# Modelling and analysis of network design for a reverse supply chain by considering Greenhouse limitations

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## Abstract

*Due to increase the importance of environmental issues, nowadays, various factories not only have to provide the customers' needs but have to create a cycle for returned products in order to recycle, dispose or remanufacture them. In this paper, a study was conducted to provide a model for reverse supply chain. At first, an introduction about the importance of the reverse logistics supply chain is expressed and then reverse supply chain model which includes customer zones, collection centers, remanufacturing centers, disassembly centers, recycling centers, primary markets, and secondary market delivered. The problem considered in this research involves decisions regarding the number and location of different facilities to be established in the network and the rate of flow of different products, components and materials between each stage of the reverse supply chain. This problem solved with exact solution in this paper and the result presented at the end of paper.*

**Keywords:**
Reverse Logistic, Reverse Supply Chain Network, Green Logistic, Network Designing, Greenhouse Gases, Exact Solution

## 1. Introduction

Reverse Logistics is defined as: the process of planning, implementing and controlling backward flows of raw materials, in process inventory, packaging and finished goods, from a manufacturing, distribution or use point, to a point of recovery or point of proper disposal.

Twenty years ago, supply chains were busy by the logistics of products and materials from raw material supplier to the end customer. Products are obviously still streaming in the direction of the end customer but low of products is coming back increasingly. This is happening for a whole range of industries, covering electronic goods, pharmaceuticals, beverages, and so on. Besides this, distant sellers like e-tailers who sell their product remotely, have to handle high return rates and many times at no cost for the customer. It is not surprising that the Reverse Logistics Executive Council has announced that US firms have been losing billions of dollars on account of being ill prepared to deal with reverse flows. [32]

Nowadays various industries have to design reverse supply chain for their products in order to three reasons: 1) environmental aspects and moral obligations and values 2) government regulation that forces organizations to have responsibility for their returned product 3) the impact of environmental issues that have an effect on the of customers portfolios.

Three Items mentioned above are pressurizing organizations to collect back the used products before causing any damage to the environment. Hence, many organizations have already started reverse logistics activities to decrease environmental damages. According to the Environmental Protection Agency, according to the article [19] there are 20–50 million metric tons of waste electrical and electronic products generated worldwide every year, that is represent more than 5% of all municipal solid waste. Many developing countries has a large and growing market for electrical and electronic equipment, automobiles etc. therefore, if not treated properly after using any product it may cause problems for the environment.

However, there are new regulations about treating properly with used products but they are not be effectively implemented in many countries. There are several reasons why organizations not interested in the implementation of these rules. First, Returned goods is generally have more complex nature of the products than that are in direct logistics. Second, reverse logistics cost is an additional cost and reverse supply chain may not be as much profitable as that of a forward supply chain. There are several reasons for this extra cost. First, due to the return of used products in small quantities, transportation cost will be more in the case of reverse supply chain as compared to the forward supply chain, where the vehicle capacity can be more or less fully utilized. Another aspect is the quality variations of the returned products. Due to this, all the products collected cannot be remanufactured or sometimes, more advanced operations are required for making the returned product resalable. This will also increase the total cost in the reverse supply chain and reduce the total profit as compared to the forward supply chain. So to stay in the business the total cost should be minimized.

According to the article [11] Srivastava states that a well-managed reverse logistics network not only provides important cost savings in procurement, recovery, disposal, inventory holding and transportation but also help in customer retention. If we do not model the network properly, it may result in a solution which may be too far from the optimal solution. This increases the total cost of the supply chain as well as affects the customer satisfaction. Thus, proper modelling is essential to reduce the total cost associated with the reverse supply chain. As the concerns on environment pollution start to affect the customer's purchasing decisions, manufacturers are increasingly forced to consider their product's impact on the environment according to the article [34]. According to the article [33] there are different recovery options such as recycling, repairing, remanufacturing etc. associated with the returned products. The type of product return has an effect on the selection of suitable recovery option. The returned products can be classified into a number of categories. In this paper we consider two types of products return: (1) end of use and (2) end of life. The former ones can be remanufactured and sent for a new sale. The latter ones can be disassembled for material recycling and for the proper disposal of hazardous items. The proper network design of a reverse supply chain minimizes the total cost associated with it, reduces environmental impact and improves customer satisfaction. There are different firms such as Kodak, Xerox, and HP which focus on remanufacturing and recovery activities, thereby achieving significant gains according to article [35]

## 2. Literature review

The research on RL has develop gradually over the years and authors have defined RL in different ways. Earliest definition of RL was stated by Murphy and Poist in article [31] mentioning about the reverse flow of goods. Afterwards in article [30] Carter and Ellram introduced the term "environment" in the definition of RL. Rogers and according to article [32] Tibben-Lembke stressed on the purpose of the RL and established the most widely accepted definition as "RL is the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in process inventory, finished goods and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal". Definition of RL has been changing over time and widening its scope with the interest of researchers.

According to article [1] in 1999 DS Rogers and S Ronald authored a book called reverse logistics trends and practices that are generally made up of seven chapters. In the first chapter of this book points out the importance of reverse logistics, and includes the following sections beneath: 1) the importance of reverse logistics 2) Reverse logistics activities 3) Reverse logistics strategies 4) Reverse logistics challenges 5) A good reverse logistics barriers.

According to article [5] Guide and Van Wassenhove Suggest a framework of based on the concept of economic value and the attractiveness of the potential economic value of reuse activities. The concept of returned product quality acts as a driver in the proposed framework.

In the article [6] discussed RL systems for recycling and reuse of beverage containers. Studies on reverse logistics impel-mentation have been done in many sectors such as carpet industry by Biehl et al., retail industry by Bernon et al., bottling sector by González-Torre et al, paper industry by Ravi and Shankar, packaging firms by González-Torre and Adenso-Diaz, cell phone industry by Rathore et al., pharmaceuticals industry by Narayana et al., and battery recycling by Wang et al.. (See [36], [37], [38] , [39] , [40] , [41] , [42] , and [43] ).

In article [7] Srivastava develop a model to manage product returns for reverse logistics by focusing on the estimation of returns of products in the Indian context. They conduct interviews with many stakeholders to capture real life practices and requirements in product return management.

According to the article [8] Min and his colleagues design a reverse logistics network involving products returned due to either defects or changes in customers' needs/preferences. They solve the model using genetic algorithm approach. Determination of the number and location of centralized return centers are the design decisions considered in their study.

RL has recently received growing importance and more firms are adopting it as a strategic tool for economic benefits and corporate social image [16]. Alumur et al. in the article [18] present a mixed-integer linear programming formulation that is flexible to incorporate most of the reverse network structures. They conduct a case study in the context of reverse logistics network design for washing machines and tumble dryers in Germany. In the article [19] present a mathematical programming model which minimizes the total processing cost of multiple types of waste electric and electronic equipment. Based on their proposed model, the optimal facility locations and the material flows in the reverse logistic network can be determined.

Daim et al. according to the article [20] develop a decision making model for the selection of a third party logistics provider using analytical hierarchy process.

Mahmoudzadeh et al.in the article [21] formulate a mixed integer linear programming model to determine the optimal locations of scrap yards for the end-of-life vehicles in Iran as well as their optimal allocations and material flows. They categories the end-of-life vehicles into three quality levels with different output material streams.

The review of the literature shows that, even though, there are lots of works in the area of reverse supply chain, only a few researchers have addressed the issue of development of a general framework for the network design. Most of the works in this area are limited to either a single type of product return (e.g. end-of-life) or a single type of recovery option (e.g. remanufacturing). In this study, we model a generalized multi-stage reverse supply chain and analyze it under different situations. The reverse supply chain considered in this study consists of market or customer zones, collection centers, remanufacturing centers, and disassembly centers, recycling centers, disposal centers, primary markets and secondary markets. The problem involves the determination of the number and location of different facilities to be established in the network and the quantity of flow of products, components and materials between each stage of the supply chain. The objective minimizes the total cost comprising of transportation cost, processing cost, fixed facility cost and disposal cost. The network is modelled using mixed integer linear programming formulation and solved using solver Excel.

## 3. Mathematical model

This paper developed the model with reference to the basic idea presented by [24] by adding the following issues that were not considered previously.

- Adding Greenhouse gas constraints to the model. This development is very vital because one of the most important role of reverse logistic supply chain is improving environmental issues, therefore we should consider environmental aspects completely. Thus Greenhouse constraints should be consider in this model too, in order to decrease Greenhouse gases volume in the world. For this purpose we add 7 constraints and 2 parameter to the model.
- Solve the model with new method and conduct sensitivity analysis on the different parameter Involved in the model.
- Eliminate bugs of the model especially in definition and usage of the parameter b in the model.

Figure 1 shows the seven section of the reverse supply chain considered in the present study. The network has different entities such as market or customer zones (to collect returned products from customers), collection centers (to sorting returned products), and remanufacturing centers (to rebuilding products), disassembly centers (to disassemble products to valuable items and disposable items), recycling centers, primary markets, secondary markets and disposal centers.

The following are the assumptions made in the formulation of the problem:

(a) The reverse flow is deterministic.

(b) The network is considered only for a single period.

(c) The flow is only allowed to be transformed between two sequential echelons.

(d) The capacities of different entities are fixed.

(e) Transportation, processing, disposal and fixed facility costs are deterministic and known a priori.

(f) There is only a single mode of transportation.

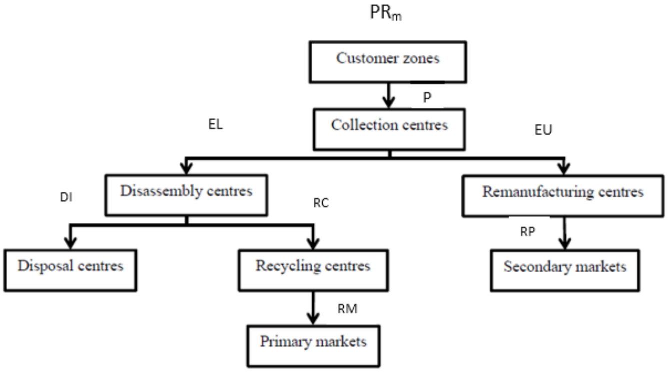

Figure 1 Reverse supply chain

The products from customers are collected through customer zones after while they transferred to the collection centers. In this section products sorted by two groups. The end-of-use items have the option of remanufacturing, since its useful life is not over. The remanufactured products are finally transported to the secondary markets for a new sale. If the products cannot be remanufactured, these are transported to disassembly centers, because they are in the end of their useful life. In the disassembly centers end-of-life items divided to two groups: Recyclable components and disposable items. Recyclable items from the disassembly centers are recycled at recycling centers and the rest need to be disposed at disposal centers.

The problem considered in this work involves the decisions regarding the number and location of different facilities to be established in the network and the quantity of flow of products, components and materials between each stage of the reverse supply chain, so that all the returned products are processed with the objective of minimizing the total cost containing of transportation cost, processing cost, disposal cost and fixed facility cost.

In the following Notations, parameters, Decision variables, Objective function and constraints are presented:

Table 1 the notations:

**Table 1. Notations of mathematical model**

| Parameter | Description |
|---|---|
| $Z$ | Set of market zones or customer zones |
| $C$ | Set of collection centers |
| $R$ | Set of remanufacturing centers |
| $D$ | Set of disassembly centers |
| $L$ | Set of recycling centers |
| $M$ | Set of primary markets |
| $S$ | Set of secondary markets |
| $K$ | Set of disposal sites |
| $P$ | Products returned |
| EU | End of use products |
| EL | End of life products |
| RC | Recyclable components |
| DI | disposable items |
| RM | Recycled materials |
| RP | Remanufactured products |

| | |
|---|---|
| $PR_m$ | Returned product from customer zone m, m ∈ Z |
| $HC_n$ | Handling cost per unit at collection center n, n ∈ C |
| $PC_n^i$ | Processing cost of product, component or material per unit at facility n, where n ∈ R, D, L and i ∈ EU, EL, RC |
| $U_i$ | Unit cost of disposal of material i, where i ∈ DI |
| $d_{mn}$ | Distance between facilities m and n, where m,n ∈ Z×C, C×R, C×D, R×S, D×L, D×K,L×M |
| $tc_i$ | Transportation cost per unit product/component/material i |
| $f_n$ | Fixed cost of facility n, where n ∈ C, R, D, L |
| $Cap_n^i$ | Capacity of facility n, for product/component/material i |
| $\alpha$ | Maximum flow rate of the collected products to the remanufacturing centers |
| $b$ | The proportion of recyclable products in the collection centers |
| $P_{m,n}^i$ | The greenhouse gas emissions per unit of product i between facility m and n is produced |
| GHG | The upper limit for the amount of greenhouse gas emissions |

Table 2 describes decision variables:

**Table 2. Decision variables**

| Parameter | Description |
|---|---|
| $X_{m,n}^i$ | Quantity of product/component/material i shipped from facility m to facility n, where m,n ∈ Z×C, C×R, C×D, R×S, D×L, D×K, L×M and i ∈ P, EU, EL, RC, DI, RM,RP |
| $Y_C$ | ۱-۰ variable, $Y_C$ =1 if collection center C is used<br>else $Y_C$ =0 |
| $Y_R$ | ۱-۰ variable, $Y_R$ =1 if remanufacturing center R is used<br>else $Y_R$ =0 |
| $Y_D$ | ۱-۰ variable, $Y_D$ =1 if disassembly center D is used<br>else $Y_D$ =0 |
| $Y_L$ | ۱-۰ variable, $Y_L$ =1 if recycling center L is used<br>else $Y_L$ =0 |

Objective function and constraints:

The objective is to minimize the total cost of the multi-stage reverse supply chain containing of transportation cost, processing cost, disposal cost and fixed facility cost.

Minimise:

$$\begin{aligned}
&\sum_{m\in Z}\sum_{n\in C}\sum_{i\in P} X_{m,n}^{i}\times(tc_i\times d_{mn}+HC_n)+\\
&\sum_{m\in C}\sum_{n\in R}\sum_{i\in EU} X_{m,n}^{i}\times(tc_i\times d_{mn}+PC_n^i)+\\
&\sum_{m\in C}\sum_{n\in D}\sum_{i\in EL} X_{m,n}^{i}\times(tc_i\times d_{mn}+PC_n^i)+\\
&\sum_{m\in R}\sum_{n\in S}\sum_{i\in RP} X_{m,n}^{i}\times(tc_i\times d_{mn})+\\
&\sum_{m\in D}\sum_{n\in L}\sum_{i\in RC} X_{m,n}^{i}\times(tc_i\times d_{mn}+PC_n^i)+\\
&\sum_{m\in D}\sum_{n\in K}\sum_{i\in DI} X_{m,n}^{i}\times(tc_i\times d_{mn}+U_i)+\\
&\sum_{m\in L}\sum_{n\in M}\sum_{i\in RM} X_{m,n}^{i}\times(tc_i\times d_{mn})+\\
&\sum_{m\in C} f_m\times Y_m+\sum_{m\in R} f_m\times Y_m+\\
&\sum_{m\in D} f_m\times Y_m+\sum_{m\in L} f_m\times Y_m
\end{aligned}\tag{1}$$

Subject to:

$$\sum_{n\in C} X_{m,n}^{i}=PR_m \qquad \forall m\in Z,\forall i\in P \tag{2}$$

$$\sum_{m\in Z}\sum_{i\in P} X_{m,n}^{i}\times(1-\alpha)\le\sum_{m\in D} X_{\mathrm{n,m}}^{j} \qquad \forall n\in C,\forall j\in EL \tag{3}$$

$$\sum_{m\in Z}\sum_{i\in P} X_{m,n}^{i}=\sum_{m\in R} X_{\mathrm{n,m}}^{j}+\sum_{m\in D} X_{\mathrm{n,m}}^{j} \qquad \forall n\in C,\forall j\in EU,EL \tag{4}$$

$$\sum_{m\in C}\sum_{i\in EU} X_{m,n}^{i}=\sum_{m\in S} X_{\mathrm{n,m}}^{j} \qquad \forall n\in R,\forall j\in RP \tag{5}$$

$$\sum_{m\in C}\sum_{i\in EL}(b\times X_{m,n}^{i})=\sum_{m\in L} X_{\mathrm{n,m}}^{j} \qquad \forall n\in D,\forall j\in RC \tag{6}$$

$$\sum_{m\in C}\sum_{i\in EL} X_{m,n}^{i}(1-\mathrm{b})=\sum_{m\in K} X_{\mathrm{n,m}}^{j} \qquad \forall n\in D,\forall j\in DI \tag{7}$$

$$\sum_{m\in D}\sum_{i\in RC} X_{m,n}^{i}=\sum_{m\in P} X_{\mathrm{n,m}}^{j} \qquad \forall n\in L,\forall j\in RM \tag{8}$$

$$\sum_{m\in Z} X_{m,n}^{i}\le Cap_n^i\times Y_n \qquad \forall n\in C,\forall i\in P \tag{9}$$

$$\sum_{m\in C} X_{m,n}^{i}\le Cap_n^i\times Y_n \qquad \forall n\in R,\forall i\in EU \tag{10}$$

$$\sum_{m\in C} X_{m,n}^{i}\le Cap_n^i\times Y_n \qquad \forall n\in D,\forall i\in EL \tag{11}$$

$$\sum_{m\in D} X_{m,n}^{i}\le Cap_n^i\times Y_n \qquad \forall n\in L,\forall i\in RC \tag{12}$$

$$\sum_{n\in}\sum_{m\in}\sum_{i\in} X_{mn}^{i}P_{mn}^{i}\le GHG \qquad i\in P,EU,EL,RP,RC,DI,RM \tag{13}$$

$$m,n\in Z\times C,C\times R,C\times D,R\times S,D\times L,D\times K,L\times M$$

$$Y_n \ is\, binary \qquad \forall n\in C,R,D,L \tag{14}$$

$$X_{m,n}^{i}\ge 0 \ \ and \ \ \text{integer} \ in \ product \ level \ flow \qquad \forall m,n,and\, i \tag{15}$$

The objective (1) minimises the total cost of the supply chain consisting of the transportation cost between different facilities, processing cost at remanufacturing centers and recycling centers, handling and sorting cost at collection centers, disposal cost and fixed facility cost associated with different facilities. Constraints (2) to (8) ensure preservation of flow between different stages. Constraint (2) implies that all the products available at customer zones should be collected through different collection centers. Constraint (3) ensures that all the end-of-life products should go for disassembly operation. Constraint (4) represents the conservation of flow of collection centers. It means all the products are transported to collection centers should transferred to remanufacturing centers and disassembly centers from each those centers. Constraint (5) represents the conservation of flow of remanufacturing centers. It means all the remanufactured product should transported to the secondary markets to sale. Constraint (6) implies that the total outflow from a disassembly center to all recycling centers is equal to the inflow of products into the disassembly center multiplied by the number of recyclable components produced from that product it means all the recyclable items should be recycled in the recycling centers. Constraint (7) represents the conservation of flow of disposable items.it means all the disposable items should be disposed in the disposal centers. Constraint (8) represents the conservation of flow of recycling centers. It means all the recyclable items that be recycled in the recycling centers should transported to the primary markets to sale. Constraints (9) to (12) show the capacity limitation of different facilities. Constraint (9) represents the capacity of collection centers. The total flow of returned products into a collection center should not exceed its capacity. Constraint (10) implies that the total reverse flow of products into a remanufacturing center should be less than or equal to its capacity. Constraint (11) implies that the total flow of returned products into a disassembly center should be less than or equal to its capacity. Constraint (12) implies that the total reverse flow of recyclable components into a recycling center should be less than or equal to its capacity. Constraint (13) Due to increasing importance of environmental issues nowadays, these constraints is added to the model, in order to limit Greenhouse gas emissions. Total Greenhouse gases volume must be less than the GHG parameter. Constraint (14) represents the binary variables that help the model for optimizing the quantity of the facilities. Constraint (15) ensures the non-negative flow of products, components and materials. Also, the variables are restricted to an integer value, when the flow is in product level.

## 4. Model Experimentation

In this section, the salient aspects of the experimentation carried out are described for a realistic reverse supply chain network design problem. For exact solution and understand the applicability of the model, we need a realistic experiment. Thus, For this study must first be initialized different parameters.A reverse supply chain consisting of five market zones, seven potential locations for collection centers, three potential locations for remanufacturing centers, four potential locations for disassembly centers, three potential locations for recycling centers, one disposal center, two secondary markets and two primary markets are considered. The coordinates of the different facilities are generated randomly.

The potential locations of different facilities are shown in Figure 2.

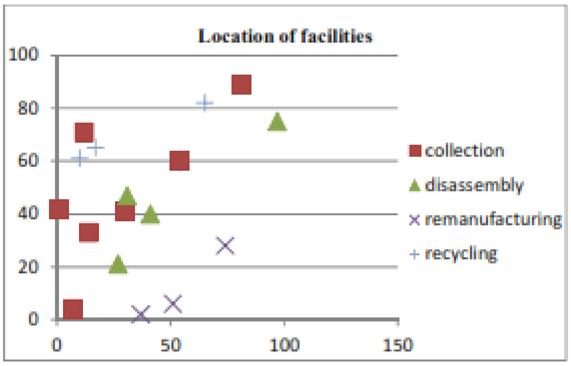

Figure 2 Potential locations of facilities

The quantity of used products available for collection at customer zones are shown in Table 3.

| Market zone | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Product return | 81 | 67 | 99 | 52 | 60 |

Table 3 Quantity of product return

The distances between different facilities are calculated by using Euclidean distance method. Table 4 shows the distance matrix between market zones and collection centers.

| | Market zone 1 | Market zone 2 | Market zone 3 | Market zone 4 | Market zone 5 |
|---|---|---|---|---|---|
| Collection center 1 | 8 | 69 | 105 | 70 | 62 |
| Collection center 2 | 64 | 13 | 64 | 67 | 33 |
| Collection center 3 | 105 | 57 | 9 | 55 | 52 |
| Collection center 4 | 32 | 36 | 66 | 37 | 22 |
| Collection center 5 | 62 | 22 | 37 | 34 | 9 |
| Collection center 6 | 85 | 25 | 38 | 64 | 35 |
| Collection center 7 | 80 | 27 | 26 | 46 | 26 |

Table 4 Distance matrix between market zones and collection centers

Table 5 shows the distance matrix of collection centers with disassembly centers and remanufacturing centers.

| | Col. 1 | Col. 2 | Col. 3 | Col. 4 | Col. 5 | Col. 6 | Col. 7 |
|---|---|---|---|---|---|---|---|
| Disassembly center 1 | 21 | 85 | 115 | 46 | 75 | 102 | 93 |
| Disassembly center 2 | 65 | 31 | 49 | 26 | 6 | 30 | 22 |
| Disassembly center 3 | 63 | 42 | 50 | 24 | 11 | 40 | 28 |
| Disassembly center 4 | 87 | 52 | 26 | 47 | 20 | 33 | 18 |
| Remanufacturing center 1 | 88 | 76 | 44 | 54 | 41 | 62 | 46 |
| Remanufacturing center 2 | 61 | 75 | 71 | 38 | 46 | 74 | 60 |
| Remanufacturing center 3 | 97 | 73 | 30 | 60 | 40 | 54 | 39 |

Table 5 Distance matrix of collection centers with disassembly centers and remanufacturing centers

Table 6 shows the distance matrix between remanufacturing centers and secondary markets.

| | Secondary market 1 | Secondary market 2 |
|---|---|---|
| Remanufacturing center 1 | 45 | 35 |
| Remanufacturing center 2 | 14 | 39 |
| Remanufacturing center 3 | 58 | 36 |

Table 6 Distance matrix between remanufacturing centers and secondary markets

Table 7 shows the distance matrix of disassembly centers with recycling centers and disposal center.

| | Recycling center 1 | Recycling center 2 | Recycling center 3 | Disposal center |
|---|---|---|---|---|
| Disassembly center 1 | 33 | 88 | 81 | 17 |
| Disassembly center 2 | 49 | 25 | 23 | 71 |
| Disassembly center 3 | 48 | 37 | 35 | 69 |
| Disassembly center 4 | 72 | 43 | 45 | 92 |

Table 7 Distance matrix of disassembly centers with recycling centers and a disposal center

Table 8 shows distance matrix between recycling centers and primary markets.

| | Primary market 1 | Primary market 2 |
|---|---|---|
| Recycling center 1 | 66 | 61 |
| Recycling center 2 | 39 | 17 |
| Recycling center 3 | 40 | 20 |

Table 8 Distance matrix between recycling centers and primary markets

The unit transportation costs and unit disposal costs of different items are given in Table 9.

| | P | EU | EL | RP | RC | DI | RM |
|---|---|---|---|---|---|---|---|
| Transportation cost | 10 | 4.5 | 4 | 5 | 2.5 | 3.5 | 1.75 |
| Disposal cost | | | | | | 90 | |

Table 9 Unit transportation cost and unit disposal cost (in monetary units)

Other data sets such as capacity of different facilities, fixed facility costs, processing costs are also generated randomly in a realistic manner and given in Tables 10 to 13.

| | Collection center | | | | | | |
|---|---|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| Capacity | 90 | 100 | 80 | 90 | 70 | 110 | 100 |
| Fixed facility cost | 8300 | 9800 | 8700 | 10500 | 7000 | 12000 | 11200 |
| Unit processing cost | 70 | 71 | 79 | 76 | 65 | 62 | 73 |

Table 10 Capacity, unit processing and fixed costs (in monetary units) of collection centers

| | Disassembly center | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Capacity | 120 | 170 | 70 | 150 |
| Fixed facility cost | 20000 | 19000 | 15000 | 16500 |
| Unit processing cost | 186 | 195 | 190 | 182 |

Table 11 Capacity, unit processing and fixed costs (in monetary units) of disassembly centers

| | Recycling center | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Capacity | 320 | 300 | 350 |
| Fixed facility cost | 18000 | 27500 | 24000 |
| Unit processing cost | 306 | 367 | 457 |

Table 12 Capacity, unit processing and fixed costs (in monetary units) of recycling centers

| | Remanufacturing center | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Capacity | 60 | 80 | 70 |
| Fixed facility cost | 20000 | 24000 | 28000 |
| Unit processing cost | 803 | 898 | 968 |

Table 13 Capacity, unit processing and fixed costs (in monetary units) of remanufacturing centers

The maximum rate of flow of returned products from a collection center to different remanufacturing centers is set at 30% and the proportion of recyclable products in the collection centers (b parameter) is set at 30%.

In this paper two scenario is considered for the upper limit in order that the amount of Greenhouse gas emissions. (GHG parameter) In the first scenario that parameter is set at 15000 and in the second scenario that parameter is set big M in order to eliminate Greenhouse gasses limitation constraints.

The Greenhouse gas emissions per unit of product i between facility m and n is produced ( $P^{i}_{m,n}$ parameter) is set like Distance between facilities because both of them are correlated to each other closely. The more distance traveled by any vehicle the more pollution is generated.

## 5.1 Computational results and sensitivity analysis:

In this section the model was solved with the initialization has been done in the previous section and optimized model in presented in the following. In the solving the model, to emphasize the impact of greenhouse gas constraints on the model we considered two scenarios:

1) Considering the limitation of Greenhouse gas emissions
2) without considering limits Greenhouse gas

### 5.1.1 First scenario:

This paper uses an exact solution procedure. The problem instances are solved using Excel 2013 on a computer with Intel Core i7 processor of 3.60 GHz speed and 8 GB RAM. The network design problem is solved using Solver Excel and the optimum design of the network is obtained. Table 14 shows the different performance measure values.

| Performance criteria | Value |
|---|---|
| Total cost | 741809.8007 |

Table 14 Total Cost (in monetary units) of the objective function

The decisions regarding the number and location of different facilities are also obtained as given in Table 15.

| Type of facility | Open |
|---|---|
| Collection center | 1,2,3,4,5,6,7 |
| Disassembly center | 1,2,3,4 |
| Remanufacturing center | 1,3 |
| Recycling center | 1,2 |

Table 15 Facility opening decisions

The final locations of different facilities are shown in Figure 3.

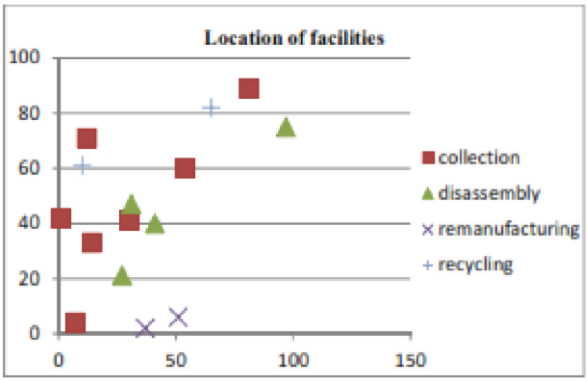

Figure 3 Final locations of facilities

The quantity of flow of products, components and materials between different stages are also obtained and given in Tables 16-22.

| | Col. 1 | Col. 2 | Col. 3 | Col. 4 | Col. 5 | Col. 6 | Col. 7 |
|---|---|---|---|---|---|---|---|
| Market zone 1 | 41 | 7 | 0 | 8 | 7 | 7 | 12 |
| Market zone 2 | 7 | 10 | 9 | 10 | 10 | 10 | 10 |
| Market zone 3 | 26 | 11 | 17 | 11 | 11 | 11 | 12 |
| Market zone 4 | 7 | 7 | 7 | 8 | 8 | 7 | 8 |
| Market zone 5 | 0 | 0 | 0 | 0 | 0 | 0 | 59 |

Table 16 Optimum flow from market zones to collection centers

| | Disassembly center | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Collection center 1 | 25 | 45 | 1 | 12 |
| Collection center 2 | 24 | 1 | 1 | 1 |
| Collection center 3 | 0 | 1 | 1 | 22 |
| Collection center 4 | 25 | 1 | 1 | 1 |
| Collection center 5 | 24 | 1 | 1 | 1 |
| Collection | 21 | 1 | 1 | 1 |

| | | | | |
|---|---|---|---|---|
| center 6 | | | | |
| Collection center 7 | 0 | 78 | 11 | 11 |

Table 17 Optimum flow from collection centers to disassembly centers

| | Remanufacturing center | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Collection center 1 | 0 | 0 | 0 |
| Collection center 2 | 0 | 0 | 8 |
| Collection center 3 | 1 | 0 | 10 |
| Collection center 4 | 0 | 0 | 8 |
| Collection center 5 | 0 | 0 | 9 |
| Collection center 6 | 2 | 0 | 9 |
| Collection center 7 | 0 | 0 | 0 |

Table 18 Optimum flow from collection centers to remanufacturing centers

| | Secondary market 1 | Secondary market 2 |
|---|---|---|
| Remanufacturing center 1 | 2 | 1 |
| Remanufacturing center 2 | 0 | 0 |
| Remanufacturing center 3 | 0 | 43 |

Table 19 Optimum flow from remanufacturing centers to secondary markets

| | Recycling center 1 | Recycling center 2 | Recycling center 3 |
|---|---|---|---|
| Disassembly center 1 | 36 | 0 | 0 |
| Disassembly center 2 | 0 | 38 | 0 |
| Disassembly center 3 | 0 | 5 | 0 |
| Disassembly center 4 | 0 | 15 | 0 |

Table 20 Optimum flow from disassembly centers to Recycling center

| | Disposal center |
|---|---|
| Disassembly center 1 | 84 |
| Disassembly center 2 | 90 |
| Disassembly center 3 | 11 |
| Disassembly center 4 | 34 |

Table 21 Optimum flow from disassembly centers to Disposal center

| | Primary market 1 | Primary market 2 |
|---|---|---|
| Recycling center 1 | 0 | 36 |
| Recycling center 2 | 0 | 58 |
| Recycling center 3 | 0 | 0 |

Table 22 Optimum flow from Recycling center to primary markets

### 5.1.2 Second scenario:

In this scenario GHG is set at big M therefore Greenhouse gasses limitation constraints do not have any effect on the model. Results is presented below in this circumstance:

| Performance criteria | Value |
|---|---|
| Total cost | 552154.8796 |

Table 23 Cost components (in monetary units) of the objective function

The final locations of different facilities are shown in Figure ٤.

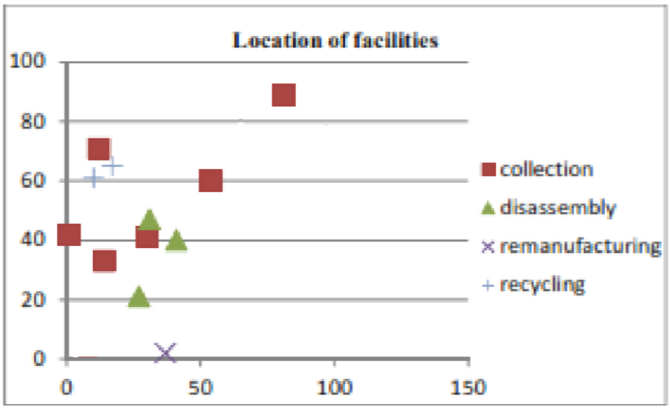

Figure ٤ Final locations of facilities

The decisions regarding the number and location of different facilities are also obtained as given in Table 15.

| Type of facility | Open |
|---|---|
| Collection center | 2,3,4,5,6,7 |
| Disassembly center | 1,3,4 |
| Remanufacturing center | 1 |
| Recycling center | 1,2 |

Table 24 Facility opening decisions

The quantity of flow of products, components and materials between different stages are also obtained and given in Tables 25-31.

| | Col. 1 | Col. 2 | Col. 3 | Col. 4 | Col. 5 | Col. 6 | Col. 7 |
|---|---|---|---|---|---|---|---|
| Market zone 1 | 0 | 0 | 0 | 81 | 0 | 0 | 0 |
| Market zone 2 | 0 | 60 | 0 | 0 | 3 | 0 | 4 |
| Market zone 3 | 0 | 0 | 74 | 0 | 0 | 0 | 25 |
| Market zone 4 | 0 | 0 | 0 | 9 | 24 | 0 | 19 |
| Market zone 5 | 0 | 0 | 0 | 0 | 9 | 0 | 51 |

Table 25 Optimum flow from market zones to collection centers

| | Disassembly center | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| Collection center 1 | 0 | 0 | 0 | 0 |
| Collection center 2 | 0 | 0 | 16 | 44 |
| Collection center 3 | 0 | 0 | 0 | 51 |
| Collection center 4 | 80 | 0 | 10 | 0 |
| Collection center 5 | 0 | 0 | 17 | 18 |
| Collection center 6 | 0 | 0 | 0 | 0 |
| Collection center 7 | 40 | 0 | 27 | 33 |

Table 26 Optimum flow from collection centers to disassembly centers

| | Remanufacturing center | | |
|---|---|---|---|
| | 1 | 2 | 3 |
| Collection center 1 | 0 | 0 | 0 |
| Collection center 2 | 0 | 0 | 0 |
| Collection center 3 | 22 | 0 | 0 |
| Collection center 4 | 0 | 0 | 0 |
| Collection center 5 | 0 | 0 | 0 |
| Collection center 6 | 0 | 0 | 0 |
| Collection center 7 | 0 | 0 | 0 |

Table 27 Optimum flow from collection centers to remanufacturing centers

| | Secondary market 1 | Secondary market 2 |
|---|---|---|
| Remanufacturing center 1 | 17 | 5 |
| Remanufacturing center 2 | 0 | 0 |
| Remanufacturing center 3 | 0 | 0 |

Table 28 Optimum flow from remanufacturing centers to secondary markets

| | Recycling center 1 | Recycling center 2 | Recycling center 3 |
|---|---|---|---|
| Disassembly center 1 | 36 | 0 | 0 |
| Disassembly center 2 | 0 | 0 | 0 |
| Disassembly center 3 | 0 | 21 | 0 |
| Disassembly center 4 | 0 | 44 | 0 |

Table 29 Optimum flow from disassembly centers to Recycling center

| | Disposal center |
|---|---|
| Disassembly center 1 | 84 |
| Disassembly center 2 | 0 |
| Disassembly center 3 | 49 |
| Disassembly center 4 | 103 |

Table 30 Optimum flow from disassembly centers to Disposal center

| | Primary market 1 | Primary market 2 |
|---|---|---|
| Recycling center 1 | 35 | 1 |
| Recycling center 2 | 0 | 65 |
| Recycling center 3 | 0 | 0 |

Table 31 Optimum flow from Recycling center to primary markets

As we expected as a result of the tow scenario provided above, the total cost if the greenhouse gas restrictions were not considered significantly less than the total cost if the greenhouse gas constraints perform effectively.
Thus determination of the GHG parameter is very important because this value have major influence on the total cost and in this model we have cost minimization objective. As a result in the following we focus on the sensitivity analysis on the GHG parameter.

## 5.2 Sensitivity analysis parameter GHG:

After solving the model we should deal with sensitivity analysis on the different parameter. Considering the importance of making decisions about greenhouse gas

emissions upper limit at first we prefer sensitivity analysis on the GHG parameter. This emphasis is because of the impact of this value on the total cost.
Therefore we consider nine scenario in the following in Table32:

| scenario | GHG | Total cost |
|---|---|---|
| 1 | 14000 | Not feasible |
| 2 | 14500 | Not feasible |
| 3 | 14750 | ۷۴۲۶۵۱/۰۶۱۳ |
| 4 | 15000 | ۷۴۱۸۰۹/۸۰۰۷ |
| 5 | 16000 | ۷۰۰۵۳۱/۵۸۸۷ |
| 6 | 16250 | ۶۹۳۲۹۲/۳۴۵۲ |
| 7 | 18000 | ۶۸۰۱۵۳/۳۴۳۷ |
| 8 | 19000 | ۵۵۲۱۵۴/۸۷۹۶ |
| 9 | 20000 | ۵۵۲۱۵۴/۸۷۹۶ |

Table32 GHG parameter scenarios for sensitivity analysis

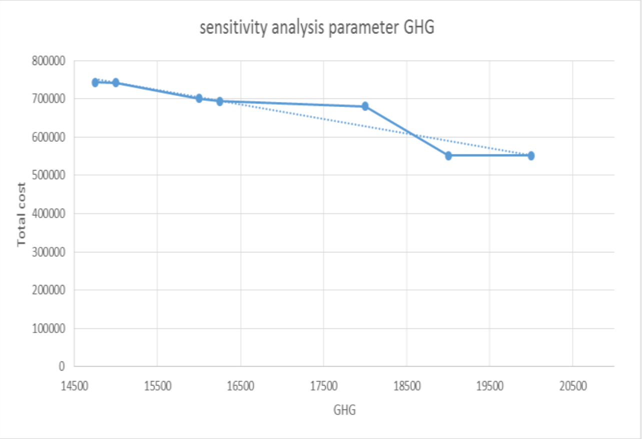

Figure۵ sensitivity analysis diagram for parameter GHG

According to the result presented above a few conclusions can be obtained:

- Over Reducing upper limit of greenhouse gas (GHG) caused problem not feasible due to constraints.
- The gradual increase upper limit of greenhouse gas (GHG) caused Reduction in total cost. This reduction is significant. Thus, it is recommended to decision makers in determining this parameter perform carefully because it is too much effective on the total cost of the organization.
- Excessive increasing the upper limit of greenhouse gas (GHG) caused these restrictions will be ineffective.

### 5.3 Sensitivity analysis parameter b:

One of the most important economically aspect of the reverse supply chain is the number of products that are recyclable because it is so important for economically feasibility of this strategy. In following we focus on this portion of item therefore we studied the Sensitivity analysis parameter b in 5 scenario in Table 33:

| scenario | b | Total cost |
|---|---|---|
| 1 | 0.1 | 717114.8 |
| 2 | 0.2 | 734225.6 |
| 3 | 0.3 | 741809.8 |
| 4 | 0.4 | 753977.5 |
| 5 | 0.5 | 763840.8 |

Table33 b parameter scenarios for sensitivity analysis

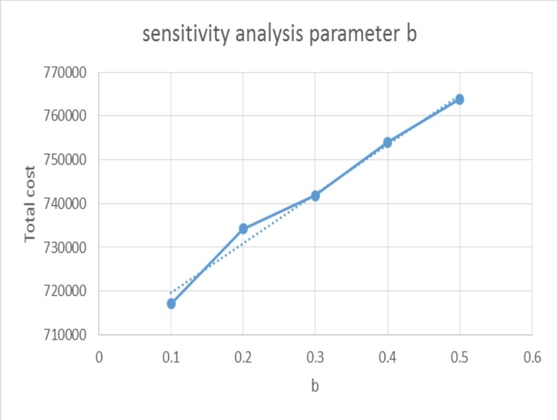

Figure٦ sensitivity analysis diagram for parameter b

According to the result presented above a few conclusions can be obtained:

- With the gradual increase in parameter b we see that the optimal total cost of the parameter b increases
- With the gradual reduction in parameter b caused reduction of the optimal total cost.

Because process cost for recycling is more than disposal cost, thus the more recyclable item we have, more money should spend on the reverse supply chain.

### 5.4 Sensitivity analysis parameter $PR_m$ :

The most effective parameter on the total cost is $PR_m$ , because if this parameter is increasing, transportation cost, process cost and disposal cost will be increasing too. In the following we study on the Sensitivity analysis parameter $PR_m$ in Table 34:

| scenario | $PR_m$ | Total cost |
|---|---|---|
| 1 | Decrease20 unit | 771976.7 |
| 2 | Assumed mode | 741809.8 |
| 3 | Increase 20 unit | 331901.3 |

Table34 $PR_m$ parameter scenarios for sensitivity analysis

The total cost changes by changing this parameter is significant therefore we should be careful about this parameter for feasibility of this reverse supply chain.
According to the result presented above a few conclusions can be obtained:

- With the gradual increase the $PR_m$ parameter caused optimal total cost increasing because an increase in the value of this parameter increases the number of returned product.

- With the gradual decrease the $PR_m$ parameter caused optimal total cost decreasing.
- Excessive increasing this parameter caused problem to be not feasible.

### 5.5 Sensitivity analysis parameter $P^i_{m,n}$ :

Determining greenhouse gas emissions from transportation systems due to the limit of pollution emission constraints is very important. . In the following we study on the Sensitivity analysis parameter $P^i_{m,n}$ in Table 35:

| scenario | $P^i_{m,n}$ | Total cost |
|---|---|---|
| 1 | Decrease20 unit | 771976.7 |
| 2 | Assumed mode | 741809.8 |
| 3 | Increase 20 unit | 331901.3 |

Table35 $P^i_{m,n}$ parameter scenarios for sensitivity analysis

According to the result presented above a few conclusions can be obtained:

- With the gradual increase the $P^i_{m,n}$ parameter caused optimal total cost increasing because an increase in the value of this parameter make harder for the model to be feasible.
- With the gradual decrease the $P^i_{m,n}$ parameter caused optimal total cost decreasing.
- Excessive increasing this parameter caused problem to be not feasible.

## 6. Conclusions and Future Work

In this study, a mathematical model is provided to design a reverse supply chain in a multi-stage environment. The developed model is able to determine the number and location of facilities in the network and optimize the flow rate of materials between each stage of the supply chain. The purpose of this model is to minimize the total cost of the supply chain. Costs, including transportation costs, processing costs, fixed costs and the cost of disposal installations in the network is considered. In this study is an important theoretical and practical aspects of the application and operation of the model is shown. This issue has been resolved to a real condition and the results are also compared and examined under different scenarios to perform sensitivity analysis for different parameter. . The results is shown the importance of the appropriate decisions for designing and analyzing of the network design. The optimal solution can be obtained in a favorable position with a small change in any lose his utility. Changes in the anticipated value of the returned product is inevitable. Hence, it is recommended that decision-makers must analyze the model and make possible changes before taking decisions on constructing the network and they must be careful in determining the various parameters are given. The proposed model is a general model and a proper analyzer of the results, it means it can help to analyze the long-term operation of a reverse supply chain. The model and its analysis can help managers make better decisions for reverse supply chain network design and decisions in this area. This model can be tested for research under various scenarios so it is applicable for the organizations for their new decisions. For future studies in this area can be considered the following issues:

- Solving the model by using multi-objective.
- Considering the uncertainty for the parameters.
- Solving the model for multi-period and multi-product circumstance.
- Considering more than one mode of transportation
- Use meta-heuristic Solving methods for optimizing this model.

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