ORIGINAL RESEARCH

Inventory management under stochastic conditions with multiple objectives

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Abstract

In this research, a complex inventory system has been analyzed under uncertain situations. The item deterioration has been considered and the shortages are allowable. The objectives of the problem are: (1) Minimization of the total present value of costs over time horizon and (2) Decreasing the total quantity of goods in the warehouse over time horizon. The numerical examples are used for evaluation and validation of the theoretical results.

Key words

Inventory management, Complex systems, Uncertainty, Deterioration, Shortages

1 Introduction

Since 1975, a series of related papers appeared that considered the effects of time value of money and inflation on the inventory system. There are a few problems in the inflationary inventory systems on obsolescence and amelioration items which have been addressed by the researchers, because, we will not use obsolesced items in the future and the amelioration products are limited in the real world. For example, Moon et al. [1] considered ameliorating/deteriorating items with a time-varying demand pattern. Another research for ameliorating items has been done by Sana [2].

The no obsolescing, deteriorating and ameliorating items have been considered in some researches on the inflationary inventory system. Misra [3] developed a discounted cost model and included internal (company) and external (general economy) inflation rates for various costs associated with an inventory system. Sarker and Pan [4] surveyed the effects of inflation and the time value of money on order quantity with finite replenishment rate. Some efforts were extended the previous works to consider more complex and realistic assumption, such as Uthayakumar and Geetha [5], Maity [6], Vrat and Padmanabhan [7], Datta and Pal [8], Hariga [9], Hariga and Ben-Daya [10] and Chung [11].

The deteriorating inventory systems have been studied considerably in the recent years. For example, Chung and Tsai [12] presented an inventory model for deteriorating items with the demand of linear trend considering the time-value of money. Wee and Law [13] derived a deteriorating inventory model under inflationary conditions when the demand rate is a linear decreasing function of the selling price. Chen and Lin [14] discussed an inventory model for deteriorating items with a normally distributed shelf life, continuous time-varying demand, and shortages under an inflationary and time discounting environment. Yang [15] discussed the two-warehouse inventory problem for deteriorating items with a constant demand rate and shortages. Chang [16] established a deteriorating EOQ model when the supplier offers a permissible delay to the purchaser if the order quantity is greater than or equal to a predetermined quantity.

Maiti et al. [17] proposed an inventory model with stock-dependent demand rate and two storage facilities under inflation and time value of money. Lo et al. [18] developed an integrated production-inventory model with assumptions of varying rate of deterioration, partial backordering, inflation, imperfect production processes and multiple deliveries. A Two storage inventory problem with dynamic demand and interval valued lead-time over a finite time horizon under inflation and time-value of money considered by Dey et al. [19]. Other efforts on inflationary inventory systems for deteriorating items have been made by Hsieh and Dye [20], Su et al. [21], Chen [22], Wee and Law [23], Sarker et al. [24], Yang et al. [25], Liao and chen [26], Balkhi [27, 28], Hou and Lin [29], Hou [30], Jaggi et al. [31], Chern et al. [32] and Sarkar and Moon [33].

It can be seen that in the mentioned researches, rate of inflation has been assumed completely known and certain. Yet, inflation enters the inventory picture only because it may have an impact on the future inventory costs, and the future rate of inflation is inherently uncertain and unstable. But, there are a few works in the inflationary inventory researches under stochastic conditions, especially with multiple stochastic parameters. Mirzazadeh and Sarfaraz [34] presented multiple-items inventory system with a budget constraint and the uniform distribution function for the external inflation rate for no obsolescence, deterioration and amelioration items and Horowitz [35] discussed an EOQ model with a normal distribution for the inflation rate. Mirzazadeh [36] assumed the inflation is time-dependent and demand rate is assumed to be inflation-proportional. Other efforts in this direction have been made by Taheri et al. [37], Mirzazadeh et al. [38], Ameli et al. [39], Mirzazadeh [40], Samadi et at. [41], Gholami-Qadikolaei et al. [42] and Ghoreishi [43].

The objectives of the problem are: (1) Minimization of the total present value of costs and (2) Decreasing the total quantity of goods in the warehouse over the random time horizon. The second objective has seldom considered in the previous research of the inventory systems. But, decreasing in the inventory level is important for company, because: (1) decreasing in inventory level causes increasing company flexibility against changes in the market conditions, customer needs and so on, (2) the quantity of the deteriorated goods is related to inventory level so that decreasing in inventory causes decreasing destroyed good, (3) low inventory system causes faster company adaptation with technology changes, (4) decreasing in inventory causes better cash flow and rate of return.

Under the mentioned situations, a new mathematical model for the optimal inventory for an inventory control system is formulated under uncertain environment, and the paper has been organized as follow. First, the assumptions and notations and then, the multi-objective model formulation are derived. Then, the solution procedure has been prepared with using the ideal point approach. The numerical example has been provided to clarify how the proposed model is applied. The final section has devoted to the discussion.

2 The assumption and notations

The following assumptions are used throughout this paper:

1) The inventory system has been considered in a bi-criteria situation;
2) Lead time is negligible. Also, the initial and final inventory level is zero;
3) The demand rate is known and constant;
4) Shortages are allowed and fully backlogged except for the final cycle;
5) The replenishment is instantaneous and lead time is zero;
6) The system operates for prescribed time-horizon of length H;
7) A constant fraction of the on-hand inventory deteriorates per unit time.

The cost components may be divided into internal and external classes. Van Hees and Monhemius have given the breakdown of the various costs of inventory system. In the real world, internal and external costs exhibit different behaviours, so that the internal cost changes by the current inflation rate of the company and the external cost varies with the inflation rate of the general economy (or of the supplier company). Therefore, two different pdfs for the inflation rates can be used in this model. The notations described as follows:

ETVC(n,k): The total present value of costs over the time horizon;
TI(n,k): The total quantity of goods in warehouse over time horizon;
T: The interval of time between replenishment ;
k: The proportion of time in any given inventory cycle which orders can be filled from the existing stock ;
n: The number of replenishments during time horizon ;
i_m: Internal (for m=1) and external (for m=2) inflation rates;
$f(i_m)$: The pdf of i_m;
r: The discount rate;
D: The demand rate per unit time;
A: The ordering cost per order at time zero;
c_{lm}: The internal (for m=1) and external (for m=2) inventory carrying cost (for l=1) and shortage cost (for l=2) per unit per unit time at time zero;
p: The external purchase cost at time zero;
θ : The constant deterioration rate;
$M_{im}(Y)$: The moment generating function of i_m for m=1 and 2;
H: The fixed time horizon.

Other notations will be introduced later. It is assumed that the length of the planning horizon is H=nT, where n is an integer for the number of replenishments to be made during period H, and T is an interval of time between replenishment. The unit of time can be considered as a year, a month, a week, etc. and k ($0 \le k \le 1$) is the proportion of time in any given inventory cycle which orders can be filled from the existing stock. Thus, during the time interval [(j-1)T, jT], the inventory level leads to zero and shortages occur at time (j+k-1)T. Shortages are accumulated until jT before they are backordered, and are not allowed in the last replenishment cycle. The optimal inventory policy yields the ordering and shortage points, which minimize the total expected inventory cost over the time horizon.

3 The system analysis

The objectives of the problem can be explained as follows:

- Minimization of the expected present value of costs over time horizon

$$Min \quad Z_1 = ETVC(n,k) \tag{1}$$

- Decreasing of the total quantity of goods in warehouse over time horizon

$$Min \quad Z_2 = TI(n,k) \tag{2}$$

The multiple objective function of the inventory system can be considered as follows

$$Min \quad Z = \left[MinETVC(n,k), MinTI(n,k) \right] \tag{3}$$

3.1 The total quantity of inventory (TI (n, k))

Let TI1 and TIn as the total quantity of the goods held as inventory in the warehouse during the first (n-1) cycles and the last cycle respectively. TI1 equals to quantity of the goods held as inventory during each cycle multiplied by n-1.

$$TI_1 = (n-1)\int_{(j-1)T}^{(k+j-1)T} (t-(j-1)T)Ddt = \frac{1}{2}DT^2k^2 \tag{4}$$

Note TI1 is an increasing function with respect to k which

$$k = 0 \;\Rightarrow\; TI_1 = 0 \tag{5}$$

Similarly, TIn is equal to

$$TI_n = \int_{(n-1)T}^{nT} (t-(n-1)T)Ddt = \frac{-1}{2}(n^2-n-1)DT^2 \tag{6}$$

So, the total inventory over time horizon is

$$TI(n,k) = TI_1 + TI_n \tag{7}$$

3.2 The expected present value of costs

Let ECP, ECH, ECS and ECR denote the expected present values of the purchasing, carrying, shortage and replenishment costs, respectively. The detailed analysis of each cost function is given as follows.

3.2.1 Expected present value of the purchasing cost

During any given period, the order quantity is consisting of both demand and deterioration for the relevant period excluding shortage part of the period and the amount required to satisfy the demand during the shortage period in the preceding time interval. For the j-th cycle (j=1, 2,…,n-1) the expected present value of the purchase cost can be formulated as follows:

$$ECP_{j-1} = E\left[pe^{-R_2(j-1)T}\int_{(j-1)T}^{(k+j-1)T} De^{\theta(t-(j-1)T)}dt + pe^{-R_2jT}\int_{(k+j-1)T}^{jT} Ddt\right]$$

$$= E\left[pD\left[e^{-R_2(j-1)T}(e^{\theta kT}-1)/\theta + e^{-R_2jT}(1-k)T\right]\right]$$

$$\text{for: } \mathrm{j=1\ldots n\text{-}1}\ ,\ \mathrm{R_2 = r\text{-}\ i_2}. \tag{8}$$

The above equation can be rewritten as

$$ECP_{j-1} = (\mathrm{pD}/\theta)\, e^{(1-j)r\mathrm{T}}(e^{\theta k\mathrm{T}}-1)\, M_{i_2}((j-1)T)$$

$$+pDT(1-k)e^{-rjT}M_{i_2}(jT), \text{for } \mathrm{j=1,\ldots,(n\text{-}1)} \tag{9}$$

In the last period shortages are not allowable, therefore the expected present value of the purchase cost is:

$$ECP_{n-1} = E\left[pe^{-R_2(n-1)T} \int_{(n-1)T}^{nT} De^{\theta(t-(n-1)T)} dt \right]$$

$$= E\left[(pD/\theta) e^{-R_2(n-1)T} (e^{\theta T} - 1) \right] \tag{10}$$

where R2=r-i2. It can similarly be rewritten as

$$ECP_{n-1} = (\mathrm{pD}/\theta)\, e^{-r(n-1)\mathrm{T}} (e^{\theta T} - 1)\, M_{i_2}((n-1)T) \tag{11}$$

Therefore, the total purchase cost for all cycles can be written as follows:

$$ECP = ECP_{n-1} + \sum_{j=1}^{n-1} ECP_{j-1} \tag{12}$$

3.2.2 Expected present value of the inventory cost

The inventory carrying cost is divided into internal (for m=1) and external (for m=2) classes. The carrying cost for the j-th cycle (j=1, 2, …, n-1) for the m-th class (m=1,2) is:

$$ECH_{jm} = E\left[c_{1m} \int_{(j-1)T}^{(k+j-1)T} (t-(j-1)T) De^{-R_m t} e^{\theta(t-(j-1)T)} dt \right]$$

$$= c_{1m} DE\left[\left[(t - \frac{1}{\theta - R_m}) \frac{e^{-R_m t + \theta(t-(j-1)T)}}{\theta - R_m} \right]_{(j-1)T}^{(k+j-1)T} - \left[\frac{(j-1)T}{\theta - R_m} e^{-R_m t + \theta(t-(j-1)T)} \right]_{(j-1)T}^{(k+j-1)T} \right]$$

$$= c_{1m} DE\left[\frac{e^{-R_m(k+j-1)T + \theta kT}}{(\theta - R_m)^2} (k(\theta - R_m) - 1) + \frac{e^{-R_m(j-1)T}}{(\theta - R_m)^2} \right]$$

$$= c_{1m} DE\left[\frac{e^{-R_m(j-1)T} (1 + e^{(\theta - R_m)kT} (kT(\theta - R_m) - 1))}{(\theta - R_m)^2} \right]$$

$$\text{for } \mathrm{j} = 1, \ldots, (\mathrm{n} - 1), \mathrm{R}_{\mathrm{m}} = \mathrm{r} - \mathrm{i}_{\mathrm{m}}, \mathrm{m} = 1, 2. \tag{13}$$

In the last period for the m-th class (m=1,2) from similar machinations we have:

$$ECH_{nm} = E\left[c_{1m} \int_{(n-1)T}^{nT} (t-(n-1)T) De^{-R_m t} e^{\theta(t-(n-1)T)} dt \right]$$

$$= c_{1m} DE\left[\frac{e^{-R_m(n-1)T} (1 + e^{(\theta - R_m)T} ((\theta - R_m)T - 1))}{(\theta - R_m)^2} \right]$$

$$R_m = r - i_m, m = 1, 2. \tag{14}$$

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In the last period the inventory level comes to zero at the end of period. The total internal and external carrying costs for all cycles can be given as follows:

$$ECH = \sum_{m=1}^{2}\sum_{j=1}^{n-1} ECH_{jm} + \sum_{m=1}^{2} ECH_{nm} \tag{15}$$

3.2.3 Expected present value of the shortages cost

The expected present value of the shortages cost for the j-th cycle (j=1, 2, …, n-1) for the m-th class (m=1,2) can be computed as:

$$ECS_{jm} = E\left[c_{2m}\int_{(k+j-1)T}^{jT}(jT-t)De^{-R_m t}dt\right]$$

$$= c_{2m}DE\left[\left[\frac{e^{-R_m t}}{-R_m}(jT-t-\frac{1}{R_m})\right]_{(k+j-1)T}^{jT}\right]$$

$$= c_{2m}DE\left[\frac{e^{-R_m jT}}{R_m{}^2} - \frac{e^{-R_m(k+j-1)T}}{-R_m}((1-k)T-\frac{1}{R_m})\right]$$

$$= c_{2m}DE\left[\frac{e^{-R_m jT}(1+((1-k)R_mT-1)e^{-R_mT(k-1)})}{R_m{}^2}\right] \tag{16}$$

where Rm=r- im . It can be rewritten as

$$ECS_{jm} = c_{2m}DE\left[\frac{e^{-R_m jT} + ((1-k)R_mT-1)e^{-R_mT(k+j-1)}}{R_m{}^2}\right],$$

$$\text{for } j=1,\ldots,(n\text{-}1),\ R_m = r\text{-}i_m,\ m=1,2. \tag{17}$$

The total shortages cost during the entire planning horizon H can be written as follows:

$$ECS = \sum_{m=1}^{2}\sum_{j=1}^{n-1} ECS_{jm} \tag{18}$$

3.2.4 Expected present value of the ordering cost

The expected present value of the ordering cost for replenishment at time (j-1)T for the j-th cycle is:

$$ECR_j = Ae^{-rjT}M_{i_1}(jT), \text{for } j=1,\ldots,(n\text{-}1) \tag{19}$$

The total replenishment cost can be given as follows:

$$ECR = \sum_{j=0}^{n-1} ECR_j \tag{20}$$

Hence, the total expected inventory cost of the system during the entire planning horizon H is given by:

$$ETVC(n,k) = ECP + ECH + ECS + ECR \tag{21}$$

4 The solution procedure

The problem is to determine the optimal values of n, the number of replenishments to be made during period H, and k, the proportion of time in any given inventory cycle which orders can be filled from the existing stock ($0 \le k \le 1$). The ideal point approach will be used to solve the model. Consider the following multi-objective programming problem

$$\text{Min } f_j(x) \qquad \text{for j=1, 2, ..., k}$$

$$\text{s.t.: } g_i(x)<0 \qquad \text{for i=1, 2, …, m} \tag{22}$$

Where x is a n-dimensional decision vector. For any $f_j(x)$, define the ideal point as $f_j(x^{*j})$ which x*j minimizes $f_j(x)$. $f_j(x^{*j})$ is called the ideal point. The measure is "closeness" and LP-metric is used. LP-metric defines the distance between two points $f_j(x) and\ f_j(x^{*j})$ in k-dimensional space as

$$d_d = \left\{ \sum_{j=1}^{k} \gamma_i \left[f_j\left(x^{*j}\right) - f_j\left(x\right) \right]^d \right\}^{1/d} \qquad where \quad d \ge 1 \tag{23}$$

Where γ_j for j=1... k is relative importance (weights) of the objective function $f_j(x)$. The compromise solution for a given value of d will be minimizes the dd-metric in (47). The measurement unit of the model objectives is not equal to each other and therefore, we need to normalize the distance family of (47) by using the reference point as follow

$$d_d = \left\{ \sum_{j=1}^{k} \gamma_i \left[\frac{f_j\left(x^{*j}\right) - f_j\left(x\right)}{f_j\left(x^{*j}\right)} \right]^d \right\}^{1/d} \qquad where \quad d \ge 1 \tag{24}$$

Therefore

$$Mind_d\left(n,k\right) = \left\{ \begin{array}{l} \gamma_1 \left[\dfrac{ETVC\left(n^*,k^*\right) - ETVC\left(n,k\right)}{ETVC\left(n^*,k^*\right)} \right]^d \\ + \gamma_2 \left[\dfrac{TI\left(n^*,k^*\right) - TI\left(n,k\right)}{TI\left(n^*,k^*\right)} \right]^d \end{array} \right\}^{1/d} \qquad where \quad d \ge 1 \tag{25}$$

If k=0, the total inventory over time horizon, ETI(n,k), will be minimized for a given value of n. In this condition, the inventory level is zero over time horizon, except the last cycle, because, the shortages are not allowable. When n increases, the time interval between replenishments, especially the last cycle, will be decreases. So

$$\{n \to \infty, k = 0\} \Rightarrow TI(n,k) \to 0 \tag{26}$$

The absolute zero inventory level is impossible for any company and therefore, the inventory system manager has to consider a minimum value none zero inventory up to internal (company) and external (market) situations. Let TI(n*,k*) as the determined minimum inventory.

Since ETVC(n,k) is a function of a discrete variable n and a continuous variable k (0 < k < 1), therefore, for any given n, the necessary condition for the minimum of ETVC(n,k) is

$$\frac{dETVC(n,k)}{dk} = 0 \tag{27}$$

For a given value of n, derive k* from Equation (27). ETVC(n,k*) derives by substituting (n,k*) into equation (28). Then, n increase by the increment of one continually and ETVC(n,k*) calculate again. The above stages repeat until the minimum ETVC(n,k*) be found. The (n*,k*) and ETVC(n*,k*) values constitute the optimal solution and satisfy the following conditions

$$\Delta ETVC\left(n^* - 1, k^*\right) \langle 0 \langle \Delta ETVC\left(n^*, k^*\right) \tag{28}$$

Where

$$\Delta ETVC\left(n^*, k^*\right) = ETVC\left(n^* + 1, k^*\right) - ETVC\left(n^*, k^*\right) \tag{29}$$

5 Numerical example

According to the results, the following example is providing. Let r=\$0.2/\$/year, D=1000units/year, A=\$100/order, c11=\$0.2/unit/year, c12=\$0.4/unit/year, c21=\$0.8/unit/year, c22=\$0.6/unit/year, p=\$5/unit, H=10years, θ=0.01. The internal and external inflation rates have the normal distribution function with means of $\mu 1=0.08$ and $\mu 2=0.14$, standard deviations of $\sigma 1=0.04$ and $\sigma 2=0.06$, respectively.

Table 1. Optimal solution for numerical example

n	k	ETVC (n,k)	n	k	ETVC (n,k)
2	0.657362	98 743.29	40	0.664614	44 539.42
3	0.659947	76 905.97	41*	0.664623	44 537.26
5	0.661980	61 198.56	45	0.664656	44 556.16
10	0.663489	50 521.04	50	0.664689	44 629.30
15	0.663990	47 319.78	55	0.664716	44 743.37
20	0.664240	47 257.46	60	0.664739	44 888.07
25	0.664390	45 170.48	70	0.664774	45 243.00
30	0.664489	44 789.17	80	0.664801	45 657.88
35	0.664561	44 603.47	100	0.664838	46 595.31

The problem is the optimum ordering policy for minimizing (1) the expected present value of the total inventory system costs, ETVC(n,k), and (2) the total quantity of the goods in warehouse over time horizon, TI(n,k). As stated in the ideal point method, we have to first optimize objectives, separately. The ideal point of the first objective with considering the above mentioned parameters values and using the numerical methods, is calculated and the results are illustrated in Table

1. It can be seen that the minimum expected cost over the planning horizon is 44 537.26 for n*=41 and k*=0.664623. Optimal interval of time between replenishment, T*, equals to H/n*=0.244 year. The results are illustrated in table 1.

Let TI(n*,k*)=4000.00 as the determined minimum inventory up to the internal (company) and the external (market) situations. According to d=1 and the different combinations of γ_1 and γ_2 with considering ETVC(n*,k*)=44537.26 and ETI(n*,k*)=4000.00, the problem is evaluated and the results are shown in Table 2. The manager can determine the optimum value of n and k with considering company policy about the importance of the goals.

Table 2. Solution of the problem

γ_1	γ_2	n*	k*	TI*	ETVC*
0	1	61	0.182364	4000.00	48 712.05
0.25	0.75	55	0.368253	4702.87	47 562.27
0.5	0.5	50	0.419534	5267.23	46 350 .16
0.75	0.25	45	0.547623	5692.12	45 4487.90
1	0	41	0.664623	6043.17	44 537.26

6 Case study

The model has employed in one of the automotive supplier company as a real case. This supplier is Sanayeh Dashboard Iran that is located in Tehran, Iran. The product of this company is Dashboard which produce with using a frame with ABS/PVC covering and injection of the Isocyanat and Polyol mixture (semi rigid foam) into it. We want to determine order policy for Isocyanat. First, we surveyed inflation rates information that is reported by the Central Bank of Iran. The Chi-square test is applied in order to determining the pdfs of the inflation rates. The results show the Normal distribution with following means and variances is the goodness fit distribution for the internal and external inflation rates

$$i_1 \sim Normal\left(0.30, 0.13^2\right);\ i_2 \sim Normal(0.35, 0.19^2)$$

Then, other data is gathered from financial, marketing, production and engineering departments of the Sanayeh Dashboard Iran. The parameters values are summarized as follows (R is an abbreviation form of Rial, Persian monetary unit):

H=10year
r=R0.40/R/year
D=320000 units/year
θ=0.02
A=R50,000,000/order
c=R50,500/unit
c11=R720/unit/year
c12=R1250/unit/year
c21=R1900/unit/year
c22=R1510/unit/year.

Also, ETI(n*,k*)=160000.00 has been determined. The problem is solved for $\gamma_1 = 0.75$ and $\gamma_2 = 0.25$ the optimal vale of the number of replenishments during time horizon and the proportion of time in any given inventory cycle which orders can be filled from the existing stock will be obtained as: n*=23, k*=0.72.

7 Conclusions

In the recent decades, the companies try to maintain survival and increase their contributions in the market with considering additional objectives. Decreasing in the inventory level is one of the most important objective for the company, because: (1) decreasing in the inventory level causes increasing company flexibility against changes in the market conditions, customer needs and so on, (2) the quantity of the deteriorated goods is related to the inventory level so that decreasing in the inventory decreases the destroyed good, (3) low inventory system causes faster company adaptation with the technology changes, and (4) decreasing in the inventory causes better cash flow and rate of return. Therefore, a bi-objective inventory model has been developed in this paper.

Also, in the inventory systems under inflationary conditions, it has been assumed that the inflation rates are constant over the planning horizon. But, many economic, political, social and cultural variables may also affect the future changes in the inflation rate. Therefore, assuming constant inflation rates is not valid, especially when the time horizon is more than two years. The current paper considers uncertain inflation rates where any distribution function is applicable. The study has been conducted under the Discounted Cash Flow (DCF) approach.

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