A Comprehensive Closed Loop Supply Chain Model; Environmental, Technology and Energy Concerns

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Abstract - **Decision on end-of-life product recovery options is affected by many factors; related to amount usage of appropriate raw materials, energy, environmental factors and etc. This paper provides a model that is different from previous ones in its inclusion of all environmental effective parameters such as raw materials, clean technology, emission, energy, and waste simultaneously. Because of, supplying standard raw material, increasing using clean technology, decreasing amount of emission, optimizing used energy, recycling, and appropriate disposal products methods are required for used goods without damaging the environment by designing an efficient closed-loop supply chain (CLSC) network that as mentioned before, are simultaneously considered in the proposed model. We present a holistic modeling approach for a multiple-objective green CLSC network. The results confirm that by selecting appropriate raw materials, using clean technology and optimizing used energy can minimize manufacturing costs, in addition, they decline disposal products to cause environmental pollution.**

Keywords – **Green CLSC, Augmented epsilon constraint method, Environment factors, Multiple-objective**

I. INTRODUCTION

The zone of green operations includes all of a period of time from product extension to management of the whole product life cycle entailing such environmental practices as eco-design, clean production, recycling, and reuse with a focus on decreasing the expenses associated with production, distribution, consumption, and waste of products [1]. Because of enhancing standards of living and crowd increment, there is a rising energy and resource demand for the increased production. This comprises a decrease in the access of primary raw materials, followed by a rise of prices for the materials also an increase of emissions to the environment. Diminishing the demand of primary raw materials by increasing the use of secondary materials for instance via more effective providing appropriate raw material for to manufacture viable product and recycling practices seem to be a promising beginning. [2]. Supplier connection management is essential to the achievement of a green purchasing program. moreover, utilization of the better raw materials for products are crucial topics at the moment because of difficulties associated with the depreciation of the waste products in the environment and the economic advantages of remanufacturing products, that is lower than manufacturing costs. To encompass a positive impact, future plants will be progressively able to manufacture, reserve, and expenditure renewable energy. This will comfort an energy flexible generation for to manufacture durable product and involving an extra reduction in primary raw material demand. Waste from the manufacturing department quantities to almost fourteen percent of the total primary waste of the Organization for Economic Co-operation and Development (OECD) countries [3]. This pure quantity of waste production demonstrates a considerable damage of resources in terms of materials and energy the same. Other realized harmful impact of plants are particle emissions causing weather and earth pollution. Therefore, nowadays plants are requested by law to comply with these aims encouraging the utilization of new cleaning technologies and procedures. Eco-design may improve products via more eco-safe raw materials (e.g. fundamental, reusable materials), great durability, little energy expenditure whenever the extension of environmental or sustainable technologies (e.g. renewable energy technologies) indicate totally novel products recycling [4]. With focus on economic benefits, eco-efficiency is also frequently discussed as an arrival card to environmental and sustainability implementation advancements. More specifically, manufacturers might be able to gain short term advantages in terms of plucking the scarce hanging fruits with restricted resource commitment [5]. Considered model in this paper is different from previous ones in its inclusion of all environmental effective parameters such as raw materials, clean technology, emission, energy, and waste simultaneously. The proposed model presents decision maker flexibility to adapt for distinct conditions. It is enough comprehensive to be public and enough flexible to be special, this would make the decision taken using this precise model by selecting appropriate recovery options, and informative by introducing the most powerful factors that conduct for the decision making. In TABLE 1, we compare our proposed model with some previous researches in terms of the major characteristics or attributes applied in our mathematical model extension stage. In addition to these main attributes, and modeling attributes are contained to simplify more realistic CLSC network design. These attributes include the integration of forward and reverse flows (CLSC meaning).

TABLE 1
A comparison of previous studies considering different characteristics

	N.O	Model type	Solution Methodology	R.A	C.T	E	E.M	W
[6]	Two	LP	-	-	-	✔	-	✔
[7]	One	DNLMD	AHNP	✔	-	-	-	✔
[8]	One	NLP	Meta heuristics	-	-	-	-	-
[9]	One	NLP	LR	-	-	-	-	✔
[10]	One	MIP	Meta heuristics	✔	-	-	-	✔
[11]	One	LP	Scenario Set	✔	-	-	✔	✔
[12]	One	MIP	LR	-	-	-	✔	-
[13]	Three	Fuzzy	-	✔	-	-	-	✔
[14]	One	SD	Vensim	✔	-	-	-	✔
[15]	Two	MIP	CPLEX	✔	-	-	✔	✔
[16]	One	MIP	-	-	-	-	-	✔

N.O: Number of Objectives, R.A: Raw Materials, C.T: Clean Technology, E: Energy, E.M: Emission, W: Waste, LP: Linear Programming, MIP: Mixed-Integer Linear Programming, NLP: Non-Linear Programming, AHNP: Analytic Hierarchy Network Process, SD: System Dynamics, DNLMD: Dynamic Non-Linear Multi-Attribute Decision Model, LR: Lagrangian Relaxation

The research papers of TABLE 1 have not considered multi-objective and all environmental effective parameters such as raw materials, clean technology, emission, energy, and waste in CLSC configuration, simultaneously. In this paper, we develop a multi-objective model inclusion of environmental, technology and energy concerns for a CLSC network. This paper is organized as follows. In the next section, model description, model assumptions, model formulation, and solution methodology are described in details; then results and discussion, is presented, respectively. Finally, in the last section, conclusion is presented.

II. METHODOLOGY

A. Model description

We considered a comprehensive CLSC network to include production of new products by the plants that raw materials will be purchased from suppliers with variety qualities and distribution of new and remanufactured products to demand markets by DCs (DCs) in forward chain, and in reverse flow, collection and minor modification of end-of-life products by collection and modification centers (CMCs), waste destruction by disposal centers, recovery of returned products the same plants and redistribution of recovered products by the same DCs. Reusable products that need to minor modification, will be modified and returned to demand markets, while the useless products are disposed, and the remainder is sent to remanufacturing. For manufacturing and remanufacturing of products, plants with clean technology may use from group of environmentally friendly raw materials that may consume upper energy with least emissions, also for shipping the products to end users, DCs can use variety of clean technologies with different amount of energy consumption, as well as for collecting and modifying the returned products, collection and modification center can use as well. Otherwise, the related facilities will not be considered. Proposed closed-loop supply chain network is illustrated in Fig.1. A model corresponding to the proposed multi-echelon CLSC is configured for multi-product to determine the optimum flow of raw material, product, energy, waste, and emissions minimum in the network. Thus, the problem becomes a multi-objective problem.

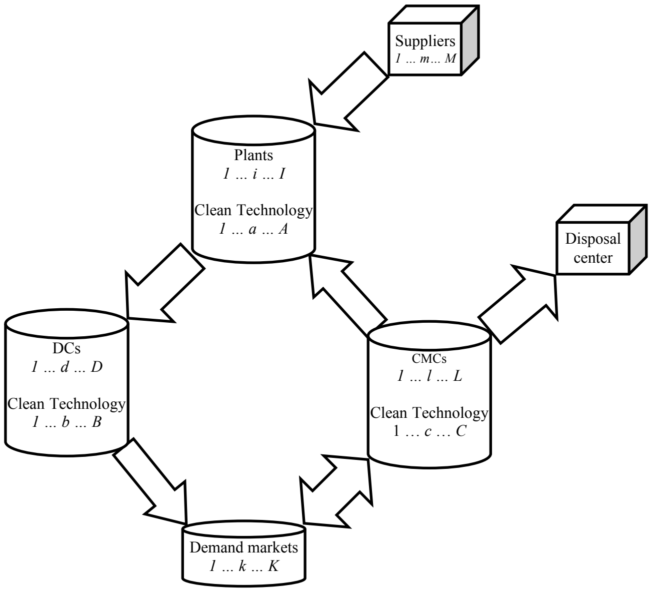

Fig. 1. Comprehensive CLSC network configuration and product flows in the proposed model

B. Model formulation

The network can be formulated as a mixed-integer linear programming model. Sets, parameters, and decision variables are defined as follows:

1) *Sets:*

M: set of group of environmentally friendly raw materials from suppliers with variety qualities

P: set of products

A, B, C: set of clean technology for plants, DCs, and CMCs, respectively.

I: set of potential manufacturing and remanufacturing plants locations

D: set of potential DCs locations

K: set of demand markets locations

L: set of potential CMCs locations

2) *Parameters:*

$PC1_m$: purchasing cost per unit of group of environmentally friendly m for plants

$PC2_{ipa}$: production cost per unit of product type p in plant i with clean technology a

$FC1_{ia}$, $FC2_{db}$, $FC3_{lc}$: investment cost by facilities with related clean technology.

$TC1_{ipa}$, $TC2_{dpb}$, $TC3_{kp}$, $TC4_{lpc}$, $TC5_{lpc}$, $TC6_{lpc}$: transportation cost of product type p per km between facilities with related clean technology.

$CS1_{lpc}$: cost saving of per unit of product type p in collection & modification center l with clean technology c (because of product recovery).

$CS2_j$: cost saving of per unit of product type p in plant i with clean technology a (because of product repair).
DC_p: disposal cost of product type p
CP_{ipa}, CD_{dpb}, CC_{lpc}: maximum capacity for product type p in facilities with related clean technology.
$D1_{id}$, $D2_{dk}$, $D3_{kl}$, $D4_{li}$, $D5_l$: the distance between facilities, generated based on the Euclidean method.
DEM_{kp}: demand of customer k for product type p
RET_{kp}: return of customer k for product type p
$MIDF_p$: minimum disposal fraction of product type p
VFM_{ima}, VFP_{ipa}, VFD_{dpb}, VFC_{lpc}: amount of emission per unit group of environmentally friendly raw materials m and clean technologies to process per unit of product type p by related facilities.
VEM_{ima}, VEP_{ipa}, VED_{dpb}, VEC_{lpc}: cost per unit of energy consumed to supply group of environmentally friendly raw materials m and to produce product type p for facilities with related clean technology.

3) *Variables:*

AMP_{ima}: amount of group of environmentally friendly m purchased by plant i with clean technology a
$X1_{idpa}$: quantity of product type p produced by plant i with clean technology a for distribution center d
$X2_{dkpb}$: quantity of product type p distributed by distribution center d with clean technology b for demand market k
$X3_{klp}$: quantity of product returned type p from demand market k to collection & modification center l
$X4_{lkpc}$: quantity of product repaired type p from collection & modification center l with clean technology c to demand market k
$X5_{lipca}$: quantity of product returned type p from collection & modification center l with clean technology c to plant i with clean technology a
$X6_{lpc}$: quantity of product dispatched type p from collection & modification center l with clean technology c to disposal center
$Y1_{ia}$: 1 if a plant is located and set up at potential site i with clean technology a and 0 otherwise
$Y2_{db}$: 1 if a distribution center is located and set up at potential site d with clean technology b and 0 otherwise
$Y3_{lc}$: 1 if a collection & modification center is located and set up at potential site l with clean technology c and 0 otherwise.
Z: main objective function

$$\begin{aligned}
z = {} & \sum_i\sum_a FC1_{ia}Y1_{ia} + \sum_d\sum_b FC2_{db}Y2_{db} \\
& + \sum_l\sum_c FC3_{lc}Y3_{lc} + \sum_i\sum_m\sum_a PC1_m AMP_{ima} \\
& + \sum_i\sum_d\sum_p\sum_a (PC2_{ipa} + TC1_{ipa}D1_{id})X1_{idpa} \\
& + \sum_d\sum_k\sum_p\sum_b (TC2_{dpb}D2_{dk})X2_{dkpb} \\
& + \sum_k\sum_l\sum_p TC3_{kp}D3_{kl}X3_{klp} \\
& + \sum_l\sum_k\sum_p\sum_c (-CS1_{lpc} + TC4_{lpc}D3_{kl})X4_{lkpc} \\
& + \sum_l\sum_i\sum_p\sum_c\sum_a (-CS2_{ipa} + TC5_{lpc}D4_{li})X5_{lipca} \\
& + \sum_l\sum_p\sum_c (DC_p + TC6_{lpc}D5_l)X6_{lpc}
\end{aligned} \tag{1}$$

$$\begin{aligned}
z_2 = {} & \sum_i\sum_m\sum_a VFM_{ima}AMP_{ima} \\
& + \sum_i\sum_d\sum_p\sum_a VFP_{ipa}X1_{idpa} \\
& + \sum_d\sum_k\sum_p\sum_b VFD_{dpb}X2_{dkpb} \\
& + \sum_l\sum_k\sum_i\sum_p\sum_c\sum_a VFC_{lpc}(X4_{lkpc} + X5_{lipca} + X6_{lpc})
\end{aligned} \tag{2}$$

$$\begin{aligned}
z_3 = {} & \sum_i\sum_d\sum_p\sum_a VEP_{ipa}X1_{idpa} \\
& + \sum_d\sum_k\sum_p\sum_b VED_{dpb}X2_{dkpb} \\
& + \sum_l\sum_k\sum_i\sum_p\sum_c\sum_a VEC_{lpc}(X4_{lkpc} + X5_{lipca} + X6_{lpc})
\end{aligned} \tag{3}$$

$$\sum_d\sum_p X1_{idpa} = \sum_m AMP_{ima} + \sum_l\sum_p\sum_c X5_{lipca} \quad \forall i,a \tag{4}$$

$$\sum_k\sum_b X2_{dkpb} = \sum_i\sum_a X1_{idpa} \quad \forall d,p \tag{5}$$

$$\sum_i\sum_d\sum_a X1_{idpa} \ge DEM_{kp} \quad \forall k,p \tag{6}$$

$$\sum_d\sum_p X1_{idpa} \le Y1_{ia}\sum_p CP_{ipa} \quad \forall i,a \tag{7}$$

$$\sum_k\sum_p X2_{dkpb} \le Y2_{db}\sum_p CD_{dpb} \quad \forall d,b \tag{8}$$

$$\begin{aligned}
& \sum_k\sum_p X4_{lkpc} + \sum_i\sum_p\sum_a X5_{lipca} + \sum_p X6_{lpc} \\
& \le Y3_{lc}\sum_p CC_{lpc}
\end{aligned} \quad \forall l,c \tag{9}$$

$$\sum_l X3_{klp} \le \sum_d\sum_b X2_{dkpb} \quad \forall k,p \tag{10}$$

$$MIDF_p\sum_k X3_{klp} \le \sum_c X6_{lpc} \quad \forall l,p \tag{11}$$

$$\sum_k X3_{klp} = \sum_k\sum_c X4_{lkpc} + \sum_i\sum_c\sum_a X5_{lipca} + \sum_c X6_{lpc} \quad \forall l,p \tag{12}$$

$$\sum_l X3_{klp} = RET_{kp} \quad \forall k,p \tag{13}$$

$$\sum_l\sum_c X4_{lkpc} \le \sum_l X3_{klp} \quad \forall k,p \tag{14}$$

$$\sum_a Y1_{ia} \le 1 \quad \forall i \tag{15}$$

$$\sum_b Y2_{db} \le 1 \quad \forall d \tag{16}$$

$$\sum_c Y3_{lc} \le 1 \quad \forall l \tag{17}$$

$$Y1_{ia}, Y2_{db}, Y3_{lc} \in \{0,1\} \quad \forall i,d,l \tag{18}$$

$$AMP_{ima}, X1_{idpa}, X2_{dkpb}, X3_{klp}, X4_{lkpc}, X5_{lipca}, X6_{lpc} \ge 0 \tag{19}$$

The first objective in equation (1), would be minimizing total cost, and the second objective in equation (2), is describing the environmental issues raised while maximizing usage of appropriate raw materials in order to degrade emissions even if used energy increases. In equation (3), the third objective ensure that consumption energy is minimizing in the network. Equation (4) show that new products are composite of raw materials and returned products. In equation (5), we define that imported products to DCs from plants, is equal with productions of plants. Equation (6) ensures that the total number of each manufactured product for each demand market is equal or greater than the demand. For capacity constraints, refer to equations (7)-(9). Equation (10) represents that forward flow is greater than reverse flow. Equation (11) enforces a minimum disposal fraction for each product. Equation (12) shows that the quantity of returned products from demand market is equal to the quantity of returned products to plants, quantity of modified products in CMCs, and quantity of products in disposal center for each collection and modification center and each product. Equation (13) shows the returned products. Equation (14) ensures that the total number of each exported product for each demand market is equal or lower than the imported product to it, from CMCs. Equations (15)-(17) show that the total number of the open facilities included of plants, DCs, and CMCs, is equal or lower than 1. Binary variables and non-negative are introduced in the equations (18)-(19).

C. Solution Methodology for the multi objective phenomena

In order to correctly handle the epsilon-constraint method, we must have the domain of at least n–1 intervals, which are applied as constraints. The nadir value is generally estimated with the minimum of the corresponding column [17]. In order to dominate this uncertainty, we suggest the use of lexicographic optimization in order to form the payoff table with only Pareto optimal solutions (TABLE 3) [18]. After termination the computation of the payoff table, domains of the objective functions is divided to 10 similar distances, and we handle the 11 grid points as the values of e2 and e3 in the epsilon-constraint method (TABLE 4) [19]. At the same moment, slack or surplus variables are used as a second term (with lower precedence in a lexicographic method) in the objective function, enforcing the program to generate alone effective solutions. In order to keep away from any scaling problems, it is suggest to substitute s_i in the second term of the objective function by s_i/r_i, where r_i is the domain of the i^{th} objective function (as computed from the payoff table). Thus, objective function of the augmented epsilon-constraint method becomes [18]:

$$Min \quad f_1(x) + eps * (s_2/r_2 + s_3/r_3) \qquad (20)$$
$$s.t.$$
$$f_2(x) + s_2 = e_2$$
$$f_3(x) + s_3 = e_3$$
$$x \in S \text{ and } s_i \in R^+$$

Where eps is an enough small number (generally between 10^{-3} and 10^{-6}).

III. RESULTS

In this section, sensitivity analyze has been accomplished with regard to a numerical example by considering uniform distribution (TABLE 2) and adding new parameters such as amount of emission and cost per unit of energy consumed between 0 and 1, to demonstrate the validity and applicability of the mathematical model and to provide managerial insights. Test problems have been solved by GAMS software. The sensitivity analysis of e_2 and e_3 according to the objective function has been demonstrated in Fig.2. As well as, in TABLE 4, the numbers of open facilities along with selected technology have been written.

TABLE 2
Data for example

PC = UNIFORM (20, 80)	*CD* = UNIFORM (756, 924)
FC = UNIFORM (20, 80)	*CC* = UNIFORM (306, 374)
TC = UNIFORM (0.0131, 0.0160)	*D* = UNIFORM (0, 100)
CS1 =UNIFORM (68.0, 78.0)	*DEM* = 300
CS2 = UNIFORM (6.3, 7.7)	*RET* = 100
DC = UNIFORM (2.25, 2.75)	*MIDF* = UNIFORM (0.27, 0.33)
CP = UNIFORM (756, 924)	

TABLE 3
Payoff table obtained by the lexicographic optimization of the objective function

Obj. function	f_1	f_2	f_3
Min f_1	17650.672	2846.970	1543.485
Min f_2	54185.329	1201.099	2150.455
Min f_3	35688.055	2276.327	1075.228

TABLE 4
Results of augmented epsilon-constraint method

	e_2	e_3	Value of f_1	Open Plants	Open DCs	Open CMCs
1	1201	1075	17187.891	I2.A2	D1.B1, D2.B2	L1.C1, L2.C2
2	1366	1182	17192.806	I2.A2	D2.B1	L1.C1, L2.C2
3	1531	1291	17382.310	I2.A2	D2.B2	L1.C1, L2.C2
4	1696	1399	17351.882	I2.A2	D2.B2	L1.C1, L2.C2
5	1861	1507	17107.280	I2.A2	D2.B1	L1.C1, L2.C2
6	2026	1615	17078.831	I2.A2	D2.B1	L1.C1, L2.C2
7	2191	1723	17050.382	I2.A2	D2.B1	L1.C1, L2.C2
8	2356	1831	17091.430	I2.A2	D2.B1	L1.C1, L2.C2
9	2521	1939	17136.402	I2.A2	D2.B1	L1.C1, L2.C2
10	2686	2047	17294.282	I2.A2	D1.B2	L1.C1, L2.C2
11	2851	2155	17265.528	I2.A2	D1.B2	L1.C1, L2.C2

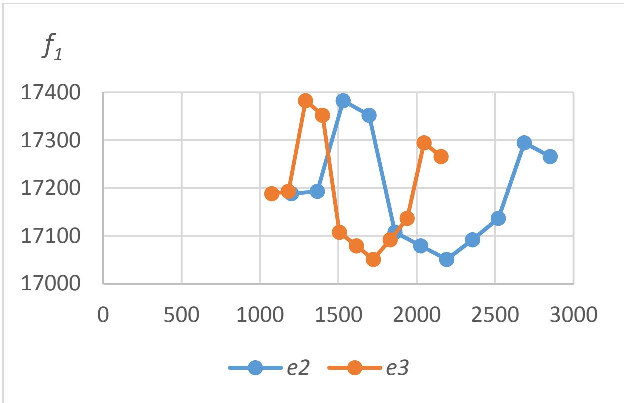

Fig. 2.Sensitivity analysis of *e*

We compare the analytical results of competition between traditional CLSC and our proposed CLSC. TABLE 5 shows optimum value of every three objective functions in traditional and our proposed CLSC.

TABLE 5
To compare the analytical results

Traditional CLSC			Proposed CLSC		
f_1	f_2	f_3	f_1	f_2	f_3
16592.660	2486.970	1423.485	17650.672	1201.099	1075.228

IV. DISCUSSION

As shown in TABLE 5, with regard to the numerical example, traditional CLSC has been solved. Value of total cost objective function in traditional CLSC is become slightly less, and value of objective functions related to emission of technology and energy is become higher than proposed CLSC. This results confirm that by selecting appropriate raw materials, using clean technology, and optimizing used energy, manufacturing costs might increase in the short term, but amount of emission and cost of energy consumed will be decreased. As well as, in the long term, total cost not only is minimized but also it will decline disposal products to cause environmental pollutions.

V. CONCLUSION

In this paper, a multi-objective mixed-integer linear programming model was developed and used to study the trade-offs between total cost, amount of emission, and cost per unit of energy consumed. The set of Pareto-optimal solutions were generated by the augment epsilon constraint method which showed the trade-offs between total cost, emission, and energy. In this paper, we considered a model inclusion of environmental, technology and energy concerns for a CLSC network, simultaneously. To compare the analytical results of competition between traditional CLSC and our proposed CLSC showed how less emission and energy consumed can minimize total cost. The proposed model presents decision maker flexibility to adapt for distinct conditions. It is enough comprehensive to be public and enough flexible to be special, this would make the decision taken using this precise model by selecting appropriate recovery options, and informative by introducing the most powerful factors that conduct for the decision making. Future related research is to develop heuristic approaches, for example scatter search because it is difficult to solve the problem for large size instances in a dedicated time. By the way, the proposed model has been designed for a single period. The model can be extended to consider more periods. For this purpose, the inventory level must considered.

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