Global Journal
of Technology
& Optimization
GJTO
Volume 2, 2011

A MULTI OBJECTIVE MODEL FOR OPTIMIZATION OF A GREEN SUPPLY CHAIN NETWORK

Turan Paksoy[a], Eren Özceylan[a], Gerhard-Wilhelm Weber[b]

[a] Selçuk University, Department of Industrial Engineering, Campus, Konya, Turkey
[b] Middle East Technical University, Institute of Applied Mathematics, Ankara, Turkey
Emails: tpaksoy@yahoo.com, eozceylan@selcuk.edu.tr, gweber@metu.edu.tr

Abstract
Because of leading the environmental disasters, the global climate alteration has been one of the most important controversial issues in decades. The greenhouse gas emissions (CO_2, methane, nitric oxide, ozone etc.) begin with the industrial revolution. After this milestone, the global warming is getting worst as long as the energy demands are met by the fossil fuels. There are a lot of factors to evaluate the performance of the supply chains such as customer service, quality, lead time, cost etc. But due to the environmental requirements (social responsibilities, Kyoto Protocol, government agencies etc.) an increasing attention has to be given to develop environmental strategies. If the aforementioned environmental applications are considered in the supply chains, then we called Green Supply Chain (GrSC). This study develops a model of a closed-loop supply chain network which starts with the suppliers and recycles with the decomposition centers. As a traditional network design, we consider minimizing the all transportation costs and the raw material purchasing costs. To pay attention for the green impacts, different transportation choices are presented between echelons according to their CO_2 emissions. The plants can purchase different raw materials in respect of their recyclable ratios. The focuses of this paper are conducting the minimizing total CO_2 emissions. Also we try to encourage the customers to use recyclable materials as an environmental performance viewpoint besides minimizing total costs. A multi objective linear programming model is developed via presenting a numerical example. We close the paper with recommendations for future researches.

Keywords: Supply Chain Network, Closed-Loop, Greenhouse Gas Emission, Green Supply Chain, Multi-Objective Optimization.

1. Introduction
Supply chain and management is a business and academic term that has emerged in the last few years and is gaining in popularity quickly.

Bowersox and Closs [7] defined the supply chain that the supply chain refers to all those activities associated with the transformation and flow of goods and services, including their attendant information flows, from the sources of materials to end users. All processes even the supply chains need certain capacities and resources. The most indications point out that the earth is changing from a world of abundant, fresh, cheap energy to a world of limited, expensive energy, drought and polluted. Aforetime whereas the most important thing was transportation or production costs, now the enterprises have to take into account environmental factors because of inadequate resources.

A supply chain design problem comprises the decisions regarding the number and location of production facilities, the amount of capacity at each facility, the assignment of each market region to one or more locations, and supplier selection for sub-assemblies, components and materials [20]. The GrSC design extends this definition by including:

(i)   Waste of all processes,
(ii)   Using efficient energy resources,
(iii)   Greenhouse gas emissions,
(iv)   Using capacities and resources efficiently,
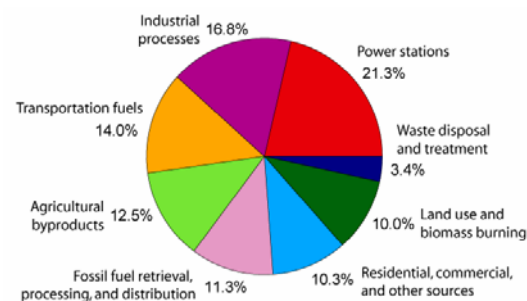(v)   Considering legal environmental factors.

Figure 1. Greenhouse gas emissions by sectors [1]

This is a fact that a supply chain network consists of industrial/distribution processes and needs transportation fuels to actualize these processes. We consider the greenhouse gas emission and recyclable products factor while designing the GrSC in our study. As seen in the Figure 1, these supply chain

activities are significant sources (totally %30.8) of greenhouse gas emissions and air pollution, also creating harmful effects on living health and leading to global warming. International organizations or governments would encourage the decision makers to take measures to increase the aforementioned damages via limiting their environmental impacts. Actually, in an era with more environmental conscience on a global level (Kyoto, Social Responsibilities, Local Governments etc.), the enterprises and service providers could no longer reject indefinitely on the community of environmental costs and will be, in all probability, subjected to heavy environmental tax in next years [4]. These sanctions have raised the concerns on decreasing negative effects on green world. In this respect, many enterprises, including local or global supply chain networks, have set strict targets to build a green structure. For example, presenting companies highlighted these major results [16]:

- In 2007, $92B computer maker HP reports it will eliminate 30,000 cubic feet of polystyrene computer packaging and more than six million pounds of PVC packaging from its inkjet printer business. The company will also reduce its carbon footprint by 20 percent by 2010.
- To secure its 500,000 farmers a living wage and retain a skilled labor pool, Starbucks pays its farmers 42% more than the going commodity price of Arabica coffee beans.
- $1.5B footwear and apparel maker Timberland says it will achieve carbon neutrality in all of its retail and production facilities by 2010. The company has chosen to convert to renewable sources of energy, use green building techniques, and establish carbon offsets by planting trees in equatorial regions—where carbon is more readily absorbed by the vegetation.
- Through its Zero Waste initiative, $312B retailer Wal-Mart has so far saved 478.1 million gallons of water, 20.7 million gallons of diesel fuel, and millions of pounds of solid waste. Through its 100% Renewable Energy program, the company expects to reduce energy consumption by 30% at all of its new stores in seven years.

Figure 2 shows that totally 35% ratio of transportation greenhouse gas emission is actualized via heavy and light trucks which are ommonly used in the supply chain transportation. It is clear that the first job has to adjust the transportation gas emissions to change the extant network to green one. Choosing new models, diesel motors, intermodal transportation [4], alternative energy resources etc. would be solutions for harmful gas emissions. According to Figure 4, CO_2 is 72%, CH_4 is 18% and NO_3 is 9% of total gas emissions.
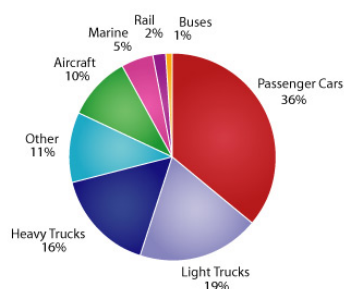

Figure 2. Trans. greenhouse gas emissions [2]

Waste is another serious issue in supply chains besides the gas emissions. In response, recycling is drawing attention as it converts what was once seen as waste into useful materials. Thus, it improves supply chain management by helping to close the "material loop" of products from resource extraction, through production, use, and end of life (Figure 3).
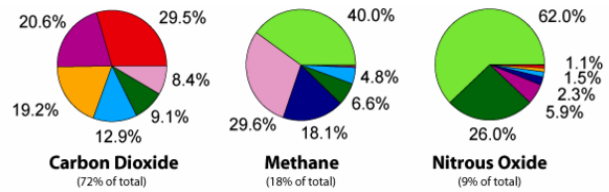

Figure 3. Greenhouse gas emission distribution [1]

To further develop supply chains for recyclable and recycled materials, it will be necessary to improve recycling technologies, to allow recyclable materials to be reprocessed into recycled materials of sufficient quality that they can compete with virgin materials [3]. In response to increasing customers' demand for environmentally products enterprises and manufacturers of final products are exerting greater pressure on their suppliers to raise their environmental standards. The enterprises have been trying to develop products that are more energy efficient, less toxic and less hazardous to the environment. The concept of GrSC has been introduced and manufacturers are changing product designs to be greener. In order to change product design and to improve the recycled content of their products, enterprises must have recycled-materials and work with the recycled-parts suppliers. Therefore, the enterprises need to develop a closed loop relationships with suppliers of recycled materials and recycled parts (Figure 4).

In this study, we are motivated to study a GrSC network optimization problem where CO_2 gas emissions according to trucks options and recyclable products are considered to become a mirror of greenness. We determined a penalty cost to prevent more CO_2 gas emissions and encouraged the customers to use recyclable products via giving a small profit. Trucks' rental fees and purchasing costs of recyclable products can influence the environmental indicators in the model because of an existing a trade-off. With such a concern, we optimize the network also under transportation costs and capacity allocation constraints. The rest of the paper is organized as follows: In the next section a literature of green and closed-loop supply chain is given. In Section 3, we detail our proposed model with its' mathematical formulation. And then we conduct a numerical example to characterize the optimal solutions. Finally, the paper is ended with conclusions and suggestions for further researches.

2. Literatures Review

In this section, we probe the literature and categorize studies into two. The first one is the GrSCs, and the second one is the closed-loop supply chains in designing the networks.

2.1 The Green Supply Chain

There is a large of amount of literature on supply chain network design concerned with environmental issues through the GrSC networks.

Graedel and Allenby [13] defined Industrial Ecology is the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity, given continued economic, cultural and technological evolution. It is a systems view in which
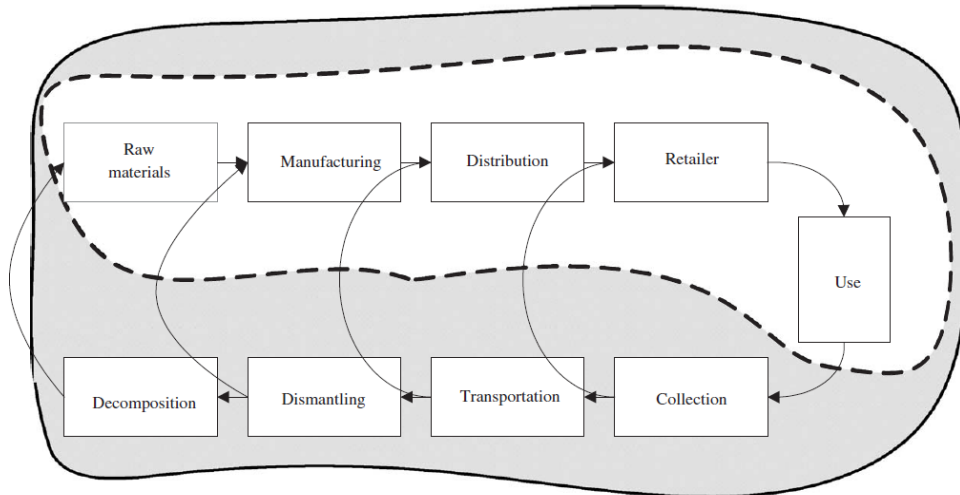
Figure 4. Recycling in a supply chain [18]

one seeks to optimize the total materials cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal. GrSC management involves environmental criteria, or concerns, into organizational purchasing decision and long term relationships with suppliers. A GrSC aims at confining the wastes within the industrial system in order to conserve energy and prevent the dissipation of dangerous materials into the environment ([17], Figure 5). Beamon [5], described the current state of the natural environments, investigated the environmental factors, presented performance measures fro the GrSCs and developed a general procedure towards achieving the GrSC. Tsamboulas and Mikroudis [26] developed EFECT which is a generalized methodological framework for evaluating the impacts resulting from transportation projects with a specific orientation to environmental impacts. The innovative aspect of the methodological framework is the combination of Multi-Criteria Analysis (MCA) with Cost-Benefit Analysis (CBA) methods to come up with an overall assessment of transport initiatives impacts over different geographical regions and time periods. Sarkis [23] aimed to focus on the components and elements of GrSN management and how they serve as a foundation for the decision framework. For this, he explored the applicability of a dynamic non-linear decision model, defined as the ANP, for decision making within the GrSC. The decision support models for design of global supply chains, and assess the fit between the research literature in this area and the practical issues are handled in Meixell and Gargeya's [20] study.
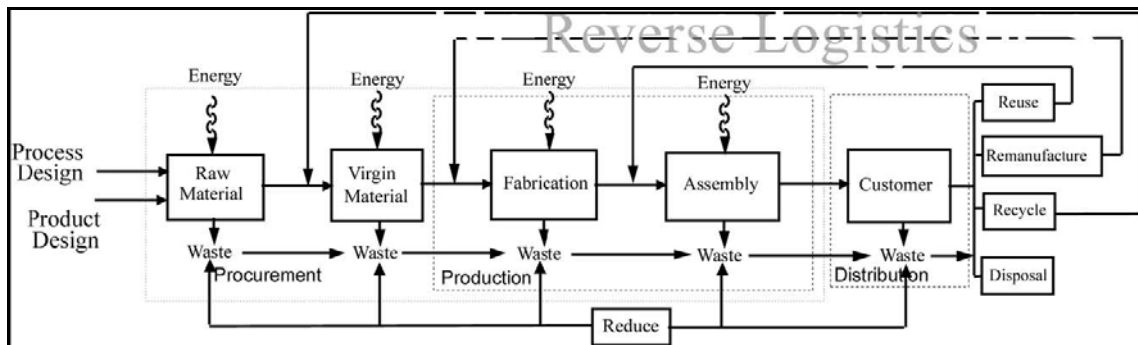

Figure 5. Functional model of a green supply chain [23]

Sheu et al. [24] presented an optimization-based model to deal with integrated logistics operational problems of green-supply chain management (G-SCM). In the proposed methodology, a linear multi-objective programming model is formulated that systematically optimizes the operations of both integrated logistics and corresponding used-product reverse logistics in a given green-supply chain. Kainuma and Tawara [18] extended the range of the supply chain to include re-use and recycling throughout the life cycle of products and services. Using their definition, they proposed the multiple attribute utility theory method assessing a supply chain considering this approach to be one of the GrSC methods. Anciaux and Yuan [4] proposed to show the issues for integrating the means of transport within the GrSC, as well as a decision-aiding model, which allows optimizing the solution choice of intermodal transport problems. Srivastava' [25] paper took an integrated and fresh look into the area of GrSC management. The literature on GrSC management is covered exhaustively from its conceptualization, primarily taking a 'reverse logistics angle'. Using the rich body of available literature, including earlier reviews that had relatively limited perspectives, the literature on GrSC management is classified on the basis of the problem context in supply chain's major influential areas. Ferretti et al. [10] originated from an industrial case study in the field of the aluminum supply chain. The supply of molten metal represents a substantial benefit for the whole supply chain, because of the energy savings implicit in the method itself (i.e. both energy and time can be saved when melting the metal at the company furnaces). Moreover, the study integrated

the concerns about transport pollution, addressing the topics of a GrSC problem and incorporating the environmental aspects in its analytical description. Beamon [6] described the challenges and opportunities facing the supply chain of the future and described sustainability and effects on supply chain design, management and integration. Traditional and GrSCs are compared and contrasted via focusing several important opportunities in GrSC management in depth, including those in manufacturing, bio-waste, construction, and packaging [17]. Chen and Sheu [8] demonstrated that a proper design of environmental-regulation pricing strategies is able to promote Extended Product Responsibility for GrSC firms in a competitive market. A differential game model comprising Vidale–Wolfe [22] equation has been established in light of sales competition and recycling dynamics as well as regulation related profit function.

2.2 The Closed-Supply Chain

The general closed-loop supply chain (CLSC) network investigated is illustrated in Figure 7. As can be seen in the network, these chain members can be classified into two groups [28]: (1) Forward logistics chain members shown at the left side of Figure 6, including raw material suppliers, manufacturers, retailers and demand markets; (2) Reverse logistics chain members shown at the right side of Figure 6, including demand markets, recovery centers and manufacturers. Manufacturers and demand markets could be recognized as the nodes to combine the forward supply chain network and the reverse supply chain network together to form the closed-loop supply chain network. Fleischman et al. [11] subdivided the field into three main areas, namely distribution planning, inventory control, and production planning. For each of these they discussed the implications of the emerging reuse efforts, review the mathematical models proposed in the literature, and point out the areas in need of further research. Fleischmann et al. [12] considered logistics network design in a reverse logistics context. They presented a generic facility location model and discussed differences with traditional logistics settings. Moreover, they used their model to analyze the impact of product return flows on logistics Networks and then they showed that the influence of product recovery is very much context dependent. Guide et al. [14] took a contingency approach to explore the factors that impact production planning and control for closed-loop supply chains that incorporate recovery. A series of three cases are presented, and a framework
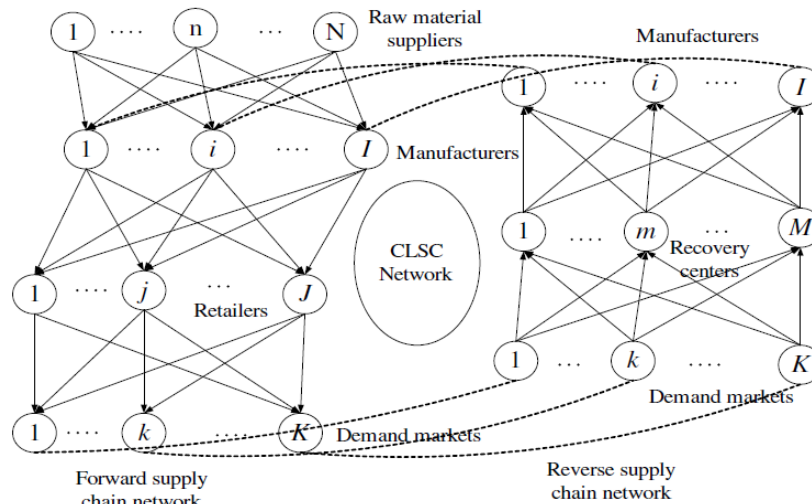

Figure 6. The closed loop supply chain network [28]

developed that shows the common activities required for all remanufacturing operations. To build on the similarities and illustrate and integrate the differences in closed-loop supply chains, Hayes and Wheelwright's product–process matrix is used as a foundation to examine the three cases representing Remanufacture-to-Stock (RMTS), Reassemble-to-Order (RATO), and Remanufacture -to-Order (RMTO). The previous studies have addressed the problem of determining the number and location of initial collection points in a multiple time horizon, while determining the desirable holding time for consolidation of returned products into a large shipment. To fill the void in such a line of research, Min et al. [21] proposed a mixed-integer, nonlinear programming model and a genetic algorithm that can solve the reverse logistics problem involving both spatial and temporal consolidation of returned products. Zhu et al. [29] reported on results from a cross-sectional survey with manufacturers in four typical Chinese industries, i.e., power generating, chemical/petroleum, electrical/electronic and automobile; to evaluate their perceived GrSC management practices and relate them to closing the supply chain loop. Chung et al. (9) analyzed an

inventory system with traditional forward-oriented material flow as well as a reverse material flow supply chain. In the reverse material flow, the used products are returned, remanufactured and shipped to the retailer for resale and then developed a CLSC inventory model and maximize the joint profits of the supplier, the manufacturer, the third-party recycle dealer and the retailer under contractual design. Kannan et al. [19] developed a multi echelon, multi period, multi product CLSC network model for product returns and the decisions are made regarding material procurement, production, distribution, recycling and disposal. The proposed heuristics based genetic algorithm (GA) is applied as a solution methodology to solve mixed integer linear programming model (MILP). Yang et al. [28] developed a model of a general closed-loop supply chain (CLSC) network, which includes raw material suppliers, manufacturers, retailers, consumers and recovery centers. The objective of the paper is to formulate and optimize the equilibrium state of the network by using the theory of variation inequalities. In Wang and Hsu' [27] study, the integration of forward and reverse logistics was investigated, and a generalized closed-loop model for the logistics planning was proposed by formulating a cyclic logistics network problem into an integer

linear programming model. Moreover, the decisions for selecting the places of manufactories, distribution centers, and dismantlers with the respective operation units were supported with the minimum cost. A revised spanning-tree based genetic algorithm was also developed by using determinant encoding representation for solving this NP model.

3. Problem Definition and Modeling
From the aforementioned concepts we described above, it is known that a CLSC network structure is necessary to design a GrSC. Regarding the traditional supply chains, CLSC and

GrSC problems involved more complex, and need more efforts to control forward and reverse logistics simultaneously considering the environmental impacts. Mostly the cost is considered via enterprises to measure the effectiveness of the network. Besides the cost factor, the following conditions are handled in our model;

- CO_2 gas emission,
- Products which consist of different recyclable ratio raw materials,
- Opportunity prices to encourage customers using recyclable products,
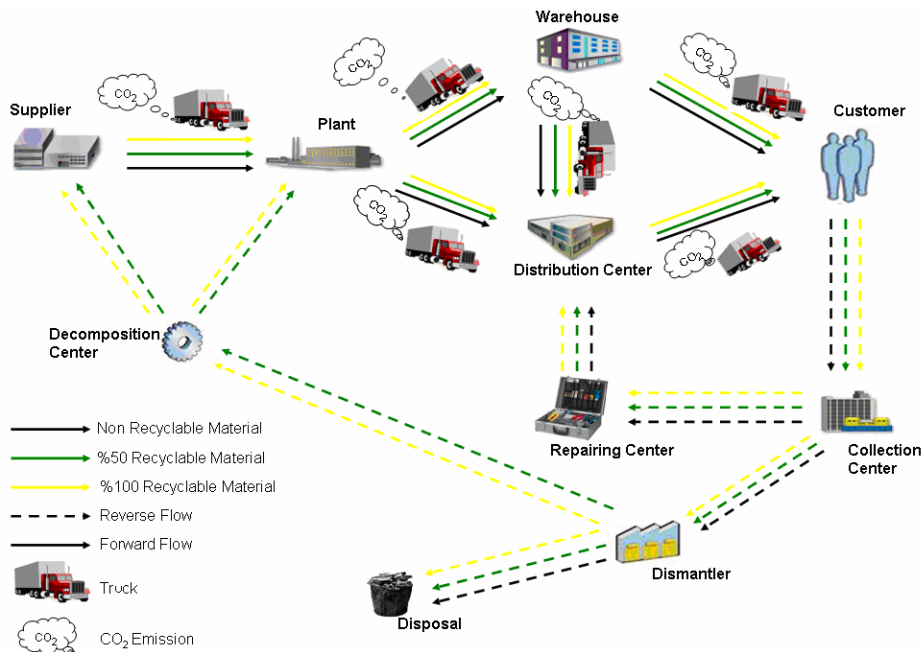

Figure 7. The proposed closed loop supply chain network across the green supply chain

- Penalty costs to prevent much CO_2 gas emission and etc.

As can be seen in Figure 7, these chain members are classified into two groups: the first part is forward supply chain members, and the second part is used-product reverse supply chain members. Here a typical 5-layer forward supply chain is proposed in corresponding layers, including raw material supply, plants, warehouses, distribution centers, and end-customers respectively. Similarly, a 5-layer used-product reverse supply chain is specified, which includes collecting centers, repairing centers, dismantlers, decomposition centers, and final disposal locations of wastes, respectively. We considered that a decision maker would rent the trucks for only forward flow. Furthermore, the suppliers provide three different raw materials (into three different products) to plants via paying attention recyclable ratios of them.

Considering the potential effects oriented from corresponding governmental regulations, the environmental protection administration and social responsibilities, the greenhouse gas emissions is tried to minimize owing to a penalty cost and encourage the customers to use recyclable products owing to a opportunity price.

To specify the study scope and facilitate model formulation, assumptions are postulated below;

(a) The demand of each customer is certain and must be satisfied.

(b) The flow is only allowed to be transferred between two sequential echelons (except warehouse-customer)
(c) The capacities of all actors are limited and certain.
(d) The transportation, purchasing, penalty and opportunity costs are given.
(e) The CO_2 emissions, and all reverse part rates are given.

Because of the first three assumptions are also basic conditions for supply chain design, we shall consider them in our proposed model. The most important issue of designing closed loop supply chain is reverse rates. Wang and Hsu [27] pointed out that in the recovery systems; a common assumption is that the amounts of the returned products. The recovery amount is assumed to be a percentage of the customer demand in the model. Minimizing the total costs (transportation, purchasing, and penalty) is aimed while maximizing the amount of product which is recycled.

3.1 Mathematical formulation of the model
Consider a supply chain network in Figure 7, in this section, based on five assumptions and the network structure; we shall propose a mathematical model to describe the goal of the paper.
Definitions of variables and parameters in the green closed-loop supply chain network are summarized below:
Indices;

I the number of suppliers with $i = 1, 2, ... I$

J the number of plants with $j = 1, 2, ... J$

K the number of distribution centers (DCs) with $k = 1, 2, ... K$

L the number of customers with $l = 1, 2, ... L$

M the number of collection centers with $m = 1, 2, ... M$

P the number of dismantlers with $p = 1, 2, ... P$

D the number of decomposition centers with $d = 1, 2, ... D$

T the number of trucks with $t = 1, 2, ... T$

R the number of raw/end material with $r = 1, 2, ... R$

Truck rental fee parameters;

H_t^{ij} the rental fee of truck t during the transportation supplier i and plant j

H_t^{jk} the rental fee of truck t during the transportation plant j and DC k

H_t^{j} the rental fee of truck t during the transportation plant j and warehouse

H_t^{k} the rental fee of truck t during the transportation warehouse and DC k

H_t^{l} the rental fee of truck t during the transportation warehouse and customer l

H_t^{kl} the rental fee of truck t during the transportation DC k and customer l

Transportation costs parameters after customers;

C_r^{lm} unit transportation cost of product r from customer l to collection center m

C_r^{m} unit transportation cost of product r from collection center m to repairing center

C_r^{k} unit transportation cost of product r from repairing center to DC k

C_r unit transportation cost of product r from repairing center to warehouse

C_r^{mp} unit transportation cost of product r from collection center m to dismantler p

C_r^{p} unit transportation cost of product r from dismantler p to disposal

C_r^{pd} unit transportation cost of product r from dismantler p to decomposition center d

C_r^{di} unit transportation cost of product r from decomposition center d to supplier i

C_r^{dj} unit transportation cost of product r from decomposition center d to plant j

Greenhouse gas emission parameters in forward logistic;

CO_2^{ijt} unit CO_2 emission of truck t during the transportation supplier i and plant j

CO_2^{jkt} unit CO_2 emission of truck t during the transportation plant j and DC k

CO_2^{jt} unit CO_2 emission of truck t during the transportation plant j and warehouse

CO_2^{kt} unit CO_2 emission of truck t during the transportation warehouse and DC k

CO_2^{lt} unit CO_2 emission of truck t during the transportation warehouse and customer l

CO_2^{klt} unit CO_2 emission of truck t during the transportation DC k and customer l

Incentives parameters for recycling;

P_r^{i} opportunity profit of supplier i because of choosing raw material r

P_r^{j} opportunity profit of plant j because of choosing material r

P_r opportunity profit of warehouse because of choosing material r

P_r^{k} opportunity profit of DC k because of choosing raw material r

Capacity parameters of facilities;

Ca_r^{i} capacity of raw material r at supplier i

Ca_r^{j} capacity of product r at plant j

Ca_r capacity of product r at warehouse

Ca_r^{k} capacity of product r at DC k

Ca_r^{m} capacity of product r at collection center m

Ca_r^{rc} capacity of product r at repairing center

Ca_r^{p} capacity of product r at dismantler p

Ca_r^{d} capacity of product r at decomposition center d

Truck' capacity parameters in forward logistic;

Ca_t^{i} transportation capacity of truck t departs from supplier i

Ca_t^{j} transportation capacity of truck t departs from plant j

Ca_t transportation capacity of truck t departs from warehouse

Ca_t^{k} transportation capacity of truck t departs from supplier i

The percentage rates parameters in reverse logistic;

$\alpha_{r\min/r\max}$ the minimum and maximum collection percentage rate from customers to collection centers for each product r

β_r the repairing percentage rate from collection centers to the repairing center for each product r

χ_r the transported repaired product percentage rate from the repairing center to DCs for each product r

δ_r the disposal rate from dismantlers to disposal for each product r

ε_r the decomposited product rate from decomposition centers to suppliers for each product r

De_r^{l} product r demand of customer l

P_r^{i} unit purchasing cost of raw material r from supplier i

$P_c^{CO_2}$ penalty cost for extra CO_2 emission

Forward logistic variables;

X_{rt}^{ij} transported raw material r via truck t from supplier i to plant j

Y_{rt}^{jk} transported product r via truck t from plant j to DC k

Z_{rt}^{j} transported product r via truck t from plant j to warehouse

Q_{rt}^{k} transported product r via truck t from warehouse to DC k

W_{rt}^{l} transported product r via truck t from warehouse to customer l

E_{rt}^{kl} transported product r via truck t from DC k to customer l

A_{r}^{i} total amount of raw material i purchased from supplier i

Reverse logistic variables;

K_{r}^{lm} transported product r from customer l to collection center m

T_{r}^{m} transported product r from collection center m to repairing center

U_{r}^{k} transported product r from repairing center to DC k

O_{r} transported product r from repairing center to warehouse

S_{r}^{mp} transported product r from collection center m to dismantler p

D_{r}^{p} transported product r from dismantler p to disposal

F_{r}^{pd} transported product r from dismantler p to decomposition center d

G_{r}^{di} transported product r from decomposition center d to supplier i

H_{r}^{dj} transported product r from decomposition center d to plant j

Given the aforementioned assumptions and definitions, now it is turn to describe the four objective functions (OBJF) below;

OBJF 1

$$\sum_{i}\sum_{j}\sum_{r}\sum_{t}X_{rt}^{ij}\cdot H_{t}^{ij}+\sum_{j}\sum_{k}\sum_{r}\sum_{t}Y_{rt}^{jk}\cdot H_{t}^{jk}+\sum_{j}\sum_{r}\sum_{t}Z_{rt}^{j}\cdot H_{t}^{j}+$$

$$\sum_{k}\sum_{r}\sum_{t}Q_{rt}^{k}\cdot H_{t}^{k}+\sum_{l}\sum_{r}\sum_{t}W_{rt}^{l}\cdot H_{t}^{l}+$$

$$\sum_{k}\sum_{l}\sum_{r}\sum_{t}E_{rt}^{kl}\cdot H_{t}^{kl} \tag{1}$$

The first OBJF is to minimize the total cost of the transportation which actualize via different trucks (forward logistics), and the OBJF 1 represents this goal (1).

OBJF 2

$$\sum_{l}\sum_{m}\sum_{r}K_{r}^{lm}\cdot C_{r}^{lm}+\sum_{m}\sum_{r}T_{r}^{m}\cdot C_{r}^{m}+\sum_{k}\sum_{r}U_{r}^{k}\cdot C_{r}^{k}+$$

$$\sum_{r}O_{r}\cdot C_{r}+\sum_{m}\sum_{p}\sum_{r}S_{r}^{mp}\cdot C_{r}^{mp}+\sum_{p}\sum_{r}D_{r}^{p}\cdot C_{r}^{p}+$$

$$\sum_{p}\sum_{d}\sum_{r}F_{r}^{pd}\cdot C_{r}^{pd}+\sum_{d}\sum_{i}\sum_{r}G_{r}^{di}\cdot C_{r}^{di}+$$

$$\sum_{d}\sum_{j}\sum_{r}H_{r}^{dj}\cdot C_{r}^{dj} \tag{2}$$

The second OBJF is to minimize the total cost of transportation which are from customers (reverse logistics), and the OBJF 2 represents this goal (2).

OBJF 3

$$P_{c}^{CO_2}(\sum_{i}\sum_{j}\sum_{r}\sum_{t}X_{rt}^{ij}\cdot CO_{2}^{ijt}+\sum_{j}\sum_{k}\sum_{r}\sum_{t}Y_{rt}^{jk}\cdot CO_{2}^{jkt}+$$

$$\sum_{j}\sum_{r}\sum_{t}Z_{rt}^{j}\cdot CO_{2}^{jt}+\sum_{k}\sum_{r}\sum_{t}Q_{rt}^{k}\cdot CO_{2}^{kt}+$$

$$\sum_{l}\sum_{r}\sum_{t}W_{rt}^{l}\cdot CO_{2}^{lt}+\sum_{k}\sum_{l}\sum_{r}\sum_{t}E_{rt}^{kl}\cdot CO_{2}^{klt}) \tag{3}$$

The third OBJF is representing the greenness of the model. By adding this OBJF, we aimed to minimize total CO_2 emissions which is produced by trucks on forward logistic. To dissuade the decision makers not to cause more CO_2 emissions, we determined a penalty cost based on an environmental legislation, the decision makers have to pay attention this issue due to not be punished.

OBJF 4

$$\sum_{i}\sum_{r}A_{r}^{i}\cdot P_{r}^{i}-\sum_{k}\sum_{r}U_{r}^{k}\cdot P_{r}^{k}-\sum_{r}O_{r}\cdot P_{r}-$$

$$\sum_{d}\sum_{i}\sum_{r}G_{r}^{di}\cdot P_{r}^{i}-\sum_{d}\sum_{j}\sum_{r}H_{r}^{dj}\cdot P_{r}^{j} \tag{4}$$

The fourth and last OBJF is formulated to encourage the customers to choose and use recyclable products. We encourage using recycling by minimizing the purchasing costs ($A_{r}^{i}\cdot P_{r}^{i}$) minus the total opportunity profits which is gained via using recyclable products. Let's think two different products, one of them is cheap but not recyclable, and the other is more expensive because of its recyclability. If the second one is chosen, we will not to purchase it again due to its recyclability and also the environmental responsibility will be accomplished. We determine the price difference, which is caused by the re-purchasing cost minus recyclable cost, as an opportunity profit.

Facility capacity constraints in forward logistic

$$\sum_{j}\sum_{t}X_{rt}^{ij}\leq Ca_{r}^{i}, \qquad \forall_{i,r} \tag{5}$$

$$\sum_{t}Z_{rt}^{j}+\sum_{k}\sum_{t}Y_{rt}^{jk}\leq Ca_{r}^{j}, \qquad \forall_{j,r} \tag{6}$$

$$\sum_{t}\sum_{k}Q_{rt}^{k}+\sum_{l}\sum_{t}W_{rt}^{l}\leq Ca_{r}, \qquad \forall_{r} \tag{7}$$

$$\sum_{l}\sum_{t}E_{rt}^{kl}\leq Ca_{r}^{k}, \qquad \forall_{k,r} \tag{8}$$

The constraints mainly contain two types: one is for limited capacities and the other is for the balance of the flow conversation in both of forward and reverse logistics. Constraints (5), (6), (7), (8) represent the limit of the capacity and provide not to exceed these capacities for suppliers, plants, warehouse and distribution centers for each products, respectively in forward logistic.

Facility capacity constraints in reverse logistic

$$T_{r}^{m}+\sum_{p}S_{r}^{mp}\leq Ca_{r}^{m}, \qquad \forall_{m,r} \tag{9}$$

$$\sum_{k}U_{r}^{k}+O_{r}\leq Ca_{r}^{rc}, \qquad \forall_{r} \tag{10}$$

$$D_{r}^{p}+\sum_{d}F_{r}^{pd}\leq Ca_{r}^{p}, \qquad \forall_{p,r} \tag{11}$$

$$\sum_{i}G_{r}^{di}+\sum_{j}H_{r}^{dj}\leq Ca_{r}^{d}, \qquad \forall_{d,r} \tag{12}$$

Constraints (9), (10), (11) and (12) guarantee that collection centers, repairing center, dismantlers and decomposition centers could not

exceed the given capacity limit for each products, respectively in reverse logistic.

The trucks capacity constraints in forward logistic

$$\sum_i \sum_j \sum_r X_{rt}^{ij} \leq Ca_t^i, \qquad \forall_t \qquad (13)$$

$$\sum_j \sum_k \sum_r Y_{rt}^{jk} + \sum_j \sum_r Z_{rt}^j \leq Ca_t^j, \qquad \forall_t \qquad (14)$$

$$\sum_k \sum_r Q_{rt}^k + \sum_l \sum_r W_{rt}^l \leq Ca_t, \qquad \forall_t \qquad (15)$$

$$\sum_k \sum_l \sum_r E_{rt}^{kl} \leq Ca_t^k, \qquad \forall_t \qquad (16)$$

Constraints (13), (14), (15) and (16) show that the trucks could not move more than their capacity limits during departing from suppliers, plants, warehouse and DCs, respectively in forward logistic.

$$\sum_j \sum_t X_{rt}^{ij} = A_r^i, \qquad \forall_{i,r} \qquad (17)$$

Constraint (17) shows that the total amount of product r which is transported from supplier i to plants by truck t is equal the total amount of product r which is purchased from supplier i.

The equilibrium constraints in forward logistic

$$\sum_i \sum_t X_{rt}^{ij} = \sum_t Z_{rt}^j + \sum_k \sum_t Y_{rt}^{jk}, \qquad \forall_{j,r} \qquad (18)$$

$$\sum_j \sum_t Z_{rt}^j = \sum_k \sum_t Q_{rt}^k + \sum_l \sum_t W_{rt}^l, \qquad \forall_r \qquad (19)$$

$$\sum_j \sum_t Y_{rt}^{jk} + \sum_t Q_{rt}^k = \sum_l \sum_t E_{rt}^{kl}, \qquad \forall_{k,r} \qquad (20)$$

$$\sum_t W_{rt}^l + \sum_k \sum_t E_{rt}^{kl} \geq De_r^l, \qquad \forall_{l,r} \qquad (21)$$

to DCs and warehouse, respectively. Constraint (27) and (28) guarantee the recycled product equilibrium from dismantlers to disposal and decomposition centers, respectively. Constraint (29) and (30) guarantee the recyclable product equilibrium from decomposition centers to suppliers and plants, respectively.

$$X_{rt}^{ij}, Y_{rt}^{jk}, Z_{rt}^j, Q_{rt}^k, W_{rt}^l, E_{rt}^{kl}, K_r^{lm}, T_r^m, U_r^k, O_r, S_r^{mp},$$

$$D_r^p, F_r^{pd}, G_r^{di}, H_r^{dj}, A_r^i \geq 0 \quad \forall_{i,j,k,l,m,p,d,t,r} \qquad (31)$$

Finally, constraint (31) restrict that the variables are non-negative in our model.

4. A Computational Experiment

4.1 General Information and Data

In this section, in order to evaluate the proposed model, we create an imaginary supply chain network based on a hypothetical data. We shall use a small example to illustrate the properties of the problem and the model. In the numerical example, we design a closed loop supply chain network which considers the environmental impacts (Figure 7). Consider the network in Figure 8. The network of the example contains two mainly part. The first part is forward logistic and consists of three suppliers, three plants, one warehouse, two DCs and five customers. Suppliers provide three kinds of raw materials which are 100% recyclable, 50% recyclable, non-recyclable raw materials, respectively. It is known that 100% recyclable products have to contain re-useable materials. But producing

Constraints (18), (19) and (20) satisfy the law of the flow of each products conversation by in-flow equal to out-flow for plants, warehouse and DCs, respectively, in forward logistic. Constraint (21) is to satisfy the customer demand for each product.

The equilibrium constraints in reverse logistic

$$\alpha_{r\min}(\sum_t W_{rt}^l + \sum_k \sum_t E_{rt}^{kl}) \leq \sum_m K_r^{lm}, \ \forall_{l,r}$$

$$\sum_m K_r^{lm} \leq \alpha_{r\max}(\sum_t W_{rt}^l + \sum_k \sum_t E_{rt}^{kl}), \ \forall_{l,r} \qquad (22)$$

$$\beta_r(\sum_l K_r^{lm}) = T_r^m, \qquad \forall_{m,r} \qquad (23)$$

$$(1-\beta_r)(\sum_l K_r^{lm}) = \sum_p S_r^{mp}, \qquad \forall_{m,r:1,2} \qquad (24)$$

$$\chi_r(\sum_m T_r^m) = \sum_k U_r^k, \qquad \forall_r \qquad (25)$$

$$(1-\chi_r)(\sum_m T_r^m) = O_r, \qquad \forall_r \qquad (26)$$

$$\delta_r(\sum_m S_r^{mp}) = D_r^p, \qquad \forall_{p,r:3} \qquad (27)$$

$$(1-\delta_r)(\sum_m S_r^{mp}) = \sum_d F_r^{pd}, \qquad \forall_{p,r:1,2} \qquad (28)$$

$$\varepsilon_r(\sum_p F_r^{pd}) = \sum_i G_r^{di}, \qquad \forall_{d,r:1,2} \qquad (29)$$

$$(1-\varepsilon_r)(\sum_p F_r^{pd}) = \sum_j H_r^{dj}, \qquad \forall_{d,r:1,2} \qquad (30)$$

Constraint (22) describes the customer recovery relationship between the minimum and maximum recovery rate. Constraint (23) and (24) provide the recycled product equilibrium from collection centers to repairing center and dismantlers, respectively. Constraint (25) and (26) show the repaired product equilibrium from repairing center

and using recyclable raw materials are expensive than the normal products because of standing the high technological processes and the 100% natural raw materials. So the decision maker faces a trade-off purchasing costs versus the recyclable rate. To present recyclable products to customers and consider greenness, the decision maker has to choose re-usable raw materials. Besides this environmental factor, we consider the greenhouse gas emissions in forward logistic. We assume that an outsourcing is used for only transportation. The 3PL firm presents three kinds of trucks for transporting which are 0-3 years, 4-7 years and 8-11 years old, respectively. Inherently, as aging the trucks, their rental fees will be cheaper. So, choosing always the oldest trucks are the best option but to consider greenness of the model, we pay the attention CO_2 emission of trucks. It is clear that as aging the trucks, their CO_2 emissions are also increased because of the engine differences. The added deterrent penalty cost ($P_c^{CO_2} = 0.05$ \$/gr than more 2000 kg CO_2) in model puts the decision maker into another trade-off situation which is penalty cost versus CO_2 emissions (Tables 1, 2, 3).

The plants purchase raw materials in three kinds mentioned above from the suppliers. The plants, warehouse and DCs triangular has a flexible structure. After the production in plants, the end-products flow can be actualize to warehouse and also DCs. The warehouse sends the end-products to customers directly, and also it can be happen by DCs. The capacity limits of suppliers, plants, warehouse, DCs and trucks are given in Tables 4 and 5.

Table 1. The rental costs (\$/unit) of each truck and the CO_2 emissions (gr/unit) during the transportation between Suppliers-Plants-Warehouse

	Suppliers									Plants		
	1			**2**			**3**			**1**	**2**	**3**
	Plants									Warehouse		
	1	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**1**	**1**
Truck 1	3	2.5	3.2	2.8	2.6	3.1	3	2.5	3.3	1.5	1.4	1.8
Truck 2	2.2	2	1.9	2.3	2.1	1.7	1.9	1.8	1.6	1.2	1.1	1
Truck 3	1.5	1.7	1.3	2	1.5	1.6	1.45	1.76	1.8	0.9	0.7	0.6
	CO_2 Emission (gr/unit)											
Truck 1	0.9	0.9	1.1	1.2	1	0.8	0.7	1.1	1.2	1	0.9	1.1
Truck 2	1.3	1.5	1.6	1.4	1.2	1.4	1.3	1.7	1.4	1.3	1.2	1.5
Truck 3	1.7	1.8	1.9	1.6	1.5	1.7	1.5	1.7	1.9	2	1.3	1.7

Table 2. The rental costs (\$/unit) of each truck and the CO_2 emissions (gr/unit) during the transportation between Plants-DCs

	Plants					
	1		**2**		**3**	
	Distribution Centers					
	1	**2**	**1**	**2**	**1**	**2**
Truck 1	2.6	2.4	2.7	2.4	2.5	2.8
Truck 2	2.1	2	1.9	2.1	2.3	2.1
Truck 3	1.7	1.6	1.9	1.7	1.8	1.5
	CO_2 Emission (gr/unit)					
Truck 1	0.8	0.7	0.9	1	0.7	0.8
Truck 2	1.4	1.3	1.6	1.5	1.2	1.4
Truck 3	1.8	1.9	2	1.6	1.8	1.9

Table 3. The rental costs (\$/unit) of each truck and the CO_2 emissions (gr/unit) during the transportation between Warehouse-DCs-Customers

								DC									
	Warehouse							**1**						**2**			
	DC		Customers					Customers									
	1	**2**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**	**1**	**2**	**3**	**4**	**5**
Truck 1	1.7	1.6	2.4	2.3	2.2	2.1	2.1	2.1	2.2	2.4	2.4	2.1	2	2.2	2.1	2.2	2.1
Truck 2	1.4	1.4	2.2	1.8	1.6	1.9	1.7	1.9	1.6	1.9	1.7	1.9	1.8	2.1	2.1	2.2	1.9
Truck 3	1.2	1.3	1.9	1.8	1.7	1.9	1.6	2	1.7	1.8	1.7	1.9	2.1	1.7	1.6	1.6	1.8
	CO_2 Emission (gr/unit)																
Truck 1	0.7	0.7	1.1	1.2	1	0.8	0.7	1.1	1.2	1	0.9	1.1	0.8	0.9	1.1	1.2	1
Truck 2	1.1	1.2	1.6	1.4	1.2	1.4	1.3	1.7	1.4	1.3	1.2	1.5	1.4	1.5	1.3	1.6	1.7
Truck 3	1.4	1.5	1.9	1.6	1.5	1.7	1.5	1.7	1.9	2	1.3	1.7	1.7	1.8	1.9	1.8	1.9

Table 4. The material capacities of Suppliers-Plants-Warehouse-Distribution Centers (unit)

	Suppliers			Plants			Warehouse	Distribution Center	
Material	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**1**	**2**
%100 Recyc.	10000	9000	11000	9500	11500	12500	22000	12000	11000
%50 Recyc.	11000	10000	12000	10500	11500	11500	19000	10000	9000
Non Recyc.	12000	11000	13000	11500	10500	12500	18000	11000	11000

Table 5. The transportation capacities of each truck between Suppliers-Plants-Warehouse-DCs (unit)

Trucks	**Suppliers**	**Plants**	**Warehouse**	**Distribution Centers**
Truck 1	32000	35000	22000	18000
Truck 2	34000	37000	21000	17000
Truck 3	31000	34000	23000	19000

The second part is reversing logistic and it contains two collection centers, two dismantlers, one repairing center, one disposal and two decomposition centers. The collection centers are responsible for collecting the used-products from customers.

- Minimum and maximum collection rates of collection centers are assumed to be $\alpha_{r\min} = \%30$ and $\alpha_{r\max} = \%60$.

- According the decisions in collection centers, the products which need just repairing, are sent to repairing center ($\beta_r = \%40$).

- After the repairing in repairing center, products could be sent to warehouse and also DCs ($\chi_r = \%70, \%30$).

- The rest of the products in collection centers are transported to dismantlers ($1-\beta_r$ =%60).

- After the dismantling processes, half of the secondary and total of the tertiary products are disposal ($\delta_{r:2,3}$ = %50, %100).

- Full of the primary and the rest of the secondary products are transported to decomposition centers. According to decomposition situations, some of them are sent to suppliers (ε_r =%70) and the rest of them to plants ($1-\varepsilon_r$ =%30).

All transportation in reverse logistic is actualized by the decision makers. Tables 6, 7 and 8 give the unit transportation costs between reverse facilities.
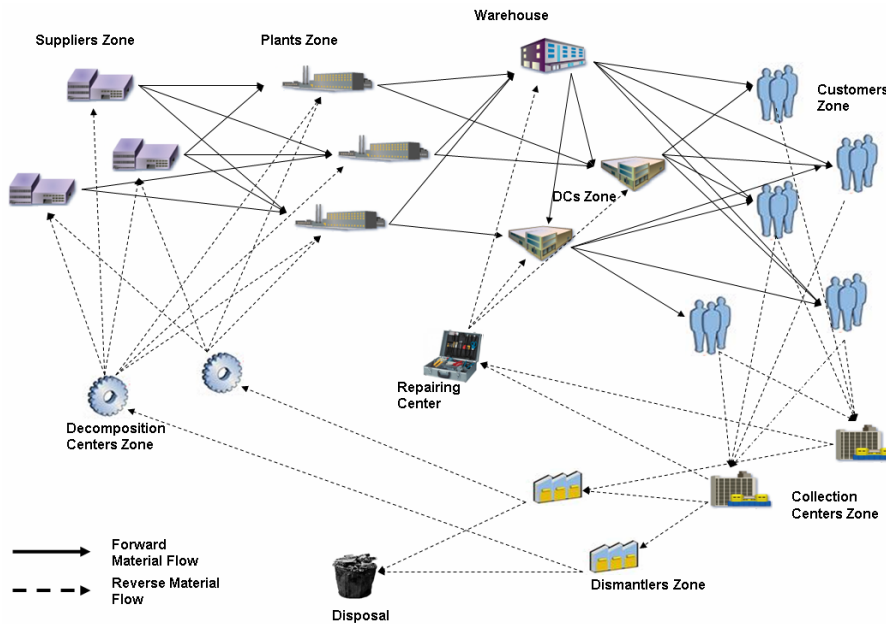

Figure 8. The network of the illustrative example

Table 6. The unit transportation costs between Customers-Collection Centers-Dismantlers-Repairing Centers ($)

	Customers										Collection Centers					
	1		2		3		4		5		1	2	1		2	
	Collection Centers										Repairing Center		Dismantlers			
Material	1	2	1	2	1	2	1	2	1	2	1	1	1	2	1	2
%100 Recyc.	1.2	1.3	1.2	1.4	1.2	1.3	1.2	1.3	1.2	1.1	1.3	1.2	1.3	1.2	1.3	1.2
%50 Recyc.	1.2	1.3	1.2	1.4	1.2	1.3	1.2	1.3	1.2	1.1	1.3	1.2	1.3	1.2	1.3	1.2
Non Recyc.	1.2	1.3	1.2	1.4	1.2	1.3	1.2	1.3	1.2	1.1	1.3	1.2	1.3	1.2	1.3	1.2

Table 7. The unit transportation costs between Repairing C.-Warehouse-DCs-Dismantlers-Disposal-Decomposition Centers ($)

	Repairing Center			Dismantlers				
	1			1	2	1		2
	Warehouse	DCs		Disposal		Decomposition Centers		
Material	1	1	2	1	1	2	1	2
%100 Recyc.	1.2	1.1	1.4	1.2	1.3	1.4	1.3	1.5	1.2
%50 Recyc.	1.2	1.1	1.4	1.2	1.3	1.4	1.3	1.5	1.2
Non Recyc.	1.2	1.1	1.4	1.2	1.3	1.4	1.3	1.5	1.2

Table 8. The unit transportation costs between Decomposition Centers-Suppliers-Plants ($)

	Decomposition Centers											
	1			2			1			2		
	Suppliers						Plants					
Material	1	2	3	1	2	3	1	2	3	1	2	3
%100 Recyc.	1.1	1	0.9	1.2	1.1	0.9	1.1	1.2	1	1	1.1	1.2
%50 Recyc.	1.1	1	0.9	1.2	1.1	0.9	1.1	1.2	1	1	1.1	1.2
Non Recyc.	1.1	1	0.9	1.2	1.1	0.9	1.1	1.2	1	1	1.1	1.2

Table 9. The material capacities of Collection Centers-Repairing Center-Dismantlers-Decomposition Center (unit) and the demands of each Customer (unit)

	Collection Centers		Repairing Center	Dismantlers		Decomposition Centers		Customers				
Material	1	2	1	1	2	1	2	1	2	3	4	5
%100 Recyc.	6000	5400	4200	4000	4500	4600	4600	6000	4000	7000	5000	6000
%50 Recyc.	5000	5500	4100	4500	4800	4800	4800	6700	5700	6700	5700	7700
Non Recyc.	4500	4500	4050	4600	4000	4700	4700	5900	5900	6900	4900	5900

All flow decisions in reverse logistic are calculated via considering the capacity information and customer demands in Table 9.

We mentioned the encouraging factors at the beginning of paper. Using recyclable raw materials are better than re-purchasing these raw materials with a high cost. We determined an opportunity profit gained choosing recyclable raw materials and products (Table 10).

Table 10. Gained the net profit of Suppliers-Plants-Warehouse-DCs due to recycling each material ($) and raw material purchasing costs ($/unit).

	Suppliers			Plants			Warehouse	DCs	
Material	1	2	3	1	2	3	1	1	2
%100 Recyc.	3.5	3.2	3.6	4	4.1	4.2	3.7	3.9	4.1
%50 Recyc.	2.7	2.5	2.9	2.9	3.1	2.7	2.5	2.8	2.9
Non Recyc.	-	-	-	-	-	-	1.9	1.8	1.9
Purchasing costs ($/unit)									
%100 Recyc.	6	6.2	5.8	-	-	-	-	-	-
%50 Recyc.	3.2	3.5	3	-	-	-	-	-	-
Non Recyc.	2.3	2	2.1	-	-	-	-	-	-

4.2 The Outputs of the Illustrative Example

In this example, with $I=3$, $J=5$, $K=2$, $L=5$, $M=2$, $P=2$, $D=2$, $T=3$ and $R=3$, there are 445 variables, and 602 constraints. Using LINDO 6.1 with the most 1(s) elapsed time, we obtained the optimal solution as shown in Table 11. Calculated objective values are given in Table 12. All the experiments are conducted on a notebook with the Intel Core2 Duo 1.66 GHz and 2 GB RAM.

Table 11. The optimal solution of numerical example

Variable	Value	Variable	Value	Variable	Value	Variable	Value
X_{1123}	1000	Z_{322}	4700	K_{311}	2100	U_{11}	2352
X_{1211}	9500	Z_{332}	6900	K_{313}	1260	U_{12}	2730
X_{1221}	10000	W_{212}	100	K_{322}	2010	U_{13}	2478
X_{1231}	5500	W_{213}	3900	K_{323}	810	D_{12}	525
X_{1313}	500	W_{232}	300	K_{411}	1500	D_{13}	1310
X_{2213}	2000	W_{312}	7000	K_{412}	1280	D_{22}	2400
X_{2223}	1500	W_{322}	6700	K_{413}	1470	D_{23}	4000
X_{2233}	5000	W_{332}	6900	K_{422}	430	F_{111}	440
X_{2312}	5000	W_{411}	5000	K_{521}	1800	F_{121}	100
X_{2322}	8000	W_{421}	4600	K_{522}	2310	F_{122}	525
X_{2332}	6000	W_{431}	4900	K_{523}	1770	F_{221}	4500
X_{3113}	6000	W_{511}	1600	T_{11}	2400	F_{222}	2400
X_{3123}	8500	W_{513}	4400	T_{12}	2000	G_{131}	308
X_{3133}	6500	W_{523}	7700	T_{13}	1800	G_{231}	3220
X_{3312}	5000	W_{531}	5900	T_{21}	960	G_{232}	2047
X_{3322}	3500	E_{1222}	5700	T_{22}	1900	H_{131}	132
X_{3332}	6500	E_{1232}	5600	T_{23}	1740	H_{211}	1380
Y_{1211}	6000	E_{1422}	1100	S_{112}	1050	H_{222}	877
Y_{1221}	6700	E_{2111}	6000	S_{121}	3600	A_{11}	10000
Y_{1231}	5900	E_{2121}	6100	S_{122}	1950	A_{12}	11000
Y_{3121}	6800	E_{2122}	600	S_{123}	2700	A_{13}	5500
Y_{3131}	5600	E_{2131}	5900	S_{211}	540	A_{21}	7000
Z_{121}	2800	K_{111}	1200	S_{213}	1310	A_{22}	9500
Z_{131}	600	K_{112}	2010	S_{221}	900	A_{23}	11000
Z_{213}	11500	K_{121}	600	S_{222}	2850	A_{31}	11000
Z_{223}	11500	K_{123}	1770	S_{223}	1300	A_{32}	12000
Z_{233}	10500	K_{211}	1200	O_1	1008	A_{33}	13000
Z_{312}	10000	K_{212}	1710	O_2	1170		
Z_{313}	500	K_{213}	1770	O_3	1062		

Table 12. Calculated objective function values

OBJF	Definition	Value
OBJF1	Minimization the total transportation cost in forward logistic	453530.00 $
OBJF2	Minimization the total transportation cost in reverse logistic	105613.00 $
OBJF3	Minimization the total CO_2 emission and the penalty cost	317800 gr – 200000gr= 117800 gr Penalty Cost: 117800*0.05= 5890 $
OBJF4	Minimization the total purchasing costs via maximization the total opportunity profit	Total purchasing costs: 333600.00 $ Total opportunity profit: 57382.80 $
	Total	841251.00 $

According to the results obtained by LINDO 6.1 package program, the total cost is 841251.00 $ (Table 12). Total transportation cost in forward logistic is calculated 453530.00 $. This money is expended for transporting 90000 units product which are consist of 28000 unit %100 recyclable, 32500 unit %50 recyclable, and 29500 unit non-recyclable. All trucks emissions totally 317800 gr CO_2 gas during the all transportation in forward logistic. We determined a lower limit (2000 kg CO_2) for emissions, and a penalty cost for each a gr CO_2 after this lower limit. So, the decision maker paid 5890 $ as the total penalty cost. To answer all customers demand, totally 90000 units of raw material is purchased from three suppliers via paying 333600.00 $. 27000 units of re-used products are collected from customers and sent to the collection centers. Because of preferring the recyclable raw materials, the decision maker gained 57382.80 $ via saving the re-purchasing costs.

5.   Conclusion

Changes in the state of the environment, leading to subsequent public pressure and environmental legislation have necessitated a fundamental shift in supply chain practices [5]. Anymore, the supply chain does not describe only the all production stage from raw material to end-product delivery. Thus, the concept of the supply chain has to be handled in a green frame. Therefore, to consider the 'greenness' and the serious legislations, the traditional structure of the supply chain will be inadequate. This shortage can be solved by assembling a product recovery process as called the closed loop supply chain.

In this paper, we developed and proposed a multi objective mathematical model to solve the green supply chain problems which are emerged because of environmental responsibilities. The distinguishing feature of the proposed model is considering the environmental effects on supply chains. First we explained why we developed this model via mentioning the greenness impacts and a closed loop supply chain in the introduction section. The reasons why we added the CO_2 emission factor and encouraging the recyclable using are clarified. In the literature section, we reviewed the model-based literature for the green and closed loop supply chain. We examined the ongoing and emerging issues in green closed loop supply chains. At third section, the minimizing the total cost model is given with its mathematical formulation. We aimed to minimize the total cost via;

- minimizing the transportation costs in both forward and reverse logistic,
- minimizing the total CO_2 emission amount,
- minimizing the total purchasing costs,
- maximizing the total opportunity profit in the model.

At fourth section, the model is tested with an illustrated example, and the promising results have shown the applicability of the proposed model with the solution procedure.

For further researches, the model could be extended in a few directions. For example, the uncertainty embedded in demand, capacity and recovery rates should be handled to facilitate practical applications. Another extension is associating the reverse part of this model with plants or other facilities in other supply chains. And as a last suggestion, the model's environmental and greenness factors can be enlarged via adding noise pollution, accident risk and time assessment factors etc.

6.   References

[1] http://en.wikipedia.org/wiki/File:Greenhouse_Gas_by_Sector.png

[2] http://www.greenprintdenver.org/getinvolved/reduce-your-emissions/

[3] http://www.iges.or.jp/APEIS/RISPO/spo/pdf/sp2102.pdf

[4] D. Anciaux, K. Yuan, "Green Supply Chain: Intermodal Transportation Modeling With Environmental Impacts", Association of European Transport and Contributors, Metz, France, 2007.

[5] B.M. Beamon, "Designing The Green Supply Chain", Logistics Information Management, Vol. 12, No. 4, 1999, pp. 332-342.

[6] B.M. Beamon, "Sustainability and the Future of Supply Chain Management", Operations and Supply Chain Management, Vol. 1, No.1, 2008, pp. 4-18.

[7] D.J. Bowersox, D.J. Closs, "Logistical Management: The Integrated Supply Chain Process", 1996, McGraw-Hill, New York.

[8] Y.J. Chen, J-B. Sheu, "Environmental-regulation Pricing Strategies for Green Supply Chain Management", Transportation Research Part E, Vol. 45, 2009, pp. 667-677

[9] S-L. Chung, H-M. Wee, P-C. Yang, "Optimal Policy for a Closed Loop Supply Chain Inventory System with Remanufacturing", Mathematical and Computer Modelling, Vol. 48, No. 5-6, 2008, pp. 867-881

[10] I. Ferretti, S. Zanoni, L. Zavanella, A. Diana, "Greening the Aluminum Supply Chain", International Journal Production Economics, Vol. 108, 2007, pp. 236-245.

[11] M. Fleischmann, J.M. Bloemhof-Ruwaard, R. Dekker, E. Laan, J. Nunen, L. Wassenhove, "Quantitative Models for Reverse Logistics: A Review", European Journal of Operational Research, Vol. 103, 1997, pp. 1-17.

[12] M. Fleischmann, P. Beullens, J.M. Bloemhof-Ruwaard, L. Wassenhove, "The Impact of Product Recovery on Logistics Network Design", Production and Operation Management, Vol. 10, 2001, pp. 156-173.

[13] T.E. Graedel, B.R. Allenby, "Industrial Ecology", 1995, Englewood, NJ: Prentice Hall.

[14] V.D.R. Guide, V. Jayaraman, D.L. Jonathan, "Building Contingency Planning For Closed-Loop Supply Chains With Product Recovery", Journal of Operations Management, Vol. 21, 2003, pp. 259–279

[15] R.H. Hayes, S.C. Wheelwright, "Link Manufacturing Process and Product Life Cycles", Harvard Business Review, Vol. 57, No. 1, 1979, pp. 133–140.

[16] S. Hochman, "Green Supply Chain: Real World Lessons from Demand Driven Leaders", AMR Research, http://www.amrresearch. com/ Content/View.aspx?comp URI = t cm:7-18944& title=Green+Supply+Chain%3a+RealWorld+Lessons+From +Demand-Driv en+ Leaders, 2007.

[17] C.H. Johnny, K.S. Maurice, T. Tzu-Liang, S.A. David, "Opportunities in Green Supply Chain Management", The Coastal Business Journal, Vol. 8, No. 1, 2009, pp. 1-14.

[18] Y. Kainuma, N. Tawara, "A Multiple Attribute Utility Theory Approach to Lean and Green Supply Chain Management", International Journal of Production Economics, Vol. 101, 2006, pp. 99-108.

[19] G. Kannan, P. Sasikumar, K.. Devika, "A Genetic Algorithm Approach for Solving a Closed Loop Supply Chain Model: A Case of Battery Recycling", Applied Mathematical Modelling, doi:10.1016/j.apm.2009.06.021, 2009.

[20] M.J. Meixell, V.B. Gargeya, "Global Supply Chain Design: A Literature Review and Critique", Transportation Research Part E, Vol. 41, 2005, pp. 531-550.

[21] H. Min, C.S. Ko, H.J. Ko, "The Spatial And Temporal Consolidation Of Returned Products In A Closed-Loop Supply Chain Network", Computers and Industrial Engineering, Vol. 51, 2006, pp. 309–320.

[22] A. Prasad, S. Sethi, "Competitive Advertising Under Uncertainty: A Stochastic Differential Game Approach", Journal of Optimization Theory and Applications, Vol. 123, No. 1, 2004, pp. 163–185.

[23] J. Sarkis, "A Strategic Decision Framework for Green Supply Chain Management", Journal of Cleaner Production, Vol. 11, 2003, pp. 397-409.

[24] J.B. Sheu, Y.H. Chou, C. Hu, "An Integrated Logistic Operational Model for Green Supply Chain Management", Transportation Research Part E, Vol. 41, 2005, pp. 287-313.

[25] S.K. Srivastava, "Green Supply Chain Management: A State of the Art Literature Review", International Journal of Management Reviews, Vol. 9, No. 1, 2007, pp. 53-80.

[26] D. Tsamboulas, G. Mikroudis, "EFECT- Evaluation Framework of Environmental Impacts and Costs of Transport Initiatives", Transportation Research Part D, Vol. 5, 2000, pp. 283-303.

[27] H-S. Wang, H-W. Hsu, "A Closed-Loop Logistic Model with A Spanning Tree Based Genetic Algorithm", Computers & Operations Research, Vol. 37, 2010, pp. 376-389.

[28] G. Yang, Z. Wang, X. Li, "The Optimization of the Closed-Loop Supply Chain Network", Transportation Research Part E, Vol. 45, 2009, pp. 16-28.

[29] Q.H. Zhu, J. Sarkis, K.H. Lai, "Green Supply Chain Management Implications For ''Closing The Loop''", Transportation Research Part E, Vol. 44, 2008, pp. 1–18.