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A NOTE ON INVENTORY MODEL FOR AMELIORATING ITEMS WITH TIME DEPENDENT SECOND ORDER DEMAND RATE

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ABSTRACT. Background: This paper is concerned with the development of ameliorating inventory models. The ameliorating inventory is the inventory of goods whose utility increases over the time by ameliorating activation.

Material and Methods: This study is performed according to two areas: one is an economic order quantity (EOQ) model for the items whose utility is ameliorating in accordance with Weibull distribution, and the other is a partial selling quantity (PSQ) model developed for selling the surplus inventory accumulated by ameliorating activation with linear demand. The aim of this paper was to develop a mathematical model for inventory type concerned in the paper. Numerical examples were presented show the effect of ameliorating rate on inventory polices.

Results and Conclusions: The inventory model for items with Weibull ameliorating is developed. For the case of small ameliorating rate (less than linear demand rate), EOQ model is developed, and for the case where ameliorating rate is greater than linear demand rate, PSQ model is developed. .

Key words: Inventory model, Ameliorate rate, Economic order quantity, partial selling-quantity, second order demand.

INTRODUCTION

A number of mathematical models have been developed for these deteriorating items. To get an idea of the trends of recent research in this area, one may refer to the works Mukherjee [1987], Bhunia and Maiti [1997], Datta and Pal [1991], Giri, Pal, Goswami, and Chaudhuri [1996], Goyal and Gunasekaran [1997], Mandal and Phaujdar [1989], and Sarkar, Mukherjee, and Balan [1997] Sahu and Parida [2001], Sahu, Acharya and Tripathy [2002], Sahu and Acharya [2002], Sahu, Kalam, Sukla, and Chand [2005], Dash, Kerketa, and Sahu [2005], Sahu, Ota, Sukla, Panda [2006], Sahu, Kalam, Sukla, Dash [2006], Sahu, Dash, Sukla, [2007] and others. Moreover, it is well known that the life time of some perishable items like medicines, perfumes, cosmetics, blood, etc. is fixed and these cannot be used after the prescribed period (i.e. after the expired date). In the recent years, there are some inventory models for this type of perishable product developed by Abad [1996], Luo [1998], and Padmanabhan and Vrat [1995]. Except deteriorating or perishable items, there are other types of items made of glass, ceramic, etc. which are stored one after another in the form of heaped stock. These items break/get damaged due to the accumulated stress. Recently, Mandal and Maiti [1997] have developed some inventory models for damageable items.

Deb and Chaudhuri [1987] were the first to permit shortages for an inventory item having a linear trend in demand. In their formulation of the resulting inventory problem a cycle starts with replenishment. Sachan [1984] looked at a model that can be considered as a special case of our model. He assumed that

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the demand rates are proportional with time. In this paper, he did not suggest an optimal solution to the model but, rather, an approximate method by assumed equal replenishment periods. Goswami and Chauduri [1991] considered a model with linear demand rates. They also suggested an approximate replenishment schedule. This is concerned with the development of ameliorating inventory models. The ameliorating inventory is the inventory of foods whose utility increases over the time by ameliorating activation. This study is performed according to areas; one is an economic order quantity (EOQ) model for the items whose utility is ameliorating in accordance with Weibull distribution, and the other is a partial selling quantity (PSQ) model developed for selling the surplus inventory accumulated by ameliorating activation with linear demand. Numerical examples to show the effect of ameliorating rate on inventory polices are illustrated.

MODEL DEVELOPMENT

The notations and assumptions are used in this paper are the time dependent demand rate is $R(t) = a + bt + ct^2, a > 0, b > 0, c > 0$, Here a is initial rate of demand, b is the rate with which the demand rate increases. The rate of change in the demand rate itself increases at a rate c.

$\alpha\beta t^{\beta-1}$ = The Weibull distribution.
C_0 = Ordering cost.
C_a = Ameliorating cost.
C_p = Purchasing cost.
P_s = Selling price.
C_h = Carrying cost.
C_s = Shortage cost.
Q = Partial ordering size.
S = Partial selling amount.
A (t) = Instantaneous ameliorating rate.
TC = Total cost/unit time.

ECONOMIC ORDER QUANTITY MODEL

When the ameliorating rate is less than the demand rate, we considered a cycle time that the amount of total demand is filled partially with the amount of ameliorated and partially with the amount of replenished amount of from an ordering quantity.

Since the inventory level at time t, I_t will change at a varying rate, it must be expressed as a differential equation. The depletion, dI, during the infinite estimate time, dt, following time t, is a function of those; the ameliorating rate, demand rate, and the remaining inventory level at the inventory system.

$$dI = IA(t)dt - (a + btct^2)dt \qquad (1)$$

$$\frac{dI}{dt} - (\alpha\beta t^{\beta-1})I = -(a + bt + ct^2) \qquad \text{where}$$

$$(2)\; I = e^{\alpha t^\beta}\left[\int_0^t (a + bt + ct^2)e^{-\alpha t^\beta}dt + K\right] \qquad (3)$$

The value of the constant integration *K*, Using the boundary conditions. When *t=0, I=* I_0

$$I_0 = -\int_0^0 (a + bt + ct^2)e^{-\alpha t^\beta}dt + K$$

$$K = I_0 \qquad (4)$$

and when *t=T* , *I=0*, solving for I_0 given,

$$I_0 = \int_0^T (a + bt + ct^2)e^{-\alpha t^\beta}dt \qquad (5)$$

and

$$I = e^{\alpha t^\beta}\left[-\int_0^t (a + bt + ct^2)e^{-\alpha x^\beta}dx + I_0\right] \qquad (6)$$

Thus, to find the total cost equation we have to consider the ameliorating cost as well as the holding cost and ordering cost.

The equation for the total cost per unit time, TC, can be obtained by

$$TC(T) = I_0\left(\frac{C_p - C_a}{T} + \frac{C_h}{2}\right) + (a + bt + ct^2)C_a + \frac{C_0}{T}$$

$$= (C_p - C_a)\left[a\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta}}{k!(k\beta+1)} + b\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+1}}{k!(k\beta+2)} + c\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+2}}{k!(k\beta+3)}\right]$$

$$+\frac{C_h}{2}\left[a\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{K\beta+1}}{k!(k\beta+1)} + b\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+2}}{k!(k\beta+2)} + c\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+3}}{k!(k\beta+3)}\right]$$

$$+ (a + bt + ct^2)C_a + \frac{C_0}{T} \qquad (7)$$

The average inventory on hand is given by

$$\frac{I_A}{T} = \frac{1}{T}\int_0^T I dt$$

$$= \frac{1}{T}\int_0^T e^{\alpha t^\beta}\left[-\int_0^t (a+bx+cx^2)e^{-\alpha x^\beta}dx + I_0\right]$$

$$= \sum_{k=0}^{\infty}\frac{(-1)^k \alpha^{2k} T^{2k\beta+1}}{(k!)^2(k\beta+1)}\left[\frac{a}{k\beta+1}+\frac{bT}{k\beta+2}+\frac{cT^2}{k\beta+3}\right]$$

$$-\sum_{k=0}^{\infty}\sum_{n=0}^{\infty}\frac{(-1)^k \alpha^{k+n} T^{k\beta+n\beta+1}}{k!n!}\left[\begin{array}{l}\frac{a}{(k\beta+1)(k\beta+n\beta+2)} \\ +\frac{bT}{(k\beta+2)(k\beta+n\beta+3)} \\ +\frac{cT^2}{(k\beta+3)(k\beta+n\beta+4)}\end{array}\right] \quad (8)$$

To find the optimal cycle time, T^*, it must be differentiated with respect to T, and by setting it equal to zero, gives

$$\frac{dTC}{dT} = (C_p - C_a)$$

$$\left[a\sum_{k=0}^{\infty}\frac{(-\alpha)^k k\beta T^{k\beta-1}}{k!(k\beta+1)} + b\sum_{k=0}^{\infty}\frac{(-\alpha)^k (k\beta+1)T^{k\beta}}{k!(k\beta+2)} + c\sum_{k=0}^{\infty}\frac{(-\alpha)^k (k\beta+2)T^{k\beta+1}}{k!(k\beta+3)}\right]$$

$$+\frac{C_h}{2}\left[a\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta}}{k!} + b\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+1}}{k!} + c\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+2}}{k!}\right]$$

$$-\frac{C_0}{T^2} = 0 \quad (9)$$

From equation $\frac{dTC}{dT} = 0$, we get

$$T = \frac{1}{C_0}\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+2}}{k!}\left[a\left[\left(C_p - C_a\right)\frac{k\beta}{k\beta+1}+\frac{C_h T}{2}\right]\right.$$

$$+bT\left[\left(C_p - C_a\right)\frac{k\beta+1}{k\beta+2}+\frac{C_h T}{2}\right]$$

$$\left.+cT^2\left[\left(C_p - C_a\right)\frac{k\beta+2}{k\beta+3}+\frac{C_h T}{2}\right]\right] \quad (10)$$

We can find the optimal cycle time, T^* by computer search.

When $\beta = 1$ in the proposed model, ameliorating rate becomes constant and the initial inventory level I_0 is

$$I_0 = \frac{a}{\alpha}\left[1-e^{-\alpha T}\right] + \frac{b}{\alpha^2}\left[1-(1+\alpha T)e^{-\alpha T}\right]$$

$$+\frac{2c}{\alpha^3}(\alpha T - e^{-\alpha T} - \alpha T e^{-\alpha T})$$

And

$$I = \frac{a}{\alpha}\left[e^{\alpha(T-t)}-1\right] + \frac{b}{\alpha^2}\left[(1+\alpha t)e^{\alpha(T-t)} - (1+\alpha T)\right]$$

$$+\frac{2c}{\alpha^3}\left[(1+\alpha t+\frac{\alpha t^2}{2})e^{\alpha(T-t)} - e^{\alpha T}(1-\alpha T) - (1+\alpha T)\right]$$

PARTIAL SELLING QUANTITY MODEL

When the amount of unit ameliorated during the infinite estimate time is greater than the depleted amount for demands the surplus amount of storages will be accumulated in the inventory system as time elapsed. On the other hand the carrying cost per unit time will increase as the surplus amount of storages increases. Hence, at a proper point of time, it will be better to sell out this surplus amount of storages, S_0, at appropriate selling price, C_s and selling process cost C_0.

Immediately after the selling points of time, the inventory level will be dropped to I_0 (base line initial inventory level). Initial inventory, I_0 and partial selling quantity, S_0, can be found from the equation (13) where k is found from the boundary conditions. When t=0, I= I_0

Thus K= I_0.

And

$$I_t = e^{\alpha t^\beta}\left[-\int_0^t (a+bt+ct^2)e^{-\alpha t^\beta}dt + I_0\right] \quad (11)$$

When t=T, I= $I_0 + S_0$

$$I_0 + S_0 = e^{\alpha T^\beta}\left[-\int_0^T (a+bt+ct^2)e^{-\alpha t^\beta}dt + I_0\right] \quad (12)$$

Thus

$$I_0 = \frac{1}{e^{\alpha T^\beta}-1}\left[e^{\alpha T^\beta}\int_0^T (a+bt+ct^2)e^{-\alpha t^\beta}dt + S_0\right] \quad (13)$$

And

$$S_0 = e^{\alpha T^\beta}\left[-\int_0^T (a+bt+ct^2)e^{-\alpha t^\beta}dt\right] \quad (14)$$

$$+I_0(e^{\alpha T^\beta}-1)$$

$$TC=(P_s-C_a)(a+bt+ct^2)+\left[\frac{P_s-C_a}{T}-\frac{C_h}{2}\right]\left[I_0\left(e^{\alpha T^\beta}-1\right)-\left(a+bt+ct^2\right)e^{\alpha T^\beta}\sum_{k=0}^{\infty}\frac{(-\alpha)^k T^{k\beta+1}}{k!(k\beta+1)}\right]-C_hI_0-\frac{C_0}{T} \quad (15)$$

From equation $\frac{dTC}{dT}=0$, we get

$$T=\frac{(P_s-C_a)}{C_0}I_0T\left(e^{\alpha T^\beta}-1\right)-\frac{1}{C_0}\left[(P_s-C_a)-\frac{C_hT}{2}\right]I_0\alpha\beta T^{\beta+1}e^{\alpha T^\beta}$$
$$+\left(a+bt+ct^2\right)\alpha\beta e^{\alpha T^\beta}T^3\frac{(P_s-C_a)}{C_0}\sum_{k=0}^{\infty}\frac{(-\alpha)^kT^{(k+1)\beta-1}}{k!(k\beta+1)}$$
$$-\frac{1}{2}\alpha\beta\frac{C_h}{C_0}\left(a+bt+ct^2\right)T^4e^{\alpha T^\beta}\sum_{k=0}^{\infty}\frac{(-\alpha)^kT^{(k+1)\beta-1}}{k!(k\beta+1)}$$
$$+(a+bt)\frac{(P_s-C_a)}{C_0}e^{\alpha T^\beta}T^3\sum_{k=0}^{\infty}\frac{(-\alpha)^k k\beta T^{k\beta-1}}{k!(k\beta+1)}$$
$$-\frac{1}{2}\frac{C_h}{C_0}\left(a+bt+ct^2\right)e^{\alpha T^\beta}T^3\sum_{k=0}^{\infty}\frac{(-\alpha)^kT^{k\beta}}{k!} \quad (16)$$

We can find the optimal cycle time T^* by computer search from the equation (16).

NUMERICAL EXAMPLES

Two examples are given to illustrate the models derived: the first example illustrates the application of the EOQ model where ameliorating rate is less than the demand rate in the system, and in the second example, PSQ model is presented and partial selling quantity S_0 was obtained by the proposed procedure where the ameliorating rate is greater than the demand rate.

Example 1

A fish breeder sells raw fish in a small sea village .The average demand rate of raw fish is 1000kg/day, thus he orders fish periodically when the tank is almost empty. The fish in the water tank is almost empty. The fish in the water tank ameliorate by the rate, $\alpha\beta t^{\beta-1}$ where α and β are estimated by the historical data.

Table 1. Results of Example (Optimal Cycle Time T*, Optimal Order Level I_0, Minimum cost TC*)
Tabela 1. Wyniki przykładu optymalna czas cyklu T*, optymalny poziom zamówienia I_0, koszt minimalny TC*)

α	**β = 0.05**	**β = 0.10**	**β = 0.15**	**β = 0.20**	**β = 0.25**	**β = 0.30**
α = 0.05	0.8677 13.4148 654.3691	0.8696 13.3145 645.3895	0.8707 13.2595 640.7897	0.8788 13.2287 638.5575	08795 13.2070 638.3567	0.8854 13.1710 638.1224
α = 0.10	0.8863 12.7850 577.0362	0.8754 13.2195 532.6083	0.9917 13.0097 530.4795	1.0342 12.8575 511.4327	1.2342 12.4495 503.4782	1.5763 12.0876 490.5728
α = 0.15	1.0171 11.3444 466.4275	1.0197 11.2052 466.0275	1.0292 11.0095 465.8793	1.0497 10.9782 465.3475	1.0875 10.7775 465.1175	1.0999 10.3575 464.8792
α = 0.20	1.0417 10.0803 425.8881	1.0385 10.0203 425.8023	1.0475 9.8883 423.2372	1.0871 9.8655 .422.8873	1.0892 9.8472 421.4188	1.0922 9.8237 420.4855
α = 0.25	1.0657 8.7764 377.4221	1.0591 8.4611 355.1482	1.0676 8.1271 338.0237	1.0759 7.6488 302.1273	1.0840 7.1375 264.4525	1.0919 6.5933 257.4377
α = 0.30	1.0694 7.6472 355.0633	1.0801 7.3445 313.0663	1.0909 7.0808 285.3861	1.1015 6.5828 257.4649	1.1117 6.0353 229.6248	1.1217 5.4877 202.4027

The data needed are given as:

$$R(t)=a+bt+ct^2=1000+100t+20t^2$$
$$C_a=4{,}000W/unit$$
$$C_h=400W/kg/day$$
$$C_p=10{,}000W/kg$$
$$C_0=300{,}000W$$
$$p_s=20{,}000W/kg$$
$$\alpha=\beta=0.05\sim 0.3$$

The results of the computer program output are in Table 1.

Example 2

This example is the case that the amount of unit ameliorated is greater than demand rate. The input data for PSQ model are given as

$R(t) = 1000 + 100t + 20t^2$

$C_a = 1{,}000W / kg$

$C_0 = 30{,}000W / unit$

$C_p = 8{,}000W / unit$

$C_h = 400W / unit / time$

$p_s = 10{,}000W / unit$

$\alpha = \beta = 0.5 \sim 1.2$

When $\alpha = 0.5$ and $\beta = 0.5$, the optimal partial selling quantity and the total cost per cycle time are

$$T^* = 0.0032$$

$$TC^* = 79.4201$$

$$S_0^{\ *} = 6.0018$$

The results from example 1 and 2 which show different cases of ameliorating inventory models are obtained by programming with equation (8), (10), (14) and (16).

CONCLUSIONS

The inventory model for items with Weibull ameliorating is developed. For the case of small ameliorating rate (less than linear demand rate), EOQ model is developed, and for the case where ameliorating rate is greater than linear demand rate, PSQ model is developed. So the surplus amount of items accumulated in the inventory system during the time elapsed can be sold by economic conditions. In the proposed models can be used to analyze the ameliorating inventory systems well, and known to be useful practice can be done.

In the example, α and β are assumed to proper fraction (i.e. $0 < \alpha < 1, 0 < \beta < 1$) When β increases the optimal cycle time, optimal order level and the total cost will decreases. This indicates that the ameliorating rate is a decreasing function with respect to time. Generally, the fast growing animals or high speed fishes, the rate of amelioration is initially high and then it decreases over time

The present model is very importance in the developing countries like India, Pakistan, Nepal, etc. as the culture of life stocks like high breed broiler, pig, fish, etc. has been taken up now-a-days in a very large scale.

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UWAGI DOTYCZĄCE MODELU ZARZĄDZANIA ZAPASEM PRODUKTÓW PRZETWORZONYCH UZALEŻNIAJĄCEGO WIELKOŚĆ ZAMÓWIENIA OD ZMIENNEJ CZASU

STRESZCZENIE. **Wstęp:** Praca porusza zagadnienie rozwoju modeli zarządzania zapasem dla produktów przetworzonych. Dotyczy ona produktów, których użyteczność wzrasta wraz z upływem czasu poprzez zastosowanie procesów ich obróbki ulepszania.

Materiały i metody: W pracy oparto się na dwóch modelach: pierwszy z nich to model ekonomicznej wielkości zamówienia (EOQ) dla towarów, których użyteczność wzrasta zgodnie z dystrybucją Weibulla, natomiast drugi to model częściowej sprzedaży (PSQ) nadwyżek zapas nagromadzonych poprzez aktywności mające poprawę ich użyteczności i charakteryzujące się popytem liniowym. Celem tej pracy było wypracowanie matematycznego modelu dla zarządzania zapasem dla typu towarów omawianych tutaj. Praktyczne działanie modelu przedstawiono na zaprezentowanych przykładach.

Wyniki i wnioski: Wypracowano model zarządzania zapasem towarów podlegających wzroście wartości Weibulla. Dla przypadku, gdy wskaźnik poprawy przybierał niską wartość (mniejszą niż wskaźnik popytu liniowego) opracowano model EOQ, natomiast dla przypadku, gdy ten wskaźnik był większy niż wskaźnik popytu liniowego, opracowano model PSQ.

Słowa kluczowe: zarządzanie zapasem, wskaźnik poprawy, ekonomiczna wielkość zamówienia, wielkość sprzedaży częściowej, powtórne zamówienie.

BEMERKUNGEN ZUM MODELL FÜR BESTANDSFÜHRUNG VON VERARBEITETEN PRODUKTEN IN HINSICHT AUF DIE ABHÄNGIGKEIT DER BESTELLGRÖßE VON DER VARIABLEN DER ZEIT

ZUSAMMENFASSUNG. Einleitung: Die Arbeit geht auf die Problematik der Entwicklung von Modellen für die Bestandsführung von verarbeiteten Produkten ein. Sie betrifft die Produkte, deren Brauchbarkeit durch die Anwendung von Veredelungsverfahren mit der Zeit wächst.
Material und Methoden: In der vorliegenden Arbeit stützte man sich auf zwei Modelle: das erste stellt ein Modell der wirtschaftlichen Bestellgröße (EOQ) für die Waren, deren Brauchbarkeit gemäß der Weibull-Distribution wächst dar, das andere dagegen bezieht sich auf den teilweisen Verkauf (PSQ) von Überständen der Bestandsvorräten, die sich durch die lineare Nachfrage charakterisieren und durch Anwendung von den auf die Verbesserung deren Brauchbarkeit hinzielenden Veredelungsverfahren bereitgestellt wurden. Das Ziel der Arbeit war es, das mathematische Modell der Bestandsführung der besagten Warentypen auszuarbeiten. Die praktische Funktionsausübung des Modells stelle man anhand der angeführten Beispiele dar.
Ergebnisse und Fazit: Man hat ein Modell für Bestandführung von Produkten, die dem Ansteigen des Weibull-Wertes unterliegen, ausgearbeitet. Für den Fall, in dem die Verbesserungskennziffer niedrig (niedriger als die Kennziffer der linearen Nachfrage) bemessen war, hat man das EOQ-Modell konzipiert, dagegen für den Fall, in dem die Verbesserungskennziffer als die Kennziffer der linearen Nachfrage größer war, hat man das PSQ-Modell in Anspruch genommen.

Codewörter: Bestands- und Vorratsführung, Verbesserungskennziffer, wirtschaftliche Bestellgröße, Teilverkaufsgröße, wiederholte Bestellung.

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