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Statistics

AN EOQ MODEL WITH TWO LEVELS OF STORAGE AND TEMPORARY STOCK DEPENDENT DEMAND

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ABSTRACT This paper deals with a deterministic inventory model where the demand is the stock dependent for some time immediately after the arrival of stock. The duration of the dependency is considered as a random variable with known distribution. The EOQ is determined for the case when there is a limitation on the storage space, leading to L2-system. The feasibility conditions and the sensitivity of the EOQ due to duration of the Stock Dependent Demand (SDD) and the stock dependency factor have been explored. The conditions which recommend the use of L¬2-system are also derived.

KEYWORDS : Two-levels of storage, stock dependent demand

Introduction

We reconsider the classical inventory problem with deterministic demand in which the demand rate D is dependent on the stock available at the beginning of the inventory cycle. For instance, an airline may announce the availability of Q tickets from a specified date even though there is steady demand. This induces accelerated demand as some new customers may join the regular demand stream. This type of stock dependency of demand will be temporary either at the beginning or end of the inventory cycle. For instance, customers may rush to buy items immediately when the stock position is made known to public. In this case, the SDD occurs for a short time at the beginning of the cycle. In some cases customers rush at the end of the cycle when the stocks are likely to vanish and the accelerated sales takes place. This type of demand pattern is known as stock dependent demand (SDD).

Rakesh Gupta and Prem Vrat (1986) wrote a basic article on this issue. They have viewed SDD to be active during the entire cycle with demand rate D(Q) = +Q, where Q is the order quantity and , are constants. Baker and Urban (1988) and Datta and Pal (1990), have formulated the demand rate as D(t) = +I(t), where I(t) denotes the on-hand inventory at 't' and D(t) denotes the demand at 't'. This is termed as Inventory-Level-Dependent Demand (ILDD). During the last decade several articles appeared in modeling this type of demand in the presence of other factors like product deterioration, delay in payments, inflation, price dependent demand and supply chain context. Work in this area can also be found in Mandal and Phaujdar (1989), Gerchak and Wang (1994), Pal, Bhunia and Mukherjee (2006), Sarkar and Sarkar (2013), Chang, C.T. (2004).

Let Q^0 denotes the EOQ when the demand rate is constant and shortages are not allowed. The inventory cycle will have length $t_0 = Q^0/D$. When SDD is active in a cycle, keeping other things constant the cycle length becomes shorter than t_0 and this leads to reduced holding cost. In other words identification of SDD leads to a potential gain in inventory cost.

Due to several reasons like price discounts, delayed payments or inflationary conditions, the stockiest would order for higher quantity. This sometimes creates a problem of physical storage when the Own Warehouse (OW) of the management has finite capacity W. One practice is to use a Rented Warehouse (RW) to keep the extra stock. Hartley (1976) discussed this basic problem while Sarma (1983,1987), used the term L_2-system to indicate a two-level context. Pakkala and Achari (1992) have studied the problem of two levels of storage under varied back ground conditions. GSN Reddy and Sarma (2001) studied a periodic review inventory problem with variable SDD and studied the effect of SDD factor on the EOQ.In all the models with L_2-system the filling order of the warehouses is fixed as OW followed by the RW. The depletion sequence is RW followed by OW. Recently Sarma and Prasuna (2012) have extended the logic of L_2- inventory system to the L_n-system. As a part of determining the EOQ for the n-warehouse problem, they have proposed optimal filling and depletion sequences using the principle of SPT sequencing (see Conway, Maxwell and Miller (1967)).

In this paper we reexamine the classical EOQ problem for the L_2-system assuming temporary SDD at the beginning of the cycle. The force of SDD is explained by a linear model and the conditions which recommend the use of L_2-system are derived and a decision support system is developed.

2. Operation of the system

The inventory cycle starts with the receipt of an order for Q units and consumed till the on hand stock comes down to zero. Assuming that shortages are not allowed and that the lead time is zero, another order is placed and the next cycle starts.

The following basic notation is used in developing the model. Additional notations are used wherever required.

a) Q = Order Quantity in units
b) A = Fixed cost of ordering
c) = Constant demand rate
d) H = Unit holding cost per unit time in the OW
e) F = Unit holding cost per unit time in the RW (F > H)

When a lot of Q units is received and if Q > W, the OW is first filled with W units and the rest is stored in a RW. When a demand arrives, it is met from the RW either by a direct delivery at the RW or by bringing it to the OW (for quality checking, packing etc.). Since F > H by assumption, it is economical to empty the RW before drawing from the OW.

Then the EOQ for the L_2-system is given by Hartley (1976) as

$$\tilde{Q} = \sqrt{\frac{2A\alpha+(F-H)W^2}{H}} \qquad (1)$$

A linear form of SDD is taken as $D(Q) = \alpha+\beta Q$, where β denotes the marginal linear effect of stock on the demand rate. In the light of the result proposed by Rakesh Gupta and Prem Vrat (1986), Narasimhulu *et al* (1991) have shown that for this type of demand the EOQ will be

$$Q^* = \sqrt{\frac{2A\alpha+(F-H)W^2}{(H+2\beta c)}} \qquad (2)$$

where c denotes the unit cost of item. When both warehouses are equally costly then F = H and there is no need to distinguish between OW and RW so that (1) reduces to the Wilson's classical EOQ formula for the L1-system. Further if $\beta = 0$, the SDD effect vanishes and (2) also reduces to Wilson's formula. In the absence of SDD the inventory cycle will be $t0 = \tilde{Q}/\alpha$ where $\tilde{Q}$ is derived from (1).

2. The EOQ model with temporary SDD

While deriving (2) it is assumed that the SDD prevails throughout the inventory cycle, which means the force of SDD influences the buying pattern until the on-hand inventory drops to zero. Usually this is not the case and the SDD will be like an *episode* that is realized for a short period $u(<t_0)$ immediately when stock is received. For instance if t_0 is one month then u can be taken as 0.25 month (a week) after which the influence of SDD vanishes and the demand occurs at the constant rate α.

Let t_w denotes the time at which the RW becomes empty and $t_w < t_0$ since the usage of RW is usually for a period shorter than the full cycle length. Then two mutually distinct cases arise according as $u \le t_w$ and $u > t_w$.

Case-1: $u \le t_w$

The inventory situation is shown in Figure-1(a).The on-hand inventory during the period $(0,u)$ will be

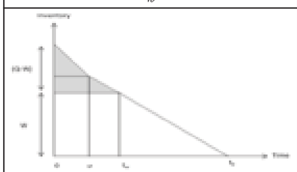
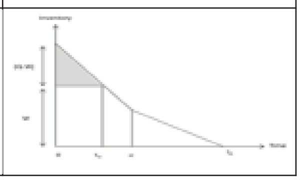
$$I(t) = (Q-W) - (\alpha+\beta Q)t,\ 0 \le t \le u \qquad (3)$$

so that the inventory held during this period is $A_1 = \int_0^u I(t)dt$ and this reduces to

$$A1 = (Q-W)u - (\alpha+\beta Q)u^2/2.$$

From (3) the on hand inventory is $I(u)$ at u the inventory held in RW during (u,t_w) will be $A_2 = \{(Q-W)u - (\alpha+\beta Q)\}^2/2\alpha$.

From the geometry of the inventory cycle we get $t_w = u + I(u)/\alpha$ which reduces to $tw = \{Q(1-\beta u)-W\}/\alpha$. Now the inventory held in OW during $(0,t_w)$ will be $A_3 = Wt_w$.

Figure-1(a): Inventory situation when SDD vanishes before the RW (shaded area) is emptied ($u \le t_w$)	Figure-1(b): Inventory situation when SDD vanishes after the RW (shaded area) is emptied ($u > t_w$)
	

Finally the inventory held in OW is $A_4 = W^2/2\alpha$. Therefore the total holding cost will be $F\{A_1+A_2\} + H\{A_3+A_4\}$. The cost of material in the cycle is cQ. Assuming that the selling price is p per unit, the additional drop in inventory of βQu units leads to $p\beta Qu$ as extra revenue. The sum of costs in this case during the cycle, after rearranging the terms becomes

$$K_{2a}(Q,t_0) = \left\{A\alpha + \frac{(F-H)(Q-W)^2}{2\alpha} + \frac{HQ^2}{2\alpha} + cQ\right\} - \beta u\left\{pQ + \frac{FQ^2}{\alpha} - \frac{FQ^2\beta u}{2\alpha} - \frac{(F-H)WQ}{2}\right\}$$

The cycle length in this context is $t_0 = \{t_w + W/\alpha)$ which reduces to $t_0 = Q(1-\beta u)/\alpha$.

Adding the fixed ordering cost A and summing the components and dividing by t_0 gives the cost per unit time will be $K_{2a}(Q,t_0)/t_0$. This is given by

$$K_{2a}(Q) = \left\{\frac{A\alpha}{Q} + \frac{(F-H)(Q-W)^2}{2Q} + \frac{HQ}{2} + cQ\right\} - \frac{\beta u}{(1-\beta u)}\left\{(p-c)\alpha + \frac{FQ(1-\beta u)}{2} - \left\{\frac{A\alpha}{Q} + \frac{F\alpha u}{2} + \frac{(F-H)W^2}{2Q}\right\}\right\} \qquad (4)$$

The terms in (4) are so arranged that the second term is proportional to β and simply vanishes when SDD effect is ignored (β = 0) and (4) represents the usual cost function for the L_2-system without SDD. It is to be mentioned that by writing the term $\frac{1}{(1-\beta u)}$ is written as $\left\{1 + \frac{\beta u}{(1-\beta u)}\right\}$ so that the terms involving β can be separated and additional effect of SDD can be evaluated. The subscript '2' in K_{2a} indicates L_2-system and '*a*' indicates the state[$u \le t_w$].

It can be shown that (4) is convex in Q when $(1-\beta u) > 0$ and minimizing (4) with respect to Q yields the optimal value Q^*_{2a} given by

$$Q^*_{2a} = \left[\frac{2A\alpha + (F-H)W^2}{F(1-\beta u)^2}\right]^{1/2} \qquad (5)$$

It is easy to see that when F = H and β = 0, (5) reduces to the classical EOQ formula.

Case -2: $u > t_w$

The inventory situation is shown in Figure-1(b) from it follows that $t_w = (Q-W)/(\alpha+\beta Q)$ and the inventory held in RW during $(0,t_w)$ is $B_1 = (Q-W)^2\{2(\alpha+\beta Q)\}^{-1}$. The on-hand inventory during $(0,u)$ is $I(t) = Q - (\alpha+\beta Q)t$, $0 \le t \le u$ which when integrated in this range gives the inventory held $B_2 = \{Qu - (\alpha+\beta Q)u^2/2\} - B_1$. Again, during (u,t_0) the inventory held in the OW can be worked out as $B_3 = \{Q - (\alpha+\beta Q)^2\}/2\alpha$. The holding cost for the units in RW is FB_1 and for the items in OW the holding cost will be $H\{B_1 + B_2\}$. The length of the inventory cycle in this case will be $t_0 = u + \{Q - (\alpha+\beta Q)u\}/\alpha$ which reduces to $Q(1-\beta u)/\alpha$. The cost per unit time can be obtained as follows proceeding on the lines of Case-1, wherethe subscript '*b*' indicates the state [$u > t_w$] on the L_2-system.

$$K_{2b}(Q) = \left\{\frac{A\alpha}{Q(1-\beta u)} + \frac{c\alpha}{(1-\beta u)} + \frac{\alpha(F-H)(Q-W)^2}{2Q(1-\beta u)(\alpha+\beta Q)} + \frac{HQ(1-\beta u)}{2} + \frac{H\alpha\beta u^2}{2(1-\beta u)} - \frac{p\alpha\beta u}{(1-\beta u)}\right\} \qquad (6)$$

Attempting to minimize this cost function with respect to Q leads to a fourth degree polynomial in Q and a closed form solution cannot be obtained. The third term in (6) can be written as $\left\{\frac{(F-H)(Q-W)^2}{2Q(1-\beta u)}\right\}\left\{1 + \frac{\beta Q}{\alpha}\right\}^{-1}$ and by using the first order Taylor series approximation to $\left\{1 + \frac{\beta Q}{\alpha}\right\}^{-1}$ leads to the following simpler form of (6) when the terms with and without β are segregated.

$$K_{2b}(Q) = \left\{\frac{A\alpha}{Q} + \frac{(F-H)(Q-W)^2}{2Q} + \frac{HQ}{2} + cQ\right\} - \frac{\beta u}{(1-\beta u)}\left\{(p-c)\alpha + \frac{(F-H)Q(1-\beta u)}{2\alpha u} + \frac{HQ(1-\beta u)}{2} - \left\{\frac{A\alpha}{Q} + \frac{H\alpha u}{2} + \frac{(F-H)(Q-W)^2}{2Q}\right\}\right\} \qquad (7)$$

Minimizing (7) with respect to Q produces the following first order condition

$$\frac{-A\alpha}{Q^2(1-\beta u)} + \frac{(F-H)(Q-W)}{(1-\beta u)}\left[\frac{1}{Q} - \frac{\beta}{\alpha}\right] - \frac{(F-H)(Q-W)^2}{2Q^2(1-\beta u)} + \frac{H(1-\beta u)}{2} = 0 \qquad (8)$$

The ratio β/α being very small can be ignored, in which case (8) can solved to yield the EOQ as Q^*_{2b} given by

$$Q^*_{2b} = \left[\frac{2A\alpha + (F-H)W^2}{F(1-\beta u)^2}\right]\left[\frac{2A\alpha + (F-H)W^2}{(F-H) + H(1-\beta u)^2}\right]^{1/2} \qquad (9)$$

Again when F=H and β = 0 in (9) we get back to the classical EOQ formula.

Remark: It may be noticed that in both (5) and (9) the denominator denotes the *effective holding cost* that works out when SDD is taken into account.

The parameter u is independent of the cycle length and as such, we do not know whether $u \le t_w$ or $u > t_w$ in a given context. This leads to the choice between (5) and (9) for the optimal Q.

In the following section we propose a probability based method of combining (5) and (9).

3. The EOQ based on Expected Cost function

Let $0 \le \eta \le 1$ denotes the probability that $u \le t_w$. The value of η can be estimated from past data on consumption or by an expert opinion (if no data is available). Then the expected cost for the L_2-inventory system with temporary SDD will be given by

$$E\{K_2(Q)\} = \eta\, K_{2a}(Q) + (1-\eta)K_{2b}(Q).$$

Substituting the terms from (4) and (7) and after proper grouping we get the following expression

$$\begin{aligned} E\{K_2(Q)\} = {} & \frac{A\alpha}{Q} + (1-\eta)\left\{\frac{(F-H)(Q-W)^2}{2Q} + \frac{HQ}{2}\right\} + cQ \\ & + \left(\frac{\eta}{2}\right)\left\{FQ + \frac{(F-H)(Q-W)^2}{Q}\right\} - \eta(F-H)W + c\alpha \\ & - \frac{\beta u}{(1-\beta u)}\left\{\frac{HQ(1-\beta u)}{2} - (1-\eta)\left\{\frac{(F-H)(Q-W)^2}{2Q} + \frac{H\alpha u}{2}\right\}\right\} \\ & - \frac{\beta u}{(1-\beta u)}\left\{\frac{\eta(F-H)Q(1-\beta u)}{2} + \frac{(1-\eta)(F-H)(Q-W)^2}{2\alpha u} - \frac{\eta F\alpha u}{2}\right\} \\ & - \frac{\beta u}{(1-\beta u)}\left\{(p-c)\alpha - \frac{A\alpha}{Q} - \frac{\eta(F-H)W^2}{2Q}\right\} \end{aligned} \quad (10)$$

This function is convex in Q being the convex combination of two convex combinations of (4) and (7). Minimizing (10) with respect to Q gives the optimal order quantity Q* given by

$$Q_2^* = \left[\frac{2A\alpha + (F-H)W^2}{X}\right]^{1/2}$$

(11)

where $X = \{\eta F(1-\beta u)^2 + (1-\eta)[H(1-\beta u)^2 + (F-H)]\}$.

When β = 0, automatically u and η are set to zero and X reduces (F-H) so that (11) becomes the EOQ for the L_2-system without SDD. The corresponding optimal cost can be found from (10) using (11) for Q_2^*.

In the following section we derive few parametric conditions on the inputs for the model, to ensure both feasibility and optimality under the L_2-system.

4. Feasibility and Optimality conditions

At the end of deriving an expression for the EOQ, issues relating to the feasibility and optimality conditions arise because it is assumed that a RW is compulsorily required. The following observations can be made on the new result.

a) *L_2-feasibility:* For certain values of W, A, H, F, α, β and η the formula given in (11) may lead to $Q_2^* < W$ in which case the use of L_2-system is at question. This calls for examining the feasibility conditions for L_2-system in terms of the input parameters.

b) *L_2-optimality:* Mere L_2-feasibility ensures that the EOQ exceeds W but among all possible Q values, we select the one which minimizes $K_2(Q_2^*)$ for the L_2-system. However, it is possible that the cost evaluated at Q = W on the L_1-system has to be compared with that of L_2-system before fixing the optimal order quantity as in (11).

Consider the following propositions.

Propositon-1: Define $A^+ = \frac{\eta W^2(F-H)\{(1-\beta u)^2 - 1\}}{2\alpha} + \frac{HW^2(1-\beta u)^2}{2\alpha}$. Then $A > A^+$ is a necessary sufficient condition for L_2-feasibility.

Proof: The necessity of the condition follows by requiring $Q_2^* > W$. In order to establish the sufficiency of this condition, consider $A = (A^+ + \delta)$ for δ> 0. Using this $(A^+ + \delta)$ in place of A in (11) and simplifying we get ${Q_2^*}^2 = \frac{2(A+\delta)\alpha + (F-H)W^2}{X}$. The numerator after simplification reduces to $W^2\{\eta F(1-\beta u)^2 + (1-\eta)[H(1-\beta u)^2 + (F-H)]\} + 2\alpha\delta$, which is same as $\{W^2X + 2\alpha\delta\}$ in view of (11). Therefore it follows that $Q^{*2} = W^2 + 2\alpha\delta/X$. Since both X and δ are positive it follows that $Q^{*2} > W^2$ or $Q_2^* > W$ which is the condition for L_2-feasibility.

Hence the proved the proposition.

When F = H and η = 0, we get from (11) the EOQ for the L_1-system given as

$$Q_1^* = \left[\frac{2A\alpha}{H(1-\beta u)^2}\right]^{1/2} \quad (12)$$

and the corresponding cost on the L_1-system would be

$$K_1(Q_1^*) = \left\{\frac{A\alpha}{Q_1^*(1-\beta u)} + c\alpha + \frac{HQ_1^*(1-\beta u)}{2} + \frac{H\alpha\beta u^2}{2(1-\beta u)} - \frac{(p-c)\alpha\beta u}{(1-\beta u)}\right\}. \quad (13)$$

Propositon- 2: Let $K_1(W)$ be the inventory cost when exactly W units are ordered (on the L_1-system). Then the L_2-system is both optimal only if $E\{K_2(Q^*)\} \le K_1(W)$

Proof: Any value of Q > W is only feasible for the L_2-sysem but need not be optimal in the sense of minimizing the sum of inventory costs. The Q_2^* given in (11) provides the least cost on the L_2-system among all values of Q exceeding W. If we put F = H in (11) we get the EOQ for the L_1-system as $\left[\frac{2A\alpha}{H(1-\beta u)^2}\right]^{1/2}$ because the effect of η is nullified and the value of u is taken as a known constant instead of a random variable.

The optimal cost on L_1-system with Q = W can be obtained from (6) by putting F = H and there is no need for the expectation sign (E). This gives

$$K_1(W) = \left\{\frac{A\alpha}{W(1-\beta u)} + c\alpha + \frac{HW(1-\beta u)}{2} + \frac{H\alpha\beta u^2}{2(1-\beta u)} - \frac{(p-c)\alpha\beta u}{(1-\beta u)}\right\} \quad (12)$$

This will be called the *boundary cost*o be verified before choosing the L_2-system. Thus even if $A>A^+$ and the EOQ for the L_2-system is obtained, it would he optimal only when the corresponding cost is less than the boundary cost.

Hence the proposition.

The following stepwise method can be adopted for implementing the model.

5. Stepwise method and numerical results

The following procedure is helpful in decision making.

Step-1: Given the input parameters c, p, F, H, A,W,α, β, u and η, compute A^+

Step-2: If $A > A^+$ go to step-4; else go to step-3

Step-3: Compute Q_1^* for the L_1-system using (12) and $E(K_1(Q_1^*)$ using (13). Stop.

Step-4: Compute $E(Q_2^*)$ for the L_2-system using (11) and $E(K_2(Q_2^*)$ using (10)

Step-5: Compute $K_1(W)$ using (12). If $E(K_2(Q_2^*) < K_1(W)$ the optimal policy is to use L_2-system with EOQ = $E(K_2(Q_2^*)$; else the EOQ is W and optimal cost $K_1(W)$

We will illustrate below the working of the model.

Illustraton -1:

Consider the parameters A = 100 per order, p = 32 per month, c = 25 per month, H = 2.0 per unit per month, F = 3.2 per unit per month, α = 800 units per month, W = 300 units, u = 20% of the usual cycle length, β = 0.2 and η = 0. With these values we get A^+ = 112.5 which is more than A. So L_1-system is recommended with Q_1^* = 287 (less than W) and the optimal cost turns out to be 20486 which includes the material cost of 20000. We can as well drop this fixed component and consider $E(K_1(Q_1^*))$ = 486.

Suppose we increase A from 100 to 200. Then the L_2-system has to be activated and we get Q_2^* = 370 with cost 699 following the stepwise procedure. The gain due to SDD is the difference between the costs with β = 0 and β > 0. Table-1 to Table-3 shows the results for different combinations of A, β and η.

Table-1:Sensitivity of the model due to changes in the ordering cost A and the SDD factor and = 0

Beta	A = 100					A = 200				
	EOQ	Cost	B_cost	System	Gain	EOQ	Cost	B_cost	System	Gain
0.0	283	566	--	L1	--	366	810	833	L2	--
0.2	287	486	--	L1	80	370	699	726	L2	111
0.4	291	404	--	L1	162	375	582	614	L2	228
0.6	295	320	--	L1	246	380	461	497	L2	349
0.8	300	233	--	L1	333	385	334	376	L2	476

Table-2:Sensitivity of the model due to changes in the ordering cost A and the SDD factor and = 0.5

Beta	A = 100					A = 200				
	EOQ	Cost	B_cost	System	Gain	EOQ	Cost	B_cost	System	Gain
0.0	283	566	--	L1	--	366	810	833	L2	--
0.2	287	486	--	L1	80	372	699	726	L2	111
0.4	291	404	--	L1	162	378	582	614	L2	228
0.6	295	320	--	L1	246	384	461	497	L2	349
0.8	303	235	233	L1, Q* = 300	333	391	334	376	L2	476

Table-3:Sensitivity of the model due to changes in the ordering cost A and the SDD factor and = 1.0

Beta	A = 100					A = 200				
	EOQ	Cost	B_cost	System	Gain	EOQ	Cost	B_cost	System	Gain
0.0	283	566	--	L1	--	366	810	833	L2	--
0.2	287	486	--	L1	80	373	699	726	L2	111
0.4	291	404	--	L1	162	381	582	614	L2	228
0.6	302	322	320	L1,Q* = 300	246	389	461	497	L2	349
0.8	307	236	233	L1,Q* = 300	333	398	335	376	L2	476

From the above illustration the following observations can be made.

1. The EOQ is found to increase as the force of SDD () increases. When the ordering cost A increased from 100 to 200 the EOQ at all values of was feasible for the L_2-system, which is an expected result. The gain due to SDD is also found to increase, when increases.
2. The parameter has a very marginal effect on both the EOQ and the optimal cost. Its impact is seen only higher values of and .
3. The gain due to SDD is also found to increase as increases.

Conclusions

The classical EOQ needs suitable changes when the demand rate temporarily depends on the displayed stock. In this process, a higher lot size may become economical and hence this needs relaxing the constraint on storage space. We have proposed new formula to handle this situation by hiring a rented warehouse. A decision support mechanism is developed to determine the EOQ.

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