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Two-Warehouse Inventory Model with Multivariate Demand and K-Release Rule

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Abstract

In this paper, we've projected a two-warehouse inventory model for deteriorating things beneath the impact of inflation and continuance of cash, wherever demand follows a rare combination of the linear time variable and on-hand inventory level. In one in the entire warehouse (OW), time-varying linear deterioration was thought-about and within the different (RW) weibull distributed deterioration was studied. Here, shortages were allowed and part backlogged. The stock is transferred from the RW to the OW following a bulk unharness rule. The target here is to seek out the optimum amount to that ought to be ordered and also the optimum variety of cycles during which the number from RW should be transferred to OW to maximize world wide web profit per unit time. The model has additionally been exemplified with the many numerical examples. The results have additionally been understood diagrammatically.

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Keywords: Two-warehouse system, K-release rule, multivariate demand, lost sale and time value of money.

1. Introduction

Inflation plays an awfully attention-grabbing and vital role: it will increase the value of products. To safeguard from the economic process, throughout the inflation regime, the organization prefers to stay a better inventory, thereby increasing the mixture demand. Further this extra inventory desires additional space for storing that's expedited by a rented warehouse. Ignoring

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the consequences of your time worth of cash and inflation may yield dishonest results. The warehouse storage capability is outlined because the quantity of space for storing required accommodating the materials to be keep to fulfill a desired service level that specifies the degree of space for storing availableness. Stock things to be delivered precisely once required square measure impractical. Therefore, it's necessary to analyze the influence of warehouse capability in varied inventory policy issues. In recent years, varied researchers have mentioned a two warehouse inventory system. This type of system was first mentioned by Hartely [1]. Hartely [1] conferred a basic two-warehouse model, within which the value of transporting a unit from rented warehouse (RW) to possess warehouse (OW) wasn't thought-about. Sarma [2] developed a settled inventory model with infinite refilling rate and 2 levels of storage. In this model, he extended Hartely's [1] model by introducing the transportation value. Murdeshwar and Sathe [3] extended this model to the case of finite refilling rate. Dave [4] additional mentioned the cases of bulk unleash pattern for each finite and infinite refilling rates. He corrected the errors in Murdeshwar and Sathe [3] and gave a whole answer for the model given by Sarma [2]. Within the on top of cited references, deterioration development wasn't taken under consideration.

The assumption that the products in inventory forever preserve their physical characteristics isn't true normally as a result of their square measure some things that square measure subject to risks of breakage, evaporation, devolution etc. Decay, modification or spoilage that forestalls the things from getting used for its original purpose is typically termed as deterioration. Food items, prescription drugs, photographic material, chemicals and hot substances, to call solely many things square measure amongst those within which considerable deterioration will happen throughout the traditional storage of the units. the primary decide to get best refilling policies for deteriorating things was created by Ghare and Schrader [5], un agency derived a revised style of the economic order amount (EOQ) model presumptuous decay. Later, presumptuous the deterioration in each warehouses taken as constant, Sarma [6] extended his earlier model to the case of infinite refilling rate with shortages. Pakkala and Achary [7, 8] extended the two-warehouse inventory model for deteriorating things with finite refilling rate and shortages, taking time as distinct and continuous variable, severally. Pakkala and Achary [9] conferred a two level storage inventory model for deteriorating things with bulk unharness rule. In these models mentioned on top of, the demand rate was assumed to be constant. Afterward, the concepts of time-varying demand and stock-dependent demand were thought of by other authors, like Goswami and Chaudhuri [10, 11], Bhunia and Maiti [12, 13], Benkherouf [14], and Kar Bhunia and Maiti [15].

In addition, because of high rate of inflation, the results of inflation and duration of cash area unit very important in sensible setting, particularly within the developing national market. To relax the belief of no inflationary effects on prices, Buzacott [16] and Misra [17] at the same time developed EOQ models with constant demand and one rate of inflation for all associated prices. Due to the factors mentioned on top of, Yang [18] provided a two-warehouse inventory model for one item with constant demand and shortages underneath inflation. rather than the classical read of accumulating shortages at the tip of every replacement cycle, an alternate model within which every cycle begins with shortages has been planned here. Zhou and Yang [19] studied stock-dependent demand while not shortage and deterioration with amount based mostly transportation price. Wee et al. [20] thought of a two-warehouse model with constant demand and weibull distribution deterioration underneath inflation. Yang [21] extended Yang's [19] to include partial backlogging then compared the two-warehouse models supported the minimum price approach. Jaggi et al. [22] conferred the optimum inventory replacement policy for deteriorating things underneath inflationary conditions employing a discounted income (DCF) approach over a finite time horizon. Hsieh et al. [23] developed a settled inventory model for deteriorating things with two warehouses by minimizing cyberspace gift price of the entire price. In this model, they allowed shortages that were fully backlogged. Ghosh and Chakrabarty [24] urged an order-level inventory model with two levels of storage for deteriorating things. The inventory control in RW was transferred to OW in bulk size (K) wherever, K was but the capability of OW until the stock in RW gets exhausted Associate in nursingd there was an associated transportation price. Shortages were allowed and totally backlogged. Jaggi and Verma [25] developed a two-warehouse inventory model with linear trend in demand underneath the inflationary conditions with constant deterioration rate. Singh et al. [26] developed a listing model for deteriorating things with shortages and stock-dependent demand underneath inflation for two-shops underneath one management. Singh et al. [27] conferred a settled two-warehouse inventory model for deteriorating things with sock-dependent demand and shortages. Kumar et al. [28] developed an inventory model with time – dependent demand and limited storage facility under inflation. Kumar et al. [29] presented a two-warehouse inventory model with three – component demand rate in fuzzy environment.

In the present work, a two-warehouse inventory model with shortage underneath inflation and time variable rate of degradation is delineated with the motive of providing an answer to a drag that's near real life; because the managers of inventory need to touch upon issues wherever shortages happens, deterioration depends on time and having effects of inflation on inventory connected prices. During this paper, we have projected a two-warehouse inventory model for deteriorating things underneath the impact of inflation and note value of cash, wherever demand follows a rare combination of the linear time variable and on-hand inventory level. In one amongst the warehouse (OW), time-varying linear deterioration was thought-about and within the alternative (RW) weibull distributed deterioration was studied. Here, shortages were allowed and partly backlogged. The stock is transferred from the RW to the OW following a bulk unleash rule. The target here is to seek out the optimum amount ought to be ordered and therefore the optimum range of cycles within which the number from RW should be transferred to OW to maximize internet profit per unit time. The model has additionally been exemplified with the many numerical examples within the later a part of this paper. The results have additionally been understood diagrammatically.

2. Assumptions and Notations

The mathematical model developed in this paper is based on the following assumptions:

1. The demand rate is deterministic and is a function of both time and on-hand inventory level.
2. Shortages are allowed. Unsatisfied demand is backlogged, and the fraction of shortages backordered is $1/(1 + \delta x)$, where x is the waiting time up to the next replenishment and δ is a positive constant.
3. Deterioration rate in owned warehouse (OW) is time dependent.
4. Deterioration rate of the item in rented warehouse (RW) follows a two parameter Weibull distribution.
5. There is no replacement or repair of deteriorating items during the period under consideration.
6. The OW has a fixed capacity of W units and the RW has unlimited capacity.
7. The holding costs in RW are higher than those in OW.
8. Inflation and time value of money are considered.
9. The transfer of stocks from RW to W follows a K-release rule.
10. Lead time is zero and the replenishment rate is infinite.

The following notations were used throughout the study:

D(t)	Demand rate, where $D(t) = a + bt + cI(t)$, a, b and c are positive constants where $a > b$.
W	Capacity of OW.
R	Amount of goods stored in RW.
S	Per unit selling price of the item.
r	Constant representing the difference between the discount rate and inflation rate.
P	Purchasing cost per unit item.
H	Holding cost per unit per unit time in OW.
F	Holding cost per unit per unit time in RW, $F > H$.
s	Shortage cost per unit per unit time.
π	Opportunity cost unit per unit time.
A	Setup cost per cycle.
$I_0(t)$	Inventory level at any time t in OW.
$I_r(t)$	Inventory level at any time t in RW.
M(t)	Rate of deterioration in OW where $M(t) = \theta t$, θ is a positive constant where $0 < \theta << 1$.
f(t)	Two parameter probability density function for the rate of deterioration, $f(t) = \alpha\beta t^{\beta-1}e^{-\alpha t\beta}$ where α is the scale parameter ($\alpha > 0$), β is the shape parameter ($\beta > 0$).
Z(t)	Weibull instantaneous rate function for the stocked items in RW, $Z(t) = (f(t) / -e^{\alpha t\beta}) = \alpha\beta t^{\beta-1}$

3. Formulation and Solution of the Model

In the development of the model, a company purchases S ($S > W$) units out of which W units are kept in OW and $(S - W) = R$ units are kept in RW, is being assumed. Initially, the demands are not using the stocks of OW until the stock level drops to $(W - K)$ units at the end of T_1. At this stage, K ($K \leq W$) units are transported from RW to OW. As a result, the stock level of OW again becomes W and the stocks of OW are used to meet further demands.

This process is continued until the stock in RW is fully exhausted. After the last shipment, only W units are used to satisfy the demand during the interval $[T_{n-1}, T_n]$ and then the shortages occur and completely backlogged during the interval $[T_n, \bar{T}]$. The graphical representation of the whole process is shown in the figures 1 and 2 below:

OW inventory system can be represented by the following differential equation:

$$I_0'(t) = -M(t) I_0(t) - D(t), \qquad T_i \le t \le T_{i+1}$$

$$\Rightarrow \quad I_0'(t) = -M(t) I_0(t) - \left(a + bt + cI_0(t)\right), \qquad T_i \le t \le T_{i+1}$$

$$\Rightarrow \quad I_0'(t) = -(\theta t + c) I_0(t) - (a + bt), \qquad T_i \le t \le T_{i+1} \tag{1}$$

With the boundary condition $I_0(T_i) = W,\ i = 0,1,2,...,n-1$.

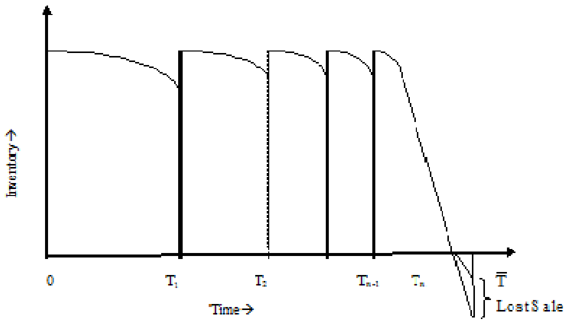

Fig. 1 Graphical representation of inventory in own-warehouse

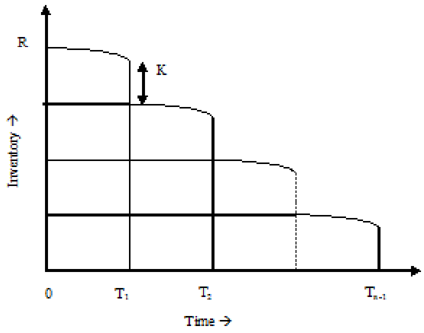

Fig. 2 Graphical representation of inventory in rented-warehouse

With the boundary condition $I_0(T_i) = W,\ i = 0,1,2,...,n-1$.

For $i = n$, $I_0(T_i) = 0$ and also $T_0 = 0,\ T_n = T$.

$$I_0'(t) = -\frac{D(t)}{1 + \delta(\bar{T} - t)}, \qquad T_n \le t \le \bar{T} \tag{2}$$

With the boundary condition $I_0(T_n) = 0$.

Using the boundary conditions, the solution of equation *(1)* and *(2)* is given by

$$I_0(t) e^{(ct + \theta t^2/2)} = a(T_i - t) + \frac{ac}{2}\left(T_i^2 - t^2\right) + \frac{b}{2}\left(T_i^2 - t^2\right) + \frac{a\theta}{6}\left(T_i^3 - t^3\right) + \frac{bc}{3}\left(T_i^3 - t^3\right)$$
$$+ \frac{b\theta}{8}\left(T_i^4 - t^4\right) + We^{(cT_i + \theta T_i^2/2)}, \qquad T_i \le t \le T_{i+1},\ i = 0, 1, 2 \ldots, n-1$$

$$\Rightarrow$$

$$I_0(t) = \left[a(T_i - t) + \frac{ac}{2}\left(T_i^2 - t^2\right) + \frac{b}{2}\left(T_i^2 - t^2\right) + \frac{a\theta}{6}\left(T_i^3 - t^3\right) + \frac{bc}{3}\left(T_i^3 - t^3\right)\right.$$
$$\left. + \frac{b\theta}{8}\left(T_i^4 - t^4\right)\right] e^{(ct + \theta t^2/2)} + We^{\left(c(T_i - t) + \theta\left(T_i^2 - t^2\right)/2\right)},$$
$$T_i \le t \le T_{i+1},\ i = 0,1,2,...,n-2 \tag{3}$$

$$I_0(t)e^{(ct+\theta t^2/2)} = a(T_i - t) + \frac{ac}{2}\left(T_i^2 - t^2\right) + \frac{b}{2}\left(T_i^2 - t^2\right) + \frac{a\theta}{6}\left(T_i^3 - t^3\right) + \frac{bc}{3}\left(T_i^3 - t^3\right) + \frac{b\theta}{8}\left(T_i^4 - t^4\right), \qquad T_i \le t \le T_{i+1},\ i = n-1$$

$$\Rightarrow \qquad I_0(t) = \left[a(T_i - t) + \frac{ac}{2}\left(T_i^2 - t^2\right) + \frac{b}{2}\left(T_i^2 - t^2\right) + \frac{a\theta}{6}\left(T_i^3 - t^3\right) + \frac{bc}{3}\left(T_i^3 - t^3\right) + \frac{b\theta}{8}\left(T_i^4 - t^4\right)\right]e^{-(ct+\theta t^2/2)}, \qquad T_i \le t \le T_{i+1},\ i = n-1, \tag{4}$$

and $$I_0(t) = -\frac{b}{\delta}(T_n - t) + \frac{1}{\delta}\left(a + \frac{b}{\delta} + b\overline{T}\right)\left[In\left(1+\delta\left(\overline{T} - t\right)\right) - In\left(1+\delta\left(\overline{T} - T_n\right)\right)\right],\ \mathrm{T_n} \le t \le \overline{T} \tag{5}$$

The RW inventory system can be represented by the following differential equation:

$$I_r'(t) = -Z(t)\mathrm{I_r}(\mathrm{t}), \qquad T_i \le t \le T_{i+1} \tag{6}$$

With the boundary condition $I_r(0) = R$ and $I_r(T_{i+1}) = I_r(T_i) - K$, for i = 1, 2…, $n-2$.

Using the boundary condition, the solution of equation *(6)* is given by

$$I_r(t) = Re^{-\alpha t^{\beta}}, \qquad 0 \le t \le T_1 \tag{7}$$

$$I_r(t) = \left(I_r(T_1) - K\right)e^{\alpha\left(T_2^{\beta} - t^{\beta}\right)}, \qquad T_1 \le t \le T_2$$

$$I_r(t) = \left(I_r(T_2) - K\right)e^{\alpha\left(T_3^{\beta} - t^{\beta}\right)}, \qquad T_2 \le t \le T_3$$

In general $$I_r(t) = \left(I_r(T_i) - K\right)e^{\alpha\left(T_i^{\beta} - t^{\beta}\right)}, \qquad T_i \le t \le T_{i+1},\ \mathrm{I} = 1, 2\ldots, n-2 \tag{8}$$

1. Present worth set-up cost

   Order is placed at the beginning of each cycle and hence for every cycle

   $$\mathrm{SPC} = \mathrm{A} \tag{9}$$

2. Present worth item cost

Inventory is bought at the beginning of the cycle and stored separately at the two warehouses. Hence,

$$\mathrm{IC} = \mathrm{SP} \tag{10}$$

3. Present worth holding cost in OW

Inventory is available during $T_i \le t \le T_{i+1}$, i = 0, 1, 2…, $n-1$. Hence the holding cost needs to be computed during these time periods.

$$HO_{OW} = \sum_{i=0}^{n-1} He^{-rT_i} \int_{\mathrm{T_i}}^{\mathrm{T_{i+1}}} I_0(t)\,\mathrm{e}^{-\mathrm{rt}}dt \tag{11}$$

4. Present worth holding cost in RW

Inventory is available during $T_i \le t \le T_{i+1}$, i = 0, 1, 2…, $n-2$. Hence the holding cost is:

$$HO_{RW} = \sum_{i=0}^{n-2} Fe^{-rT_i} \int_{T_i}^{T_{i+1}} I_r(t)\, e^{-rt} dt \tag{12}$$

5. Present worth shortage cost in OW

Shortage occurs during the period $T_n \le t \le \overline{T}$. Hence the shortage cost is:

$$SC = s e^{-rT_n} \int_{T_n}^{\overline{T}} \left[-I_0(t)\right] e^{-rt} dt \tag{13}$$

6. Opportunity cost due to lost sales occurs during the period $T_n \le t \le \overline{T}$. The OW present worth lost sale cost is

$$OP = \pi e^{-rT_n} \int_{T_n}^{\overline{T}} \left(1 - \frac{1}{1+\delta\left(\overline{T}-t\right)}\right) D(t)\, e^{-rt} dt \tag{14}$$

7. Present worth Sales revenue

Since the inventory is available for sale during $T_i \le t \le T_{i+1}$, i = 0, 1, 2…, $n-1$, profit can be gained in this time only. The present worth of profit gained during this time is obtained by the following expression;

$$SR = \sum_{i=0}^{n-1} S\, e^{-rT_i} \int_{T_i}^{T_{i+1}} D(t)\, e^{-rt} dt \tag{15}$$

8. Present worth transportation cost

Inventory is transferred from the RW to OW at T_i, $i = 0,1,2,..., n-1$, therefore we have

$$TRC = T_c \sum_{i=1}^{n-1} e^{-rT_i} \tag{16}$$

9. Present worth total profit

The present worth net profit is found by deduction of all the costs from the sales profit. Using the equations from *(9)* to *(16)*,

P = SR – SPC – IC – HO_{OW} – HO_{RW} – SC – TRC □ OP

$$P = \sum_{i=0}^{n-1} S\, e^{-rT_i} \int_{T_i}^{T_{i+1}} D(t)\, e^{-rt} dt - A - SP - LS - \sum_{i=0}^{n-1} He^{-rT_i} \int_{T_i}^{T_{i+1}} I_0(t)\, e^{-rt} dt$$

$$-\sum_{i=0}^{n-2} Fe^{-rT_i} \int_{T_i}^{T_{i+1}} I_r(t)\, e^{-rt} dt - s e^{-rT_n} \int_{T_n}^{\overline{T}} \left[-D(t)\right] e^{-rt} dt - T_c \sum_{i=1}^{n-1} e^{-rT_i} - \pi e^{-rT_n}$$

$$\int_{T_n}^{\overline{T}} \left(1 - \frac{1}{1+\delta\left(\overline{T}-t\right)}\right) D(t)\, e^{-rt} dt \tag{17}$$

Here, the objective of the study is to find that quantity, which should be stored in the RW, and the number of times the inventory should be transferred from the RW to the OW so that the net profit may be maximized. This is being discussed in the following numerical examples, taking different parameters.

4. Numerical Example

For an inventory system, the following data for solving the equations of the model was taken into consideration:

$a = 200$, $b = 5$, $\alpha = 0.005$, $\beta = 2$, $W = 500$, $\theta = 0.01$, $s = 1$, $P = 5$, $H = 1$, $F = 1.5$, $T_c = 100$, $r = 0.08$, $S = 20$, $A = 100$. With these values the solutions of the system for integral values of n i.e. 1, 2 ...5 were found as follows:

Table 1

Time values for different number of cycles							Optimal values for different number of cycles					
n	T_1	T_2	T_3	T_4	T_5	T_6	R	Cost	Revenue	Shortage Cost	Net Profit	NP/T
1	1.8132	4.0742	–	–	–	–	381.2154	7432.5744	3627	966.5023	5227.9233	1283.1779
2	1.8132	3.5092	5.6519	–	–	–	780.0307	10540.3737	16964	1953.1384	4470.4879	790.9708
3	1.8132	3.5092	5.1086	7.1519	–	–	1207.3	13436.3723	19591	2498.2347	3656.3923	511.2477
4	1.8132	3.5092	5.1086	6.6272	8.5872	-	1674.4	16275.7224	21638	2739.1215	2623.1561	366.7775
5	1.8132	3.5092	5.1086	6.6272	8.078	9.9699	2194.1	19224.5237	23257	2768.9548	1263.5215	126.7336

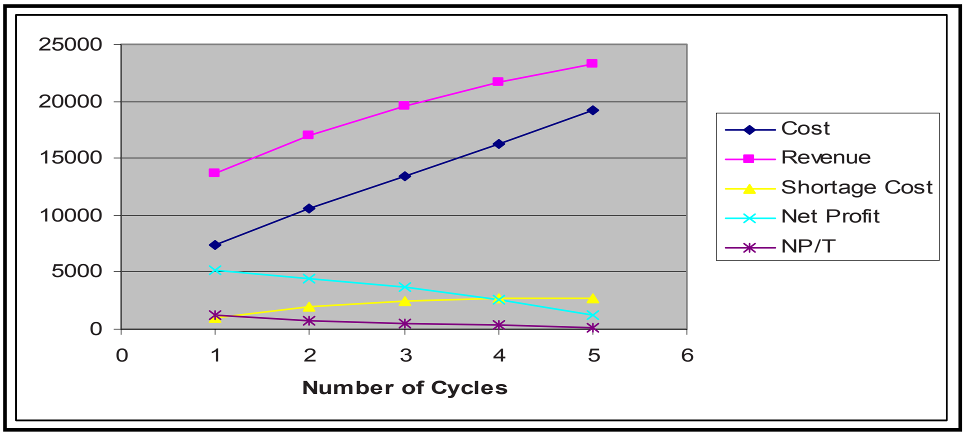

Fig. 3 Variation of Cost, Revenue, Shortage cost, Net Profit and Average Profit with number of cycles

It was observed that as the number of cycles increased, the net profit decreased, but the net profit per unit time was found to be maximum for n =1. Consecutively, it was observed that the net profit as well as the net profit per unit time was found to decrease for the increasing number of cycles. The above mentioned variations in system parameters have been depicted graphically in Fig. 3.

5. Conclusion

In this study, an inventory model was developed for deteriorating items with two- warehouse, permitting shortage under inflation and time-value of money. Holding costs and deterioration costs are different in OW and

RW due to different preservation environments. The inventory costs (including holding cost and deterioration cost) in RW were assumed to be higher than those in OW. To reduce the inventory costs, it would be economical for firms to store goods in OW before RW, and clear the stocks in RW before OW. The stock is transferred from the RW to the OW following a bulk release rule. Most of the researchers till now have ignored the effects of deterioration in both the warehouses or had considered a constant rate of deterioration. But in the present study deterioration taken as linear time dependent in OW and weibull distribution type deterioration rate in RW. The model is solved for different system parameters for up to five cycles and the optimal solution is selected from amongst the available solutions. The outcome showed that the net profit per unit time was found to be maximum for the first cycle. Consecutively, it is observed that the net profit as well as the net profit per unit time was found to decrease for increasing number of cycles

The present model is applicable for food grains like paddy, rice, wheat, etc., as the demand of the food grains increases with time for a fixed time horizon, i.e., for a calendar year. It is also applicable for other items where the demand is dependent linearly with time.

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