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Designing a Green Supply Chain Transportation System for an Automotive Company Based On Bi-Objective Optimization

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Abstract. Recently, due to the increasing awareness of communities regarding environmental issues and environmental regulations, companies have evolved to provide products with lower prices and better quality to retain and attract customers. Economics should also pay attention to environmental goals. Therefore, it is essential to provide a supply chain model that can consider both economic and environmental objectives. In this

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paper, the green direct supply chain network is presented to an automotive company, including five suppliers, primary warehouses, manufacturing plants, distributors, and sales centers. The objectives of this model are to minimize the total cost of construction, transportation, and the amount of carbon dioxide emissions during forwarding network transportation at all levels. The proposed model is also drawn using the weight method, which is one of the methods for solving multi-objective problems, and the solution of the model part. Ultimately, it has been discussed how much the automobile company should focus on reducing carbon dioxide so that managers can determine the best solutions from the Pareto border according to their organization's priorities, which can be environmental or financial.

Keywords: Multi-Objective Optimization, Green Supply Chain; Transportation; Weighting Method.

1. Introduction

The phrase sustainable or green supply chain intends to integrate sustainable environmental approaches into the conventional supply chain. That phenomenon is able to incorporate processes, including product design, supplier selection and purchasing material, product manufacturing and assembling, distribution, and end-of-life management [1,2]. Rather than alleviating the detrimental effect of business and supply chain functions, the green supply chain implicates value addition and value creation via the processes of the entire chain [3]. Undoubtedly, decreasing water, air, and waste pollution is the primary objective of the green supply chain. Furthermore, green operations improve firms' performance in less waste manufacturing, reuse, and recycling of products, decreasing manufacturing expenses, more significant assets, favorable image building, and more outstanding customer satisfaction [4,5].

The direct green supply chain includes all activities through which raw materials are turned into final products. Managers attempt to improve the function of direct supply chains in the area of demand management and also take environmental issues into account. In research, Wang et al. solved the green supply chain model by the normal constraint (NC) method [6]. In another study, Abdallah et al. developed a mixed-integer program for the carbon-sensitive supply chain that minimizes emissions throughout the supply chain [7]. Moreover, Pishvaee and Razmi proposed a multi-objective fuzzy mathematical programming model for designing a needle and syringe manufacturer network and solved their model by the Epsilon-Delta limit [8]. Fartaj et al. presented a transportation model in a supply chain network based on a network disruption approach [9]. In another research, Zhang et al. used the game theory to investigate four green supply chain models [10]. Furthermore, Hota proposed a novel direct solution method for designing a three-level logistics network [11]. On the other hand, Ramezani et al. applied the fuzzy technique for designing a green supply chain model [12].

In 2015, a boiler manufacturing plant presented an optimal flow of products and the number of trucks [13]. In addition, the green supply chain model of the electronics factory was modeled in 2017 [14]. In 2018, Sadeghi Rad et al. solved a green supply chain planning model by weighting [15]. In 2020, new research on the green supply chain is presented; for instance, Micheli et al. investigated the structure of a green supply chain and its stimulators. These scholars assessed 169 chains in Italy and extracted relationships

between the pillars of the green supply chain [16]. Lin and Zhang presented an incentive model between a contractor and multiple subcontractors in a green supply chain in another study. To this end, a mathematical model was developed to reduce supply chain costs [17]. Afterward, the robust optimization approach was exploited to consider environmental performance with uncertainty. Mahjoob et al. designed a green supply chain network emphasizing inventory decisions. In this respect, they presented a bi-objective formulation where multiple inventory components were integrated into the location and routing decisions throughout the supply chain network. Notably, revolutionary algorithms were used to solve the model [18].

In another study, Qu et al. [19] optimized a supply chain in two mathematical models while considering product warranty and environmental pollutions. They proposed a Stackelberg equilibrium, the optimal decisions of which were obtained in the two models generated for the leader and the follower. The results were obtained on different samples, and the model's accuracy was analyzed [19-22]. Another relevant analysis is performed by Hugo et al. [23], who designed a multi-objective optimization technique for hydrogen networks, where they analyzed trade-offs between investment and greenhouse gas emissions. Bojarski et al. [24] investigated optimizing the design and planning of the supply chains, taking the economic and environmental issues into account. In general, incorporating CO2 emissions and multi-modality in supply chain design is lacking in the literature. Nonetheless, as most literature recommends integrating environmental topics and multi-modality is growing vital [25].

Overall, the study's primary aim is to provide the green direct supply chain network to an automotive company, involving five suppliers, primary warehouses, manufacturing plants, distributors, and sales centers. This model is provided and designed to reduce the total cost of construction, transportation, and carbon dioxide emissions throughout forwarding network transportation. Most studies have focused on the green supply chain in production units in small industries. It seems that few studies have been performed on the green supply chain of automotive companies. Moreover, most models presented have been of single-product type, and designing a multi-product model can help the research in this field. Hence, the novelty of this study is to provide a more comprehensive and sophisticated mathematical model compared to previous models. Thus, designing this model can assist managers in having more excellent knowledge of their organization’s external and internal transportation system and make more informed decisions to enhance the organization.

2. Statement of the Problem

The present study proposes a bi-objective, five-layer, and multi-product model of the forward green supply chain for transportation of automotive companies, which can consider both economic and environmental goals. The first objective is to minimize construction and transportation costs. In contrast, the second objective focuses on minimizing the amount of carbon dioxide emissions during forwarding network transportation at all levels. This model includes the five-layer supply chain network, the levels of which respectively include raw material suppliers (who transfer raw material to warehouses), raw material storage warehouses (from where the raw material is transferred to the manufacturing plants for producing the product), manufacturing plants (where the final product is produced and transferred to distribution centers), and distribution centers (from where the final product is

transferred to the fifth level to be sold to the customers). There are several candidate locations, and one operation is performed at each level.

3. Proposed Model

3.1. Model Premises

Any produced product requires pre-determined raw materials. On the other hand, any supplier can produce and supply only some of the pieces, and pallets transfer raw materials and pieces with pre-determined capacities. The cost of transporting raw materials per kilometer is pre-determined by vehicles moving between suppliers to the initial temporary warehouses and from the temporary warehouses to the plant. It varies according to the type of transportation. In addition, the cost of transporting a product between distribution centers and customers is also pre-determined. Notably, the fixed cost of building a new distribution unit, a temporary warehouse, and a new plant is different. Different vehicles are needed to transport raw materials and products depending on their capacities. Moving raw materials and products between different facilities are fixed per kilometer. Moreover, each product and raw material has a specific and pre-determined capacity. In general, five percent of the parts and two percent of products need to be repaired. A 20-year vision plan is considered (meaning that a 20-year facility is exploited). All parameters are estimated and entered into the model monthly, and at least 10% of raw materials (pieces) are provided from each supplier to create competition among the suppliers.

3.2. Model Indexes

The required model indexes for designing the model are presented below:

n: the number of raw material suppliers (n=1, 2…, N)

n': the number of suppliers other than the n supplier (n'=1, 2…, N')

l: the number of raw material warehouses (l=1, 2…, L)

k: the number of plants (k=1, 2…, K)

k': the number of plants other than the k plant (k'=1, 2…, K')

q: the number of transportation vehicles (q=1, 2…, Q)

j: the number of distribution centers (j=1,2,…,J)

i: the number of customers (i=1, 2…, I)

w: the number of raw materials (w=1, 2…, W)

m: the number of products (m=1, 2…, M)

t: the number of vehicles transporting raw material from the supplier to the warehouse (t=1, 2…, T)

t': the number of vehicles transferring raw material from the warehouse to the plant (t'=1, 2…, T)

3.3. Model Parameters

Next, the parameters involved in the modeling are introduced, as below:

$Cap1_{tnl}$: The capacity of t-type raw material transportation vehicles for the transfer of raw material from the n supplier to the l initial warehouse (based on the standard pallet size)

$Cap2_{t'lk}$: The capacity of t'-type raw material transportation vehicles for the transfer of raw material from l initial warehouse to k plant (based on the standard pallet size)

$Cap3_q$: The capacity of q-type trucks

V_w: The volume (capacity) of w raw material (based on standard pallet size)

$TC1_{tnl}$: The transportation cost of t-type transportation vehicle per each km for transportation of raw material from n supplier to l initial warehouse

$TC2_{t'lk}$: The transportation cost of t'-type transportation vehicle per each km for transportation of raw material from l initial warehouse to k plant

$TC3_q$: The transportation cost of q-type transportation vehicle per km

$CC1_l$: The cost of construction of a new l temporary warehouse

$CC1_2$: The cost of construction of a new j distribution center

$CC3_k$: The cost of construction of a new k plant

$D1_{nl}$: The distance between supplier and l temporary warehouse

$D2_{lk}$: The distance between l temporary warehouse and k plant

$D3_{kj}$: The distance between k plant and j distribution center

$D4_{ji}$: The distance between j plant and i distribution center

D_{mi}: The amount of m product required for presentation to i customer

$Rate_{wm}$: The rate of consumption of w material in the production of m product

CO_2^{nlt}: CO2 generated in t-type transportation from the n supplier to the l initial warehouse

$CO_2^{lkt\prime}$: CO2 generated in t'-type transportation from the l initial warehouse to the k plant

CO_2^{kjq}: CO2 generated in q-type transportation from the k plant to the j distribution center

CO_2^{jiq}: CO2 generated in q-type transportation from the j distribution center to the i customer

$Cap1_{nw}$: The capacity of n supplier

$Cap2_{lw}$: The capacity of l candidate temporary warehouse centers

Cap_{jm}: The capacity of j candidate distribution location

ε: The rate of transfer of raw material to the next levels of supply chain

σ: The rate of transfer of products to the next levels of supply chain

θ: 10% as competition between suppliers

3.4. Decision Variables of Model

The model's Decision Variables are as follows:

$X1_{wnl}$: The amount of w raw material transferred from n supplier to l initial warehouse

$X2_{wlk}$: The amount of w raw material transferred from l raw material warehouse to k plant

$X3_{mkj}$: The amount of m product transferred from k plant to j distribution center

$X4_{mji}$: The amount of m product transferred from j distribution centers to i customer

$N1_{tnl}$: The number of t transportation vehicles that have traveled from n supplier to l raw material warehouse

$N2_{t'lk}$: The number of t' transportation vehicles that have traveled from the l raw material warehouse to the k plant

$N3_{qkj}$: The number of q transportation vehicles that have traveled between the k plant and the j distribution center

$N4_{qji}$: The number of q transportation vehicles that have traveled between the j distribution center and the i customer

$Y1_l$: Construction or lack of construction of the new l warehouse

$Y2_j$: Construction or lack of construction of the new j distribution center

$Y3_k$: Construction or lack of construction of the new k plant

δ_{wn}: Supply or lack of supply of parts by the supplier

3.5. Mathematical Model Equations

The first and second objective functions of the mathematical model, the number of products transferred from the distribution center to the sales units, equilibrium limit of input and output current, and other related features are presented as equations below:

$$\begin{aligned} minZ1 = & \sum_{n}\sum_{l}\sum_{t} N1_{tnl} \times D1_{nl} \times TC1_{tnl} \\ & + \sum_{l}\sum_{k}\sum_{t} N2_{t'lk} \times D2_{lk} \times TC2_{t'lk} \\ & + \sum_{k}\sum_{j}\sum_{q} N3_{qkj} \times D3_{kj} \times TC3_{q} + \sum_{j}\sum_{i}\sum_{q} N4_{qji} \times D4_{ji} \\ & \times TC4_{q} + \sum_{l} Y1 \times CC1_{l} + \sum_{k} Y3_{k} \times CC3_{k} + \sum_{j} Y2_{j} \times CC2_{j} \end{aligned} \quad (1)$$

$$\min Z2 = \sum_{n}\sum_{l}\sum_{w} N1_{tnl} \times CO_2^{nlt} \times D1_{nl} + \sum_{l}\sum_{k}\sum_{w} N2_{t'lk} \times CO_2^{lkt'} \times D2_{lk} + \sum_{k}\sum_{j}\sum_{m} N3_{qkj} \times CO_2^{kjq} \times D3_{kj} + \sum_{j}\sum_{i}\sum_{m} N4_{qji} \times CO_2^{jiq} \times D4_{ji} \quad (2)$$

$$\forall i, m$$

$$\sum_{i} X4_{mji} \geq D_{mi} \quad (3)$$

$$\forall j, m$$

$$\sigma \times \left(\sum_{k} X3_{mkj}\right) \geq \sum_{i} X4_{mji} \quad (4)$$

$$\forall w, k$$

$$\varepsilon \times \left(\sum_{l} X2_{wlk}\right) \geq \sum_{m}\sum_{j} X3_{mkj} \times Rate_{wm} \quad (5)$$

$$\forall l, w$$

$$\sum_{n} X1_{wnl} \geq \sum_{k} X2_{wlk} \quad (6)$$

$$\forall n, w$$

$$\sum_{l} X1_{wnl} \leq \delta_{wn} \times Cap1_{tnl} \quad (7)$$

$$\forall n, w$$

$$\sum_{l} X1_{wnl} - \left(\theta \times \sum_{n}\sum_{l} X1_{wnl}\right) \geq -\left(\theta \times \sum_{n}\sum_{l} Cap1_{tn1}\right) \times (1 - \delta_{wn}) \quad (8)$$

$$\forall n, l$$

$$\sum_{t} N1_{tnl} \times Cap1_{tnl} \geq \sum_{w} X1_{wnl} \times V_w \quad (9)$$

$$\forall l, k$$

$$\sum_{t} N2_{tlk} \times Cap1_{t'lk} \geq \sum_{w} X2_{wlk} \times V_w \quad (10)$$

$$\forall k, j$$

$$\sum_{q} N3_{qkj} \times Cap3_q \geq \sum_{m} X3_{mkj} \quad (11)$$

$$\sum_{q} N4_{qji} \times Cap3_{q} \geq \sum_{m} X4_{mji} \qquad \forall j, i \qquad (12)$$

$$\sum_{k} X2_{wlk} \times Cap2_{lw} \times Y1_{l} \qquad \forall l, w \qquad (13)$$

$$\sum_{i} X4_{mji} \leq Cap3_{jm} \times Y2_{j} \qquad \forall j, m \qquad (14)$$

$$\sum_{i} X3_{mkj} \leq Cap4_{km} \times Y3_{k} \qquad \forall k, m \qquad (15)$$

$$\sum_{l} Y1_{l} \leq L/2 \qquad (16)$$

$$\sum_{j} Y2_{j} \leq J/2 \qquad (17)$$

$$\sum_{k} Y3_{k} \leq K/2 \qquad (18)$$

$$X1_{wnl}, X2_{wlk}, X3_{mkj}, X4_{mji}, N1_{tnl}, N1_{t'lk}, N3_{qkj} \geq 0 \qquad \forall w, n, l, m, l, q \qquad (19)$$

$$Y1_{i}, Y2_{j}, Y3_{k}, \delta_{wn} \epsilon \{0,1\} \qquad j, k, n \forall l \qquad (20)$$

Equation [1] shows the first objective function of the mathematical model, which demonstrates the overall decrease in the system's costs. Equation [2] expresses the second objective function of the mathematical model, which shows the general reduction in environmental pollutions of the supply chain network. Constraints [3] show that the number of products transferred from the distribution center to the sales units should be as many as needed. Constraints [4] are an equilibrium limit of input and output current, showing that each distribution center delivers products to customers to the maximum of its capacity. Constraints [5] demonstrate that the amount of raw material input to each plant, considering the loss rate, must be greater than the output product. Constraints [6] guarantee the balance of the input and output of raw materials for the raw material warehouse. Constraints [7] and [8] express that if suppliers supply a quantity of w raw material, this quantity must be more than 10% of the total amount of W raw material (minimum capacity limit). Constraints [9-12] are related to the capacity of raw material and product transportation vehicles and guarantee the minimum ability of transportation vehicles. Constraints [13-15] are related to facility location, whereas constraints [16-18] limit the number of distribution centers,

plants, and temporary warehouses. Finally, constraints [19] and [20] are the logical constraints of the model.

3.6 Proposed Model Solution

Model parameters are presented in Table 1.

Table 1. Parameters of the bi-objective green supply chain model

Parameter	Range
CO_2^{kjq}, CO_2^{jiq}	[1,0,7]
CO_2^{lkt}	[1,0,2]
CO_2^{nlt}	[0.9, 0.5, 0.2]
$Cap1_{nw}$, $Cap4_{km}$, $Cap2_{lw}$, $Cap3_{jm}$	It can be determined according to the rate of use of raw material and the amount of demand in each issue.
The minimum and maximum number of plants, distribution centers, and opened initial warehouses	[2, 4]
$Rate_{wm}$	$U\sim(0,3)$
Dm_{1i}	$U\sim(30,120)$
Dm_{2i}	$U\sim(90,180)$
Dm_{3i}	$U\sim(60,150)$
$Cap3_q$	[6, 8]
$D1_{nl}$, $D2_{lk}$, $D3_{kj}$, $D4_{ji}$	$U\sim(20,100)$
$CC1_l$	$U\sim(25*10^6, 30*10^6)$
$CC2_j$	$U\sim(35*10^6, 46*10^6)$
$CC3_k$	$U\sim(380*10^6, 460*10^6)$
$TC1_{tnl}$	[10000,7000,5000]
$TC2_{t'lk}$	[7000, 5000]
$TC3_q$	[11000, 10000]
V_w	$U\sim(0.125,30.5)$
$Cap1_{tnl}$	[4, 16, 32]
$Cap2_{t'lk}$	[4, 18]
$D1_{nl}$, $D2_{lk}$, $D3_{kj}$, $D4_{ji}$	$U\sim(20,100)$

Data of three problem samples are presented in Table 2.

Table 2. Problem samples

Problem	Supplier	Initial Warehouses	Plants	Distribution Centers	Sales Centers	Products	Raw Materials
1	7	3	3	3	13	3	6
2	25	15	15	20	40	3	7
3	50	20	20	30	70	4	10

The weighting method [24-26] is one of the methods used for solving multi-objective problems. The objectives must be normalized to add two incompatible objective functions and convert those two objectives into one objective. The normalization method in the weighting method is as follows:

$$\min \quad w * \frac{Z1}{f1^{*}-f1'} + (1-w) * \frac{Z2}{f2^{*}-f2'} \qquad (21)$$

f1': The amount of Z1 objective function when Z2 objective function is optimized (the worst amount of Z1 objective function). f2': the amount of Z2 objective function when the objective function is optimized (the worst amount of Z2 objective function). f1*: the optimum amount of Z1 objective function without considering the second objective function (the best amount of Z1 objective function). f2*: the optimum amount of Z2 objective function without considering the first objective function (the best amount of Z2 objective function). w: weight of the objective functions, which can be any number between zero and one [15]. CPLEX solves the proposed mathematical model in GAMS software. Accordingly, the Pareto border is drawn from the set of model's solutions. Pareto solutions are provided to the organization's managers to choose the best solution based on organizational priorities.

3.7. Model Solution Results

Table 3 shows the results related to solving each problem. The second column shows the weights of each objective function. In total, six weight combinations are considered to solve each of these sample problems. The second column shows the set of Pareto solutions based on different weights. The last column reports the solution time for each sample problem. As observed, the solution time increases with the increased size of the sample problem.

Table 3. Model results

Problem Number	Weight of Objective Functions		Values of Objective Functions (Optimal Pareto Solutions)		Accurate Problem-solving Time
	W1	W2	Z1	Z2	
1	0	1	68771.1	333.9	00:08:00
	0.2	0.8	29600111.0	285.0	
	0.4	0.6	42453729.9	258.2	
	0.6	0.4	52834452.2	224.2	
	0.8	0.2	68318685.5	202.7	
	1	0	81728184.0	197.2	
2	0	1	89273189.7	193.7	00:35:00
	0.2	0.8	410980736.6	177.5	
	0.4	0.6	416355775.8	164.8	
	0.6	0.4	442134440.1	146.7	
	0.8	0.2	502168744.1	127.8	
	1	0	524560365.5	113.1	
3	0	1	884550871.3	108.8	01:58:00
	0.2	0.8	920996639.6	107.5	
	0.4	0.6	1457742816.4	107.5	
	06	04	1639171873.0	105.6	
	0.8	0.2	1711376067.6	104.3	
	1	0	3240534252.2	103.5	

The Pareto border of problem 1 is drawn in Figure 1, which shows the competition between environmental and economic objective functions:

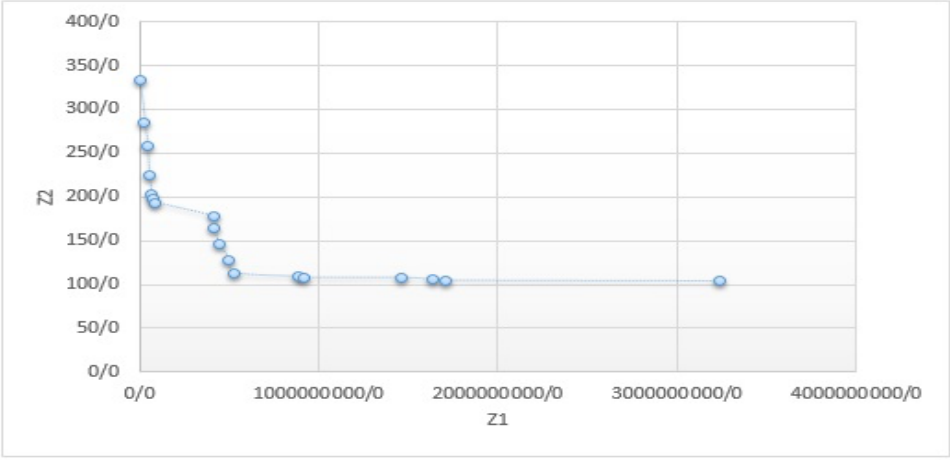


Figure 1. Pareto border of the bi-objective model for problem 1

4. Conclusion and Recommendation for Future Studies

In the present study, we considered a bi-objective five-level green supply chain model for automotive companies, where two environmental and economic objectives were considered. The network included suppliers, initial warehouses, manufacturing plants, distributors, and sales centers. The first objective was to minimize the construction and transportation costs, while the second objective was to minimize the amount of carbon dioxide during the transportation process in the entire levels of the supply chain. The proposed model was solved by the weighting method, which is one for solving multi-objective problems. In addition, three examples were run in GAMS software to show the application of the model, and the Pareto border of the model was drawn. This article made attempts to determine the costs imposed on automotive companies caused by the maximum percentage reduction in the amount of carbon dioxide released from the economic perspective of transportation system greening. This would help managers choose the best solution from the Pareto border based on organizational priorities, environmental priorities, or PROFITABILITY. Therefore, providing such a model can help managers have a better and faster understanding of their organization's external and internal transportation system and make better decisions to improve the organization. It is recommended that a probable amount of demand in each period be considered in future studies. In addition, it is suggested that the problem's parameters (e.g., facility capacity) be considered at an uncertain level. Furthermore, future studies can use metaheuristic algorithms to solve the model at larger sizes.

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