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Vendor-Buyer Model with Imperfect Supply Process and Environmental Impacts

W. Ritha, S. Infancy Vimal Priya
Department of Mathematics, Holy Cross College (Autonomous), Tiruchirapalli -2 (Tamilnadu)

Abstract: One of the most important problems the world is facing today is the environmental pollution, which is continuously increasing and causing severe and irreparable damage to the earth. In an effort the new actions could be taken to reduce the negative impact of human species on the environment. This paper presents an integrated vendor-buyer inventory model for a single-vendor and a single-buyer considering a single item.The purpose of this paper is to investigate the impact of emission costs on the replenishment order sizes and the total profit of a Vendor-Buyer in an imperfect supply process, where the buyer receives the batches containing a percentage of imperfect quality items. In this context, an integrated inventory model with imperfect supply process and emission costs, which are the result of warehousing, waste disposal, packaging and transportation is derived with numerical example.
Keywords: Inventory, Coordinated, imperfect supply, Environmental impacts

1. Introduction

In the past few decades, firms have realized that an efficient management across the different parties in a supply chain is critical to reducing inventory costs. This efficient management can be achieved through greater cooperation and better coordination among the different parties. This means that the vendor and the buyers should work cooperatively towards minimizing their costs and maximizing their profits. Integrated inventory management has received a great deal of attention. The classical EOQ modelassumes that items produced are of perfect quality.However, the quality of a product is not always perfect butdirectly affected by the reliability of the productionprocess used to produce the products. Therefore, the process may produce defectives or poorquality items. While considering the production process with imperfect items, it may cause various emissions to the environment.Environmental pollution is one the greatest challenges that the world is facing today. It began since industrial revolution, increasing day by day and causing irreparable damage to Mother Earth. Environmental pollution has its own causes, effects and solutions. Pollution is the contamination of the environment by introduction of contaminants that can cause damage to environment and harm or discomfort to humans or other living species. In this context, we considered the environmental impacts, which are the results of warehousing, production, waste disposal transportation and packaging.The purpose of this paper is to develop an integrated vendor-buyerinventory model for items with imperfect quality and emission costs. The rest ofthis paper is organized as follows. In Section 2, Literature review. In Section 3, we develop a mathematical model that integrates thevendor's and the buyer's total profit cost and takes into consideration imperfect-quality itemsand emissions. Section 4 provides numerical example to illustrate important aspects of the model. Finally, the paper concludes in Section 5.

2. Literature Review

Inventory models with imperfect quality items have received significant attention in the literature. Many researchers have developed the models with integrated inventory model consisting of a vendor and a buyer under various cases.Benjaafar, Li, and Daskin[4] investigated single and multiple lot-sizing models and showed how carbon emission constraints could be incorporated into both models. Bouchery et al.[8] included sustainable criteria into the classical EOQ model and formulated a new multi-objective type model, which considered carbonemission in inventory holding and transportation. Arıkan and Jammernegg[2] studied a newsvendor problemwith two supply options and carbonemission constraints, where emissions from manufacturing,warehousing and transportation are considered.Amodel that linked carbon emission and price tothe demand offered by Hovelaque and Bironneau[22],who made a trade-off between retailers' total profit andcarbon emission reduction, with some policies as results. Helmrich et al.[21] developed a Non-deterministicPolynomial-time (NP) hard model that includes a constrainton the set-up, holding and production emission. Dye and Yang[11] combined carbon emissionin an inventory model with deteriorating items andtrade credit under differentemission policies to obtain joint decisions on emissionreduction, trade credit and replenishment policies. Jaber et al.[2013] developed a JELSmodel inspired by The European Union Emissions

TradingSystem, which includes emission tax and emissionpenalty. In their model, the emission released from thesupply chain is linked to the production rate of themanufacturer.

Zanoni,Mazzoldi, and Jaber[44]investigatedthe model of Jaber et al.[26] with a vendor-managedinventory with consignment stock (VMI-CS) agreementin lowertotal costs and lower emissions levels. Finally,Hammami,Nouira, and Frein[18]optimized a multi-echelonsupply chain model with environmental measures andlead time constraint with the objective to minimize thetotal cost of the supply chain. Salameh and Jaber[37] proposed a type of EOQ model where buyerreceives a lot mixed with imperfect and good qualityitems. They maximized the total profit of the buyer with the assumption that afterthe screening process, imperfect quality items could besold in a single batch at a lower price. All the extensionsof this model until 2011 are reviewed in Khan, Jaber,Guiffrida, and Zolfaghari[28] and Khan, Jaber, andBonney[31]. Salameh and Jaber[37], Goyaland Cardenas-Barron[17] presented an easy to implementversion of this model. Rezaei[35] extended thismodel by relaxing the assumption of the basic model andassumed that shortage can be incurred, where the shortageis completely backordered. The extension of this model with backordersis also offered by Eroglu and Ozdemir[13] andWee,Jonas, and Wang[42]. Furthermore, other extensionsthat worth mentioning here are included, supply chain (Khan, Jaber, & Ahmad[30]; Huang[24], learning in inspection (Khan, Jaber, &Wahab,2010), inspection errors (Khan, Jaber, &Bonney, 2011),supplier–buyer relationship in inspection (Rezaie&Salimi[36]), repairing or buying from local sources (Jaber,Zanoni, &Zavanella[27]) and inspection speed (Hauck&Vörös[22]).NimaKazemi[33] extended an EOQ models for items with imperfect quality and emission considerations using different cases.

3. Model Formulation

In this section, we extended the model for a buyer with imperfect quality items and emissions in the in NimaKazemi[33] as the integrated Vendor-Buyer model considering imperfect quality and environmental impacts including transportation, packaging and its emission costs..

The following notations and assumptions are used to develop the model.

Notations

P	Vendor's production rate
D	buyer's demand rate(units/yr)
x	buyer's screening rate(unit/time)
S_v	vendor's setup cost for a batch
S_b	buyer's ordering cost($/order)
n	number of shipments in a batch for vendor to buyer
F	fixed transportation cost
E	initial cost of packaging equipment
m	number of parcels
k	cost of material used for packaging($/parcel)
h_b	buyer's unit holding cost for both good and imperfect items($/unit/yr)
b	space occupied by an item(m^3/unit)
c_{eh}	average of carbon emission cost of the warehouse($/$m^3$)
a	weight of an item stored in the warehouse(ton/unit)
t_{eh}	rate of the emission tax for the warehouse($/ton)
μ	average annual rate of inventory obsolescence for good quality items
c_p	buyer's purchasing price($/unit)
p_{sc}	scrap price($/unit)
β	social cost of emission from packaging
c_{eo}	average carbon emission cost coefficient of obsolete items($/ton)
α	social cost of emission from transportation
h_v	vendor's holding cost($/unit/yr)
t	screening time
d	buyer's screening cost($/unit)
c	unit cost for the vendor
v	selling price of imperfect items for buyer($/unit)
s	selling price of good items for buyer($/unit)
γ	fraction of imperfect items which is a random variable with support in [0,1]
f(γ)	probability density function of fraction of imperfect items
T	cycle length

H_e emission cost of inventory holding($/unit/yr)
T_e emission tax for inventory holding($/unit/yr)
W_e annual emission cost of obsolescence disposal($/yr)
W_c annual cost of obsolescence($/yr)
V_e cost of emission from transportation
P_e cost of emission from packaging($/yr)
Q_e lot size with emission considerations(unit/cycle)

Assumptions

1. A single item is considered.
2. Demand rate is constant
3. Production rate is greater than the demand rate.
4. The defective units are sold with discounted price by the buyer as a single batch atthe end of the screening period.
5. The production rate is uniform and finite.
6. Shortages and backorder are not allowed.
7. There is a single vendor and a single buyer.

Vendor's cost formation

The vendor's inventory cost per cycle consists of the setup and holding cost of an inventory,

$$TC_V(n, Q_e) = S_v + ch_v\left\{\frac{Q_e}{2n} + \frac{(n-2)Q_e}{2n}\left(1 - \frac{D}{P}\right)\right\} \quad \text{-- (1)}$$

Buyer's cost formation

The buyer's inventory cost per cycle includes the ordering cost, unit purchasing cost, unit screening , holding, transportation, packaging and emission costs,

Where ,

Emission costs = Emission cost of inventory holding + Emission tax for inventory holding + Holding cost of the obsoleted items + Emission cost of obsolescence disposal + Emission from packaging + Emission from transportation

$=H_e + T_e + W_c + W_e + P_e + V_e$

$$\text{Emission costs} = \left\{\frac{{Q_e}^2(1-\gamma)^2}{2D} + \frac{\gamma {Q_e}^2}{x}\right\}\left(bc_{eh} + at_{eh} + \mu(c_p - p_{sc}) + \mu ac_{eo} + m\beta\right) + n\alpha Q_e$$

Thus, from the above considerations the buyer's inventory cost per cycle can be written as,

$$TC_B(n, Q_e) = S_b + c_pQ_e + dQ_e + nF + (E + mk) + n\alpha Q_e$$
$$+\left\{\frac{{Q_e}^2(1-\gamma)^2}{2D} + \frac{\gamma {Q_e}^2}{x}\right\}\left(h_b + bc_{eh} + at_{eh} + \mu(c_p - p_{sc}) + \mu ac_{eo} + m\beta\right) \text{-- (2)}$$

Coordinated Vendor-Buyer model

The total vendor-buyer coordinated cost per cycle is expressed as,

$$TC_e(n, Q_e) = TC_V(n, Q_e) + TC_B(n, Q_e)$$
$$= S_v + S_b + c_pQ_e + dQ_e + nF + (E + mk) + n\alpha Q_e + ch_v\left\{\frac{Q_e}{2n} + \frac{(n-2)Q_e}{2n}\left(1 - \frac{D}{P}\right)\right\}$$
$$+\left\{\frac{{Q_e}^2(1-\gamma)^2}{2D} + \frac{\gamma {Q_e}^2}{x}\right\}\left(h_b + bc_{eh} + at_{eh} + \mu(c_p - p_{sc}) + \mu ac_{eo} + m\beta\right) \text{-- (3)}$$

The total profit per cycle for the supply chain is the sum of the selling price of good items and the discounted selling price of imperfect items less total cost. Thus, it is written as

$$TPU_e(n, Q_e)\gamma = sQ_e(1-\gamma) + vQ_e\gamma$$
$$-\begin{bmatrix} S_v + S_b + c_pQ_e + dQ_e + nF + (E + mk) + n\alpha Q_e \\ + ch_v\left\{\frac{Q_e}{2n} + \frac{(n-2)Q_e}{2n}\left(1 - \frac{D}{P}\right)\right\} + \left\{\frac{{Q_e}^2(1-\gamma)^2}{2D} + \frac{\gamma {Q_e}^2}{x}\right\} \\ \left(h_b + bc_{eh} + at_{eh} + \mu(c_p - p_{sc}) + \mu ac_{eo} + m\beta\right) \end{bmatrix} \text{-- (4)}$$

Since the cycle length in the emission case is $T = \frac{(1-\gamma)Q_e}{D}$, we have the expected value of cycle length as,$E[T] = \frac{(1-E[\gamma])Q_e}{D}$.

Using the Renewal-Reward theorem, the expected total profit per unit time of vendor-buyer is,

$$ETPU_e(n, Q_e) = \frac{E[TC_e(n, Q_e)]}{E[T]}$$

$$= sD + \frac{D}{(1-E[\gamma])}\begin{bmatrix} vE[\gamma] - c_p - d - n\alpha - \frac{1}{Q_e}(S_v + S_b + nF + E + mk) \\ -ch_v\left\{\frac{1}{2n} + \frac{(n-2)}{2n}\left(1 - \frac{D}{P}\right)\right\} - Q_e\left\{\frac{E[(1-\gamma)^2]}{2D} + \frac{E[\gamma]}{x}\right\} \\ \left(h_b + bc_{eh} + at_{eh} + \mu(c_p - p_{sc}) + \mu ac_{eo} + m\beta\right) \end{bmatrix} \text{-- (5)}$$

Taking the first derivative of $E[TPU_e(n, Q_e)]$ with respect to Q_e , we have

$$\frac{\partial(ETPU_e(n,Q_e))}{\partial Q_e} = \frac{D}{(1-E[\gamma])}\begin{bmatrix} \frac{1}{Q_e^2}(S_v + S_b + nF + E + mk) - \left\{\frac{E[(1-\gamma)^2]}{2D} + \frac{E[\gamma]}{x}\right\} \\ \left(h_b + bc_{eh} + at_{eh} + \mu(c_p - p_{sc}) + \mu ac_{eo} + m\beta\right) \end{bmatrix} \text{-- (6)}$$

Taking the second derivative, we have

$$\frac{\partial^2(ETPU_e(n,Q_e))}{\partial Q_e^2} = -\frac{2D}{(1-E[\gamma])Q_e^3}(S_v + S_b + nF + E + mk) \quad \text{-- (7)}$$

Clearly it can be seen in (7) that $\frac{\partial^2(ETPU_e(n,Q_e))}{\partial Q_e^2} < 0$ for all values of n, Q_e. Hence n and Q_e become optimum. Then, $ETPU_e(n, Q_e)$ is strictly said to beconcave.

By setting $\frac{\partial(ETPU_e(n,Q_e))}{\partial Q_e} = 0$, we get

i.e. $\frac{1}{Q_e^2}(S_v + S_b + nF + E + mk) = \left\{\frac{E[(1-\gamma)^2]}{2D} + \frac{E[\gamma]}{x}\right\}\left(h_b + bc_{eh} + at_{eh} + \mu(c_p - p_{sc}) + \mu ac_{eo} + m\beta\right)$

i.e. $Q_e^* = \sqrt{\frac{2Dx(S_v+S_b+nF+E+mk)}{\{xE[(1-\gamma)^2]+2DE[\gamma]\}(h_b+bc_{eh}+at_{eh}+\mu(c_p-p_{sc})+\mu ac_{eo}+m\beta)}}$ -- (8)

4. Numerical Example

In this paper, w consider an example with the following parameters,

$D = 50{,}000$, $x = 175{,}200$, $S_v = 300$, $S_b = 100$, $n = 5$, $F = 25$, $E = 3000$, $m = 2500$, $k = 3$,
$h_b = 5$, $b = 0.017$, $c_{eh} = 0.55$, $a = 0.002$, $t_{eh} = 13$, $\mu = 0.06$, $c_p = 25$, $p_{sc} = 6$, $\beta = 0.2$,
$c_{eo} = 13$, $\alpha = 0.5$, $h_v = 2$, $d = 0.5$, $c = 10$, $v = 20$, $s = 50$, $P = 160{,}000$.

If the fraction of imperfect items follows a uniform distributionwith, $f(\gamma) = \begin{cases} 25, & \text{for } 0 \le \gamma \le 0.04 \\ 0, & \text{otherwise.} \end{cases}$, then we have $E[\gamma] = 0.02$, $E[(1-\gamma)^2] = 0.96$.

- From (8),Optimal lot size $\boldsymbol{Q_e^*} = \mathbf{1497.4}$ **units**
- From(5),Expectedtotal profit for Vendor-Buyer $\mathbf{ETPU_e(n, Q_e)}$**=$28056.95/yr.**

5. Conclusion

Environmental factors are the main concerns of the decision makers. Therefore, in this context, an Economic order quantity modelwith Vendor-Buyer coordination for items with imperfect quality and emission costs, which are the result of warehousing, transportation, packaging and waste disposal activities, is formulated . The equations to calculate the expected average total profit per unit time for vendor-buyer and optimal lot size quantities are presented. A numerical example is provided to demonstrate its practical usage.

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