A Proposed Multi-Objective Mixed Integer Programming For Greening Supply Chains

Javad Nematian, and Seyed Salar Ghotb

Abstract**—**Today the importance of environmental concerns is obvious for everyone. Governments and industries increasingly are trying to perform their function in a way that is compatible with environment, so one of the proper solution is reducing the negative effects of supply chains which are destroying environment. This paper proposes a multi-objective mixed integer programming which is trying to minimize costs and CO_2 emissions simultaneously. To illustrate the use of the model, a numerical example which is based on real data is presented.

Index Terms**—** CO_2 emissions, environment, Green supply chain, multi-objective model

I. Introduction

Nowadays if firms and businesses want to be successful in competitive market, they should increasingly focus on customers' behavior and try to satisfy their needs immediately. To reach to this goal, firms and organizations must service to their customers in better quality and in shorter time. As customers' expectations are changing rapidly, firms and companies should be flexible enough to be compatible to these changes and uncertainties. It is clear that organizations have to cooperate with each other to have the best performance in meeting their customers' expectations, so the solution is supply chain. Supply chains can provide a framework which can be so practical for businesses to gain more profit.

Recently environmental issues have become one of the important concerns of public opinion. Environmental problems like global warming have been more focused than before. In our competitive world, if countries want to reach to sustainable development, they should pay attention to environment and resources. Consequently unions and governments try to legislate laws like KYOTO PROTOCOL to reduce destruction of environment. To response to these concerns, firms and organizations have to take into account environmental practices to apply green philosophy in their activities [1]-[3]. As we know supply chain is a key to success for industries in their business, but it can cause negative effects. Green supply chain management (GSCM) can cover many concepts that businesses and industries can response to both economic and environmental concerns by greening their activities [4]. Greening of a supply chain is not easy and it may need new perspective and new designing. If organizations want to be successful in greening supply chains, they should know about traits and the current situation of their supply chains. They can reach to this goal by careful evaluating the supply chain, determining its week points and finding areas which can be improved. GSCM adds environmental issues to managers' priorities and affects their decisions [5]. Buying and guessing adequate amount of raw materials, cost of manufacturing, choosing proper distributors, assigning appropriate vehicle and marketing are the most important areas in GSCM. Suppliers, manufacturers, distributors, retailers and vehicles are the main players in GSCM [6]. In many cases GSCM can be defined as a location finding problem. It means that if an organization wants to design a supply chain, it should consider a network of suppliers, candidates for opening factories and distribution centers, retailers and sets of vehicles, the problem is choosing the best locations for building factories and distribution centers and selecting an appropriate vehicle in order to minimize the total costs and also reduce pollution.

Transportation has an undeniable role in green supply chains because it can be one of the main resources of co_2 production, and it can also influence directly on total costs and delivery time, for example some vehicles like trains are economical and also maybe cleaner, but they can influence on delivery time so in this case industries and firms should choose an appropriate vehicle according to delivery policy and distances between suppliers, manufacturers and distributors.

One of the most important problems in green supply chain management is finding a best solution to balance economic and environmental concerns. This paper concentrates on finding a proper way to optimize and balance total costs and Carbon Dioxide emissions by creating a multi-objective mixed integer model. Efficient solution techniques are needed for solving complex green supply chains modeling efforts [7]. To solve this non-linearity and complexity, we use a specific method.

This paper is organized as follows: section 2 reviews the literature about green supply chain management; section 3 explains formulating the model; section 4 presents a numerical example; section 5 contains conclusion and discussions of future research.

II. Literature Review

By increasing concerns about environment, researchers try to definite green supply chain and introduce new ways to apply green practices. Testa and Iraldo [8] showed that green supply chain is closely related to other management practices. Sundarakani *et al.* [9] suggested an analytical model with Lagrangian and the Eulerian transport methods. Diabat and Govindan [10] proposed a model for participants in green supply chain by using an Interpretive Structural Modeling Framework. Paksoy *et al.* [11] suggested a linear programming for balancing different costs. Naini *et al.*[12] used game theory and balancing scorecard in green supply

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chain to create a system of measuring that evaluated the performance of business in aspects of monetary, business process, customer and development and learning. Chaabane *et al.* [13] suggested a mixed integer linear programming framework to balance environmental and economic in aluminum industry. Elhedhli and Merrick [14] proposed a model with using a concave function and they used Lagrangian heuristic method to solve it. Lee [15] used eco-control method for carbon management in Korean automobile manufacturers. Wang *et al.* [16] applied fuzzy logic to analytical hierarchy process (AHP) in order to make a better decision in choosing strategy among green inventions in fashion industry. Caniëls *et al.* [17] tried to concentrate on supplier's role in greening supply chains, they proved the framework by using data of 54 German automotive suppliers. Yang *et al.* [18] analyzed the relationships between green practices and firm competitiveness in the container shipping context, they employed a survey of 163 containers shipping firms in Taiwan and used structural equation model. Zhu *et al.* [19] proposed a theoretical model of pressures persuading firms to apply green supply chain management practices and proportionate performance results. Kannan *et al.* [20] proposed an integrated approach, of fuzzy utility theory and multi-objective programming, for ranking and choosing the best green suppliers according to monetary and environmental factors and determined the optimum order quantities among them. Green restaurant standards were developed by Wang *et al.* [21], they applied Delphi Technique to combination of green practices and food and beverage management. Mirhedayatian *et al.* [22] considered fuzzy data, undesirable outputs and dual-role factors and offered a new (DAE) model for assessing green supply chains. Sazvar *et al.* [23] suggested a linear model by assuming transportation and inventory costs inside the green practices in the proposed model. Tian *et al.* [24] tried to develop green supply chain practices in China by proposing a system dynamics model and used game theory to show relationships of stakeholders. Stefanelli *et al.* [25] concluded that green supply chain management practices strengthened the Brazilian bioenergy sector. Ramanathan *et al.* [26] tried to improve the environmental sustainability of companies' supply chains by concentrating on suppliers, logistics and retailers, and they also provided the framework to help firms to facilitate reaching to their environmental goals. Kuei *et al.* [27] introduced the important items in implementing green supply chain practices in Chinese firms, they also concluded from data that environmental factors outside of firms like government supports, laws, etc. had a very essential role in applying green practices to supply chains.

III. MODEL FORMULATION

A. Description

We consider a green supply chain as a network of suppliers, manufacturers, distributors, retailers and sets of vehicles for transporting products. There are candidates for building factory for manufacturing and distribution center for distributing final products that each candidate has a fixed-cost to build. The problem is choosing the best suppliers, factory, distribution center and vehicle in order to meet the demands of the retailers and optimize total costs and co_2 emissions. In the proposed model we assumed that the demands of the retailers are deterministic and vehicles are the main resources of co_2 production.

B. Notation

Indices

i	index of retailers
j	index of distribution centers
k	index of factories
l	index of vehicle type
m	index of suppliers

Parameters

c_m	cost of unit of raw material by supplier m
b_k	cost of building factory at location k
s_j	cost of building distribution center at location j
g_l	transportation cost by vehicle type l per unit of distance
d_{mk}	distance between supplier m and factory at location k
d_{kj}	distance between factory at location k and distribution center at location j
d_{ji}	distance between distribution center at location j and retailer i
α	percent of raw materials that are converted into final products
t_i	demand of retailer i
p_l	amount of gas emissions in gram by vehicle type l per unit of distance

Decision variables

x_{mk}	amount of raw materials transporting from supplier m to factory at location k
y_{kj}	amount of final products transporting from factory at location k to distribution center at location j
u_{ji}	amount of final products transporting from distribution center at location j to retailer i
cost	total costs
co_2	total carbon dioxide emissions in gram

$$v_k \begin{cases} 1 & \text{if factory is built at location k} \\ 0 & \text{otherwise} \end{cases}$$

$$w_j \begin{cases} 1 & \text{if distribution center is opened in location j} \\ 0 & \text{otherwise} \end{cases}$$

$$a_l \begin{cases} 1 & \text{if vehicle type l is chosen} \\ 0 & \text{otherwise} \end{cases}$$

C. The Model

$$\text{Min cost}=\sum_m\sum_k c_m.x_{mk} + \sum_k b_k.v_k + \sum_j s_j.w_j + \sum_l\sum_m\sum_k g_l.d_{mk}.a_l.x_{mk} + \sum_l\sum_k\sum_j g_l.d_{kj}.a_l.y_{kj} + \sum_l\sum_j\sum_i g_l.d_{ji}.a_l.\text{u}_{ji} \quad (1)$$

$$\text{Min co}_2 = \sum_l\sum_m\sum_k a_l.p_l.v_k.d_{mk} + \sum_l\sum_k\sum_j a_l.p_l.w_j.v_k.d_{kj} + \sum_l\sum_j\sum_i a_l.p_l.w_j.d_{ji} \quad (2)$$

Subject to:

$$\alpha.\sum_m\sum_k x_{mk}.v_k = \sum_i t_i \quad (3)$$

$$\sum_j u_{ji}.w_j = t_i \qquad \forall i \quad (4)$$

$$\sum_i u_{ji}.w_j \le \sum_k y_{kj}.v_k \qquad \forall j \quad (5)$$

$$\sum_k v_k = 1 \quad (6)$$

$$\sum_l a_l = 1 \quad (7)$$

$$\sum_j w_j = 1 \quad (8)$$

$$v_k = \{0,1\} \qquad \forall k \quad (9)$$

$$a_l = \{0,1\} \qquad \forall l \quad (10)$$

$$w_j = \{0,1\} \qquad \forall j \quad (11)$$

$$x_{mk}, y_{kj}, u_{ji} \ge 0 \quad (12)$$

Objective function (1) tries to minimize total costs including cost of purchasing raw materials from suppliers, fixed cost of building selected factory and distribution center, transportation costs of raw materials and final products between suppliers, factory, distribution center and retailers. Objective function (2) is minimizing total co_2 emissions. Constraint (3) asserts that only specific percent of raw materials are converted into final products. Constraint (4) satisfies demand of each retailer. Constraint (5) tries to balance the input and output of distribution center. Constraint (6) ensures that only one of the candidates for building the factory is chosen. Constraint (7) asserts that only one of the vehicles should be selected. Constraint (8) ensures that only one of candidates for establishing distribution center will be chosen. Constraints (9)-(11) assert that decision variables including v_k , a_l and w_j should be binary variables. Constraint (12) asserts that other decision variables are non-negative.

Now to solve the aforementioned multi-objective model, Nematian [28] manner and Zimmermann [29] method are applied as follows:

Let z^1 be lower bound of cost and $z_l^1 + \rho^1$ be its' initial value and let z^2 be lower bound of co_2 and $z_l^2 + \rho^2$ be its' initial value. We assume:

$$z_1 = \sum_m\sum_k c_m.x_{mk} + \sum_k b_k.v_k + \sum_j s_j.w_j + \sum_l\sum_m\sum_k g_l.d_{mk}.a_l.x_{mk} + \sum_l\sum_k\sum_j g_l.d_{kj}.a_l.y_{kj} + \sum_l\sum_j\sum_i g_l.d_{ji}.a_l.\text{u}_{ji} \quad (13)$$

$$z_2 = \sum_l\sum_m\sum_k a_l.p_l.v_k.d_{mk} + \sum_l\sum_k\sum_j a_l.p_l.w_j.v_k.d_{kj} + \sum_l\sum_j\sum_i a_l.p_l.w_j.d_{ji} \quad (14)$$

By applying this method our model is converted into following model:

$$\max\ \eta \quad (15)$$

subject to:

$$z_1 \le z_l^1 + (1-\eta)\rho^1 \quad (16)$$

$$z_2 \le z_l^2 + (1-\eta)\rho^2 \quad (17)$$

$$\alpha.\sum_m\sum_k x_{mk}.v_k = \sum_i t_i \quad (18)$$

$$\sum_j u_{ji}.w_j = t_i \qquad \forall i \quad (19)$$

$$\sum_i u_{ji}.w_j \le \sum_k y_{kj}.v_k \qquad \forall j \quad (20)$$

$$\sum_k v_k = 1 \quad (21)$$

$$\sum_l a_l = 1 \quad (22)$$

$$\sum_j w_j = 1 \quad (23)$$

$$0 \le \eta \le 1 \quad (24)$$

$$v_k = \{0,1\} \qquad \forall k \quad (25)$$

$$a_l = \{0,1\} \qquad \forall l \quad (26)$$

$$w_j = \{0,1\} \qquad \forall j \quad (27)$$

$$x_{mk}, y_{kj}, u_{ji} \ge 0 \quad (28)$$

D. Linearization

If we want to reach to a global optimized answer we should convert our mixed integer non-linear programming to mixed integer linear programming. For this purpose we use the following method:

Suppose x is a binary variable and y is a positive variable. Clearly $x.y$ is a non-linear variable and in order to linearize, we rewrite it as follows:

$$z = x.y \tag{29}$$

By writing equation(29), three following inequalities are added :

$$z - M.x \le 0 \tag{31}$$

$$z - y + M.x \le M \tag{32}$$

$$z - y - M.x \ge -M \tag{33}$$

Where M is a very large number. After the linearization, the model can be solved by using CPLEX solver in GAMS.

IV. Numerical Example

This section presents a numerical example to illustrate the proposed model. We surveyed flour industry in Iran and considered a firm and analyzed its' supply chain which was a network of four suppliers, two candidates for building factory, four candidates for establishing distribution center, seven retailers and three vehicle types and our aim was designing a supply chain. In order to obtain data, we designed a questionnaire and experts filled it.

TABLE I
: COST OF PURCHASING A UNIT OF RAW MATERRIAL FROM SUPPLIER M($)

Cities	Tabriz	Rasht	Zanjan	Sanandaj
C	249	260	255	245

TABLE II
: COST OF BUILDING A FACTORY ($)

Cities	Qazvin	Tehran
B	185000	200000

TABLE III
: COST OF OPENING A DESTRIBUTION CENTER ($)

Cities	Esfahan	Kerman	Babol	Semnan
S	2000	1500	1700	1400

Some other data like distances between suppliers, candidates for building factories, candidates for opening distribution center and retailers are accessible in [30]. To have production, manufacturer should purchase adequate raw materials from suppliers, and suppliers provide raw materials in different prices (See Table I). If organizations want to reduce costs they should consider several locations for opening factories and distribution centers, and each location has a fixed-cost to build factories and distribution centers (as shown in Tables II and III). The main purpose of managers and firms in using supply chains is meeting customers' expectations in the shortest time and in an economic manner. In our example, we assume that demands of retailers are deterministic which are given in Table IV.

As transportation can influence on total costs and co_2 emissions directly, managers must assign the best vehicle and each vehicle can be evaluated in two aspects, the first one is related to transportation costs and the other is its' role in damaging environment. Our example has three vehicle types that one of them should be chosen according to costs, delivery policy and amount of co_2 emissions. Table V shows the cost of transportation and amount of co_2 emissions by vehicle types.

Factories usually can't convert the whole raw materials into final products and they often produce wastes, so for specifying the percent of raw materials that is transformed to final products, we considered factories and collected their statistics and also asked manufacturers, by analyzing the data, we assumed $\alpha = 0.75$ as an average of capacity of factories. Then we linearized the non-linear model by using the mentioned approach.

TABLE IV
DEMAND OF RETAILERS (TON)

Demand	t
Ahvaz	46
Mashhad	75
Zahedan	30
Shiraz	52
Bandarabbas	40
Bushehr	27
Sari	30

TABLE V
COST OF TRANSPORTATION ($) AND AMOUNT OF EMISSIONS BY VEHICLE PER UNIT OF DISTANCE (GRAM)

Vehicle	Type1	Type2	Type3
G	0.35	0.68	1
P	0.085	0.036	0.009

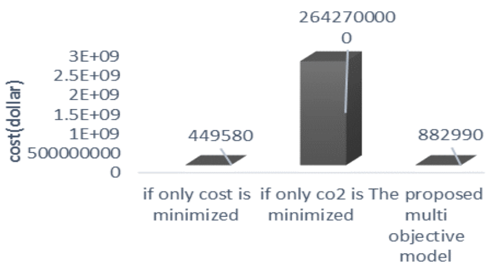

Fig. I. Differences between three types of modelling in total costs

Finally we employed the data in three models and solve them by CPLEX solver in GAMS, in the first model we minimized costs, in the second one co_2 is minimized and the third one is our proposed model in which costs and co_2 are minimized simultaneously. As shown in fig.1 the proposed model balanced costs and fig. II shows that the proposed model has optimized co_2 emissions.

V. CONCLUSION

Managers, all around the world, are trying to gain more profit and also green their businesses. This paper introduced a multi-objective mixed integer model. Because of non-linearity and complexity, the model is linearized to reach to a global optimum answer and this model can be solved by CPLEX solver in GAMS. The main aim of this paper was finding new methods to insert green practices into supply chains. As shown in numerical example, the proposed model can optimize costs and co_2 emissions, so this model can help managers to be more careful in choosing vehicles for transportation and also in finding the path to meet demands.

For future work, we intend to consider uncertainty retailers' demands.

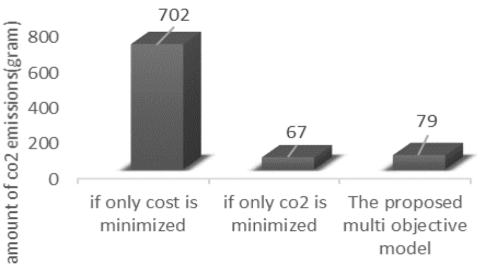

Fig. II. Differences between three types of modelling in co_2 emissions

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