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AN IMPACT OF LEARNING PROCESS IN PRODUCTION UNDER INTEGRATED VENDOR-BUYER MODEL

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ABSTRACT

In co-ordination system between vendor-buyer has become an interesting issue to improve the performance of supply chain if learning is stimulated within the supply chain. Learning is the process by which proficiency in performing a repetitive task due to gain in previous work experience as a result of reduction in time or cost. It also leads to falls on increased involvement in production process and also in efficiency level. This paper provides an integrated vendor buyer model for quality inspection errors at the buyer's end and learning in production process at the vendor's end. A mathematical model is proposed to find the optimal order quantity and safety factor. A numerical example is provided to illustrate the vendor's learning in production in the expected joint total cost of the system.

KEYWORDS: defective item; Joint economic lot-sizing problem; JELP; learning effect; inspection error; variable lead time

INTRODUCTION

Inventory management is an important part of a business because it ensures quality control in the business and all around consumer goods. Without proper inventory control, a large retail store may run out of stock on an important item or at an important time. The business industries basically use an inventory management system that will trace and maintain the requirement of inventory to meet customer's demand. JELP models are useful for inventory management to established long term relationship with their suppliers or customers which is common in automotive industry. For example, the members of the supply chain have an incentive to work together towards a reduction of total system cost, such co-operation gains that emerge as a result of investments in the order and production policies of the companies can be distributed among the members of the supply chain. The model concerning jointly making lot sizing decisions involving two or more parties in supply chain is known as joint economic lot-sizing problem (JELP).

Consider a two-layer supply chain consisting of a vendor and buyer. The buyer observes a deterministic demand and orders lots from the vendor. The vendor produces the requested product in lots. Each produced lot is shipped to the buyer in batches. The vendor and buyer work in a cooperative manner synchronize the supply with the actual customer demand. The lot transferred from vendor to buyer contains some defective items. The buyer conducts an inspection process to classify the quality of the items.The inspection process is imperfect. The inspector may incorrectly classify non-defective item as defective or incorrectly classify defective item as non-defective. The lead time is assumed to be variable and consists of the sum of production time and non-production time. The shortage occurs but assumed to be fully backordered. At last, end customers who buy the defective items will return the items to the buyer and then buyer will return all defective items to the vendor and finally vendor's learning in production for finished products to improve the performance in any cycle.

In this paper extends the work of Wakhid Ahmad Jauhari (2016) considered a single – vendor single – buyer supply chain under stochastic JELP whereas defective items and inspection error. In our model, discuss about production inventory that incorporates the effect of learning, which may be achieved by vendor and optimum production quantity and safety factor can be calculated. The aim of this paper is to develop a vendor's learning in production to manufacture the product at an increasing production rate (M.Khan, M.Y.Jaber and A.L.Guiffrida (2012); Mehmood Khan, Mohamad Y. Jaber, Abdul-Rahim Ahmad (2014)).

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The rest of the paper is organized as follows. Section 2 presents literature review on inventory model. Section 3 describes the notations and assumptions used in developing the proposed model. Section 4 provides mathematical model and section 5 provides solution methodology. Finally, numerical examples and conclusion are presented in section 6 and 7 respectively.

LITERATURE REVIEW

Goyal (1976) was the first to consider integrated vendor-buyer model in which the vendor produces a batch of product in an infinite rate and then deliveries it to buyer on a lot-for-lot basis. Banerjee (1986) then developed vendor-buyer model by assuming that the vendor has a finite production rate. Goyal(1988) extended Banerjee's (1986) model by proposing a more general lot size model that resulted lower total cost. Salameh and Jaber (2000) studied EOQ model in which the amount of defective items in each shipment lot is random. Then each arriving shipment lot will be inspected to categorise the quality of the items. The defective items founded by inspector will be sold to the customers at discounted price at the end of the inspection time.

Wee et.al (2007) incorporated shortage backordering case on EPQ model. Bera et.al (2009) proposed a fuzzy inventory model dealing with defective production process and learning effect. They used the assumptions that the demand varies with marketing cost and mark-up to production cost.

Kok and Shang (2007) studied the impact of inventory record inaccuracy on single-period inventory system. Yoo et.al (2009) proposed EPQ model by considering both imperfect production process and imperfect inspection process. They introduced two types of inspection error. Khan et.al (2011b) extended Salamehand Jaber(2000) model by considering defective items and inspection error. Hsu (2013) studied EPQ models by considering defective items, inspection errors, sales returns and planned backorder. The learning effect on optimal lot size in intermittent production has been discussed by E.C.Keachie and Robert J.Fontana (1966). A.W.Wortham and A.M.Mayyasi (1972) explains a method for the consideration of learning impacts on EOQ is presented for the simple inventory model. In 1982, Models are developed for determining optimal production lot sizes under a learning effect. These models consider both bounded and unbounded learning is assumed to occur which is proposed by John.C.Fisk and Donald P.Ballou.

The production, remanufacture and waste disposal model by assuming learning to require for improving capital investment which was developed by M.Y.Jaber, Ahmed.M.A.El.Saadany (2009). The learning effect in inspection process was discussed by Konstantaras et.al (2012). They assumed that the percentage of defective items in each lot reduces as the number of deliveries because of learning. Soni and Patel (2014) developed single-vendor single-buyer integrated production inventory model with defective items and lead time reduction. Khan et.al (2011a) discusses a review of the extensions of EOQ model for imperfect items.

The above mentioned paper concerned on developing vendor – buyer model which considers defective items, inspection error, variable lead time, learning effect and stochastic demand.

NOTATIONS AND ASSUMPTIONS

3.1 Notations

To develop the model we use the following notations:

D :demand in units per year
σ : standard deviation of demand per year
A : buyer's ordering cost per order
K : vendor's setup cost
H_b : buyer's holding cost per unit per year
H_v : vendor's holding cost per unit per year
γ : the probability of defect
b_i : learning exponent in cycle i of production
e_1 :The probability of a type I inspection error (classifying a non-defective item as defective)
e_2:The probability of a type II inspection error (classifying a defective item as non-defective)
S : buyer's unit screening cost
P : production rate
T_1 : vendor's time to produce the first unit, in case of learning $(= {}^{1}/_{P})$
T_{P_i} : vendor's total time for production in a cycle i

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x : screening rate
n : number of shipments made by vendor for each production run.
Q: shipment lot
k: safety factor
π: backorder cost per unit backordered
w: vendor's unit cost for producing a defective item
B_b: buyer's cost of a post-sale defective item
B_v: vendor's cost of a post-sale defective item
C_a: cost of false acceptance of defective items ($C_a = B_b + B_v$)
C_r: cost of false rejection of non-defective items
J_1: number of items that are classified as defective in each shipment lot
J_2: number of items that are returned from the market in each shipment lot.

3.2 Assumptions

1. We consider production-inventory model comprising of a vendor and a buyer with single product.
2. The demand in buyer side is assumed to be normally distributed with mean D and standard deviationσ.
3. The buyer orders a size of nQ products to the vendor. The vendor produces the products with a batch size of nQ and delivers a quantity of Q to the buyer in each shipment.
4. Each arriving shipment lot contains some defective items with defective rateγ. Upon arrival of a shipment, all items will be screened by the buyer with screening rate x.The screening rate is greater than demand rate $x > D$.
5. The screening process is imperfect. The inspector may incorrectly classify the quality of the items.
6. The buyer adopts continuous review policy to manage his inventory level.
7. The shortages are allowed in the model and assumed to be fully backordered.
8. The production rate of non-defective items is greater than the demand rate.
9. End customers who buy the defective items will return the items to the buyer and then buyer will return all defective items to the vendor at theend of the screening process and finally vendor's learning in production process occurs.

MATHEMATICAL MODEL

In this paper extends the work of Wakhid Ahmad Jauhari(2016) which consider vendor ship the lot of production to the buyer with each shipment have some defective rate γ. The objective is to determine the expected joint total cost of the system for the effect of learning on production inventory.

Buyer's cost

Let us assume that buyer orders a quantity nQ to the vendor when the non-defective items reach the reorder point. The reorder point can be defined as

$$D\left({}^{Q}/_{P} + T_s\right) + k\sigma\sqrt{{}^{Q}/_{P} + T_s}$$

By adopting the model of Khan et.al(2011b), the number of items that are classified as defective in each shipment lot is

$$J_1 = Q(1-\gamma)e_1 + \gamma Q(1-e_2)$$

The number of items that are returned from the market in each shipment lot is given by

$$J_2 = \gamma Q e_2$$

Thus, the Buyer's average inventory level is given by

$$\text{IVB} = k\sigma\sqrt{{}^{Q}/_{P} + T_s} + \frac{DQ(1-\gamma)e_1 + D\gamma Q(1-e_2)}{x(1-\gamma)(1-e_1)} + \frac{\gamma Q e_2}{2} + \frac{Q-[Q(1-\gamma)e_1 + \gamma Q(1-e_2)]}{2}$$

The formulation of transportation cost under tapering rate function model is:

TB $= a + b\ln Q$

where $a, b > 0$ and $Q > Q', Q'$ is minimal shipment quantity specified by shipper.

The screening cost can be formulate as

$$\frac{DnSQ}{nQ(1-\gamma)(1-e_1)}$$

The buyer's post sale of defective item can be formulate as

$$\frac{DnB_b\gamma Qe_2}{nQ(1-\gamma)(1-e_1)}$$

The shortage cost can be formulate as

$$\frac{\pi D\sigma\sqrt{Q/_P + T_s}\psi(k)}{Q(1-\gamma)(1-e_1)}$$

where $\psi(k) = f_s(k) - k[1 - F_s(k)]$
Here, $f_s(k)$,$F_s(k)$ are probability density function and the cumulative distribution function of standard normal distribution.
The expected total cost per unit time for the buyer is

$$\boldsymbol{ETCB(n,Q,k)} = \frac{D\{A + n(a + b\ln Q)\}}{nQ(1-\gamma)(1-e_1)}$$

$$+H_b\left\{k\sigma\sqrt{Q/_P + T_s} + \frac{DQ(1-\gamma)e_1 + D\gamma Q(1-e_2)}{x(1-\gamma)(1-e_1)} + \frac{\gamma Qe_2}{2} + \frac{Q-[Q(1-\gamma)e_1+\gamma Q(1-e_2)]}{2}\right\} + \frac{D}{nQ(1-\gamma)(1-e_1)}\{nSQ + nB_b\gamma Qe_2\} + \frac{\pi D\sigma\sqrt{Q/_P+T_s}\psi(k)}{Q(1-\gamma)(1-e_1)} \quad \textbf{(1)}$$

Vendor's cost
The vendor produces a batch size of nQ and transfers to the buyer are made in T units of time, where $T = \frac{Q(1-\gamma)(1-e_1)}{D}$, until vendor's production batch is finished.

Learning in vendor's production process
It is assumed that vendor's production process follows Wright's (1936) learning curve. That is, the vendor produces the final product at an increasing production rate which is consumed at a constant rate, Dunits per unit time. Let us assume that T_{p_i}, T_{d_i} and T_i are the production time, depletion time and the cycle time respectively, in any cycle. The process produces a fixed quantity nQ and builds up a maximum inventory Z_i, in each cycle i. The level of inventory in each cycle can be expressed as a function of time as:

$$\Phi_i(t) = \begin{cases} nQ(t) - Dt, & 0 < t \le T_{p_i} \\ -Dt + DT_i, & T_{p_i} < t \le T_i \end{cases}$$

where $T_i = T_{p_i} + T_{d_i}$
Let us assume that b is the learning exponent, where $0 \le b_i < 1$ is the learning exponent in cycle i of production.
The production time in a cycle $i$is written as

$$T_{p_i} = \int_{(i-1)Qn}^{iQn} T_1 x^{-b_i}\left[1 + (n-2)\left\{1 - \frac{D}{P(1-\gamma)(1-e_1)}\right\}\right]dx$$

Now T_{p_i}can be written as

$$T_{p_i} = \frac{T_1 n^{1-b_i} Q^{1-b_i}\left[1 + (n-2)\left\{1 - \frac{D}{P(1-\gamma)(1-e_1)}\right\}\right]\{i^{1-b_i} - (i-1)^{1-b_i}\}}{(1-b_i)}$$

Solving for Q,

$$Q = \left[\frac{t(1-b_i)}{T_1 n^{1-b_i}\left[1 + (n-2)\left\{1 - \frac{D}{P(1-\gamma)(1-e_1)}\right\}\right]\{i^{1-b_i} - (i-1)^{1-b_i}\}}\right]^{1/_{1-b_i}}$$

Now, the average inventory of finished products in a cycle i can be written as

$$\int_0^{T_i} \Phi_i(t)dt = \int_0^{T_{p_i}} (nQ(t) - Dt)dt + \frac{Z_i T_{d_i}}{2}$$

After simplification, it can be written as:

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$$\int_{0}^{T_i} \Phi_i(t)dt = \frac{Q^2}{2D} - \frac{T_1 Q^{2-b_i}\{i^{1-b_i} - (i-1)^{1-b_i}\}\left[1+(n-2)\left\{1-\frac{D}{P(1-\gamma)(1-e_1)}\right\}\right][n^{1-b_i}(2-b_i)-1+b_i]}{(1-b_i)(2-b_i)}$$

Where $T_1 = {}^1\!/_P$ is the time to produce the first unit on learning curve.

The vendor's expected total cost per unit time of the finished products in cycle i would be

$$\boldsymbol{ETCV(n,Q,k)} = \frac{DK}{nQ(1-\gamma)(1-e_1)} + \frac{H_v}{2}\left[\frac{Q^2}{2D} - \frac{T_1 Q^{2-b_i}\{i^{1-b_i} - (i-1)^{1-b_i}\}\left[1+(n-2)\left\{1-\frac{D}{P(1-\gamma)(1-e_1)}\right\}\right][n^{1-b_i}(2-b_i)-1+b_i]}{(1-b_i)(2-b_i)}\right] + \frac{D}{nQ(1-\gamma)(1-e_1)}\{nw\gamma Q + nC_r(1-\gamma)Qe_1 + nB_v\gamma Qe_2\} \quad \textbf{(2)}$$

Joint total cost

The expected joint total cost for vendor-buyer system can be determined by summing up equation (1) and (2) which is given by

$$\boldsymbol{EJTC(n,Q,k)} = \frac{D\{A+n(a+b\ln Q)\}}{nQ(1-\gamma)(1-e_1)} + H_b\left\{k\sigma\sqrt{{}^Q\!/_P + T_s} + \frac{DQ(1-\gamma)e_1 + D\gamma Q(1-e_2)}{x(1-\gamma)(1-e_1)} + \frac{\gamma Qe_2}{2} + \frac{Q-[Q(1-\gamma)e_1+\gamma Q(1-e_2)]}{2}\right\} + \frac{D}{nQ(1-\gamma)(1-e_1)}\{nSQ + nB_b\gamma Qe_2\} + \frac{\pi D\sigma\sqrt{{}^Q\!/_P + T_s}\psi(k)}{Q(1-\gamma)(1-e_1)} + \frac{DK}{nQ(1-\gamma)(1-e_1)} + \frac{H_v}{2}\left[\frac{Q^2}{2D} - \frac{T_1 Q^{2-b_i}\{i^{1-b_i} - (i-1)^{1-b_i}\}\left[1+(n-2)\left\{1-\frac{D}{P(1-\gamma)(1-e_1)}\right\}\right][n^{1-b_i}(2-b_i)-1+b_i]}{(1-b_i)(2-b_i)}\right] + \frac{D}{nQ(1-\gamma)(1-e_1)}\{nw\gamma Q + nC_r(1-\gamma)Qe_1 + nB_v\gamma Qe_2\}$$

SOLUTION METHODOLOGY

The minimum value of $EJTC(n,Q,k)$ occurs at the point (Q,k) which satisfies $\frac{\partial EJTC(n,Q,k)}{\partial Q} = 0$ and $\frac{\partial EJTC(n,Q,k)}{\partial k} = 0$ simultaneously. Now to find the solution of $EJTC(n,Q,k)$ w.r.to Q and k which are given by

$$Q^* = \sqrt{\frac{\frac{2D}{(1-\gamma)(1-e_1)}\left\{\frac{A+K}{n}\right\}}{H_b\left\{\frac{2D(1-\gamma)e_1 + 2D\gamma(1-e_2)}{x(1-\gamma)(1-e_1)} + \gamma e_2 + 1 - (1-\gamma)e_1 - \gamma(1-e_2)\right\} + H_v\left\{\frac{Q}{D} - \frac{(2-b_i)}{P}\frac{Q^{1-b_i}\{i^{1-b_i} - (i-1)^{1-b_i}\}\left[1+(n-2)\left\{1-\frac{D}{P(1-\gamma)(1-e_1)}\right\}\right][n^{1-b_i}(2-b_i)-1+b_i]}{(1-b_i)(2-b_i)}\right\}}}$$

This is optimal solution of Q.

And

$$F_s(k) = 1 + \frac{H_b Q(1-\gamma)(1-e_1)}{\pi D}$$

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CODEN: IJESS7

NUMERICAL EXAMPLE

In this section, we provide the numerical example so as to show the applicability of the model developed in the previous section. Consider the following data.

D=1000 units/yearb_i=0.1
n =1 S =1/unit
i =1P =3200 units/year
σ=5 units/year$x$ =3500 units/year
A=400/order$a$ =68.29
K =600/setup$b$ =78.18
H_b =5/unit/yearπ =15/unit
H_v =4/unit/year$w$ =50/unit
γ =0.01T_s =5 days
e_1 =0.01B_b =200/unit
e_2 =0.01B_v =300/unit
C_r =100/unit

Table 1 shows the solutions of different value of learning exponent. If the value of $b_i$is gradually increases, shipment lot and reorder point gradually increases as well. The buyer cost and vendor cost and total cost decreases significantly when learning exponent b_i increases. Thus learning effect is useful for business field to improve their performance.

Table 1 The impact of the learning exponent on model's solutions

b_i	n	Q	ROP	$Buyer\ cost$	$Vendor\ cost$	$Total\ cost$
0.05	1.00	541.36	5182.52	4637.51	2951.73	7589.24
0.1	1.00	540.18	5182.16	4639.35	2957.82	7597.17
0.2	1.00	538.46	5181.55	4641.18	2966.30	7607.48
0.3	1.00	537.48	5181.31	4642.51	2971.38	7613.89
0.4	1.00	536.92	5181.14	4643.33	2974.38	7617.71
0.5	1.00	536.58	5181.03	4643.71	2976.37	7620.08

CONCLUSION

In this paper we study integrated inventory model with learning in production process. In business environment, learning achieves more involvement in production process and performs the same job in faster pace. Numerical examples are performed to see the impact of production learning exponent on model's solution. Introducing the learning in production helps to reduce the defective item from the vendor's end.

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