Designing a Closed-Loop Logistic Network in Supply Chain by Reducing its Unfriendly Consequences on Environment

Kiran Garg, Sanjam, Aman Jain and P. C. Jha

Abstract This paper examines the relationship between the operations of forward and reverse logistics and the environmental performance measures like CO_2 emission in the network due to transportation activities in closed-loop supply chain network design. A closed-loop structure in the green supply chain logistics and the location selection optimization was proposed in order to integrate the environmental issues into a traditional logistic system. So, we present an integrated and a generalized closed-loop network design, consisting four echelons in forward direction (i.e., suppliers, plants, and distribution centers, first customer zone) and four echelons in backward direction (i.e., collection centers, dismantlers, disposal centers, and second customer zone) for the logistics planning by formulating a cyclic logistics network problem. The model presented is bi objective and captures the trade-offs between various costs inherent in the network and of emission of greenhouse gas CO_2. Numerical experiments were presented, and the results showed that the proposed model and algorithm were able to support the logistic decisions in a closed loop supply chain efficiently and accurately.

Keywords Environmental performances · Cradle to cradle principle · Closed loop supply chain network · Trade off · Greenhouse gas

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1 Introduction

Supply chain consists of set of activities such as transformation and flow of goods, services, and information from the sources of materials to end-users. Due to the government legislation, environmental concern, social responsibility, and customer awareness, companies have been forced by customers not only to supply environmentally harmonious products but also to be responsible for the returned products. So, interest in supply chains lies in the recovery of products, which is achieved through processes such as repair, remanufacturing and recycling, which, combined with all the associated transportation and distribution operations, are collectively termed as *Reverse Chain activities.* In reverse logistics there is a link between the market that releases used products and the market for "new" products. When these two markets coincide, it is called *Closed Loop Network*. Thus the supply chain in which forward and reverse supply chain activities are integrated is said to be closed-loop, and research on such chains have given rise to the field of closed-loop supply chains (CLSCs) and Supply chain network design concerned with environmental issues, collectively named as *Green Supply Chain*.

At present, researcher's emphasis on green supply chain due to global warming and wants to minimize the waste at landfills. A closed-loop logistics management ensures the least waste of the materials by following the cradle to cradle principle and conservation law along the life cycles of the materials. In reverse logistics used products, either under warranty or at the end of use or at the end of lease are taken back, so that the products or its parts are appropriately disposed, recycled, reused, or remanufactured. Beside it they explicitly focus on significant sources of greenhouse gas emission, and one of those sources is transportation. CO_2 is very prominent in its hazardous consequences on human health. Transport is the second-largest sector of global CO_2 emission. CO_2 constraints in logistics markets will need to be realized in the near future as it was enforced by protocols, and a shift in freight transportation could be expected to reduce the CO_2 emissions within the reasonable cost and time constraints.

In this study, we model and analyze a CLSC for its operational and environmental performances, i.e., a multi-echelon forward–reverse logistics network model is described for the purpose of design with the reflection of the effects on environment of greenhouse gas emission. Objectives of the model is to maximize the total expected profit earned and minimizing CO_2 emission due to transporting material in forward and reverse logistics networks with the use of different type of vehicles for transport, each of which has its own emission rates and transportation costs. Using the proposed model and a numerical illustration result of computational experiments shed light on the interactions of various performance indicators, primarily measured by cost and then captures the environmental aspects.

2 Literature Review

This section presents a brief overview of the existing literature on closed loop supply chain (CLSC). Beamon [1] describes the challenges and opportunities facing the supply chain of the future and describes sustainability and effects on supply chain design, management and integration. Network chain members of a CLSC can be classified into two groups [2]: Forward logistics chain members and Reverse logistics chain members. But designing the forward and reverse logistics separately results in suboptimal designs with respect to objectives of supply chain; hence the design of forward and reverse logistics should be integrated [3–5]. This type of integration can be considered as either horizontal or vertical integration [6]. Manufacturers and demand nodes (i.e., customers) could be seen as 'junction' points where the forward and the reverse chains are combined to form the CLSC network. A closed-loop logistics model for remanufacture has been studied in [7], in which decisions relevant to shipment and remanufacturing of a set of products, as well as establishment of facilities to store the remanufactured products are taken into consideration [8]. Consider a reverse logistics network design problem which analyzes the impact of product return flows on logistics networks. A strategic and tactical model for the design and planning of supply chains with reverse flows was proposed by [9]. Authors considered the network design as a strategic decision, while tactical decisions are associated to production, storage and distribution planning. A general reverse logistics location allocation model was developed in [10] in a mixed integer linear programming form. The model behavior and the effect of different reverse logistics variables on the economy of the system were studied. Demand in this proposed model is deterministic. The problem of consolidating returned products in a CLSC has been studied in [11]. Kannan et al. [12] developed a multi-echelon, multiperiod, multi-product CLSC network model for product returns, in which decisions are made regarding material procurement, production, distribution, recycling, and disposal. For an excellent review of methodological and case study-based papers in reverse and closed-loop logistics network design, the reader is referred to [13].

Meixell and Gargeya [14] focused on the design of supply chains of production, purchasing, transportation, and profit and has neglected the environmental aspects. Given recent concerns on the harmful consequences of supply chain activities on the environment, and transportation in particular, it has become necessary to take into account environmental factors when planning and managing a supply chain. The list of environmental performance metrics of a supply chain includes emissions, energy use and recovery, spill and leak prevention, and discharges is discussed in [15]. A comprehensive survey of the field is provided by [16]. Sarkis [17] provides a strategic decision framework for green supply chain management, in which he investigates the use of an analytical network process for making decisions within the GrSC. Sheu et al. [18] present a multiobjective linear programming model for optimizing the operations of a green supply chain, composed of forward and reverse flows, including decisions pertaining to shipment and inventory [19]. Consider environmental issues within CLSCs and examine a supply chain design problem for refrigerators,

offer a comprehensive mathematical model that minimizes costs associated with distribution, processing, and facility set-up, also takes into account the environmental costs of energy and waste.

The remainder of the paper is structured as follows. In Sect. 3 a CLSC model is proposed for single product, with the underlying assumptions. In Sect. 4, used methodology of goal programming is described. In Sect. 5, we present a numerical implementation in order to highlight the features of the proposed model. The paper ends with concluding remarks.

3 Model Description

The CLSC problem discussed in this paper is an integrated multiobjective multi-echelon problem in a forward/reverse logistic network, which requires more efforts to analyze than both forward and backward logistic simultaneously. Here we are considering the flow of a product in the network. The model considers modular product structure and every component of the product has an associated recycling rate, specifying the rate at which the component can be recycled. For instance, a rate of 100 % indicates that the used product can be fully recovered or transformed into a new one, whereas a rate of 50 % denotes that the product can only be partially recovered.

In the network suppliers are responsible for providing components to manufacturing plants. The new products are conveyed from plants to customers via distribution centers (d/c) to meet their demands. Returned products from customers are collected at collection centers where they are inspected. After testing in collection centers, the repairable and recyclable products are shipped to plants and dismantlers respectively, after completing the demand of secondary market of used products. At plant repairable used products are repaired and supplied back to distribution centers as new product. Dismantled components at dismantlers are drives back to suppliers if they are repairable else to disposal site to be disposed of.

The purpose of this paper is to evaluate a forward/reverse logistic system with respect to given objectives in order to determine the facility locations and flows between facilities using which type of transport. The transportation operations from one layer to another can be realized via a number of options. These options consist of different types of transport alternatives, e.g., different models of trucks. The proposed model considers the following assumptions and limitations:

1. Supplier and customer locations are known and fixed.
2. The demand of product is deterministic and no shortages are allowed.
3. The potential locations of manufacturing facilities, distribution centers, collection centers, and dismantlers are known.
4. The flow is only permitted to be transported between two consecutive stages. Moreover, there are no flows between facilities at the same stage.
5. The numbers of facilities that can be opened are restricted.

6. The other costs (i.e., operational costs and transportation costs) are known.
7. The estimated emission rate of CO_2 for all type of vehicle available is known.

Notations:
Sets:

S set of component's suppliers index by s, $s = 1, 2, \ldots, S$

P set of manufacturing plants index by p, $p = 1, 2, \ldots, P$

K set of distribution centers (d/c) index by k, $k == 1, 2, \ldots, K$

E set of first market customer zones index by e, $e = 1, 2, \ldots, E$

C set of collection centers (CC) index by c, $c == 1, 2, \ldots, C$

M set of dismantlers (d/m) position index by m, $m == 1, 2, \ldots, M$

H set of second market customer zones index by h, $h = 1, 2, \ldots, H$

F set of disposal sites (d/p) index by f, $f = 1, 2, \ldots, F$

A set of subassemblies index by a, $a = 1, 2, \ldots, A$

N set on nodes in the network ($N = S \cup P \cup K \cup E \cup C \cup M \cup H \cup F$)

Parameters:

SC_{sa} Unit purchasing cost of sub assembly a by supplier s

PC_p Unit production cost of product at manufacturing plant p

OC_k Unit operating cost of product at d/c k

IC_c Unit inspection cost of product at collection center c

RPC_p Unit repairing cost of used product at manufacturing plant p

DMC_m Unit dismantling cost of product at d/m position m

RCC_{sa} Unit recycling cost of sub assembly a at supplier s

D_e Demand of product at first customer e

D_h Demand of used product at second customer h

TPC^t Unit transportation cost per mile of product or component shipped from one node to another via type of truck t

D_{ij} Distance between any two nodes $i, j \in$ N of given CLSC network

CAP_{sa} Capacity of supplier s for sub assembly a

$PCAP_p$ Production capacity of plant p

$KCAP_k$ Capacity of distribution center k

$CCAP_c$ Capacity of collection center c

$MCAP_m$ Capacity of dismantler m

$FCAP_f$ Disposal capacity of disposal site f

$RPCAP_p$ Repairing capacity of plant p

$RCCAP_s$ Recycling capacity of supplier s

PF_a Unit profit made in the network from recycling component a

PF Unit profit made in the network from repairable product

PR_e Unit price of product at customer e

PR_h Unit price of product at customer e

ER^t Per mile emission rate of CO_2 gas from the type of transport $t \in T$

Rr Return ratio at the first customers

Rc_a Recycling ratio of component a

Rp Repairing ratio

W   Weight of product in kg

W_a Weight of component $a \in A$ in kg

U_a Utilization rate of component $a \in A$

Decision variables:

x_{ija}^t Quantity of component a shipped from node i to node j, $i, j \in N$ in the network via transport of type $t \in T$

x_{ij}^t Quantity of product shipped from node i to node j, $i, j \in N$ in the network via transport of type $t \in T$

W_{ij}^t Weighted quantity transported from node i to node j, $i, j \in N$ in the network via transport of type $t \in T$

$$X_i = \begin{cases} 1, \text{if facility } i, (i \in P \cup K \cup C \cup M) \text{ is opened} \\ 0, \text{ otherwise} \end{cases}$$

$$L_{ij}^t = \begin{cases} 1, \text{ if a transportation link is established between any two locations} \\ \quad i \text{ and } j, i, j \in N \text{ via mode } t \\ 0, \text{ otherwise} \end{cases}$$

Model

Maximize, Z_0 $= \sum_k \sum_e \sum_t x_{ke}^t PR_e + \sum_c \sum_h \sum_t x_{ch}^t PR_h + \sum_m \sum_s \sum_a \sum_t PF_a x_{msa}^t$

$$+ \sum_c \sum_p \sum_t PF x_{cp}^t - \left(\sum_s \sum_p \sum_a \sum_t x_{spa}^t SC_{sa} + \sum_p \sum_k \sum_t x_{pk}^t PC_p \right.$$

$$+ \sum_k \sum_e \sum_t x_{ke}^t OC_k + \sum_e \sum_c \sum_t x_{ec}^t IC_c + \sum_c \sum_p \sum_t x_{cp}^t RPC_p$$

$$+ \sum_c \sum_m \sum_t x_{cm}^t DMC_m + \sum_m \sum_s \sum_a \sum_t x_{msa}^t RCC_{sa}$$

$$+ \sum_m \sum_f \sum_a \sum_t x_{mfa}^t DPC_f + \sum_s \sum_p \sum_t TPC^t D_{sp} x_{sp}^t$$

$$+ \sum_p \sum_k \sum_t TPC^t D_{pk} x_{pk}^t + \sum_k \sum_e \sum_t TPC^t D_{ke} x_{ke}^t$$

$$+ \sum_e \sum_c \sum_t TPC^t D_{ec} x_{ec}^t + \sum_c \sum_p \sum_t TPC^t D_{cp} x_{cp}^t$$

$$+ \sum_c \sum_m \sum_t TPC^t D_{cm} x_{cm}^t + \sum_c \sum_h \sum_t TPC^t D_{ch} x_{ch}^t$$

$$+ \left. \sum_m \sum_s \sum_a \sum_t TPC^t D_{ms} x_{msa}^t + \sum_m \sum_f \sum_a \sum_t TPC^t D_{mf} x_{mfa}^t \right)$$

Minimize, Z_1 $= \sum_t ER^t \left(\sum_s \sum_p D_{sp} L_{sp}^t W_{sp}^t + \sum_p \sum_k D_{pk} L_{pk}^t W_{pk}^t + \sum_k \sum_e D_{ke} L_{ke}^t W_{ke}^t \right.$

$$+ \sum_e \sum_c D_{ec} L_{ec}^t W_{ec}^t + \sum_c \sum_p D_{cp} L_{cp}^t W_{cp}^t$$

$$+ \sum_c \sum_m D_{cm} L_{cm}^t W_{cm}^t + \sum_c \sum_h D_{ch} L_{ch}^t W_{ch}^t + \sum_m \sum_s D_{ms} L_{ms}^t W_{ms}^t$$

$$+ \left. \sum_m \sum_f D_{mf} L_{mf}^t W_{mf}^t \right)$$

Subject To
(Flow balancing constraints)

$$\sum_s \sum_t x_{spa}^t + \sum_c \sum_t x_{cp}^t * U_a = \sum_k \sum_t x_{pk}^t * U_a \quad \forall p, a \tag{1}$$

$$\sum_p \sum_t x_{pk}^t = \sum_k \sum_e x_{ke}^t \quad \forall k \tag{2}$$

$$\sum_k \sum_e x_{ke}^t >= D_e \quad \forall e \tag{3}$$

$$\sum_c \sum_t x_{ec}^t = Rr * D_e \quad \forall e \tag{4}$$

$$\sum_c \sum_t x_{ch}^t <= D_h \quad \forall h \tag{5}$$

$$\sum_p \sum_t x_{cp}^t = Rp * \left(\sum_e \sum_t x_{ec}^t - \sum_h \sum_t x_{ch}^t \right) \quad \forall c \tag{6}$$

$$\sum_m \sum_t x_{cm}^t = (1 - Rp) * \left(\sum_e \sum_t x_{ec}^t - \sum_h \sum_t x_{ch}^t \right) \quad \forall c \tag{7}$$

$$\sum_s \sum_t x_{msa}^t = Rc_a * U_{a*} \sum_c \sum_t x_{cm}^t \quad \forall m, a \tag{8}$$

$$\sum_f \sum_t x_{mfa}^t = (1 - Rc_a) * U_{a*} \sum_c \sum_t x_{cm}^t \quad \forall m, a \tag{9}$$

Capacity constraints

$$\sum_s \sum_t x_{spa}^t <= CAP_{sa} \quad \forall s, a \tag{10}$$

$$\sum_k \sum_t x_{pk}^t <= PCAP_p * X_p \quad \forall p \tag{11}$$

$$\sum_e \sum_t x_{ke}^t <= KCAP_k * X_k \quad \forall e \tag{12}$$

$$\sum_e \sum_t x_{ec}^t <= KCAP_k * X_k \quad \forall c \tag{13}$$

$$\sum_c \sum_t x_{cp}^t <= RPCAP_p * X_p \quad \forall p \tag{14}$$

$$\sum_c \sum_t x_{cm}^t <= MCAP_m * X_m \quad \forall m \tag{15}$$

$$\sum_m \sum_t x_{msa}^t <= RCCAP_s \quad \forall s, a \tag{16}$$

$$\sum_m \sum_a \sum_t x_{mfa}^t <= FCAP_s \quad \forall f \tag{17}$$

$$w_{sp}^t = \sum_a x_{spa}^t * w_a \quad \forall s, p, t \tag{18}$$

$$w_{pk}^t = x_{pk}^t * w \quad \forall p, k, t \tag{19}$$

$$w_{ec}^t = x_{ec}^t * w \quad \forall e, c, t \tag{20}$$

$$w_{ke}^t = x_{ke}^t * w \quad \forall k, e, t \tag{21}$$

$$w_{cp}^t = x_{cp}^t * w \quad \forall c, p, t \tag{22}$$

$$w_{ch}^t = x_{ch}^t * w \quad \forall c, h, t \tag{23}$$

$$w_{cm}^t = x_{cm}^t * w \quad \forall c, h, t \tag{24}$$

$$w_{ms}^t = \sum_a x_{msa}^t * w_a \quad \forall s, m, t \tag{25}$$

$$w_{mf}^t = \sum_a x_{mfa}^t * w_a \quad \forall m, f, t \tag{26}$$

Maximum number of activated locations constraints

$$\sum_p X_p <= P \tag{27}$$

$$\sum_k X_k <= K \tag{28}$$

$$\sum_c X_c <= C \tag{29}$$

$$\sum_m X_m <= M \tag{30}$$

Linking–shipping constraints

$$L_{sp}^t <= \sum_a x_{spa}^t \quad \forall s, p, t \tag{31}$$

$$L_{pk}^t <= x_{pk}^t \quad \forall p, k, t \tag{32}$$

$$L_{ke}^t <= x_{ke}^t \quad \forall k, e, t \tag{33}$$

$$L_{ec}^t <= x_{ec}^t \quad \forall e, c, t \tag{34}$$

$$L_{cp}^t <= x_{cp}^t \quad \forall c, p, t \tag{35}$$

$$L_{ch}^t <= x_{ch}^t \quad \forall c, h, t \tag{36}$$

$$L_{cm}^t <= x_{cm}^t \quad \forall c, m, t \tag{37}$$

$$L_{ms}^t <= \sum_a x_{msa}^t \quad \forall s, m, t \tag{38}$$

$$L_{mf}^t <= \sum_a x_{mfa}^t \quad \forall m, f, t \tag{39}$$

Shipping linking constraints

$$\sum_a x_{spa}^t <= MI * L_{sp}^t \quad \forall s, p, t \tag{40}$$

$$x_{pk}^t <= MI * L_{pk}^t \quad \forall p, k, t \tag{41}$$

$$x_{ke}^t <= MI * L_{ke}^t \quad \forall k, e, t \tag{42}$$

$$x_{ec}^t <= MI * L_{ec}^t \quad \forall e, c, t \tag{43}$$

$$x_{cp}^t <= MI * L_{cp}^t \quad \forall c, p, t \tag{44}$$

$$x_{cm}^t <= MI * L_{cm}^t \quad \forall c, m, t \tag{45}$$

$$x_{ch}^t <= MI * L_{ch}^t \quad \forall c, h, t \tag{46}$$

$$\sum_a x_{msa}^t <= MI * L_{ms}^t \quad \forall s, m, t \tag{47}$$

$$\sum_a x_{mfa}^t <= MI * L_{mf}^t \quad \forall m, f, t \tag{48}$$

$$x_{ija}^t, x_{ij}^t >= 0$$

$$X_i, L_{ij}^t \in \{0, 1\}$$

The first objective is to maximize the total profit including the total income and profit obtained by introducing recycled materials back into the (forward) supply chain (which is used as an incentive for the companies to choose and use recyclable products) minus the total cost which includes cost of purchasing components from suppliers, production cost incurred at plants, operating costs incurred at d/c, inspection cost for the returned products in collection centers, remanufacturing cost of recoverable products in plants, dismantling cost in dismantling the product, recycling cost at supplier and disposal costs for scrapped products. Second objective is to minimize the CO_2 emission by choosing various available type of transport.

Constraints are divided in five sets: first set is consisting of flow balancing constraints. Constraint (1) assures that the flow entering in the manufacturing plant is equal to the flow exit from it. Constraint (2) is for d/c. Constraint (3) insures that demands of all first customers are satisfied. Constraint (4) insures the flow entering in collection center through a customer will be equal to demand of the customer multiplied by return ratio. Constraint (5) insures that flow entering to each second customer from all collection centers does not exceed the second customer demand. Constraint (6) and (7) imposes that, the flow exiting from each collection center to all plants and dismantler is equal to the amount remaining at each collection

center after satisfying second customer demand multiplied by the repairing ratio and (1-repairing ratio) respectively. Constraint (8) and (9) shows that, the flow exiting from each dismantler to supplier and disposal sites are equal to the flow entering from all CC multiplied by recycling ratio and (1-recycling ratio) respectively. Constraint (10–17) insures that flow either exiting or entering at any facility does not exceed the respective facility capacity. Constraints (27–30) limit the number of activated locations, where the sum of binary decision variables which indicate the number of activated locations, is less than the maximum limit of activated locations. Constraints (31–39) insure that there are no links between any locations without actual shipments during all periods. Constraints (40–48) ensure that there is no shipping between any non-linked locations.

4 Multiobjective Methodology: Goal Programming

The basic approach of **goal programming** is to establish a specific numeric goal for each of the objectives, formulate an objective function for each objective, and then seek a solution that minimizes both positive and negative deviations from set goals simultaneously or minimizes the amount by which each goal can be violated. There is a *hierarchy of priority levels* for the goals, so that the goals of primary importance receive first priority attention, those of secondary importance receive second-priority attention, and so forth.

Generalized model of goal programming is:

$$\min a = \{g_1\left(\overline{\eta_1}, \overline{\rho_1}\right), \ldots, g_k\left(\overline{\eta_2}, \overline{\rho_2}\right)\}$$

$$s.t \quad f_i\left(\overline{x}\right) + \eta_i - \rho_i = b_i \quad \forall i = 1, 2, \ldots, m$$

$$\overline{x}, \overline{\eta}, \overline{\rho} \geq 0;$$

x_j is the jth decision variable, a is denoted as the achievement function; a row vector measure of the attainment of the objectives or constraints at each priority level, $g_k\left(\overline{\eta}, \overline{\rho}\right)$ is a function (normally linear) of the deviation variables associated with the objectives or constraints at priority level k, K is the total number of priority levels in the model, b_i is the right-hand side constant for goal (or constraint)i, $f_i\overline{(x)}$is the left-hand side of the linear goal or constraint i.

We seek to minimize the non-achievement of that goal or constraint by minimizing specific deviation variables. The deviation variables at each priority level are included in the function $g_k\left(\overline{\eta}, \overline{\rho}\right)$ and ordered in the achievement vector, according to their respective priority. Algorithm of sequential goal programming:

Step 1: Set $k = 1$ (k represents the priority level and K is the total of these).
Step 2: Establish the mathematical formulation as discussed above using positive and negative deviations for priority level k only.

Step 3: Solve this single-objective problem associated with priority level k and the optimal solution of $g_k (\overline{\eta}, \overline{\rho})$ is a*.

Step 4: Set $k = k + 1$. If $k >$ K, go to Step 7.

Step 5: Establish the equivalent, single objective model for the next priority level (level k) with additional constraint $g_k (\overline{\eta}, \overline{\rho}) = a_s^*$.

Step 6: Go to Step 3.

Step 7: The solution vector x*, associated with the last single objective model solved, is the optimal vector for the original goal programming model.

5 Numerical Illustration

In this section, a numerical example is presented in order to demonstrate the applicability of the model. In considered CLSC, a product which is made up of six components say 1, 2, 3, 4, 5, and 6 with respective utilization rate of 1, 4, 1, 2, 1, and 3 and recycling rate of 1, 0.5, 7.5, 1, 0.3 and 0 flows between various facilities. In forward direction, there is a set of three suppliers that can provide components to two potential locations of manufacturing plants. Three potential location of d/cs are there in the network to cater the demand of 2000, 2700, 3250, 2550, and 2700 units from respective 5 zones of first customer market at a unit selling price of 11000, 10500, 10000, 10750, and 10500. In backward direction, potential locations of CC, dismantlers and disposal sites are 3, 2, and 1 respectively. Beside its demand of 500, 350, and 550 units of used product from respective three zones of second customers can be satisfied at unit selling price of 7500, 8000, and 7000. As for transportation, road-based transportation is used to carry out the shipping operations, for which there are three types of trucks available which are 0–3, 4–7, and 8–11 years old, respectively. We assume that the older the trucks, the cheaper their rental fees, but, at the same time, the greater their CO_2 emissions, due to decreasing engine efficiency. Unit transportation costs for the different types of trucks used are 1, 0.85 and 0.70 for truck types 1, 2, and 3, respectively. Emission rate of CO_2 found to be 1.3, 2.8, and 3.1 g/mi for truck types 1, 2 and 3 respectively. Profit raised in the network by repairing the product is 5500/unit and by recycling a unit of component 1, 2, 3, 4, and 5 are 250, 50, 90, 55, and 300 respectively.

Other parameters are set as follows: $Rr = 0.60$, $Rp = 0.25$, and $Rc_a = (1, 1, 1, 1, 1, 0)$. Set of unit purchasing costs of components (in order) from supplier 1, 2, and 3 are (460, 0, 190, 125, 0, 80), (480, 120, 200, 150, 650, 100) and (470, 95, 0, 0, 620, 90), respectively. Unit recycling costs of components (in order) at supplier 1, 2, and 3 are (20, 0, 60, 10, 0, 0), (25, 90, 55, 20, 390, 0) and (0, 65, 0, 0, 380, 0), respectively. Price 0 means that component service is not provided by respective supplier. 2500 and 3000 are unit production cost, and 1500 and 2200 are unit repairing costs of the product at plant 1 and 2, respectively. Unit operating costs at d/c 1, 2, and 3 are 500, 550, and 600 respectively. Unit Inspection costs at collection centers 1, 2, and 3 are 100, 100, and 120 respectively. Unit dismantling

cost at d/m 1 and 2 are 125 and 110 respectively. Unit disposal cost of component 6 is 15.

Data on capacities at various facilities are as follows: Supplier 1 can supply at most of 8000, 0, 9000, 12000, 0, and 14000 units of component 1, 2, 3, 4, 5, and 6 respectively. Capacity of supplier 2 and 3 of components are (7500, 40000, 5000, 27000, 7700, 15000) and (0, 20000, 0, 0, 7500, 1400) respectively. Recycling capacities of supplier 1, 2 and 3 are (3000, 0, 2900, 4000, 0, 0), (2000, 15000, 2000, 6000, 2500, 0) and (0, 8000, 0, 0, 2500, 0) respectively. Production capacities of plants are 8000, 7500 and repairing capacities are 2000, 1800 respectively. Capacities of d/c's are 4800, 5000 and 5500, of CC's are 3500, 3000 and 2500; of dismantlers are 5000, 5000 and of disposal site is 250000.

Data on distance (in miles) between any two facilities is as follows:

$D_{ij} = \{D_{11}, D_{12,} D_{13}, \ldots, D_{21}, D_{22}, D_{23}, \ldots..\}$

$D_{sp} = \{200, 190, 310, 350, 290, 280\}$,

$D_{pk} = \{120, 100, 135, 170, 190, 200\}$,

$D_{ke} = \{24, 17, 22, 21, 18, 29, 19, 21, 20, 31, 33, 25, 28, 15, 28\}$,

$D_{ec} = \{6, 9, 8, 8.5, 7, 10, 11, 12, 13, 9, 8, 9.5, 11, 9, 8\}$,

$D_{cp} = \{150, 120, 135, 110, 130, 100\}$

$D_{cm} = \{8.5, 9, 11, 12, 10, 11\}$,

$D_{ch} = \{15, 21, 19, 24, 16, 18, 20, 22, 21\}$

$D_{ms} = \{100, 150, 120, 95, 154, 130\}$,

$D_{mf} = \{80, 75\}$

The above data is employed to validate the proposed model. A LINGO code for generating the proposed mathematical models of the given data was developed and solved using LINGO11.0 [20]. Problem is solved individually with each objective subject to given set of constraints. Thus, Profit and amount of CO_2 emission would be 66625630 and 252121600 respectively. Which are set as the aspiration levels for profit and emission functions. Then multiobjective programming problem combining all the objectives and incorporating the individual aspirations is solved which results in infeasible solution hence goal programming technique has been used to obtain a compromise solution to the above problem.Giving weight age 0.5 and 0.5 to profit and CO_2 objective respectively, a compromised solution of allocation of facilities and transporting vehicle is obtained. Total profit thus generated in the network is Rs. 54, 240, 470 and amount of CO_2 emitted is 543, 833, 100. The flow between facilities using different type vehicles is given below.

$x_{spa}^t : x_{111}^3 = 3016, \quad x_{113}^3 = 4016, \quad x_{114}^3 = 12000, \quad x_{121}^2 = 4984, \quad x_{123}^2 = 4984,$

$x_{126}^1 = 14000, \quad x_{211}^2 = 3570, \quad x_{212}^2 = 12860, \quad x_{213}^2 = 2570, \quad x_{214}^2 = 1172,$

$x_{215}^2 = 4070, \quad x_{216}^2 = 5758, \quad x_{222}^2 = 19080, \quad x_{224}^1 = 9968, \quad x_{226}^1 = 952,$

$x_{312}^3 = 13484, \quad x_{315}^3 = 2516, \quad x_{316}^3 = 14000, \quad x_{322}^1 = 856, \quad x_{325}^1 = 4984$

$$x_{pk}^t : x_{11}^3 = 1086, \quad x_{13}^2 = 5500, \quad x_{21}^3 = 3714, \quad x_{22}^2 = 2900$$

$$x_{ke}^t : x_{13}^1 = 450, \quad x_{14}^1 = 1650, \quad x_{15}^1 = 2700, \quad x_{21}^1 = 2000, \quad x_{24}^1 = 900,$$

$$x_{32}^3 = 2700, \quad x_{33}^3 = 2800$$

$$x_{ec}^t : x_{13}^3 = 1200, \quad x_{21}^1 = 150, \quad x_{22}^3 = 1470, \quad x_{31}^2 = 1950, \quad x_{42}^3 = 1530,$$

$$x_{51}^3 = 1400, \quad x_{53}^3 = 220$$

$$x_{cp}^t : x_{12}^3 = 525, \quad x_{22}^1 = 750, \quad x_{32}^3 = 355$$

$$x_{cm}^t : x_{11}^3 = 1575, \quad x_{22}^1 = 2250, \quad x_{32}^1 = 1065$$

$$x_{ch}^t : x_{11}^1 = 500, \quad x_{12}^2 = 350, \quad x_{13}^2 = 550$$

$$x_{msa}^t : x_{121}^3 = 1575, \quad x_{122}^3 = 6300, \quad x_{123}^3 = 1575, \quad x_{124}^3 = 3150, \quad x_{125}^3 = 1575,$$

$$x_{211}^2 = 2890, \quad x_{214}^3 = 3780, \quad x_{221}^3 = 425, \quad x_{222}^2 = 8700,$$

$$x_{223}^3 = 425, \quad x_{224}^2 = 2850, \quad x_{225}^3 = 925, \quad x_{232}^1 = 4560, \quad x_{235}^1 = 2390$$

$$x_{mfa}^t : x_{116}^3 = 4725, \quad x_{216}^2 = 9945$$

6 Conclusions

One of the important planning activities in supply chain management (SCM) is to design the configuration of the supply chain network. Besides, due to the global warning recently attention has been given to reverse logistic in SCM. Modeling of a CLSC network design problem can be a challenging process because there is large number of components that need to be incorporated into model. Here in this paper, trade-offs between operational and environmental performance measures of shipping product were investigated. Due to global warming, this paper focused on CO_2 emissions, One of the main findings of this paper is that, costs of environmental impacts are still not as apparent as operational measures, as far as their relative importance in a emission rate function are concerned. Operational costs of handling products, both in forward and reverse networks, seem to be dominant ignoring emissions rate. Another interesting result is relevant to the promotion of reusable products, the use of which seems to lessen the operational costs of the chain, but places a burden on the environmental costs.

References

1. Beamon, B.M.: Sustainability and the future of supply chain management. Oper. Supply Chain Manag. **1**(1), 4–18 (2008)
2. Zhu, Q.H., Sarkis, J., Lai, K.H.: Green supply chain management implications for "closing the loop". Transp. Res. Part E **44**(1), 1–18 (2008)
3. Fleischmann, M., Beullens, P., Bloemhof-ruwaard, J.M., Wassenhove, L.: The impact of product recovery on logistics network design. Product. Oper. Manag. **10**, 156–173 (2001)
4. Lee, D., Dong, M.: A heuristic approach to logistics network design for end-of-lease computer products recovery. Transp. Res. Part E **44**, 455–474 (2008)
5. Verstrepen, S., Cruijssen, F., de Brito, M., Dullaert, W.: An exploratory analysis of reverse logistics in Flanders. Eur. J. Trans. Infrastruct. Res. **7**(4), 301–316 (2007)
6. Pishvaee, M.R., Farahani, R.Z., Dullaert, W.: A memetic algorithm for bi-objective integrated forward/reverse logistics network design. Comput. Oper. Res. **37**(6), 1100–1112 (2010)
7. Jayaraman, V., Guide Jr, V.D.R., Srivastava, R.: A closed-loop logistics model for remanufacturing. J. Oper. Res. Soc. **50**(5), 497–508 (1999)
8. Fleischmann, M., Beullens, P., Bloemhof-Ruwaard, J.M., Wassenhove, L.: The impact of product recovery on logistics network design. Prod. Oper. Manag. **10**(3), 156–173 (2001)
9. Salema, M.I., Barbosa-Póvoa, A.P., Novais, A.Q.: A strategic and tactical model for closed-loop supply chains, (pp. 361–386). EURO Winter Institute on Location and Logistics, Estoril (2007a)
10. El Saadany, Ahmed M. A., El-Kharbotly, Amin, K.: Reverse logistics modeling. In: 8th International Conference on Production Engineering and Design for Development, Alexandria, Egypt (2004)
11. Min, H., Ko, C.S., Ko, H.J.: The spatial and temporal consolidation of returned products in a closed-loop supply chain network. Comput. Ind. Eng. **51**(2), 309–320 (2006)
12. Kannan, G., Sasikumar, P., Devika, K.: A genetic algorithm approach for solving a closed loop supply chain model: a case of battery recycling. Appl. Math. Model. **34**(3), 655–670 (2010)
13. Aras, N., Boyaci, T., Verter, V.: Designing the reverse logistics network. In: Ferguson, M.E., Souza, G.C. (eds.), Closed-loop Supply Chains: New Developments to Improve the Sustainability of Business Practices, pp. 67–97. CRC Press, Taylor & Francis, Boca Raton (2010)
14. Meixell, M.J., Gargeya, V.B.: Global supply chain design: a literature review and critique. Transp. Res. Part E **41**(6), 531–550 (2005)
15. Hervani, A.A., Helms, M.M., Sarkis, J.: Performance measurement for green supply chain management. Benchmarking: An International Journal **12**(4), 330–353 (2005)
16. Srivastava, S.K.: Green supply-chain management: a state-of-the-art literature review. Int. J. Manag. Rev. **9**(1), 53–80 (2007)
17. Sarkis, J.: A strategic decision framework for green supply chain management. J. Cleaner Prod. **11**(4), 397–409 (2003)
18. Sheu, J.B., Chou, Y.H., Hu, C.: An integrated logistic operational model for green supply chain management. Transp. Res. Part E **41**(4), 287–313 (2005)
19. Krikke, H., Bloemhof-Ruwaard, J., Van Wassenhove, L.: Concurrent product and closed-loop supply chain design with an application to refrigerators. Int. J. Prod. Res. **41**(16), 3689–3719 (2003)
20. Thiriez, H.: OR software LINGO. Eur. J. Oper. Res. **12**, 655–656 (2000)