Reverse Logistics Model: A Closed - Loop Supply Chain System with Energy, Transportation and Waste Disposal Costs

W. Ritha, I. Francina Nishandhi

Department of Mathematics, Holy Cross College (Autonomous), Trichirappalli-620-002

***Abstract*: Reverse logistics is important for today's business environment, and it involves the process of product returns, products wrongly delivered damaged products, and product exchange programs. Most of the reverse logistics model ignored the energy cost along with transportation and waste disposal cost. In this paper we will present the inventory model with closed - loop supply chain system with energy, transportation and waste disposal costs. Numerical examples are presented for the proposed model, and the numerical example will illustrate the importance of accounting for the three costs.**

***Keywords*: Closed – loop supply chain, energy, transportation, EOQ model with repair**

I. INTRODUCTION

The concept of reverse logistics is more familiar in the modern business world. It mainly concentrates for all the operations related to the reuse of products and materials. It is the process of moving goods from their typical final destination for the purpose of capturing value, or proper disposal. Remanufacturing and refurbishing activities also may be included in the definition of reverse logistics. Growing green concerns and advancement of green supply chain management the concepts and practices of reverse logistics more relevantly used by the many business people. The reverse logistics process involves the management and the sale of surplus as well as returned equipment and machines from the hardware leasing business. Normally, logistics deal with events that bring the product towards the customer. In the case of reverse logistics, the resource goes at least one step back in the supply chain. For instance, goods move from the customer to the distributor or to the manufacturer. When a manufacturer's product normally moves through the supply chain network, it is to reach the distributor or customer. Any process or management after the sale of the product involves reverse logistics. If the product is defective, the customer would return the product. The manufacturing firm would then have to organise shipping of the defective product, testing the product, dismantling, repairing, recycling or disposing the product. The product would travel in reverse through the supply chain network in order to retain any use from the defective product. The logistics for such matters is reverse logistics.

Managing inventory in reverse chains has been stressed in several studies (Fleischmann et al 1997). The production/repair economic order quantity model was first developed in the year 1960s, afterwards Richter (1997) solved the above model by analytically. Richter developed an EOQ model where demand is fulfilled from a serviceable stock that contains produced and recovered items. Used items or items that reached their end or economic lives are collected for recovery from the market at a constant rate. Recovered item that is repaired, remanufactured items are considered as good as new. The work of Richter (1996) has been investigated and developed by many researchers some of them are Dobos and Richter (2003, 2004, 2006),Teunter (2004),Konstantaras and Papachristos (2006), El Saadany and Jaber (2008,2011),Jaber and Rosen (2008),Jaber and El Saadany (2009),Hasonov,Jaber and Zolfaghari (2012). From this we can able to understand the last decade there has been a significant growth in the research and applications of product recovery and recycling in particular with the view of the extended manufacturer's responsibility which includes the recovery and safe disposal of their products. Winkler (2011) proposed the sustainable supply chain networks (SSCN) concepts for the design of closed – loop system and their implementation. Mitra (2012) investigated an inventory model for a closed – loop supply chain and correlates the demand and returns of used items, where deterministic and stochastic models were developed under generalised cost structures. Paksoy,Bektasb and Ozcey-lana (2011) developed a linear programming problem to investigate cases where the costs of transportation operation outweigh the emissions costs they generate in supply chains. Lambert,Riopel and Abdul-Kader (2011) divided reverse logistics into seven important elements, which are 'coordinating system, gatekeeping, collection, sorting, treatment, information system and disposal system. They investigated each of these elements in terms of process mapping, decisions, economics aspects and performance measures.

Zanoni,Ferretti, and Tang (2006) developed a simulation model to study the effects of different control policies of a logistics system with manufacturing and remanufacturing processes on the bullwhip of demand. Alinovi ,Bottani and Montanari (2012) discussed on mixed production/remanufacturing systems and proposed an EOQ model to analyse the effectiveness of a return policy of used items for a reverse logistics chain. The above existing literature model did not concentrate about an energy, transportation and waste disposal cost, although it is well recognised that these costs hold and are important components of the total cost structure of a supply chain.

Energy is fundamental for developing economies and improving the living standards of societies. Energy sources are classified as renewable energy (RW) and non-renewable energy (NRW). The fossil fuel, petrol are the examples for the non-renewable energy sources but it is more expensive and harmful for the environment. The example of renewable energy sources are solar and wind energy. The uses of renewable energy sources are increasing as they are environmentally friendly and their technologies are becoming more economical. Evaluating different technologies, the costs of generating electricity from must also consider the external (social) costs to human health and the environment (Sahin2004).the results from Sahin (2004) showed that generating electricity from wind energy was the least costly and the friendliest to the environment than the other energy options considered. El-Kordy et al. (2002) proposed a life cycle cost (LCC) approach to evaluate the economies of using RW and NRW energy sources to generate electricity. They suggested considering the external cost of a system's emission in their analysis. Khan (2006) study about the wind energy and he showed that wind energy has ecological, social and economic benefits.

Transportation costs are incurred when delivering products to the market (customers) and when collecting used items from the market for recovery. Transportation includes modes used and distances travelled in the delivery of produced /recovered items and the collection of used items. Moreover it should be considered that using transportation modes based on conventional energy is a concern as this energy is costly and damaging to the environment. Hybrid vehicles are starting to emerge, however the technology is not yet available to support long haul trips. In addition, not all the items collected from the market are repairable. Some will eventually be disposed. Disposal options remain to be limited; e.g. incineration or landfill (Dijikgraaf and Vollebergh 2004). Both options are financially and environmentally costly (e.g.Carlee 1986, Baetz and Neebe 1994; Staikos and Rahimifrad 2007).

The importance of accounting for energy, transportation and waste disposal costs has been strongly portrait in the study of Bonney and Jaber (2011) as fundamental in designing environmentally responsible inventory and logistics systems. Nowadays firms are going towards the sustainability for achieving this they reduce the energy, transportation and waste disposal cost of their supply chains. In this paper we developed the model under the closed loop supply chain system and assumes a single product that consists of two supply chains: forward and reverse (backward).In the forward supply chain raw materials are produced into items, while in the reverse supply chain, used items are collected and remanufactured into 'as-good-as new' items. We have investigated an inventory model for a closed loop supply chain system jointly considering energy, transportation and waste disposal costs. The remainder of this paper organised as follows. Section 2 presents assumption and notations for the proposed model. Section 3 provides a mathematical model along with the cost of using mixed strategy of RW and NRW energy sources is considered with transportation and waste disposal costs. Section 4 provides some numerical examples and discussion of results. Finally we summarize the conclusion of the paper in section 5.

II. NOTATIONS AND ASSUMPTIONS

The following assumptions are used in the proposed model.

1. Single productscases where items produced and recovered conform to quality characteristics.
2. Instantaneous production and recovery rates.
3. Demand is known and constant over time
4. Constant collection rate of used items.
5. Lead time is zero.
6. Unlimited storage capacity is available for serviceable
7. Transportation truck capacity is unlimited.
8. Infinite planning horizon.

The notations used in this paper are described as follows.

Input Parameters:

d : demand rate(units/unit time)

m : number of repair setups

n : number of production setups

r : repair fixed cost

s : production fixed cost

b : manufacturing unit cost

k : repair unit cost

e : disposal unit cost

h : holding cost for serviceable stock ($/unit/unit of time)

u : holding cost for repairable stock ($/unit/unit of time)

pw : a subscript representing the present worth of a cost factor

C : capital cost

M : operation and maintenance costs

F : fuel cost

X : external costs including damage prevention or damage cost

S : Salvage value of the system

T : length of the time interval T = x/d

x : lot size

WC : landfill cost

l : cost of landfilling per ton of material

b_m : cost to transport one unit (item) of production for one distance Unit ($/unit/km)

b_r : cost to transport one unit (item)of remanufacturing for one distance unit ($/unit/km)

dt_m : distance travelled for a produced item (km)

dt_m : distance travelled for a repaired item (km)

α : Percentage of demand that is disposed with αD is the waste disposal rate, Where 0 < α < 1, $\alpha = 1 - \beta$

β : repair rate (equivalent to the recovery rate of Schrady)

θ' : Percentage of RW energy sources used, ((1- θ) percentage of Conventional Energy) from the available ones

τ : Number of items an item is recovered

β_τ : Proportion of used units returned for recovery purposes when an item isRecovered a limited τ number of times, $0 < \beta_\tau < 1$

C_{inv} : remanufacturing investment cost over the life cycle of a product, $ Per year

θ : Investment increment factor, $0 \le \theta < 1$

C_{ep} : Penalty cost for carbon emissions

III. MATHEMATICAL MODEL

In this paper we considered the two stocks that is serviceable and repairable stock. The serviceable stock is for storing new and recovered items, at same way repairable stock is for storing collected used items. Along with we computed the costs of energy, transportation and waste disposal costs. Energy cost parameters used in developing the model of this paper are adopted from El-Kordy et al (2002), who considered social costs (human health, pollution etc.) when using the LCC approach to analyse different energy generation system, which are not reflected in the price of electricity. The social costs vary by the type and amount pollutants emitted by the energy technology used to generate electricity.

The LCC is computed as,

$$\text{LCC} = C_{pw} + M_{pw} + F_{pw} + X_{pw} - S_{pw} \tag{1}$$

The needed amount of electricity is generated by using different energy sources (RW and NRW).

Fixed setup cost for the production and repair is expressed as,

$$(mr+ns) \tag{2}$$

Holding cost for the serviceable stock is expressed as,

$$h = \frac{h}{2d}\left(\frac{\alpha^2 x^2}{n} + \frac{\beta^2 x^2}{m}\right) \tag{3}$$

Holding cost for the repairable stock is computed as,

$$u = \frac{u\beta Tx(m-1)}{2dm} \tag{4}$$

The linear production, waste disposal and repair cost per unit time is given as,

$$R = d[\alpha(b+e)+(1-\alpha)k] = d[\alpha(b+e-k)+k] \tag{5}$$

Landfilling cost (WC) as a function of the weight of the material and actual cost of land filling per tonne of material, which we refer to the solid waste disposal cost, i.e.

$$WC = (m+n)\,(\alpha dl) \tag{6}$$

Transportation cost computed in this paper is taken from Toptal, Cetinkaya,and Lee (2003) and Bonney and Jaber (2011), which are $A_m = nb_m dt_m \alpha d$ (for the demand filled from the stock of produced items) and $A_r = mb_r dt_r (1-\alpha)d$ (for the demand filled from the stock of remanufactured items)

The emission generated from the production process is given in terms of production rate as:

$$E = a_e P^2 - b_e p + c_e \tag{7}$$

Where,

E : GHG (CO_2) emission generated per year (ton/year)

a_e : emission function parameter (ton.year^2/unit^3)

b_e : emission function parameter (ton. year/unit^2)

c_e : emission function parameter (ton/unit)

P : production rate (units/year)

Here we calculate the production rate as,

$$P = \frac{d}{1 - \dfrac{2sd}{hx^2}}$$

Investment cost associated with the repair and recovery of returned items, it calculated as

$$C_{inv} = c_{inv}(1 - e^{-\theta\tau}) \tag{8}$$

Penalty cost from carbon emission is given by

$$C_{ep} \tag{9}$$

So the total cost of a system is expressed as the sum of set-up costs for the production and repair batches, NRW and RW energy life cycle cost for repair and production processes, holding cost for repairable and serviceable stocks, solid waste disposal cost from landfilling activities, linear production, waste disposal, repair rate cost (non- EOQ related cost), investment cost, production emission cost, penalty cost for carbon emission, and cost of transporting items of a product to and from the market respectively.

TC(x,m,n,τ)=(mr+ns)+

$$\theta'\sum_{k}^{K} LCC_k^{RW} + (1-\theta')\sum_{j}^{J} LCC_j^{NRW} + nb_m dt_m \alpha d + mb_r dt_r (1-\alpha) d + \frac{h}{2d}\left(\frac{\alpha^2 x^2}{n} + \frac{\beta^2 x^2}{m}\right) + \frac{u\beta T x(m-1)}{2dm} + d[\alpha(b+e-k)+k] + c_{inv}(1-e^{-\theta\tau}) + +(m+n)(\alpha dl) + a_e P^2 - b_e P + c_e + C_{ep} \qquad (10)$$

Where K is the number of RW energy sources available and J is the number of NRW sources available with J+K =6, where 6 is the total number of energy sources considered, consistently with El-Kordy et al.(2002) where

$$LCC^{RW} = \sum_{k}^{K} LCC_k^{RW} \text{ and } LCC^{NRW} = \sum_{j}^{J} LCC_j^{NRW} \qquad (11)$$

Therefore the average cost per unit time can be written as,

$$\frac{TC(x,m,n)}{T} = \frac{d}{x}\left[(mr+ns) + \theta' LCC^{RW} + (1-\theta')LCC^{NRW} + d\left[nb_m dt_m\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right) + mb_r dt_r\left(1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)\right) + (m+n)\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right) l\right]\right]$$

$$+\frac{x}{2}\left[h\left\{\left(\frac{\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)^2}{n}\right) + \left(\frac{1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)^2}{m}\right)\right\} + u\left(1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)\right) + \frac{u\left(1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)\right)^2 (m-1)}{m}\right]$$

$$+ d\left[\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)(b+e-k)+k\right] + c_{inv}(1-e^{-\theta\tau}) + a_e P^2 - b_e P + c_e + C_{ep}$$

(12)

Here we use the α value as $\alpha = \left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)$

Differentiating the above equation with respect to x, we get the optimal value of x as,

$$x^* = \sqrt{\frac{2dV(m,n)}{Z(m,n)}}$$

(13)

Where $V(m,n)$ is denoted as,

$$V(m,n) = (mr+ns) + \theta' LCC^{RW} + (1-\theta')LCC^{NRW} + d[nb_m dt_m\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right) + mb_r dt_r\left(1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right) + (m+n)\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)l\right)]$$

Similarly $Z(m,n)$ is denoted as,

$$Z(m,n) = \left[h\left\{\left(\frac{\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)^2}{n}\right) + \left(\frac{1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)^2}{m}\right)\right\} + u\left(1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)\right) + \frac{u\left(1-\left(\frac{1-\beta}{1-\beta^{\tau+1}}\right)\right)^2 (m-1)}{m}\right]$$

IV. NUMERICAL EXAMPLE

In this section we provide the numerical example so as to show the applicability of the model developed in the previous section. The following parameters used for finding the result, d = 10, r = 100, s = 20, h=6, u = 4, β = 0.9, m=1,n=2,b=6,e=2,k=4, θ =0.3, τ =2, a_e = 0.0000003, b_e = 0.0012, c_e = 1.4, C_{ep} =10, θ = 0.3 ,the values RW energy and NRW energy costs are taken from the study ofEl- Kordy et al (2002) where LCC^{RW} = 1.8085 (wind energy) and LCC^{NRW} = 5.4256 (for conventional steam fuel oil fired energy), transportation and landfilling parameters are $b_m = b_r = 1$, $dt_m = dt_r = 80$, l =0.5, θ' = 0.5, C_{inv} =50.

Using the above parameter values the optimal order quantity x^* = 68 and TC = 300.

V. CONCLUSION

In this paper we study about reverse logistics inventory model with closed loop supply chain system along with energy, transportation and waste disposal cost. Using reverse logistics we can reduce the overall system total cost and also we can fulfil the customer service and satisfactions. And also we insist the importance of energy, transportation and waste disposal cost in our proposed model.

REFERENCES

[1]. Alinovi,A., E.Bottani, and R.Montanari.2012. Reverse Logistics: A Stochastic EOQ–Based Inventory Control Model for Mixed Manufacturing/Remanufacturing Systems with return policies.International Journal of Production Research 50 (5):1243-1264

[2]. Bazen.E.,M.Y.Jaber, and S.Zanoni 2015, A review of mathematical inventory models for reverse logistics and the future of its modelling: an environmental perspective, Applied Mathematical Modelling,doi:10.1016/j.apm.2015.11.027.

[3]. Baetz,B. W., and A.W.Neebe.1994. A Planning model for the developmentof waste material recycling programmes. The Journal of operations research society 45 (12):1374-1384.

[4]. Bonny, M., and M.Y.Jaber.2011.Environmentally Responsible Inventory models: Non-Classical Models for a non-Classical Era. International Journal of Production Economics 133(1):43-53.

[5]. Carlee, T.R. 1986. Plastic Recycling: Economic and Institutional Issues.Conservation and Recycling 9(4):335-350.

[6]. Dijkgraaf, E., and H.R.J.Vollebergh. 2004. Burn or Bury? A Social Cost Comparison of Final Waste Disposal Methods. Ecological Economics 50(3-4):233-247.

[7]. Dobos, I., and K.Richter.2003.A Production/Recycling Model with Stationary Demand and Return Rates. Central European Journal of Operations Research 11 (1):35-46.

[8]. Dobos, I., and K.Richter.2004.An Extended Production/Recycling Model with Stationary Demand and Return Rates. International Journal of Production Economics 90(3):311-323.

[9]. Dobos,I., and K. Richter.2006.A Production/Recycling Model with Quality Consideration. International Journal of Production Economics 104(2):571-579.

[10]. El-Kordy,M.N.,M.A.Badr,K.A.Abed,andM.A.I.said.2002. Economical Evaluation of Electricity Generation Considering Externalities. Renewable Energy 25 (2): 317-328.

[11]. El Saadany,A.M.A., and M.Y. Jaber. 2008. The EOQ Repair and Waste Disposal Model with Switching. Computers and Industrial Engineering 55 (1), 219-233.

[12]. El Sasdany, A.M.A., and M.Y.Jaber 2011. Production/Remanufacture EOQ model with returns of Subassemblies Managed Differently. International Journal of Production Economics 133 (1), 119-126.

[13]. Fleischmann,M.,J.M.Bloemhof-Rwaard,R.Dekker,E.van der Laan,J.A.E.E.vanNunen,and L.N. van Wassenhove.1997. "Quantitative Models for Reserve Logistics." European Journal of Operational Research103 (1):1-17.

[14]. Hasanov, P.,M.Y.Jaber,and S.Zolfaghari.2012.Production, Remanufacturing and Waste Disposal Models for the cases of Pure and Partial Backordering. Applied Mathematical Modelling 36(11):5249-5261.

[15]. Hasanov, P.,M.Y.Jaber,S.Zanoni and L.E.Zavanella. 2013 Closed-loop supply chain system with enegy,transportation and waste disposal costs, International Journal of Suatainable Engineering, 6:4,352-358.

[16]. Khan,Q.N.2006.Alternatives to Grid Extension for Rural Electrification:Decentralised Renewable Energy Technologies in Viemam.Energy technologies in Viemam. Energy Policy 35 (4): 2579 – 2589.

[17]. Jaber, M.A., and A.M.A., El.Saadany.2009. The Production Repair and waste disposal model with lost sales. International Journal of Production Economics 120 (1), 115-124

[18]. Jaber, M.A., and M.A., Rosen 2008. The economic order quantity repair and waste disposal model with entropy cost. European Journal of Production Research 188(1) 109-120.

[19]. Konstantaras,I., and S. Papachristos 2006. Lot sizing for a single product recovery system with backordering. International Journal of Production Research 44 (10)

[20]. 2031 - 2045.

[21]. Lambert,S., D. Riopel andW.Abdul-Kader.2011. A reverse Logistics Decisions Conceptual Framework. Computers and Industrial Engineering 61 (3). 561-581.

[22]. Mitra, S., 2012 Inventory Management in a two echelon closed-loop supply chain with correlated demands and returns, Computers and Industrial Engineering 62 (4): 870-879.

[23]. Richter,K., 1996. The EOQ and waste disposal model with variable setup numbers. European Journal of Operations Research 95 (2).313-324.

[24]. Teunter,R.H., 2004 Lot sizing for inventory systems with product recovery, Computers and Industrial engineering 46(3),431-441.

[25]. Toptal,A., S. Cetinkaya, and C.Y.Lee 2003 The buyer and vendor coordination problem: Modelling inbound and outbound cargo capacity cost.IIE Transactions 35 (1): 987-1002.

[26]. Winkler,H., 2011 Closed-loop Production system – A sustainable supply chain approach, CIRP Journal of Manufacturing Science and Technology 4(3) 243-246.

[27]. Zanoni,S., I. Ferretti, and O.Tang. 2006 Cost performance and Bullwhip Effect in a hybrid Manufacturing and remanufacturing system with different control policies. International Journal of Production Research 44 (18-19): 3847 -3862.