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A Modeling and Optimization of Closed Loop Supply Chain System with Inventory at Multiple Periods

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Abstract- *This paper aims to model and optimize the closed loop supply chain for maximizing the profit by considering the fixed order quantity inventory polices in various sites at multiple periods. This model investigates the three major return-recovery pair such as commercial returns, end- of-use returns, end –of- life returns and their inventory position at multiple periods. To develop this model, closed loop supply chain networks consists of supplier, manufacturer, distributer, retailer, customers and for major returns- repair, collection site, repair site, disassembly site, recycling site and disposal site were included in the network. The Performance of the model is analyzed using numerical investigations with sensitivity analysis.*

Keywords: *Closed loop supply chain (CLSC), Product Life cycle (PLC), Mixed- Integer Linear Programming (MILP), Inventory, Reverse logistics*

I. INTRODUCTION

An efficient way of recapturing the value of product and the proper disposal of material the remanufacturing industries finds difficulty in the design of reverse Logistics [7]. During last few years, the area of reverse logistics has been given more attention by many industries and academicians. Due to environmental impact and economic performance, there should be proper management to reverse the flows of products and parts to reduce the negative impact on the environment. This necessitates a proper mix of recovery options which is great a challenge in reverse supply chain. The Options for the recovery of returned products consists of reuse, resale, repair, refurbishing, remanufacturing, cannibalization and recycling [19].

Among recovery of product, repaired ones are collected in the collecting site and usable products are cleaned, refurbished, and transported to manufacturing site. In re-manufacturing and recycling process, used products are disassembled into parts in the disassembled site and transported back to the manufacturing site.

Reverse logistics is a very vast field of study with various issues being addressed such as remanufacturing, commercial returns, end-of-life returns and so on. Designing a closed loop supply chain to address these issues would be an arduous task and may result in inefficient network. Hence there is a need to model and analyze the inventory parameters associated with the network using mathematical models. Thus, in this paper, we propose a CLSC network with the objective of maximizing the profit.

II. Literature Review

There is a considerable body of research available in Reverse logistics (RL) network, for instance in [1], [11] and [12]. The RL could be categorized broadly in to 3 major areas, namely distribution planning, inventory control and production planning as reviewed by Fleischmann et.al [1]. Though various problems have been addressed, all these problems were addressed in developed countries context. It was [8] who proposed a framework to manage the product returns by estimating selected categories of products in the

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developing country context. They have shown the impact of quality and timing of returns on the overall RL network design. Minimization of total shipping cost of RL in a multi stage network has addressed by priority based Genetic Algorithm by [2] and proposed a heuristic approach.

Apart from the context of geographical application, another gap was existing RL body of research focused on forward and closed loop networks separately. Kannan et al.[4] integrated the forward logistics multi-echelon distribution inventory supply chain model and closed loop multi-echelon distribution inventory supply chain. This model is applied for built-to- order environment using genetic algorithm and particle swarm optimization. The model is validated with two case studies one in a tyre manufacture and other from plastic goods manufacturer.

An important question of RL namely remanufacturing in which a model that jointly determines the quantities of re-manufactured product, the production quantities of new branded product and the acquisition prices of used product was addressed in Jianmai Shi et al [3]. But, product recovery options were not explored before Sasikumar et al. [13] developed a mixed integer nonlinear programming model for truck tyre re-manufacturing company to maximize the profit of multi echelon reverse logistic network that addressed the gap in this area. They concluded value creation is possible by means of successful product recovery process in the case of used tyre segments which is a high volume segment in India. Then sensitivity analysis has been done to find the maximum allowable distance between initial collection point and the customers.

As we observe in today's market, due to increasing adoption of RL processes, there is also a need to integrate with distribution channels so that the efficiency can be passed across the supply chain. Subramanian et.al [17] focused on integration with four variants of RL network with dedicated warehouse delivery locations. Here they found that for different scenarios, a single product, single period will perform well with constant demand and uncertain returns.

Thus the traditional forward supply chain and CLSC have been an area of active research in the past decade, while little is known of inventory positioning across the CLSC under the influence of multiple products, uncertainty, product life cycle. It was Subrata Mitra et.al [18] addressed the issues related to inventory management in CLSC and developed deterministic and stochastic model for a two echelon system. This model is designed for correlated demands and returns with generalized cost structures. The developed model justify with numerical examples that a higher rate of return and a higher correlation between demand and return reduce the variability of net demand. It also demonstrates that the demand and return information at the decision making will save cost. Although several models are available for the integration of forward and reverse logistics network, to bring the external suppliers in to the CLSC Saman Hassanzadeh Amin et.al [9] proposed an integrated model with two phases. In the first phase, a supplier selection with evaluation of quality criteria was framed by fuzzy method. In the second phase they identified which supplier and refurbishing site should be selected and find out the optimal number of parts and products in the CLSC network.

Most of the integrated models found in CLSC devise optimal inventory, policies, location of various sites and selection of suppliers, all for a single period. However, demand and cost in a CLSC does not remain constant over the periods especially when product lifecycle is a consideration. This is especially true in today's volatile markets. The impact of product life cycle and the resulting variation in demand on the total supply chain costs is well documented by Samin Hassanzadeh Amin et.al,[10] . For instance, Ahiska et al. [15] develop optimal inventory policies during various stages of product lifecycle. The net result of their analysis shows that frequent revision of the inventory policies are important over the entire life cycle of the product. In another paper, Saman Hassanzadeh Amin, et.al [10] proposed a single period model to determine the quantity of new products and parts to be produced in a single period. This model is used as base for our research to address multiple periods with inventory.

To the best of our knowledge, there is no model to integrate the multi-product, multi-parts, multiple periods with inventory in the CLSC network. The purpose of this research work is to develop a model to determine the quantity of products and parts at various sites for multiple periods to maximize the profit of the CLSC. In this model three types product recovery are considered (i) commercial returns of the product,(ii) end of life returns and (iii) end of use returns along with important aspect of inventory positioning. Further, if the demands of the product during multi period are more than the returned products then manufacturer has to produce new products. This model is designed based on the demand of product during multiple periods and determines the inventory of product and part mix at different sites. For purpose of calculating cost, the setup cost, inventory cost, shipping cost and maximum capacity of repair site, disassembly site, recycling site, manufacturing site are considered. The objective function is to maximize the profit of manufacturer with the various costs associated with it.

III. Problem Definition

From Industry point of view, there are various types of CLSC network. Among all these type of the network, we propose a generalized form of CLSC framework with the initial inventory at manufacturing plant and final end period inventory with various demand of product. In this study, the framework of reverse logistics consist of a manufacturer, collection site, repair site, disassembly site, disposal site and multiple recycling sites as shown in the Figure.1. After using the products, some of the customers return the used products. The returned products are then collected during different periods at collection site and are segregated in to two types of returns. One, commercial returns of the returns products which are sent to the repair site for refurbishing and small repair. Second, the products are taken to the disassembly sites for disassembled into parts. The unused parts can be disposed to the disposed site and the usable parts in the form of end –of- life can be sent to various recycling site for processing and the good parts in the form of – of- use taken to part inventory during multiple periods.

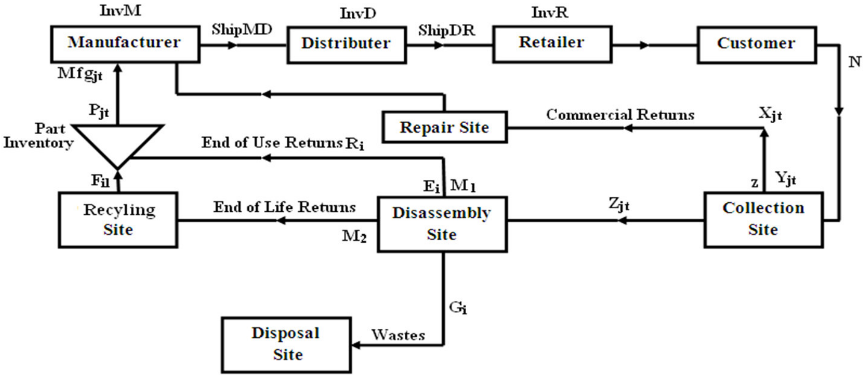

Figure.1 Proposed framework of CLSC

In this paper, the final end period inventory of a product at manufacturer, distributor and retailer are considered for numerical verifications so that it may be the initial inventory for next periods. In addition, unit inventory holding cost, shipment cost, set up cost and capacity constraints of repair site, disassembly site and recycling site are also taken in to account. If the demand and inventory of the products are more than returned products, then the manufacturer should produce new products at the manufacturing site. Most of the recycling industries like battery, printer and electronic components etc are found to adopt this kind of CLSC framework of Saman Hassanzadeh Amin, et.al [10].

IV. Model Formulations and Assumptions

The Indices, Parameters and its associated decision variables and the mathematical model formation of the proposed closed loop supply chain are shown in the table. For computation purpose, the various input data are taken from the literature Saman Hassanzadeh Amin, et.al [10].

The assumptions involved in this model are as follows:

- The Proposed model is a multi– period model.
- The demands of product is known for all the periods
- The transit lead time across various site are ignored
- Conversion process in the repair site, disassembly site, recycling site are assumed instantaneous.
- The capacity of the collection site is unlimited.
- The initial inventory of the manufacturer is known
- The final period of the inventory of manufacturer, distributor and retailer also known so that it will act as hands on inventory for next period.

The Indices, Parameters and its associated decision variables and the mathematical model formation of the proposed closed loop supply chain are specified below.

Indices

i	Set of parts, i = 1,2,..I
j	Set of products, j= 1,2.. J
l	Set of recycling site l=1,2..L.
t	Set of period t =1,2..T

Decision Variables

Xjt	Units of Product j to be repaired at period t
Pjt	Units of Product j obtained from part inventory at period t
Yjt	Units of Product j in collection site at period t

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Zjt	Units of returned Product j to be disassembled at period t
Mfgjt	Units of Product j manufactured in the manufactured site at Period t
Eit	Units of Part i that are obtained in the disassembly site at Period t
Rit	Units of end-of-use return of part i at period t
Git	Units of part i to be disposed at period t
Filt	Units of Part i to be recycled in recycling site l at period t
InvMjt	Inventory of Product j at the manufacturing site at period t
InvRjt	Inventory of Product j at the retailer at period t
InvDjt	Inventory of Product j at the distributor at period t
ShipMDjt	Shipment of Product from manufacturer to distributor of product j at period t
ShipDRjt	Shipment of Product from distributor to retailer of product j at period t
Uilt	Binary variable for set up of recycling site l for part i at period t
Vjt	Binary variable for set up of disassembly site at period t
Wjt	Binary variable for set up of repair site at period t

Parameters

Sj	Unit selling price for the product j
aj	Resource usage to produce one unit of product j
yj	Unit direct manufacturing cost of Product j
ej	Resource usage to repair one unit of product j
Cj	Max Capacity of repair site for product j
Djt	Demand for product j at period t
dj	Unit repair cost of Product j
fj	Set-up cost of disassembly site for product j
gj	Set-up cost of repair site for product j
Bi	Max capacity of disassembly site to disassemble part i
Hi	Unit disassembly cost for part i
mi	Unit disposal cost for part i
ri	Resource usage to disassemble one unit of part i
qij	Unit requirements for part i to produce one unit of product j
nil	Unit recycling cost for part i in recycling site l
oil	Set-up cost of recycling site l for part i
sil	Resource usage to recycle one unit of part i in recycling site l
Oil	Max capacity of Recycling site l to recycle part i
HRjt	Unit Inventory holding cost at retailer of Product j at period t
HDjt	Unit Inventory holding cost at Distributor of Product j at period t
HMjt	Unit Inventory holding cost at Manufacturer of Product at Period t
SHjt	Unit Shipment cost of product at period t
I	Inventory of a product at Manufacturing site at period t=1
F1	Inventory of a product at retailer at the end Period t
F2	Inventory of a Product at distributor at the end Period t
F3	Inventory of a Product at Manufacturer at the end Period t
MD	Max capacity of truck to travel from Manufacturer to Distributor
DR	Max capacity of truck to travel from Distributor to Retailer
z	Max percent of commercial returns
M	A big number
N	Max percent of total returns
M1	Max percent of end-of-use returns
M2	Max percent of end-of-life returns
L	Max number of recycling sites
A	Max capacity of the manufacturer plant

Max Z

$$\sum_{j=1}^{J}\sum_{t=1}^{T} S_j (X_{jt} + P_{jt} + Mfg_{jt}) - \sum_{j=1}^{J}\sum_{t=1}^{T} y_j\left(Mfg_{jt}\right) - \sum_{i=1}^{I}\sum_{t=1}^{T} h_i\left(E_{it}\right)$$

$$- \sum_{j=1}^{J}\sum_{t=1}^{T} f_j\left(V_{jt}\right) - \sum_{j=1}^{J}\sum_{t=1}^{T} d_j\left(X_{jt}\right) - \sum_{i=1}^{I}\sum_{t=1}^{T} m_i(G_{it}) - \sum_{j=1}^{J}\sum_{t=1}^{T} g_j(W_{jt})$$

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$$-\sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{l=1}^{L} n_{il}F_{itl}-\sum_{i=1}^{I}\sum_{t=1}^{T}\sum_{l=1}^{L} o_{il}U_{itl}-\sum_{j=1}^{J}\sum_{t=1}^{T} HR_{jt}(InvR_{jt})$$

$$-\sum_{j=1}^{J}\sum_{t=1}^{T} HD_{jt}(InvD_{jt})-\sum_{j=1}^{J}\sum_{t=1}^{T} HM_{jt}\left(InvM_{jt}\right)-\sum_{j=1}^{J}\sum_{t=1}^{T} SH_{jt}\left(ShipMD_{jt}+ShipDR_{jt}\right) \tag{1}$$

Subject to

$$\sum_{j=1}^{J} q_{ij}\left(P_{jt}\right)=R_{it}+\sum_{l=1}^{L} F_{ilt} \tag{2}$$

$$\sum_{l=1}^{L} F_{ilt}+G_{it}+R_{it}=E_{it} \tag{3}$$

$$\sum_{j=1}^{J} q_{ij}\left(Z_{jt}\right)=E_{it} \tag{4}$$

$$P_{jt}+X_{jt}=Mfg_{jt} \tag{5}$$

$$R_{it}\le M_1E_{it} \tag{6}$$

$$\sum_{l=1}^{L} F_{ilt}\le M_2E_{it} \tag{7}$$

$$G_{it}\le(1-M_1-M_2)E_{it} \tag{8}$$

$$Mfg_{jt}\le I \tag{9}$$

$$InvR_{jt}\le F_1 \tag{10}$$

$$InvD_{jt}\le F_2 \tag{11}$$

$$InvM_{jt}\le F_3 \tag{12}$$

$$InvR_{jt-1}+ShipDR_{jt-1}-D_{jt}=InvR_{jt} \tag{13}$$

$$InvD_{jt-1}+ShipMD_{jt-1}-ShipDR_{jt}=InvD_{jt} \tag{14}$$

$$Mfg_{jt}+InvM_{jt-1}-ShipMD_{jt}=InvM_{jt} \tag{15}$$

$$InvM_{jt-1}\ge P_{jt-1}+X_{jt-1}+Mfg_{t-1} \tag{16}$$

$$ShipMD_{jt}\le MD \tag{17}$$

$$ShipDR_{jt}\le DR \tag{18}$$

$$X_{jt}+Z_{jt}=Y_{jt} \tag{19}$$

$$\sum_{j=1}^{J} a_j\left(Mfg_{jt}\right)\le A \tag{20}$$

$$r_iE_{it}\le B_i \tag{21}$$

$$s_{il}F_{ilt}\le O_{il}U_{ilt} \tag{22}$$

$$e_jX_{jt}\le C_j \tag{23}$$

$$X_{jt}\le zY_{jt} \tag{24}$$

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$$Z_{jt} \leq (1 - z)Y_{jt} \tag{25}$$

$$Y_{jt} \leq ND_{jt} \tag{26}$$

$$\sum_{i=1}^{I} \sum_{t=1}^{T} \sum_{l=1}^{L} U_{ilt} \leq L \tag{27}$$

$$Z_{jt} \leq MV_{jt} \tag{28}$$

$$X_{jt} \leq M_1 W_{jt} \tag{29}$$

$$U_{ilt},\ V_{jt},\ W_{jt} \in \{0, 1\} \tag{30}$$

$$X_{jt},\ P_{jt},\ Y_{jt},\ Z_{jt},\ Mfg_{jt},\ E_{it},\ F_{ilt},\ R_{it},\ G_{it},\ InvM_{jt},\ InvR_{jt},\ InvD_{jt},\ ShipMD_{jt},\ ShipDR_{jt} \geq 0 \tag{31}$$

The objective function (1) maximizes the total profit for the manufacturer. The first term in the objective function represents the total selling profit of the product. It includes the repaired product with new product and shortage of the product to be produced in the manufacturing site for multiple periods. Second term represents the unit direct manufacturing cost multiplied by the amount of manufactured item in the manufactured site at period t. Third and fourth terms of the expression represents the unit disassembly cost and set up cost for disassembly site at period t. The fifth, sixth and seventh term represents the unit repair cost, disposal cost and set up cost for repair in the repair site. The next two terms of the objective function includes the cost related to unit recycling cost and set up cost of recycling at recycling site. Finally the last four terms of the expressions represents the inventory cost associated with the retailer, distributor, manufacturer and shipment cost from the manufacturer to distributor and from distributor to retailer respectively.

Constraint (2) ensures that the number of recycled parts is equal to the number of manufactured parts and number of end–of-use parts. The relationship between number of disassemble parts equal to the summation of number of recycling parts and end-of-use parts and disposal parts are presented in Constraint (3). Constraint (4) ensures the relationship between parts and products in disassembly site. The sum of parts from part inventory and the products from repair site is equal to manufacture product represented by constraints (5).

Constraints (6) to (8) show the Percent of end-of-use returns and end-of-life returns. Initial inventory at Manufacturer site at period 1 is represented in constrains (9). Final inventory of the product at the end period of retailer, distributor and manufacturer are considered in the Constraint (10) to (12). The inventory and shipment restriction at period t and previous period t-1 for retailer, distributer and manufacturer are enforced from the constraint (13) to (16). Capacity constraints of shipment from manufacturer to distributer and from distributer to retailer are ensured in the constraints (17) and (18).Besides the Constraints (19) represents that the collected products are sent to repair or disassembly site.

Constraint (20) to (23) ensures the maximum capacity of manufacturer, disassembly, recycling and repair sites are satisfied. Constraint (24) and (25) represents maximum percent of commercial returns.
The maximum percentage of total returns at the collecting site at various periods is considered in constraints (26). In addition to this, the limitation of recycling is represented in constraints (27). The constraints (28) and (29) ensure the units of returned products to be disassembled and repaired at multiple periods. Finally, the decisions variables are defined in the constraints (30) and (31). The proposed model is in the form of Mixed Integer linear programming problem and solved by IBM ILOG CPLEX OPL studio. The obtained results are validated through computational testing and sensitivity analysis.

V. Computational Results

The numerical examples are considered for testing the model with appropriate input parameters. The required parameters are chosen from the literature of Hassanzadeh Amin, et.al (2012) the framework where they considered for single period. Apart from these parameters the demand of the product at multiple periods and final inventory at the end period for manufacturer, distributor and retailers are known. Here the number of period, number of products, number of parts and number of recycling sites are chosen as 3. The final end period inventories F1=100, F2= 200, F3= 300, of retailer, distributor, manufacturer and shipments capacity are used. The details of input data used for other required input parameters are presented in Appendix. In this model, the optimal solution of the mixed integer program is obtained by IBM ILOG CPLEX OPL studio. The obtained computational results are presented in the Table 2 and 3. The MILP for the 3 period of computational testing for D = 1450, t = 3, j = 2 is considered. According to the optimal results, the manufacturer should manufacture 252 units in the manufacturing site and the 300 units are returned at the collecting site. Out of 300 units of product returns, 180 units are sent to repair site and 120 units are sent to disassembly site.

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Table 2 The Computational results

Product –related variables							
Y_{jt} *Units of Products j in collection site at period t*				X_{jt} *Units of Products j to be repaired at period t*			
t/j	*1*	*2*	*3*	*t/j*	*1*	*2*	*3*
1	275	300	300	*1*	165	180	180
2	300	275	275	*2*	180	165	165
3	275	275	300	*3*	165	165	180
Z_{jt} *Units of Products j to be disassembled at period t*				P_{jt} *Units of Products j to be repaired at period t*			
t/j	*1*	*2*	*3*	*t/j*	*1*	*2*	*3*
1	110	120	120	*1*	66	72	72
2	120	110	110	*2*	72	66	66
3	110	110	120	*3*	66	66	72
Mfg_{jt} *Units of Products j to be manufactured at manufacturing site at period t*							
t/j	*1*	*2*	*3*				
1	231	252	252				
2	252	231	231				
3	231	231	252				
Part –related variables							
E_{it} *Units of Part i obtained in the disassembly site at period t*				R_{it} *Units of Part i that can be end- of used at period t*			
t/j	*1*	*2*	*3*	*t/j*	*1*	*2*	*3*
1	670	680	710	*1*	201	204	213
2	690	670	690	*2*	207	201	207
3	680	690	700	*3*	204	207	210
G_{it} *Units of Parts i to be disposed at period t*							
t/j	*1*	*2*	*3*				
1	268	272	284				
2	276	268	276				
3	272	276	280				
Inventory –related variables							
$InvR_{jt}$ *Inventory of Products j in Retailer at period t*				$InvD_{jt}$ *Inventory of Products j in Distributer at period t*			
t/j	*1*	*2*	*3*	*t/j*	*1*	*2*	*3*
1	3100	1600	0	*1*	0	0	200
2	2900	1450	0	*2*	0	0	200
3	2950	1500	0	*3*	0	0	200
$InvM_{jt}$ *Inventory of Products j to be manufactured at manufacturing site at period t*							
t/j	*1*	*2*	*3*				
1	462	514	300				
2	504	535	300				
3	462	493	300				

Table 3 The Computational results

F_{ilt} *Units of Parts to be recycled in recycling site l at period t*				
Parts	*t/l*	*1*	*2*	*3*
1	2	201	204	213
2	3	207	201	207
3	2	204	207	210

The products of 120 units in disassembly site of the same period 3 of the product 2 are disassembled into number of parts of 700 units. These 700 units of parts are categorized into 3, in that 280 parts are taken in to part inventory, 210 parts are disposed in the disposed site and remaining 210 are processed at the recycling site no.3. Again these 210 parts stored as part inventory. There is 200 inventory at the distributer, and 300 units at manufacture at t=3 for the product no.2. Here it satisfies the demand of the product 2 at period 3. The Table 3 illustrate the processing of parts at different recycling site at different period

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VI. Sensitivity Analysis

To validate the above proposed model, a sensitivity analysis is performed. In this analysis we have fixed the various percentages of commercial returns (z) and studied the impact on profit for various values of total returns (N) versus Maximum profit. Here the number of products, number of parts and number of recycling sites and number of period is chosen as 3. From the Fig. 2 we observe that there is linear increase in the profit when there is varying percentage of total returns. At N > 60 percent of total returns, we find that there is only a slight increase in the profit. This analysis indicates any commercial returns over 60 Percentage does not yield any significant increase in total profit. Similar results were also observed for the incremental changes in total number of periods. Hence from the model, we understand that the manufacturer has an option of diverting the commercial returns in excess of 50% to the secondary market rather than processing the collected product in the repair site. This is one of the important observations from the study.

When the analysis is done for various percentage values of end-of –use return and end-of-life returns of the parts by fixing the disposal percentage as constant for different periods. We observed that the disposal cost has a major impact on maximizing the profit than other costs in the CLSC network for different periods. There is nearly a 20% increase in disposal costs between the first period and the subsequent periods. The sensitivity analysis graph in Fig.3 shows the various percentage values of end of use returns (M1) and end of life returns (M2) versus the disposal cost by fixing the disposal percent as constant for different periods. The graph is analyzed in such way that for constant disposal percentage of parts, the proportion of M1 and M2 mix is varied. For example, in Fig. 3, where disposal percentage is 10%, a maximum of M1=30 percentage of parts goes to part inventory as end of use returns and the remaining maximum M2= 60 percent of parts goes to recycling site as end of life returns. From the analysis it indicates that the minimum disposal cost is attained when both end of use and end of life returns have equal percent of parts. As indicated in the Fig.3 a minimum disposal cost has achieved for different periods. Also, the disposal costs remain constant for other combinations. The same results have been observed when the disposal percent is increased to 30 percent as shown in Fig.4. On the contrary, when the analysis is done for 50 percent of disposal parts the disposal cost is maximum for the equal percentage of end of use returns and end of life returns as shown in Fig.5. Hence the manufacturer should prefer to have less than 50 percent of disposal of parts when end-of-use and end-of-life returns share equal percent of returns. Beyond 50 percent of disposal returns of parts the manufacturer is not expected to attain a maximum profit from the CLSC network.

Figure 2 Sensitivity Analysis for Max .Profit Vs Max. Percentage of Total Returns

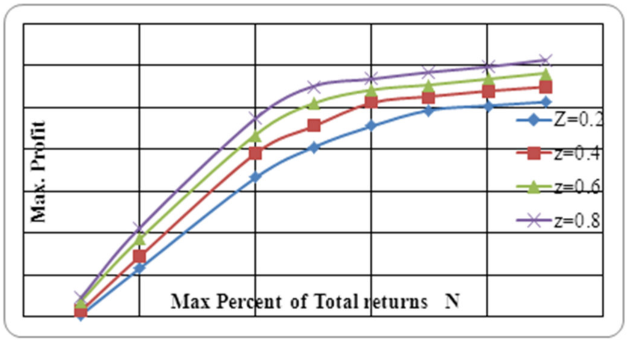

Figure 3 10 % of Disposal parts Vs Max. Percentage of end-of –use returns of parts for three periods

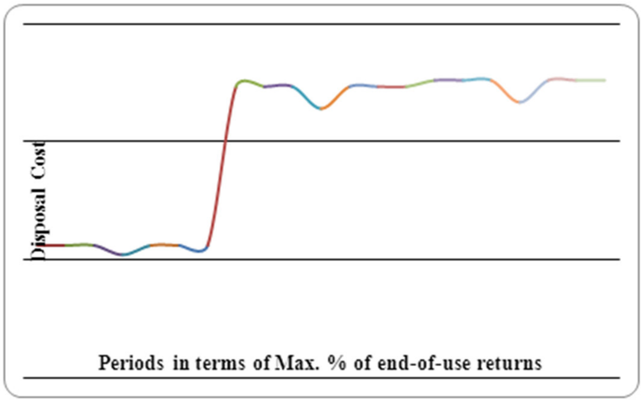

Figure 4 30 % of Disposal parts Vs Max. Percentage of end-of –use returns of parts for three periods.

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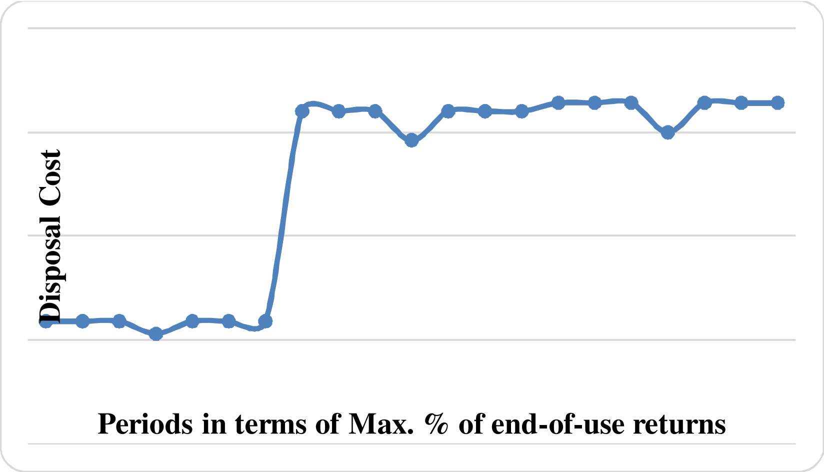
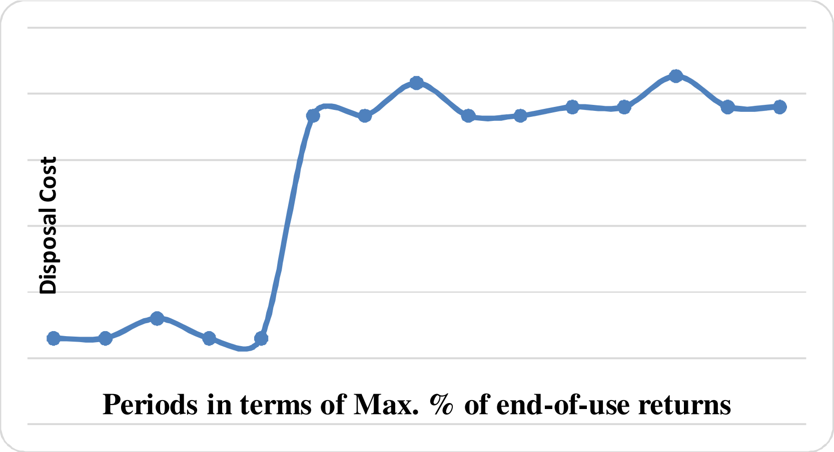


Figure 5 50 % of Disposal parts Vs Max. Percentage of end-of –use returns of parts for three periods



Appendix

Table 4 Product related parameters

j	*1*	*2*	*3*
S_j	150	200	220
a_j	1	2	2
y_j	30	35	30
e_j	1	2	1
C_j	9000	10000	8500
d_j	1	2	1
f_j	5	5	4
g_j	5	5	4

Table 5 D_{jt} Demand for Product j at period t

t/j	*1*	*2*	*3*
1	1400	1500	1600
2	1550	1450	1450
3	1400	1450	1500

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Table 6 Part related parameters

i	*1*	*2*	*3*
B_i	9000	10000	8500
h_i	4	5	2
m_i	3	4	4
r_i	1	1	1

Table 7 q_{ij}. Unit requirements for part i to produce one unit of Product j

t / j	*1*	*2*	*3*
1	2	1	3
2	1	3	2
3	3	2	1

Table 8 Recycling site- related Parameters.

<table>
<tr><td colspan="4">n_{il}(<i>Unit recycling cost for part i in recycling site l</i>)</td></tr>
<tr><td><i>i / l</i></td><td><i>1</i></td><td><i>2</i></td><td><i>3</i></td></tr>
<tr><td><i>1</i></td><td>3</td><td>2</td><td>3</td></tr>
<tr><td><i>2</i></td><td>4</td><td>4</td><td>3</td></tr>
<tr><td><i>3</i></td><td>4</td><td>3</td><td>4</td></tr>
<tr><td colspan="4">o_{il} (<i>Set-up cost of recycling site l for part i</i>)</td></tr>
<tr><td><i>i / l</i></td><td><i>1</i></td><td><i>2</i></td><td><i>3</i></td></tr>
<tr><td><i>1</i></td><td>4</td><td>5</td><td>4</td></tr>
<tr><td><i>2</i></td><td>4</td><td>4</td><td>4</td></tr>
<tr><td><i>3</i></td><td>5</td><td>5</td><td>4</td></tr>
<tr><td colspan="4">s_{il} (<i>Resource usage to recycle on unit part i in recycling site l</i>)</td></tr>
<tr><td><i>i / l</i></td><td><i>1</i></td><td><i>2</i></td><td><i>3</i></td></tr>
<tr><td><i>1</i></td><td>1</td><td>1</td><td>1</td></tr>
<tr><td><i>2</i></td><td>1</td><td>1</td><td>1</td></tr>
<tr><td><i>3</i></td><td>1</td><td>1</td><td>1</td></tr>
<tr><td colspan="4">O_{il} (<i>Max. Capacity of recycling site l to recycle part i</i>)</td></tr>
<tr><td><i>i / l</i></td><td><i>1</i></td><td><i>2</i></td><td><i>3</i></td></tr>
<tr><td><i>1</i></td><td>9000</td><td>10000</td><td>8500</td></tr>
<tr><td><i>2</i></td><td>10000</td><td>9000</td><td>8500</td></tr>
<tr><td><i>3</i></td><td>9000</td><td>10000</td><td>8000</td></tr>
</table>

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Table 9 Inventory related costs and shipments cost

HR_{il}(Unit Inventory holding cost at retailer of product j at period t			
i/l	*1*	*2*	*3*
1	2	2	2
2	2	2	2
3	2	2	2
HD_{il}(Unit Inventory holding cost at Distributor of product j at period t			
i/l	*1*	*2*	*3*
1	2	2	2
2	2	2	2
3	2	2	2
HM_{il}(Unit Inventory holding cost at Manufacture of product j at period t			
i/l	*1*	*2*	*3*
1	2	2	2
2	2	2	2
3	2	2	2
SH_{il}(Unit shipment cost of Product at period t			
i/l	*1*	*2*	*3*
1	3	3	3
2	3	3	3
3	3	3	3

Table 10 Other parameters

z	0.6	F_1	100
M	10000	F_2	200
N	0.2	F_3	300
L	100	M_1	0.3
A	250000	M_2	0.3
MD	1000	DR	2500

V. Conclusions and Future Directions

The mathematical model developed consists of one manufacturer, one collection site, one disassembly, and three recycling sites. The objective of the model is to determine the optimal inventory of products, parts at each site for various demands of the products during multiple periods. In addition to this, it also determines the parts of the products at which recycling site the parts can be recycled for different periods. The model is solved by IBM ILOG CPLEX OPL studio. To analyse the performance of the model, a numerical example are used. A sensitivity analysis is used for validating the results. The results of our study show that to maximize the profit in CLSC, the manufacturer should design the capacity of the sites by considering the demand during multiple periods.

Sensitivity analysis also illustrates the maximum profit of the CLSC can be attained up to 50 percent of disposal of parts when there is equal percent of end-of-life returns and end-of-use returns. Beyond 50 percent of disposal of parts, the manufacturer cannot expect huge profit from the CLSC network. From this model the managers can take appropriate decision for making a maximum profit of the company varying the percentage of returns of commercial product and end-of-use and end-of-life parts with various periods of demands. The main contribution of the paper lies in designing and solving the problems in recovery of product with multiple periods. As mentioned earlier, the inventory positioning in the network is also of interest academically. Presently, this work is under progress.

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Future research can include the uncertainty of demand and returns in the closed loop supply chain network by considering product life cycle.

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