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# A VENDOR-BUYER CONSIGNMENT STOCK, EOQ REPAIR AND WASTE DISPOSAL MODEL WITH SWITCHING COST

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***Abstract: A consignment stocks means that the stocks owned by the vendor and maintained by the buyer at the buyer warehouse. In this paper we present a vendor buyer consignment stock. EOQ repair and waste disposal model with switching cost. Mathematical Model is discussed the inventory model after the inclusion of switching cost. Numerical example is provided for illustrate the proposed model.***
***Keywords: EOQ, Production, Waste Disposal, Consignment Stock, Switching Cost.***

## 1. INTRODUCTION

The importance of inventory management in RL has been growing and well developed in the literature (e.g., Fleischmann et al., (1997) ; Stock and Broadus 2006). Schrady (1967) who treated the deterministic case and obtained Economic Order Quantities (EOQ) for procurement and repair. He assumed that items are returned to the system for repair at a constant rate. Items that are not repairable are scrapped and replaced by procuring new ones. Richter (1996) tackled the work of Schrady (1967) by developing an EOQ production manufacturing and waste disposal model and developed his paper with various assumptions. E.g., (Richter, 1997, Dobos and Richter, 2004, 2006).

Chung et al (2008) developed a mathematical model for a closed – loop supply chain inventory system with remanufacturing. Dobos et al., (2011) extended the work of Richter (1996) by adding a buyer (i.e.,) by integrating it with the work of Banerjee (1986) which considers a vendor and a buyer that jointly optimize the sum of the inventory costs per unit of time.

Another interesting coordination mechanism that gained attention is "Consignment Stock" (CS) policy. Consignment stock is a simple and robust mechanism that can help reduce the inefficiency caused by the supplier (Corbett, 2001).

Consignment stock has been the practice in many manufacturing items (Valentini and Zavarella, 2003, Braglia and Zavanella, 2003). CS is advantageous to the vendor and the buyer. To the vendor, when it is more expensive to hold the inventory at its end than at the buyer's. To the buyer where it does not have to worry about managing its and tying capital in it, and benefitting from trade credit where applicable. Braglia and Zaranella (2003) showed how the CS policy may improve a system performance in stochastic environments. Zanoni et al., (2012) presented an enhancement of the CS policy by considering learning in production at the vendor side.

This paper discussed a two-echelon inventory model with consignment stock and switching cost. This paper accounts for switching costs (e.g., production loss, deterioration in quality and additional labour) when alternating between production and recovery runs, when shifting from producing one product to another in the same facility. The facility may incur additional costs referred to as switching costs (EI Saadany and Jaber (2008)). The remainder of this paper is organized as follows. The next section lists notation and assumptions. Section 3 develops the mathematical model and section 4 is for numerical example. Section 5 summarizes and concludes the paper.

## 2. NOTATIONS AND ASSUMPTIONS

### 2.1. Notations

| | | |
|---|---|---|
| i | - | Subscript indicating the type of the process ; r – remanufacturing ; p – production ; s – sorting / inspection ; u – used ; and w – disposal |
| $S_i$ | - | set-up cost for process $i \neq u, w$ (mu - \$, $\in$ etc) |
| $h_u$ | - | Holding cost for used items (mu/unit/year) |
| $c_i$ | - | Unit processing cost for process $i \neq u, w$ (mu/unit) |
| $c_u$ | - | cost to acquire a used item from the customer (paid by the vendor, mu/unit) |
| $C_w$ | - | cost for disposing a non-repairable item (mu/unit) |
| $h_r$ | - | holding cost for a remanufactured item (mu/unit/year) |

 

$h_p$ - holding cost for manufactured item (mu/unit/year)

$h_b^b$ - Buyer's holding cost for an item at the buyer's side (i.e.,) physical storage cost (mu/unit/year)

$h_b^v$ - Vendor's holding cost for an item at the buyer's side (i.e.,) capital tied-up cost (mu/unit/year)

$h_b$ - Total holding cost for an item at the buyer's side (i.e.,) $h_b = h_b^b + h_b^v$ (mu/unit/year)

D - Demand rate at the buyer's end (unit/year)

$P_i$ - Production, remanufacturing or sorting/inspection rate for process $i \neq u, w$, where $P_i > D$.

$q_i$ - Shipment size (in units) for process $i \neq s, u, w$

$T_j$ - unit transportation cost ; j = F, R where
F – Forward flow and R - reverse / backward flow (mu/unit)

m - Number of remanufactured batches (integer)

n - Number of production batches (integer)

T - length of the time interval ; where $T = \frac{Mq_r + nq_p}{D}$ (year)

ρ - Collection (return) percentage $0 < \rho < 1$

α - Disposal percentage $0 < \alpha < 1$

β - Repairable percentage $0 < \beta < 1$

### 2.2. Assumptions

1. Remanufactured items are considered to be as-good-as newly produced ones.
2. Remanufacturing and production processes are always in control and no defective items are generated.
3. Shortages are not allowed.
4. The demand rate is constant over time.
5. All cost input parameters do not vary overtime.
6. Lead time is zero.
7. Infinite planning horizon
8. A single products case.

 

## 3. MATHEMATICAL MODEL

This model considers a production remanufacturing, collection, sorting/inspection and waste disposal problem with a two level consignment stock coordination scheme. The system consists of two subsystems, a vendor's system and buyer's system. The vendor firstly remanufactures m batches of size $q_r$ each at a rate $P_r$ and subsequently, it produces n batches of size $q_p$ each at a rate of $P_p$ where $P_r \neq P_p$. It should be noted that the replenishment cycle order decided, (i.e.,) remanufacturing precedes production is reasonably assumed according to the literature in the field (e.g., Richter, 1996 ; EI Saadany and Jaber 2010 ; Dobos, et al., 2011). The inventory of the serviceable stock is replenished by the remanufacturing and production processes of the system. The serviceable inventory is shipped to the buyer's warehouse in batches of size qr and qp at time intervals $t_r = q_r/p_r$ and $t_p = q_p/p_p$ respectively where $t_r \neq t_p$ and $P_r > P_p$ or $P_r < P_p$, $P_r = P_p$ (special case). It is also assumed that $q_r = q_p = q$ ; In a more general cased may occur where $q_r > q_p$ or $q_r < q_p$. To manufacture $mq_r$ units, the vendor has to collect $\rho\beta DT$ repairable units. (i.e.,) $mq_r = \rho\beta DT$ from which we have $q_r = \dfrac{n+\beta}{m(1\text{-}\rho\beta)} q_p$ where

$T = \dfrac{nq_p}{(1\text{-}\rho\beta)\,D}$.

## VENDOR'S PRODUCTION AND REMANUFACTURING COST FUNCTIONS

Vendor cost function is assured to be a sum of the set-up costs, production costs and holding costs for the serviceable stock divided by the length of the time interval $T_1$ and is given as

**Case : $q_r > q_p$ or $q_r < q_p$**

$$VC = \frac{mS_r + nS_p}{T} + C_r m \frac{q_r}{T} + C_p n \frac{q_p}{T} + \frac{1}{T}\left( h_r m \frac{q_r}{2} t_r + h_p n \frac{q_p}{2} t_p \right)$$

In this paper, we assure a switching cost is incurred when the process shifts from repair to production and from production to repair. So we denote $r_1$ as $s_1$ as the setup and switching costs of the first repair and the first production runs. (i.e.,) $r_1$ = r + switching costs from production to repair and $s_1$ = s + switching costs from repair to production, when there are more than one repair run per cycle, the setup cost per run is denoted as r except for the first run, when there are more than one production run per cycle, the setup costs per run is denoted as s except for the first run. The process incurs $(r_1 - r)$ and $(s_1 - s)$ costs when switching from repair to manufacturing and from manufacturing to repair respectively. When there are m repair and n production runs in a cycle of length T, the total setup switching cost is computed as $S_{m,n} = (m - 1)r + r_1 + (n - s) + s_1$. For the case of a single repair run (m = 1) and a single production run (n = 1) the total setup and switching costs in a cycle of length T are $r_1 + s_1$.

Therefore, the vendor's total cost after the inclusion switching cost is expressed as

**Case : $q_r > q_p$ or $q_r < q_p$**

$$VC = \frac{D(1 - \rho\beta)}{nq_p}\left[(m-1)S_r + S_{r_1} + (n-1)S_p + S_{p_1} + nq_p\left(C_r\frac{\rho\beta}{1-\rho\beta} + C_p\right)\right]$$

$$+\frac{q_p^2}{2}\left[h_r\frac{m}{P_r}\left(\frac{n\rho\beta}{m(1-\rho\beta)}\right)^2 + h_p\frac{n}{P_p}\right] \qquad \text{. . . (1a)}$$

**Case : $q_r = q_p = q$**

$$VC = \frac{1}{q}\left\{\rho\beta S_r D - S_r D + S_{r_1}D + \left[(1-\rho\beta)S_p - S_p\right]D + S_{p_1}D\right\}$$

$$+C_r\beta D + C_r\left(1-\rho\beta\right)D + \frac{Dq}{2}\left(h_r\frac{\rho\beta}{P_r} + h_p\frac{\left(1-\rho\beta\right)}{P_p}\right) \qquad \text{. . . (1b)}$$

Here the values of $q_r = \frac{n\rho\beta}{m(1-\rho\beta)}q_p$ and $m = \rho\beta$, $n = 1 - \rho\beta$

## THE BUYER'S SIDE HOLDING COST FUNCTIONS OF PRODUCED AND REMANUFACTURED ITEMS

**Case : $q_r > q_p$ or $q_r < q_p$**

Here we are substituting the values of $q_r = \frac{n\rho\beta}{m(1-\rho\beta)}q_p$ and $T = \frac{nq_p}{(1\text{-}\rho\beta)D}$ in the buyer's holding functions is expressed as

$$H_{C_b} = \frac{h_b^b n\rho^2\beta^2 D^2 q_p}{2m(1-\rho\beta)p_r^2} + \frac{h_b^b (n-1)(1-\rho\beta)D^2 q_p}{2np_p^2} + \frac{h_b^b n(m+1)\rho^2\beta^2 D q_p}{2P_r\, m(1-\rho\beta)}\left(1-\frac{D}{P_r}\right)$$
$$+\frac{h_b^b n(n-1)\rho^2\beta^2 D q_p}{m(1-\rho\beta)\,P_r}\left(1-\frac{D}{P_r}\right) + \frac{h_b^b (n-1)(1-\rho\beta)\rho D q_p}{2P_p}\left(1-\frac{D}{P_p}\right)$$
$$+\frac{h_b^b \rho(1-\rho\beta)q_p}{2n}\left[\frac{n\rho\beta}{1-\rho\beta}\left(1-\frac{D}{P_r}\right)+n-(n-1)\frac{D}{P_p}\right]^2 \qquad \text{. . . (2a)}$$

**Case : $q_r = q_p = q$**

Substituting $q_p = q$ and $\frac{m}{n} = \frac{\rho\beta}{(1-\rho\beta)}$ in equation (2a) it becomes

$$H_{C_b} = \frac{h_b^b \rho\beta D^2 q}{2P_r^2} + \frac{h_b^b (n-1)(1-\rho\beta)\rho D^2 q}{2nP_p^2} + \frac{h_b^b n(\rho\beta(n-1)+1)\rho^2\beta^2 D q}{2P_r\,(1-\rho\beta)}\left(1-\frac{D}{P_r}\right)$$
$$+\frac{h_b^b n(n-1)\rho\beta D q}{P_r}\left(1-\frac{D}{P_r}\right) + \frac{h_b^b (n-1)(1-\rho\beta)\rho D q}{2P_p}\left(1-\frac{D}{P_p}\right)$$
$$+\frac{h_b^b \rho(1-\rho\beta)q}{2n}\left[\frac{n\rho\beta}{1-\rho\beta}\left(1-\frac{D}{P_r}\right)+n-(n-1)\frac{D}{P_p}\right]^2 \qquad \text{. . . (2b)}$$

## VENDOR'S HOLDING COST FUNCTIONS FOR THE ITEMS AT THE BUYER'S SIDE

The holding cost per unit of time of produced and remanufactured items, incurred by the vendor, $HC_r$, while they are at the buyer's side can be determined for the cases $q_r > q_p$ or $q_r < q_p$ and $q_r = q_p = q$ respectively with equations (2a) and (2b) where $h_b^b$ should be submitted by $h_b^v$

## INSPECTION, SORTING AND HOLDING COST FUNCTIONS OF USED ITEMS

The cost per unit time for the collection and inspection process is sum of the unit time setup unit cost of used items, inspection, disposal and holding cost and is written as,

**Case : $q_r > q_p$ or $q_r < q_p$**

$$CIC = \frac{S_s D(1-\rho\beta)}{nq_p} + (C_u + C_s)\rho D + C_w\rho\alpha D + h_u\frac{\rho}{2}\left(1-\frac{D\rho}{P_s}\right)\left(1+\frac{D\rho}{P_s}\right)\frac{nq_p}{1-\rho\beta} \qquad \text{. . . (3)}$$

For the case $q_r = q_p = q$. Equation (3) is modified by replacing $q_p$ with q.

## TRANSPORTATION COST FUNCTIONS

The unit of time transportation cost is given as

**Case : $q_r > q_p$ or $q_r < q_p$**

$$TC = \left(m+n+1\right)\frac{AD(1-\rho\beta)}{nq_p} + T_F D + T_R \rho\beta D \qquad \text{. . . (4a)}$$

where A is a fixed transportation cost per shipment and $T_F$ and $T_R$ are respectively the unit transportation costs for produced or remanufactured items and for repairable items. For the case $q_r = q_p = q$, Equation (4a) modified by replacing qp with q and M with $\frac{n\rho\beta}{(1-\rho\beta)}$.

**Case : $q_r = q_p = q$**

$$TC = \left(n+(1-\rho\beta)\right)\frac{AD}{nq} + T_F D + T_R \rho\beta D \qquad \text{. . . (4b)}$$

The holding cost functions of collected used items

$$HC_u = \frac{h_u \rho\beta DT}{2T}\cdot\frac{Mq_r}{D} = \frac{h_u \rho^2\beta^2 nq_p}{2\left(1-\rho\beta\right)} \qquad \text{. . . (5)}$$

## THE TOTAL COST FUNCTIONS WITH SWITCHING COST

The total cost per unit of time function is written from equations (1a), (2a), 3, (4a) and 5 and (1b), (2b), 3, (4b) and (5). For both cases as

**Case : $q_r > q_p$ or $q_r < q_p$**

$C_T = VC + HC_b + HC_v + CIC + TC + HC_u$

$$\Rightarrow \frac{D\left(1-\rho\beta\right)}{nq_p}\left[(m-1)S_r + S_{r_1} + (n-1)S_p + S_{p_1} + n_{q_p}\left(Cr\frac{\rho\beta}{1-\rho\beta} + Cp\right)\right.$$

$$\left. + \frac{q^2 p}{2}\left(h_r \frac{m}{P_r}\left(\frac{n\rho\beta}{1-\rho\beta}\right)^2 + h_p \frac{n}{P_p}\right)\right] + \frac{h_b n\rho^2\beta^2 D^2 q_p}{2m(1-\rho\beta)P_r^2} + \frac{h_b (n-1)(1-\rho\beta)D^2 q_p}{2nP_p^2}$$

$$+ \frac{h_b n(m+1)\rho^2\beta^2 Dq_p}{2P_r\, m(1-\rho\beta)}\left(1-\frac{D}{P_r}\right) + \frac{h_b n(n-1)\rho^2\beta^2 Dq_p}{m(1-\rho\beta)P_r}\left(1-\frac{D}{P_r}\right)$$

$$+ \frac{h_b (n-1)(1-\rho\beta)\rho Dq_p}{2P_p}\left(1-\frac{D}{P_p}\right) + \frac{h_b \rho(1-\rho\beta)q_p}{2n}\left[n\frac{\rho\beta}{1-\rho\beta}\left(1-\frac{D}{P_r}\right) + n - (n-1)\frac{D}{P_p}\right]^2$$

$$+ \frac{S_s D(1-\rho\beta)}{nq_p} + (C_u + C_s)\rho D + C_w \rho\alpha D + \frac{h_u \rho}{2}\left(1-\frac{D\rho}{P_s}\right)\left(1+\frac{D\rho}{P_s}\right)\frac{nq_p}{1-\rho\beta}$$

 

$$+(m+n+1)\frac{AD(1-\rho\beta)}{nq_p}+T_FD+T_R\rho\beta D+\frac{h_u\rho^2\beta^2nq_p}{2(1-\rho\beta)} \qquad \ldots (6)$$

Differentiating the above equation with respect to $q_p$, to get the optimal value of $q_p^*$ as,

$$q_p^*(m, n, \beta) = \sqrt{\frac{D(1-\rho\beta)\left[\left(\frac{m-1}{n}\right)S_r+\frac{S_{r_1}}{n}+\left(\frac{n-1}{n}\right)S_p+\frac{S_s}{n}\frac{S_{p_1}}{n}+(m+n+1)\frac{A}{n}\right]}{H(m,n,\beta)}} \qquad \ldots (7)$$

where
$$H(m, n, \beta) = \frac{D(1-\rho\beta)}{2n}\left(h_r\frac{m}{P_r}\left(\frac{n\rho\beta}{m(1-\rho\beta)}\right)^2+h_p\frac{n}{P_p}\right)+\frac{h_bn\rho^2\beta^2D^2}{2m(1-\rho\beta)P_r^2}$$

$$+\frac{h_b(n-1)(1-\rho\beta)D^2}{2nP_p^2}+\frac{h_bn(m+1)\rho^2\beta^2D}{2P_r\,m(1-\rho\beta)}\left(1-\frac{D}{P_r}\right)+\frac{h_bn(n-1)\rho^2\beta^2D}{m(1-\rho\beta)P_r}\left(1-\frac{D}{P_r}\right)$$

$$+\frac{h_b(n-1)(1-\rho\beta)\rho D}{2P_p}\left(1-\frac{D}{P_p}\right)+\frac{h_b\rho(1-\rho\beta)}{2n}\left[\frac{n\rho\beta}{1-\rho\beta}\left(1-\frac{D}{P_r}\right)+n-(n-1)\frac{D}{P_p}\right]^2$$

$$+h_u\frac{\rho}{2}\left(1-\frac{D\rho}{P_s}\right)\left(1+\frac{D\rho}{P_s}\right)\frac{n}{1-\rho\beta}+\frac{h_u\rho^2\beta^2n}{2(1-\rho\beta)}$$

**Case : $q_r = q_p = q$**

$C_T = VC + HC_b + HC_v + CIC + TC + HC_u$

$$= \frac{\rho\beta S_rD-S_rD+S_{r_1}D+[(1-\rho\beta)S_p-S_p]D+S_{p_1}D}{q}+C_r\beta D+C_p(1-\rho\beta)D$$

$$+\frac{Dq}{2}\left(\frac{h_r\rho\beta}{P_r}+\frac{h_p(1-\rho\beta)}{P_p}\right)+\frac{h_b\rho\beta D^2q}{2P_r^2}+\frac{h_b(n-1)(1-\rho\beta)\rho D^2q}{2nP_p^2}$$

$$+\frac{h_bn\left((n-1)\rho\beta+1\right)\rho^2\beta^2Dq}{2(1-\rho\beta)P_r}\left(1-\frac{D}{P_r}\right)+\frac{h_bn(n-1)\rho\beta Dq}{P_r}\left(1-\frac{D}{P_r}\right)$$

$$+\frac{h_b(n-1)(1-\rho\beta)\rho Dq}{2P_p}\left(1-\frac{D}{P_p}\right)+\frac{h_b\rho(1-\rho\beta)q}{2n}\left[\frac{n\rho\beta}{1-\rho\beta}\left(1-\frac{D\rho}{P_r}\right)+n-(n-1)\frac{D\rho}{P_p}\right]^2$$

$$+\frac{S_sD(1-\rho\beta)}{nq}+(C_u+C_s)\rho D+C_w\rho\alpha D+h_u\frac{\rho}{2}\left(1-\frac{D\rho}{P_s}\right)\left(1+\frac{D\rho}{P_s}\right)\frac{nq}{1-\rho\beta}$$

$$+\left(n+(1-\rho\beta)\right)\frac{AD}{nq}+T_FD+T_R\rho\beta D+\frac{h_u\rho^2\beta^2nq}{2(1-\rho\beta)} \qquad \ldots (8)$$

 

Differentiating the above equation w.r.to ‘q’

We get the optimal value

$$q_p^*(n, \beta) = \sqrt{\frac{D\left[\rho\beta S_r - S_r + S_{r_1} D + \left[(1-\rho\beta)-1\right]S_p + S_{p_1} + \frac{S_s(1-\rho\beta)+(n+(1-\rho\beta))A}{n}\right]}{H'(n,\beta)}} \quad \ldots (9)$$

where,

$$H'(n,\beta) = \frac{D}{2}\left(h_r \frac{\rho\beta}{P_r} + h_p \frac{(1-\rho\beta)}{P_p}\right) + \frac{h_b \rho\beta D^2}{2P_r^2} + \frac{h_b(n-1)(1-\rho\beta)\rho D^2}{2nP_p^2}$$
$$+ \frac{h_b n\left(\rho\beta(n-1)+1\right)\rho^2\beta^2 D}{2(1-\rho\beta)P_r}\left(1-\frac{D}{P_r}\right) + \frac{h_b n(n-1)\rho\beta D}{P_r}\left(1-\frac{D}{P_r}\right)$$
$$+ \frac{h_b(n-1)(1-\rho\beta)\rho D}{2P_p}\left(1-\frac{D}{P_p}\right) + \frac{h_b\rho(1-\rho\beta)}{2n}\left[n\frac{\rho\beta}{1-\rho\beta}\left(1-\frac{D}{P_r}\right) + n - (n-1)\frac{D}{P_p}\right]^2$$
$$+ h_u \frac{\rho}{2}\left(1-\frac{D\rho}{P_s}\right)\left(1+\frac{D\rho}{P_s}\right)\frac{n}{1-\rho\beta} + \frac{h_u\rho^2\beta^2 n}{2(1-\rho\beta)}$$

## 4. NUMERICAL EXAMPLE

The input parameters for the two cases are listed below.

$S_r = 200$, $S_p = 200$, $S_s = 50$, $S_{r_1} = 201$, $S_{p_1} = 201$, $A = 50$, $h_p = 3$, $h_r = 2$, $h_b = 4$, $h_u = 0.5$, $C_p = 10$, $C_r = 5$, $C_u = 1$, $C_s = 0.5$, $C_w = 2$, $T_F = 0.5$, $T_R = 0.5$, $\rho = 0.8$, $D = 1000$, $M = 1$, $n = 1$, $\beta = 1$, $P_r = 3000$, $P_p = 3000$, $P_s = 4000$, $\alpha = 0.3$

For the case $q_r > q_p$ or $q_r < q_p$

The optimal order quantity $q_p^*(m, n, \beta) = 108$ and the total cost $C_T = 10829$.

For the case $q_r = q_p = q$.

The optimal order quantity $q_p^*(n, \beta) = 195$ and the total cost $C_T = 12501$.

## 5. CONCLUSION

In this paper we study about the vendor buyer consignment stock EOQ, repair and waste disposal model with switching cost. After, adding the switching cost in the total cost function, we can conclude that the case $q_r > q_p$ or $q_r < q_p$ is more preferable than the case $[q_r = q_p = q]$.

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