.976285	0.190086	-0.11155
	-10	0.790514	0.07311	-0.0472
	10	-0.6917	-0.07311	0.042906
	25	-1.77866	-0.17546	0.102973
C	-25	0.889328	0.043866	-0.08581
	-10	0.395257	0.014622	-0.03432
	10	-0.29644	-0.01462	0.030034
	25	-0.79051	-0.05849	0.081521
Π	-25	-10.6719	13.46688	-11.7433
	-10	-10.0791	13.53999	-11.769
	10	-11.3636	13.40839	-11.7175
	25	-12.253	13.32066	-11.6746
H	-25	21.64032	1.535312	-1.94791
	-10	7.806324	0.555637	-0.69507
	10	-6.81818	-0.49715	0.600678
	25	-15.6126	-1.15514	1.364397
All parameters	-25	-23.5178	12.58956	-33.1445
	-10	5.237154	5.395526	-14.6051
	10	9.881423	-3.61164	13.79843
	25	-10.3755	-10.5571	39.71339

Table-2

Case 2: $M > t_1$

Parameter	% change	t_1	T	TC
θ	-25	0.471698	0.032362	-0.10186
	-10	0.235849	0.016181	-0.05093
	10	-0.23585	0	0.045837
	25	-0.78616	-0.03236	0.147695
A	-25	-6.60377	-15.5502	-17.8711
	-10	-2.51572	-5.90615	-6.79399
	10	2.358491	5.582524	6.412019
	25	5.660377	13.4466	15.44181
a	-25	7.389937	17.57282	-9.84976
	-10	2.59434	6.18123	-3.60581
	10	-2.27987	-5.35599	3.223835
	25	-5.18868	-12.2168	7.445887
α	-25	1.415094	0.080906	-0.2903
	-10	0.550314	0.032362	-0.11714
	10	-0.55031	-0.01618	0.112045
	25	-1.41509	-0.04854	0.275019
C	-25	-2.83019	3.349515	4.914693
	-10	-1.02201	1.375405	1.991342
	10	0.943396	-1.40777	-2.03209
	25	2.201258	-3.64078	-5.15406
π	-25	-4.08805	13.98058	-11.0109
	-10	-1.57233	4.87055	-4.13038
	10	1.415094	-4.15858	3.824803
	25	3.301887	-9.41748	9.090909
h	-25	11.87107	-0.5178	-3.7535
	-10	4.481132	-0.17799	-1.40056
	10	-4.16667	0.177994	1.27833
	25	-9.82704	0.38835	3.004838
All parameters	-25	7.940252	17.60518	-32.4472
	-10	-2.04403	-5.33981	-7.1454
	10	-2.51572	-5.35599	13.60326
	25	-5.89623	-12.2492	34.52508

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