A Note on Non-linear Profit-Maximization Entropic Order Quantity (EnOQ) Model for Deteriorating Items with Stock Dependent Demand Rate

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ABSTRACT

A new type of non-linear profit maximization replenishment policy is suggested in an entropy order quantity model for deteriorating items with stock dependent demand rate. This model represents an appropriate combination of two component demand with entropy cost, particularly over a finite time horizon. Its main aim lies in the need for an entropic cost of the cycle time is a key feature of specific perishable products like fruits, vegetables, food stuffs, fishes etc. To handle this multiplicity of objectives in a pragmatic approach, entropic ordering quantity model with two component demand of perishable items to optimize its payoff is proposed. Two non-linear profit-maximization models are formulated by considering the effects of entropy cost and without entropy cost. Finally to clearly illustrate the non-linear profit maximization EnOQ model a numerical example and the sensitivity analysis are also conducted in the optimal solutions when different parameters are changed. It is considered that if the entropy is allowed in the model, the profit is approximately less in comparison to the non entropic model but the order quantity is more in EnOQ model. In addition, a comparative analysis between the profit-maximization models is conducted.

Keywords: *stock dependent demand, deterioration, entropy, profit maximization, inventory*

1. INTRODUCTION

This paper establishes and analyzes a non-linear inventory model under profit-maximization which extends the classical economic order quantity (EOQ) model. The extensions to the EOQ model by this model are introducing the entropy cost. In deriving and analyzing the optimal solutions of non-linear problem, LINGO software is used.

The predominant criterion in traditional inventory models is minimization of long-run average cost per unit time. The costs considered are usually fixed and variable ordering cost, holding cost, disposal cost. Costs associated with disorder in a system tied up in inventory are accounted for by including an entropy cost in the total costs. Entropy is frequently defined as the amount of disorder in a system. Jaber et al. (2008) proposed an analogy between the behaviour of production system and the behaviour of physical system. This paper introduced the concept of entropy cost to account for hidden cost such as the additional managerial cost that is needed to control the improvement process.

Product perishability is an important aspect of inventory control. Deterioration in general, may be considered as the result of various effects on stock, some of which are damage, decay, decreasing usefulness and many more. While kept in store fruits, vegetables, food stuffs etc. suffer from depletion by decent spoilage. Decaying products are of two types. Product which deteriorate from the very beginning and the products which start to deteriorate after a certain time. Lot of articles are available in inventory literature considering deterioration. Interested readers may consult the survey paper of Tripathy and Pattnaik (2008) investigate an entropic order quantity model for perishable items with pre and post deterioration discounts under two component demand in fuzzy decision space. Pattnaik (2010) discusses an entropic order quantity model for perishable items with constant demand where instant post deterioration discount is allowed to obtain maximum profit. Panda et al. (2009) derive an EOQ model for perishable items under two component demand where pre and post deterioration discounts are allowed in crisp decision space. Weatherford and Bodily (1992), Goyal and Giri (2001) and Raafat (1991) survey for perishable items to optimize the model.

The constant demand model appears to have received considerably less attention in the inventory literature than the two component demand function model. In last two decades the variability of inventory level dependent demand rate on the analysis of inventory system was described by researchers like Pal et al. (1993), Goswami and Choudhury (1995) and Silver and Peterson (1985). They described the demand rate as the power function of on hand inventory. There is a vast literature on stock development inventory and its outline can be found in the review article by Urban (2005) where he unified two types of inventory level dependent demand by considering a periodic review model. Researchers such as Pattnaik (2011), Chung et al. (2007), Goswami and Choudhury (1995), Goyal and Giri (2001), Pal et al. (1993), Raafat (1991), Wee and Law (2001) and Skouri et al. (2007) discussed the EOQ model assuming time value of money, demand rate, deterioration rate, shortages and so on a constant or probabilistic number or an exponential function. This paper considers two component demand function initially depending on inventory up to deterioration and then it becomes a constant function till stock is zero for

Table 1. Major Characteristics of Inventory Models on Selected Researches

Author(s) and published Year	Structure of the Model	Deterioration	Inventory Model Based on	Type of model	Discount allowed	Demand	Back-logging allowed
Panda et al. (2009)	Crisp	Yes (Heaviside)	EOQ	Profit	Yes	Stock dependent	No
Jaber et al. (2008)	Crisp	Yes (on hand inventory)	EnOQ	Profit	No	Unit selling price	No
Chung et al. (2007)	Crisp	Yes (exponential)	EOQ	Profit	No	Selling price	Yes (partial)
Skouri et al. (2007)	Crisp	Yes (Weibull)	EOQ	Cost	No	Ramp	Yes (partial)
Tripathy et al. (2008)	Fuzzy	Yes (Heaviside)	EnOQ	Profit	Yes	Stock dependent	No
Pattnaik (2010)	Crisp	Yes (constant)	EnOQ	Profit	Yes	Constant	No
Pattnaik (2011)	Crisp	Yes (Heaviside)	EnOQ	Profit	Yes	Stock dependent	No
Present paper (2011)	Crisp	Yes (Heaviside)	EnOQ	Profit	No	Stock dependent	No

the perishable products like fruits, vegetables, food stuffs, fishes etc.

The purpose of this paper is to investigate the effect of the approximation made by using the average payoff when determining the optimal values of the policy variables. This paper focuses exclusively on the cost of entropy with two component demand. A policy iteration algorithm is designed for non-linear problem with the help of Deb (2000) and optimum solution is obtained through the LINGO software. Numerical experiments are carried out to analyse the magnitude of the approximation error.

The major assumptions used in the above research articles are summarised in Table 1. The remainder of this paper is organised as follows. In section 2 assumptions and notations are provided for the development of the model. Section 3 describes the model formulation with other case. In section 4, an illustrative numerical experiment is given to illustrate the procedure of solving the model. In section 5 the paper describes the comparative evaluation and section 6 studies the sensitivity analysis of the present model. Section 7 provides the critical discussion of the present paper relating with the papers. Finally in section 8 summary and concluding remarks are provided with some suggestions for future research.

2. NOTATIONS AND ASSUMPTIONS

2.1 Notations

C_0 : set up cost
c   : per unit purchase cost of the product
s   : constant selling price of the product per unit *(s>c)*
h   : holding cost per unit per unit time
Q_i : (i=1,2)order level for crisp entropic order quantity (CEnOQ) and crisp economic order quantity (CEOQ) models respectively.
T_i : (i =1,2) cycle lengths for above all the two respective cases

2.2 Assumptions

1. Replenishment rate is infinite

2. The deterioration rate $\tilde{\theta} = \theta H (t-\tau)$, $(0 < \theta \leq 1)$ constant. Where t is the time measured from the instant arrivals of a fresh replenishment indicating that the deterioration of the items begins after a time τ from the instant of the arrival in stock. $H (t - \tau)$ is the well-known Heaviside's function. $H (t - \tau) = \begin{cases} 1, t \geq \tau \\ 0, \text{otherwise} \end{cases}$

3. Demand depends on the on hand inventory up to time τ from time of fresh replenishment beyond which it is constant and defined as follows.
$$R (I (t)) = \begin{cases} a + bI(t), & t < \tau \\ a, t \geq \tau \end{cases}$$

Where *a>0* is the initial demand rate independent of stock level and condition of inventory. *b>0* is the stock sensitive demand parameter $I(t)$ is the instantaneous inventory level at time t.

4. Entropy generation rate must satisfy $S = \dfrac{d\sigma(t)}{dt}$ where, $\sigma(t)$ is the total entropy generated by time t and S is the rate at which entropy is generated. The entropy cost is computed by dividing the total commodity flow in a cycle of duration T_1. The total entropy generated over time T_1 as $\sigma(T_1) = \int_0^{T_1} S dt$, $S = \dfrac{R(I(t))}{s}$

Entropy cost per cycle is
$EC (T_i) = (EC)_{Without\ deterioration} + (EC)_{With\ deterioration}$
$= \dfrac{D(\tau)}{\sigma(\tau)} + \dfrac{Q_{1\ With\ deterioration}}{\sigma(T_1)}$ EC is measured in an appropriate price unit with no deterioration and with deterioration respectively.

3. MATHEMATICAL MODEL

At the beginning of the replenishment cycle the inventory level raises to Q_1. As time progresses it decreases due to instantaneous stock dependent demand up to the time τ. After τ deterioration starts and the inventory level decreases for deterioration and constant demand. Ultimately inventory reaches zero level at T_1. Then the behaviour of inventory level is governed by the following system of linear differential equations.

$$D(I(t))/d = -a - b\,I(t) \qquad 0 \le t \le \tau$$
$$= -[a + \theta\,I(t)] \qquad \tau \le t \le T_1 \qquad (1)$$

With the initial boundary condition
$I(0) = Q_1,\ 0 \le t \le \tau$
$I(T_1) = 0,\ \tau \le t \le T_1$

Solving the equations,

$$I(t) = \frac{a}{b}\left[e^{-bt} - 1\right] + \left(Q_1 \times e^{-bt}\right), 0 \le t \le \tau \qquad (2)$$

$$= \frac{a}{\theta}\left[e^{\theta(T_1 - t)} - 1\right],\ \tau \le t \le T_1 \qquad (3)$$

Now, at the point $t = \tau$ we have from equation (2) and (3).

$$Q_1 = \left[\frac{a}{\theta}\left(e^{\theta(T_1-\tau)} - 1\right) + \frac{a}{b}\right] \times e^{b\tau} - \frac{a}{b} \qquad (4)$$

Holding cost of inventory in the cycle is,

$$HC = h\int_{o}^{\tau} I(t)dt + h\int_{\tau}^{T_1} I(t)\,dt$$

Purchase cost in the cycle is given by $PC = cQ_1$.
Entropy cost in the cycle is

$EC = (EC)_{without\ deterioration} + (EC)_{with\ deterioration}.$

$$= \frac{D(\tau)}{\sigma(\tau)} + \frac{Q_1 \quad with\ Deterioration}{\sigma\ (T_1)}.$$

Where

$$D(\tau) = \int_{0}^{\tau} R(I(t))dt,$$

$$\sigma(\tau) = \int_{0}^{\tau} S\,dt = \int_{0}^{\tau} \frac{R(I(t))}{s}dt = \frac{1}{s}D(\tau),$$

$$\sigma(T_1) = \int_{\tau}^{T_1} \frac{R(I(t))}{s}\,dt = \int_{\tau}^{T_1}\frac{a}{s}dt = \frac{a}{s}(T_1 - \tau),$$

$$EC = s + \frac{sQ_1}{a(T_1 - \tau)}$$

Total sales revenue in the order cycle can be found as

$$SR = s\left[\int_{0}^{\tau}[a + bI(t)]dt + \int_{\tau}^{T_1} a\ dt\right]$$

Thus total profit per unit time of the system is

$$\pi_1(T_1) = \frac{1}{T_1}[SR - PC - HC - EC - OC]$$

On integration and simplification of the relevant costs, the total profit per unit time becomes

$$\pi_1 = \frac{1}{T_1}\left[\begin{array}{l} sa\tau + sa(T_1 - \tau) + (sb - h)\left(-\frac{a\tau}{b} + \left(Q_1 + \frac{a}{b}\right)\left(\frac{1 - e^{-b\tau}}{b}\right)\right) - \frac{ha}{\theta}\left(\frac{e^{\theta(T_1-\tau)} - 1}{\theta} - (T_1 - \tau)\right) \\[2mm] -\ s - \dfrac{sQ_1}{a(T_1 - \tau)} - cQ_1 - C_0 \end{array}\right] \qquad (5)$$

Since, no discount is provided on the unit selling price of the product in CEnOQ model, no constraints will be imposed on equation (5). The only constraint is the non-negative restriction for T_1. Hence,

Maximize $\pi_1(T_1)$
$$\forall T_1 \ge 0 \qquad (6)$$

Case-1 Profit Maximization for CEOQ Model

In this case the entropy cost is ignored, so the order level and total profit per unit time is obtained from (4) and (5) by substituting $T_1 = T_2$ and $EC = 0$.

$$Q_2 = \left[\frac{a}{\theta}\left(e^{\theta(T_2-\tau)} - 1\right) + \frac{a}{b}\right]e^{b\tau} - \frac{a}{b} \qquad (7)$$

$$\pi_2 = \frac{1}{T_2}[SR - PC - HC - OC]$$

$$= \frac{1}{T_2}\left[\begin{array}{l} sa\tau + sa(T_2 - \tau) + (sb - h)\left(-\frac{a\tau}{b} + \left(Q_2 + \frac{a}{b}\right)\left(\frac{1 - e^{-b\tau}}{b}\right)\right) \\[2mm] -(h)\frac{a}{\theta}\left(\frac{e^{\theta(T_2-\tau)} - 1}{\theta} - (T_2 - \tau)\right) - cQ_2 - C_0 \end{array}\right] \qquad (8)$$

Since, no discount is provided on the unit selling price of the product in CEOQ model, no constraints will be imposed on equation (8). The only constraint is the non-negative restriction for T_2. Hence,

Maximize $\pi_2(T_2)$
$$\forall T_2 \ge 0 \qquad (9)$$

4. NUMERICAL EXAMPLE

The parameter values are a=80, b=0.3, h=0.6, s=10.0, C_0=100.0, c=4.0, θ=0.03, τ=1.2 are listed in Table 2.

After 47 and 45 iterations Table 2 reveals the optimal replenishment policy for instant deterioration order quantity model with entropy cost and without entropy cost respectively. In Table 3 the numerical results of different CEOQ and CEnOQ models are illustrated separately. For the entropic order quantity model profit per unit time is 515.9152, the optimal order quantity and cycle lengths are 344.1667 and 3.131757 respectively. The results are quite justified and agree with the model analysis at last section.

The relative differences in Table 3 is marked approximate than the ones found in the previous experiments when the ordering policy is optimal. This indicates that there exists case in which the relative difference is non-negligible. Based on the results in Tables-2 and 3, it is also noted that the relative difference can be high when the ordering policy is optimal in the entropy order quantity model.

5. COMPARATIVE EVALUATION

Table 2 shows that the entropy cost, 32.212812 in CEnOQ deteriorated model is provided on unit selling price

to lose 2.06% less profit than that with CEOQ deteriorated model. From Table 3 it indicates that the entropy cost and price discount on selling price are provided on the deterioration models to earn 0.54%, 29.84% and 29.97% more profits for CEnOQ without discount and with discount models respectively than that with present CEnOQ model. Similarly it shows that this no discounted deterioration model to lose 1.66%, 12.86% and 17.54% less profits for CEOQ with discount free model, CEnOQ and CEOQ with discount models respectively than that with present CEnOQ model. This paper investigates a computing schema for the EnOQ and EOQ in crisp sense. From Table 3 it shows that the EnOQ and EOQ results are very approximate, i.e. it permits better use of EnOQ as compared to crisp space arising with the EOQ model and other related inventory models. Tripathy and Pattnaik (2008) investigate an entropic order quantity model for perishable items under two component demand where pre and post deterioration discounts are allowed in fuzzy decision space. Pattnaik (2010) derives an entropic order quantity model for perishable items under instant deterioration post discounts are allowed in crisp decision space. It indicates the consistency of the crisp space of EnOQ from EOQ models.

Table 2. The Numerical Results of the Instant Deterioration CEnOQ and CEOQ Models (i=1,2)

Model	Local optimal solution found at iteration	T_i	Q_i	EC	π_i
CEnOQ	47	3.131757	344.1667	32.212812	515.9152
CEOQ	45	2.8799	313.0764	-	526.7771

Table 3. Comparison of Results and Relative Errors (RE) of Instant Deterioration EnOQ Model with different Models

(i=1, 2, 3, 4, 5, 6, 7, 8)

Model	Local optimal solution found at iteration	Discount	T_i	Q_i	EC	π_i
CEnOQ	47	-	3.1368	344.1667	32.2128	515.9152
CEOQ	45	-	2.8799	313.0764	-	526.7771
% Change	4.2553	-	8.1886	9.0335	-	-2.0620
CEnOQ Tripathy et al. (2008)	-	-	3.034417	331.7506	-	513.1098
% Change	-	-	3.2631	3.6076	-	0.5438
CEOQ Tripathy et al. (2008)	50	-	2.7822	301.3188	-	524.4967
% Change	-6.3830	-	11.3032	12.4498	-	-1.6634
CEnOQ Pattnaik (2011)	78	0.4138	2.8319	673.5408	61.5918	582.2379
% Change	-65.9575	-	9.7201	-95.7019	-91.2029	-12.8553
CEOQ Pattnaik (2011)	88	0.4542	2.5720	654.5585	-	606.3850
% Change	-87.2340	-	18.0056	-90.1865		-17.5358
CEnOQ Pattnaik (2010)	141	0.0464	1.9176	173.6135	21.3170	362.0803
% Change	-200	-	38.8676	49.5554	33.8244	29.8352
CEnOQ Pattnaik (2010)	49	-	2.0009	164.9528	20.3051	361.2894
% Change	-4.2553	-	36.2121	52.0718	36.9657	29.9712

Table 4: Sensitivity Analysis of Instant Deteriorated CEnOQ and CEOQ Models

Model	Parameter	% Change	T_i	% Change	Q_i	% Change	π_i	% Change
CEnOQ	c	+20	3.6747	-17.150	410.0641	-19.147	866.5516	-67.964
		+40	3.5000	-11.580	388.5565	-0.1290	777.5110	-50.705
	a	+20	5.0514	-61.039	116.7253	66.0847	76.9651	85.0818
		+40	3.9408	-25.633	177.2217	48.5070	182.7003	64.5871
	C_0	+20	2.6183	16.5284	281.6623	18.1611	541.4379	-4.9471
		+40	2.7254	13.1141	294.4872	14.4347	533.9518	-3.4960
CEOQ	c	+20	1.2000	61.7439	403.8950	-17.355	879.0136	-70.380
		+40	1.2000	61.7439	115.5402	66.4290	692.8813	-34.301
	a	+20	1.2000	61.7439	23.10805	93.2858	25.6935	95.0198
		+40	3.6832	-17.421	164.4455	52.2192	192.4358	62.7001
	C_0	+20	2.3289	25.7545	247.1813	28.1798	557.4856	-8.0576
		+40	2.4791	20.9661	265.0333	22.9928	549.1662	-6.4451

6. SENSITIVITY ANALYSIS

This paper has examined the sensitiveness of the decision variables, T_i, Q_i and π_i (i=1,2) for each set of the parameters (c, a, C_0) respectively shown in Table 4. Table 4 shows the relative changes of the cycle lengths, T_1 and T_2, the order quantities, Q_1 and Q_2 and the total profits per unit time, π_1 and π_2, respectively when each of the parameters is being changed from +20% to +40%.

From Table 4, it can be seen that in both the models the optimum cycle lengths T_1 and T_2 are less sensitive with respect to the parameters c, a and C_0 respectively. It also shows that the optimum order quantity, Q_1 and Q_2 are moderately sensitive with respect to the change in parameters c, a and C_0. On the other hand, it is observed that the optimal total profit per unit time, π_1 and π_2, are highly sensitive with respect to the parameters c and a; and are less sensitive for the change in the parameter C_0 respectively. Since the entropy cost is allowed and the discount factor is not present in the model to control over the system, the maximum profit is increased then decreased when the purchase cost is increased.

7. CRITICAL DISCUSSION

The mathematical model is developed allowing entropy cost in crisp environment. The numerical example is presented to justify the claim of model fitting. With no discount for perishable products to enhance inventory depletion rate for profit maximization is an area of interesting research. This paper introduces the concept of entropy cost to account for hidden cost such as the additional managerial cost that is needed to control the improvement of the process with insignificant difference in traditional model. This paper examines the idea by extending the analysis of other related papers by introducing entropy cost and allowing no discount in selling price to provide a firm with its optimum replenishment schedule, replenishment order quantity and entropy cost, simultaneously in order to achieve its maximum profit.

These models can be considered in a situation in which the entropy cost can be adjusted and the number of price changes can be controlled. Extension of the proposed model to unequal time price changes and other applications will be a focus of the future work.

8. CONCLUSION

This paper presented an entropic order quantity model for perishable items with two component demand in which the criterion is to optimise the expected total finite horizon payoff. Finally, in numerical experiments the solution from the entropic model evaluated and compared to the solutions of other different traditional EOQ and EnOQ policies respectively.

However, a few performance differences among a set of different inventory policies in the existing literature. Although there are minor variations that do not appear significant in practical terms, at least when solving the single level, incapacitated version of the lot sizing problem. The results of this study give managerial insights to decision maker developing an optimal replenishment decision for deteriorating product. Compensation mechanism should also be included to induce collaboration between retailer and dealer in a meaningful supply chain.

In general, for normal parameter values the relative payoff differences seem to be fairly small. The optimal solution of the suggested entropic order quantity model has a higher total payoff as compared with optimal solution for the traditional EOQ policy. Conventional wisdom suggests that workflow collaboration in an EnOQ model in a varying deteriorating product in market place are promising mechanism and achieving a cost effective replenishment policy.

The approach proposed in the paper based on EnOQ model seems to be a pragmatic way to approximate the optimum payoff of the unknown group of parameters in inventory management problems. The assumptions underlying the approach are not strong and the information obtained seems worthwhile. Investigating optimal policies when demand are generated by other process and designing models that allow for several orders outstanding at a time would also be challenging tasks for further developments. Its use may restrict the model's applicability in the real world. Future direction may be aimed at considering more general

deterioration rate or demand rate. Uses of other demand side revenue boosting variables such as promotional efforts are potential areas of future research. The proposed paper reveals itself as a pragmatic alternative to other approaches based on two component demand function with very sound theoretical underpinnings but with few possibilities of actually being put into practice. The results indicate that this can become a good model and can be replicated by researchers in neighbourhood of its possible extensions. As regards future research, one other line of development would be to allow shortage and partial backlogging in the discounted model

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