Scientific Research and Essays Vol. 5(17), pp. 2535-2546, 4 September, 2010
Available online at http://www.academicjournals.org/SRE
ISSN 1992-2248 ©2010 Academic Journals

Full Length Research Paper

Optimizing a supply chain network with emission trading factor

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Accepted 13 July, 2010

In the supply chain, producers try to plan their raw materials and final products with the production and delivery system for control of their flow, and this planning has to start from the purchase of the raw material for production to the delivery stage. Supply chain management and optimization is a promising aspect of enterprises and an exiting research area. Recently, there is a growing interest in supply chain design due to environmental impacts. It has become a necessity for the study to consider in the costs of transportation, the factor of environmental costs as social costs. In this paper, a new mixed integer mathematical model for a supply chain system is proposed. The chain system consists of two echelons and includes six suppliers, six manufacturers and six customer zones with six time period. The developed and proposed model provides the optimal values of transportation amounts of the purchased, manufactured and delivered raw material, while solving the location problem of each actor. We consider different trucks used for transporting according to their rental fees and CO_2 emission amounts. Also, we integrate a constraint of CO_2 emission quota into the supply chain as an environmental impact. The proposed model is validated by using hypothetical data and the results are discussed.

Key words: Emission trading, supply chain, network design and optimization, mixed integer programming.

INTRODUCTION

A supply chain can be explained as a network, which consists of facilities where the functions of materials procurement, transporting them to factories, transformation to finished products and distributions of these products to customers are performed. How many raw materials will be purchased and from which suppliers? How many of them will be produced and from which factory? And how will these materials be transported? To answer these questions, customer demands are very promising issues in the supply chain. These activities need strategic decisions and affect the chain in a long-term. To have a network like a clock work, the current distribution network needs to be optimized. While these decisions are handled, there are some internal and external effects, which have to be considered. Whilst inventories, labor costs and levels, facility location, capacities etc. can be defined as internal effects, environmental factors are defined as external.

The purpose of the present paper is to design and optimize a supply chain network via considering CO_2 emission trading. An emission trading is an administrative approach used to control pollution by providing economic incentives for achieving reductions in the emissions of CO_2. The new process, which begins with Kyoto protocol, binds most of the developed nations to a cap-and-trade system. According to protocol, each participating country determined an emission quota in order to reduce their overall emissions by 5.2% of their 1990 levels by the end of 2012.

It is known that heavy manufacturing and transportation are the major cause of total green gas emissions. At that point, supply chain network design became more important to provide environmental sanctions such as green gas emissions. Changes in the state of the environment, leading to subsequent public pressure and environmental legislation have necessitated a fundamental shift in the manufacturing business practices. However, it is no longer acceptable or cost effective to consider only the local and immediate effects of products and processes; it is now imperative to analyze the entire lifecycle effects of all products and processes. Therefore, the traditional structure of the supply chain must be extended to include mechanisms for considering environmental factors. This extension presents an additional level of complexity to the supply chain design and analysis. More specifically, the addition of the green gas emission mechanism gives rise to numerous issues affecting strategic and operational supply chain decisions. Consequently, the extension of the traditional supply chain requires the establishment and implementation of new performance measurement systems. These new measurement systems will serve as the centerpieces of environmentally conscious implementation plans, based on continuous improvement that will enable organizations to become and remain competitive, while achieving sustainable processes (Beamon, 1999). We embedded a CO_2 quota constraint in the model in order to consider the environmental effects in designing supply chains. Subsequently, an upper limit of CO_2 emission for each period was determined. If the total CO_2 emission, which is caused by transportation and manufacturing, exceeds the determined limit, the decision maker faces a penalty cost and the next period emission limit is determined considering this exceeded limit. Also, its opposite could be actualized, that is, if the total CO_2 amount is lower than the limit, the decision maker gains an incentive and also has a chance to increase the limit next time.

The study proceeds in the following manner. After giving the introduction, the literature review, which is related to the supply chain optimization and emission trading, is emphasized; then the main scope of the study is given via development of a multi period nonlinear mathematical model. The model is fixed based on a mixed integer linear programming to optimize a supply network, which consists of suppliers, manufacturers and customers under the emission trading quota. We explain in detail the mathematical formulation of the model with its constraints, objectives and parameters. However, the numerical example based on a hypothetical datum to test the model was proposed. The research results and discussion for managerial implications were provided.

LITERATURE REVIEW

Numerous researches have been carried out in this field of study, whilst a deterministic, mixed integer, non-linear programming with an economic order quantity technique to develop global supply chain network is presented (Cohen and Lee, 1989). A mathematical programming model, using stochastic sub-models to design an integrated supply chain, which involves manufacturers, warehouses and retailers, is developed (Pyke and Cohen, 1993). However recently, there has been an increasing attention placed on the performance, design and analysis of the supply chain as a whole. This attention is largely as a result of the rising costs of manufacturing, the shrinking resources of manufacturing bases, the shortened product life cycles, the levelling of the playing field within manufacturing and the globalization of market economies. In addition to these, Beamon (1998) provided a focused review of literature in a multi-stage supply chain modelling and defined a research agenda for future research in this area. Petrovic et al. (1999) modelled the supply chain behaviors under 'fuzzy' constraints. Their model showed that uncertain customer demands and deliveries play a major role in behaviors.

An overview of current practices in managing sustainability (social, ethical, environmental) issues in supply networks was studied and it was shown that it is largely due to the presence of external environmental drivers, such as legislation, market pressure and media attention and a lack of external pressures for social and ethical issues in most sectors (Young and Kielkiewicz-Young, 2001). A new algorithm, which is based on genetic algorithm to design a supply chain distribution network under capacity constraints for each echelon was developed (Syarif et al., 2002). Yan (2003), tried to contrive a network, which involves suppliers, manufacturers, distribution centers and customers via a mixed integer programming under logic and material requirements constraints. Collaborative supply chain management for improved business and for reducing environmentally harmful chemicals, while satisfying local regulations and Kyoto protocol for greenhouse gas emissions, was demonstrated by Turkay et al. (2004) and Soylu et al. (2006). Austin (2007) introduced the study to the mechanisms of carbon trading and examined whether carbon offsetting can viably provide off-grid systems to the developing world or not. A simple and a quite efficient separation procedure are proposed to identify cover inequalities for the multidimensional knapsack problem. It is based on the solution of a conventional integer programming model. The results of the experiments with a small set of randomly generated problems and problems taken from the literature indicate that the method may be a reasonable alternative to the one currently in use (Bektas and Oguz, 2007).

A critical review of methodologies in enhancing the decision-making process of the industrial supply chains towards the development of optimal infrastructures (assets and network) is presented (Papageorgiou, 2009). Halicioglu (2009), attempted to empirically examine the dynamic causal relationships between carbon emissions, energy consumption, income and foreign trade in the case of Turkey. Just as corporations buy and sell carbon emissions to wipe out the footprint of their less environmentally-friendly manufacturing practices, 'carbon off-setting' is all raging in the consumer world. In a special feature for renewable energy focus, Johansson (2009) discussed how the transportation sector could develop in a way that is consistent with a long-term climate target. Furthermore, the existence of other negative environmental effects would argue for the

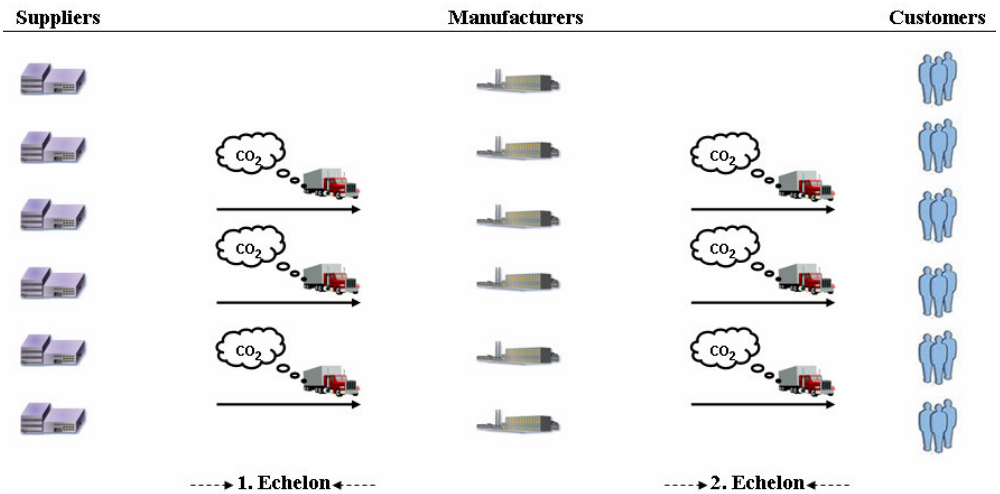

Figure 1. The proposed network.

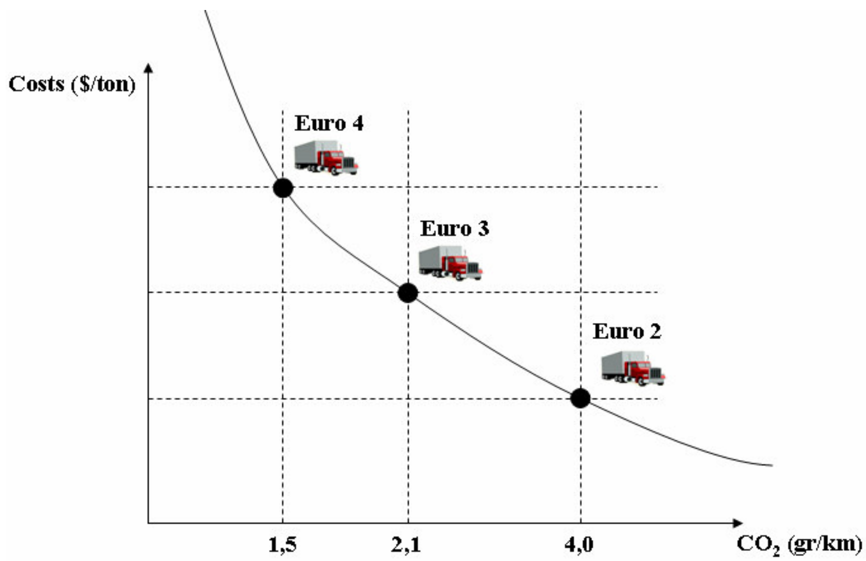

Figure 2. Trade-off between cost and emissions.

implementation of measures affecting transport demand as well. Jacques (2009) provided an analysis of the latest trends regarding the use of emission trading systems to manage environmental issues such as climate change caused by transportation. To assess the likelihood of such an inclusion, the study analyzed the main components of emission trading systems and their applicability to the different transportation sectors. Bauer et al. (2010) addressed the issue of incorporating environment-related costs (greenhouse gases, to be specific) into freight transportation planning and proposed an integer program in the form of a linear cost, multi-commodity and capacitated network design formulation that minimizes the amount of greenhouse gas emissions for transportation activities.

THE PROPOSED MODEL

In this paper, a supply chain network with two echelons is considered (Figure 1). The chain consists of six suppliers, six manufacturers and six customer zones. We try to optimize the whole chain via considering the emission trading factor with six time horizon (Biscoe, 2008).

The transportation can be actualized via three different trucks at all echelons. Trucks are different based on their types of motor, that is, Euro 2, 3 and 4 motors (mercedes-benz.com.tr, 2010). While the CO_2 emission amount is increasing from Euro 4 to 2, the rental fee of the trucks are increasing, and so, there is a trade off while choosing the truck according to its rental fee and CO_2 emission amount (Figure 2). In the model, if the total emission exceeds the quota, the decision maker is punished with a penalty cost, but if the amount is below the quota, he/she sells the difference or keeps and uses it at the next period.

To specify the study scope and facilitate the model formulation, five assumptions are postulated:

(1) Only the single-product condition is considered in the proposed model.
(2) The product flows within the six time period.
(3) Facility and truck capacities associated with chain members of the proposed integrated logistics system are known.
(4) The demand of each customer zone is known.

Mathematical formulation

Given the aforementioned assumptions, a mixed integer linear programming optimization model is formulated to seek equilibrium solutions with the goal of (1) minimizing total transportation costs at both echelons, (2) minimizing CO_2 gas emission caused by transportation, (3) minimizing CO_2 gas emission caused by manufacturing, (4) minimizing total penalty cost as a result of exceeding the emission limit and (5) maximizing the environment. The mathematical formulation of the proposed model is thus detailed. Consequently, all the notations for variables, including decision variables referring to the variables determined by the optimization process of the proposed model for the chain are summarized.

Indices:

I the number of suppliers with $i = 1, 2\ldots,$
J the number of manufacturers with $j = 1, 2...,$
K the number of customer zones with $k = 1, 2...,$
T the number of trucks with $t = 1, 2\ldots,$
P the number of periods with $p = 1, 2\ldots$

Parameters:

a_{ip} Capacity of supplier i at period p (unit)
b_{ip} Capacity of manufacturer j at period p (unit)
C_{ijtp} Unit cost of transportation from each supplier i to each manufacturer j with truck t at period p ($/ton)
C_{jktp} Unit cost of transportation from each manufacturer j to each customer zone k with truck t at period p ($/ton)
D_{ij} Distance between supplier i and manufacturer j (km)
D_{jk} Distance between manufacturer j and customer zone k (km)
CO_2^j Amount of green gas emission exposed to manufacturing one unit of product (gr/unit)
CO_2^t Amount of green gas emission, which is exposed from the truck (gr/km)
P_p Penalty cost of exceeding the emission quota at period p ($/gr)
I_p Incentive fee of usage under the emission quota at period p ($/gr)
Q_p Green gas emission quota at period p (gr)
Ca_{ip} Manufacturing capacity of manufacturer j at period p (unit)
De_{kp} Demand of each customer k at period p (gr)
Ca_{tp}^{ij} Transportation capacity of truck t between suppliers and manufacturers at period p (unit)
Ca_{tp}^{jk} Transportation capacity of truck t between manufacturers and customers zones at period p (unit)
S_0 The exposed green gas amount more than the emission quota (gr)
U_0 The exposed green gas amount less than the emission quota (gr)

Variables:

X_{ijtp} Amount transported from supplier i to manufacturer j with truck t at period p (unit)
Y_{jktp} Amount transported from manufacturer j to customer zone k with truck t at period p (unit)
Pr_{jp} Manufactured amount in manufacturer j at period p (unit)
S_p Exposed green gas amount more than the emission quota at period p (gr)
U_p Exposed green gas amount less than the emission quota at period p (gr)

$$Z_{ijtp} \begin{cases} 1 & \text{if transportation is actualized between supplier } i \text{ and manufacturer } j \text{ at period } p \\ 0 & \text{otherwise} \end{cases}$$

$$W_{jktp} \begin{cases} 1 & \text{if transportation is actualized between manufacturer } j \text{ and customer zone } k \text{ at period } p \\ 0 & \text{otherwise} \end{cases}$$

Objective function:

$$Min \sum_i \sum_j \sum_t \sum_p X_{ijtp} \cdot C_{ijtp} + \sum_j \sum_k \sum_t \sum_p Y_{jktp} \cdot C_{jktp} + \quad (1)$$

$$CO_2^t (\sum_i \sum_j \sum_t \sum_p Z_{ijtp} \cdot D_{ij} \cdot + \sum_j \sum_k \sum_t \sum_p W_{jktp} \cdot D_{jk}) + \quad (2)$$

$$\sum_j \sum_p \Pr_{jp} \cdot CO_2^j + \quad (3)$$

$$\sum_p P_p \cdot S_p + \sum I_p \cdot U_p \quad (4)$$

Subject to:

$$\sum_j \sum_t X_{ijtp} \cdot Z_{ijtp} \le a_{ip} \qquad \forall_{i,p} \quad (5)$$

Table 1. The size of the model and the other parameters (one unit is 0.1 ton).

Suppliers	Manufacturers	Customers	Trucks	Periods	P_p	I_p	U_0	S_0
6	6	6	3	6	0.1	0.05	0	0

$$\sum_j \sum_t Y_{jktp} \cdot W_{jktp} \leq b_{jp} \qquad \forall_{i,p} \tag{6}$$

$$\Pr_{jp} \leq Ca_{jp} \qquad \forall_{j,p} \tag{7}$$

$$\sum_i \sum_j X_{ijtp} \cdot Z_{ijtp} \leq Ca_{tp}^{ij} \qquad \forall_{t,p} \tag{8}$$

$$\sum_j \sum_k Y_{jktp} \cdot W_{jktp} \leq Ca_{tp}^{jk} \qquad \forall_{t,p} \tag{9}$$

$$\sum_i \sum_t X_{ijtp} \cdot Z_{ijtp} - \sum_k \sum_t Y_{jktp} \cdot W_{jktp} = 0 \qquad \forall_{j,p} \tag{10}$$

$$\sum_i \sum_t X_{ijtp} \cdot Z_{ijtp} - \Pr_{jp} = 0 \qquad \forall_{j,p} \tag{11}$$

$$\sum_j \sum_t Y_{jktp} \cdot W_{jktp} \geq De_{kp} \qquad \forall_{k,p} \tag{12}$$

$$\sum_i \sum_j \sum_t Z_{ijtp} \cdot D_{ij} \cdot CO_2^t + \sum_j \Pr_{jp} \cdot CO_2^j + U_p + U_{p-1} - S_p - S_{p-1} = Q_p \qquad \forall_{p:1} \tag{13}$$

$$\sum_i \sum_j \sum_t Z_{ijtp} \cdot D_{ij} \cdot CO_2^t + \sum_j \Pr_{jp} \cdot CO_2^j + U_p - S_p = Q_p + U_{p-1} - S_{p-1} \qquad \forall_p \tag{14}$$

$$X_{ijtp}, Y_{jktp}, \Pr_{jp}, S_p, U_p \geq 0 \qquad \forall_{i,j,k,t,p} \tag{15}$$

$$Z_{ijtp}, W_{jktp} \in \{0,1\} \qquad \forall_{i,j,k,t,p} \tag{16}$$

However, the objective of the model is to minimize the overall costs of the system. The first part of the objective function is to minimize all transportation costs between two echelons (Equation 1). The second part shows the minimization of the entire amount of CO_2 emitted, which is caused by trucks while transportation takes place (Equation 2).

The third one is the minimization of the entire amount of CO_2 emitted during the manufacturing process, and the last part of the objective function is the minimization of the penalty costs via maximization of incentive according to emission trading.

Equation (5) stipulates that the transportation amount, from suppliers to manufacturers, must not exceed the capacity of the supplier facility at any given period. Equation (6) guarantees that the transportation amount, from manufacturers to customer zones must not exceed the capacity of the manufacturer facility at any given period. Equation (7) ensures that the production quantity must not exceed the production capacity of the manufacturing facility at any given period. Equation (8) is the constraint, which ensures that the quantities distributed distributed from suppliers to manufacturers cannot exceed the capacity of trucks at any given period. Equation (9) is the constraint, ensuring that the quantities distributed from manufacturers to customer zones cannot exceed the capacity of trucks at any given period. Equation (10) is the balance equation for the manufacturers: the quantities that enter into the manufacturers' facility must be equal to the amount of products that leave the facility at any given period. Equation (11) indicates that the total amount, which is transported from suppliers to manufacturers, is equal to all products that are manufactured by these manufacturers. Equation (12) ensures that demands for products must fully be met. Equations (13) and (14) provide that all CO_2 emissions, which is caused by transportation and manufacturing, must be balanced with the given emission quota at any given period. Equation (15) enforces the non-negativity restriction on the decision variables. Lastly, Equation (16) represents the binary variables.

ILLUSTRATIVE EXAMPLE

Here, the proposed model is illustrated through the example that is given. A small set of parameters reflecting a real-life industrial case is selected for the example. A network is formulated as a mixed integer mathematical model for multi-period (six periods) in order to find the optimal values of the quantities between sites and also, to consider CO_2 emission trading. The network includes six suppliers, six manufacturers, six customer zones and three different trucks (Euro 2-3-4). The trucks, which have Euro 2-3-4 motors, expose 1.5, 2.1 and 4.0 gr/km CO_2, respectively. The model is solved by using LINGO 11.0 solver on a Pentium IV 3.2 GHz personal computer for the parameters presented in (Tables 1-9) with the intention of obtaining optimal values.

Solution

In this example with I = 6, J = 6, K = 6, T = 3 and P = 6, there are 1609 constraints, 2592 nonlinear and 2658 total

Table 2. The transportation costs between suppliers and manufacturers ($/ton).

Manufacturers		Trucks	Suppliers																	
			1						**2**						**3**					
			Periods																	
			1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
	1	1	4	4	4	5	6	6	3	4	4	5	6	6	5	4	4	5	6	6
		2	5	5	5	6	7	7	4	5	5	6	7	7	6	5	5	6	7	7
		3	6	6	6	7	8	8	5	6	6	7	8	8	7	6	6	7	8	8
	2	1	5	5	4	5	5	5	5	5	4	5	5	5	5	5	4	5	5	5
		2	6	6	6	6	7	7	6	6	6	6	7	7	6	6	6	7	7	7
		3	7	7	7	7	8	7	7	7	7	7	8	7	7	7	7	8	8	8
	3	1	3	3	5	5	6	6	3	3	5	5	6	7	3	3	5	4	6	7
		2	4	4	6	6	8	7	4	4	6	6	8	8	4	4	6	5	8	8
		3	6	6	7	7	9	8	6	6	7	7	9	9	6	6	7	6	9	9
Manufacturers		Trucks																		
	4	1	3	3	5	5	6	7	2	3	5	4	6	7	4	3	5	5	6	7
		2	4	4	6	6	8	8	3	4	6	5	8	8	5	4	6	6	8	7
		3	6	6	7	7	9	9	4	6	7	6	9	9	6	6	7	7	9	9
	5	1	3	3	5	4	5	5	3	3	5	5	6	7	3	3	5	4	6	7
		2	4	4	6	5	6	6	4	4	6	6	8	8	4	4	6	5	8	8
		3	6	6	7	7	9	9	6	6	7	7	9	9	6	6	7	6	9	9
	6	1	3	3	5	5	6	7	3	3	5	5	6	7	4	3	5	5	6	7
		2	4	4	6	6	8	8	4	4	6	6	8	8	5	4	6	6	8	8
		3	6	6	7	7	9	9	6	6	7	7	9	9	6	6	7	7	9	9

Manufacturers		Trucks	**4**						**5**						**6**					
			Periods																	
			1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
	1	1	4	4	4	4	6	6	5	4	4	5	6	6	4	4	4	5	6	6
		2	5	5	5	5	7	7	6	5	5	6	7	7	5	5	5	6	7	7
		3	6	6	6	6	8	7	7	6	6	7	8	8	6	6	6	7	8	8
	2	1	5	5	4	5	5	5	5	3	4	5	5	5	4	4	4	5	5	5
		2	6	6	6	7	7	7	6	4	6	7	7	7	5	5	6	7	7	7
		3	7	7	7	8	8	7	7	5	7	8	8	7	6	6	7	8	8	7
	3	1	4	3	5	4	6	7	3	3	5	5	6	6	3	3	5	5	6	6
		2	5	4	6	5	8	8	4	4	6	6	8	7	4	4	6	6	8	7
		3	6	6	7	6	9	9	6	6	7	7	9	8	6	6	7	7	9	8
Manufacturers		Trucks																		
	4	1	3	2	5	4	6	5	2	3	5	5	6	7	3	3	5	5	6	7
		2	4	3	6	5	8	6	3	4	6	6	8	8	4	4	6	6	8	8
		3	6	4	7	6	9	7	4	6	7	7	9	9	5	6	7	7	9	9
	5	1	4	3	5	5	6	7	3	3	5	5	6	7	3	3	5	5	6	7
		2	5	4	6	6	8	8	4	4	6	6	8	8	4	4	6	6	8	8
		3	6	6	7	7	9	9	6	5	7	7	9	9	6	6	7	7	9	9
	6	1	3	3	5	5	6	7	3	3	5	5	6	7	3	3	5	5	6	6
		2	4	4	6	6	8	8	4	4	6	6	8	8	4	4	6	6	8	7
		3	6	6	7	7	9	9	5	6	7	7	9	9	6	5	7	7	9	8

Table 3. The CO_2 emissions of each manufacturer (gr).

	Manufacturers					
	1	**2**	**3**	**4**	**5**	**6**
CO_2 emissions	4.5	4.8	4.3	4.0	4.8	4.3

Table 4. The CO_2 emission quotas during any period (gr).

	Periods					
	1	**2**	**3**	**4**	**5**	**6**
CO_2 emissions quota	285000	285000	275000	285000	235000	240000

variables. Using LINGO 11.0 with 83(s) elapsed time, the optimal solution as shown in Table 10 was obtained. When the proposed model was solved for the given example, the total cost is discovered to be 381739.10 at six periods. At the first echelon, all transportation cost was found to be 179710.00 and at the second, it was 190100.00. At all periods, a total of 316800 products' units are transported from suppliers to manufacturers.

At the first echelon, the distribution of products by trucks is shown in Figure 3. According to the results, 58% of total transportation between suppliers and manufacturers is transported with truck 1, 12% via truck 2 and 30% via truck 3. However, at the first and third periods, there was no transportation via truck 2.

At the second echelon, the distribution of products by trucks is shown in Figure 4. According to the results, 46% of total transportation between suppliers and manufacturers is transported with truck 1, 17% via truck 2 and 37% via truck 3. However, at the first period, there was no transportation via truck 2.

The distribution of manufactured products is shown in Figure 5. According to the results, only production was carried out at the first period (4100 units) in the fifth manufacturer's facility. Totally, 64600, 68400, 60500, 62300, 4100 and 56900 products are manufactured at the manufacturers' facility at any given period, respectively.

The study's model was developed under CO_2 emission constraint. For this reason, the emissions caused by transportation and manufacturing were handled. The emission amount (gr) is shown in Figure 6. At the first period, a total of 279460 gr CO_2 is exposed because of transportation and manufacturing. However, the emission quota is 285000 gr. So the emission is actualized under the quota with about 5540 gr. The decision maker adds this difference to the next period, and for the second period, the new quota is 285000+5540 = 290540 gr. At the second period, a total of 299276 gr CO_2 is exposed. Subsequently, the decision maker exceeded the quota with about 8736 gr. Considering this penalty amount, the new quota should be decreased from 275000 to 266264 gr. As a result, there are emission surpluses at the second, third, fifth and sixth periods with about 8736, 3556, 37071 and 76845 gr, respectively. Besides these surpluses, the decision maker succeeded to stay under the quota at the first and fourth periods. However, the decision maker was made to pay 12620 $ for exceeding the quota and gained 691.70 $ for usage under the quota. The optimal distribution network is shown in Figure 7.

CONCLUSION

Based on green issues, green gas emissions have become more and more important in recent years, and their resolution technologies have been critical for production companies. The reduction of primary resource use, pollution prevention, waste management and policies governing sustainable products have thus become the focuses of modern industrial societies and environmental policies. CO_2 emission is one of the most essential keys in relation to the cost incurred by companies. Since every part of the mentioned issues is related to the overall logistics in a product life-cycle system, CO_2 emission trading with its overall cost has become an urgent concern for companies in their supply-demand chain management.

In this paper, a supply chain network is designed in that it can meet different industries' requirements, and a mixed integer programming model developed a system, which includes multi-echelon and multi-periods distribution. The proposed model is illustrated through an example by using a set of data to reflect a real life situation; then the model is solved via LINGO package program and different performance indicators are given such as costs, emission amounts, manufacturing amount etc. In this study, we try to see the behaviours of the system under emission constraint. It can be concluded from the obtained results that governments should provide more incentives to enterprises in order to take into cognizance, green gas emission. Thus they will improve their competitiveness as well as become more environmentally friendly.

For practical applications and academic research, the

Table 5. The transportation costs between manufacturers and customer zones ($/ton).

Customers	Trucks	Manufacturer 1						Manufacturer 2						Manufacturer 3					
		Periods																	
		1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
	1	3	4	4	5	6	5	5	4	4	5	6	6	4	4	5	5	6	6
1	2	4	5	5	6	7	6	6	5	5	6	7	7	5	5	6	6	7	7
	3	5	6	6	7	8	7	7	6	6	7	8	8	6	6	7	7	8	8
	1	5	5	4	5	5	5	5	5	4	5	5	5	4	5	4	5	5	5
2	2	6	6	6	7	7	7	6	6	6	7	6	6	5	6	6	7	7	7
	3	7	7	7	8	8	7	7	7	7	8	7	7	6	7	7	8	8	7
	1	3	3	5	5	6	7	3	3	4	5	6	7	3	3	5	5	6	6
3	2	4	4	6	6	7	8	4	4	5	6	8	8	4	4	6	6	8	7
	3	6	6	7	7	8	9	6	6	6	7	9	9	6	6	7	7	9	8
	1	4	4	4	5	6	6	4	4	5	5	6	7	3	4	5	5	6	7
4	2	5	5	5	6	8	7	5	5	6	6	8	8	4	5	6	6	7	8
	3	6	6	6	7	9	8	6	6	7	7	9	9	6	6	7	7	8	9
	1	3	3	5	5	6	7	3	3	5	5	6	7	4	3	4	5	6	7
5	2	4	4	6	6	8	8	4	4	6	6	8	8	5	4	5	6	8	8
	3	6	6	7	7	9	9	6	6	7	7	9	9	6	6	6	7	9	9
	1	3	3	4	5	6	7	3	3	5	5	5	6	3	3	5	5	6	7
6	2	4	4	5	6	8	8	4	4	6	6	6	7	4	4	6	6	8	8
	3	6	6	6	7	9	9	6	6	7	7	7	8	6	6	7	7	9	9

Customers	Trucks	Manufacturer 4						Manufacturer 5						Manufacturer 6					
		Periods																	
		1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
	1	4	4	4	5	4	6	4	4	4	5	6	6	4	4	4	5	6	5
1	2	5	5	5	6	5	7	5	5	5	6	7	7	5	5	5	6	7	6
	3	6	6	6	7	6	8	6	6	6	7	8	8	6	6	6	7	8	7
	1	4	5	5	5	5	5	5	4	4	5	5	5	5	5	5	5	5	5
2	2	5	6	6	7	7	7	6	5	6	7	7	7	6	6	6	7	7	7
	3	6	7	7	8	8	7	7	6	7	8	8	7	7	7	7	8	8	7
	1	3	3	5	5	6	6	4	3	5	5	5	6	4	3	5	5	6	7
3	2	4	4	6	6	8	7	5	4	6	6	6	7	5	4	6	6	7	8
	3	6	5	7	7	9	8	6	6	7	7	7	8	6	6	7	7	8	9
	1	3	3	5	5	6	7	3	3	5	5	6	7	3	3	5	5	6	7
4	2	4	4	6	6	8	8	4	4	6	6	8	8	4	4	6	6	8	7
	3	6	6	7	7	9	9	6	6	7	7	9	9	6	5	7	7	9	8
5	1	4	3	5	5	6	7	3	3	4	5	6	7	3	3	5	5	6	9
	2	5	4	6	6	7	8	4	4	5	6	8	8	4	4	6	6	8	8
	3	6	6	7	7	8	9	6	6	6	7	9	9	6	6	7	7	9	9
6	1	3	3	4	5	6	6	4	3	5	5	5	7	3	3	4	5	6	7
	2	4	4	5	6	8	7	5	4	6	6	6	8	4	4	5	6	7	8
	3	6	6	6	7	9	8	6	5	7	7	7	9	6	6	6	7	8	9

Table 6. The distances between suppliers, manufacturers and customer zones (km).

		Manufacturers													
		1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**		
Suppliers	1	900	950	1100	1100	1100	1100	900	1200	1100	1100	1100	1100	1	Customers
	2	1200	1000	950	1200	1000	950	950	1000	980	980	980	980	2	
	3	1100	980	1150	1100	980	1150	1100	950	1150	1150	1150	1150	3	
	4	1100	980	1150	1100	980	1150	1100	1200	1100	1100	1100	1100	4	
	5	1100	980	1150	1100	980	1150	1100	1000	980	980	980	980	5	
	6	1100	980	1150	1100	980	1150	1100	950	1150	1150	1150	1150	6	

Table 7. Capacities of suppliers and manufacturers (unit).

Periods	Suppliers						Manufacturers					
	1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
1	12000	10000	10000	14000	16000	12000	12000	10000	10000	14000	16000	12000
2	10000	14000	13000	13000	14000	13000	10000	14000	13000	13000	14000	13000
3	11000	13000	12000	10000	15000	10000	11000	13000	12000	10000	15000	10000
4	13000	12000	11000	12000	10000	14000	13000	12000	11000	12000	10000	14000
5	10000	13000	12000	10000	10500	15000	10000	13000	12000	10000	10500	15000
6	12000	14000	15000	10000	13000	12000	12000	14000	15000	10000	13000	12000

Table 8. Capacities of production and demands of customers (unit).

Periods	Production						Demands					
	1	**2**	**3**	**4**	**5**	**6**	**1**	**2**	**3**	**4**	**5**	**6**
1	12000	14000	13000	12000	14000	13000	8500	8500	8600	8500	8500	8500
2	13000	15000	14000	13000	15000	14000	9500	9500	9500	9500	9700	8900
3	14000	15000	15000	14000	15000	15000	7500	8500	8500	8500	9500	9000
4	15000	14000	14000	15000	14000	14000	8000	8800	8400	8300	8500	9800
5	14000	13000	12000	14000	13000	12000	7500	9500	9500	9500	9700	8500
6	13000	12000	13000	13000	12000	13000	7500	7500	8500	8500	9900	9700

Table 9. Trucks capacities of each echelon (unit).

Periods	Trucks (ij)			Trucks (jk)		
	1	**2**	**3**	**1**	**2**	**3**
1	35000	35000	35000	35000	35000	35000
2	36000	36000	36000	36000	36000	36000
3	34500	34500	34500	34500	34500	34500
4	35000	35000	35000	35000	35000	35000
5	36000	36000	36000	36000	36000	36000
6	37000	37000	37000	37000	37000	37000

given model could be developed via adding more environmental effects such as recycling, noise, accidents or the other green gas sorts. The model can be expanded by considering alternative transportation modes between echelons for each point pairs. In this situation, new decision variables emerge and the model complexity

Table 10. The optimal solution of the numerical example.

Variable	Value	Variable	Value	Variable	Value	Variable	Value	Variable	Value	Variable	Value
X_{1124}	1000	Y_{1224}	4700	Y_{4431}	900	Z_{3115}	1	W_{2312}	1	P_{12}	10000
X_{1211}	2000	Y_{1226}	2700	Y_{4432}	5100	Z_{3116}	1	W_{2314}	1	P_{13}	11000
X_{1214}	12000	Y_{1311}	8600	Y_{4533}	7000	Z_{3531}	1	W_{2315}	1	P_{14}	13000
X_{1311}	10000	Y_{1313}	8500	Y_{4535}	9700	Z_{4426}	1	W_{3111}	1	P_{15}	10000
X_{1312}	9500	Y_{1316}	800	Y_{4631}	8500	Z_{4431}	1	W_{3112}	1	P_{16}	12000
X_{1313}	10500	Y_{1412}	4400	Y_{4634}	7900	Z_{4433}	1	W_{3115}	1	P_{21}	4400
X_{1315}	10000	Y_{1414}	8300	Y_{4636}	9700	Z_{4434}	1	W_{3231}	1	P_{22}	14000
X_{1316}	12000	Y_{1415}	9500	Y_{5431}	4100	Z_{4632}	1	W_{3233}	1	P_{23}	13000
X_{2111}	7600	Y_{1416}	8500	Y_{6124}	4400	Z_{5425}	1	W_{3326}	1	P_{24}	12000
X_{2114}	12000	Y_{1513}	2500	Y_{6235}	3000	Z_{5634}	1	W_{3335}	1	P_{25}	13000
X_{2211}	2400	Y_{1632}	5600	Y_{6423}	8500	Z_{6222}	1	W_{3526}	1	P_{26}	1200
X_{2212}	1000	Y_{2113}	7500	Y_{6431}	3500	Z_{6334}	1	W_{3534}	1	P_{31}	10000
X_{2213}	13000	Y_{2114}	3600	Y_{6511}	8500	Z_{6611}	1	W_{3633}	1	P_{32}	9500
X_{2215}	13000	Y_{2116}	7200	Y_{6522}	9700	Z_{6626}	1	W_{4131}	1	P_{33}	10500
X_{2216}	12000	Y_{2211}	4400	Y_{6526}	5600	Z_{6633}	1	W_{4136}	1	P_{34}	8500
X_{2432}	10100	Y_{2212}	9500	Y_{6632}	3300	Z_{6634}	1	W_{4233}	1	P_{35}	10000
X_{3111}	1000	Y_{2213}	5500	Y_{6634}	1900	Z_{6635}	1	W_{4234}	1	P_{36}	12000
X_{3112}	10000	Y_{2215}	6500	Y_{6635}	8500	W_{1125}	1	W_{4332}	1	P_{41}	12000
X_{3113}	11000	Y_{2226}	4800	Z_{1124}	1	W_{1224}	1	W_{4431}	1	P_{42}	10100
X_{3115}	10000	Y_{2312}	4500	Z_{1211}	1	W_{1226}	1	W_{4432}	1	P_{43}	8500
X_{3116}	12000	Y_{2314}	8400	Z_{1214}	1	W_{1311}	1	W_{4533}	1	P_{44}	12000
X_{3531}	4100	Y_{2315}	6500	Z_{1311}	1	W_{1313}	1	W_{4535}	1	P_{45}	9700
X_{4426}	10000	Y_{3111}	5900	Z_{1312}	1	W_{1316}	1	W_{4631}	1	P_{46}	10000
X_{4431}	12000	Y_{3112}	9500	Z_{1313}	1	W_{1412}	1	W_{4634}	1	P_{51}	4100
X_{4433}	8500	Y_{3115}	7000	Z_{1315}	1	W_{1414}	1	W_{4636}	1	P_{61}	12000
X_{4434}	12000	Y_{3231}	4100	Z_{1316}	1	W_{1415}	1	W_{5431}	1	P_{62}	13000
X_{4632}	13000	Y_{3233}	1500	Z_{2111}	1	W_{1416}	1	W_{6124}	1	P_{63}	8500
X_{5425}	9700	Y_{3326}	7700	Z_{2114}	1	W_{1513}	1	W_{6235}	1	P_{64}	6300
X_{5634}	800	Y_{3335}	3000	Z_{2211}	1	W_{1632}	1	W_{6423}	1	P_{65}	11500
X_{6222}	13000	Y_{3526}	4300	Z_{2212}	1	W_{2113}	1	W_{6431}	1	P_{66}	5600
X_{6334}	8500	Y_{3534}	8500	Z_{2213}	1	W_{2114}	1	W_{6511}	1	U_{1}	5540
X_{6611}	12000	Y_{3633}	9000	Z_{2215}	1	W_{2116}	1	W_{6522}	1	U_{4}	8294
X_{6626}	5600	Y_{4131}	2600	Z_{2216}	1	W_{2211}	1	W_{6526}	1	S_{2}	8736
X_{6633}	8500	Y_{4136}	300	Z_{2432}	1	W_{2212}	1	W_{6632}	1	S_{3}	3556
X_{6634}	5500	Y_{4233}	1500	Z_{3111}	1	W_{2213}	1	W_{6634}	1	S_{5}	37071
X_{6635}	11500	Y_{4234}	4100	Z_{3112}	1	W_{2215}	1	W_{6635}	1	S_{6}	76845
Y_{1125}	500	Y_{4332}	5000	Z_{3113}	1	W_{2226}	1	P_{11}	8600		

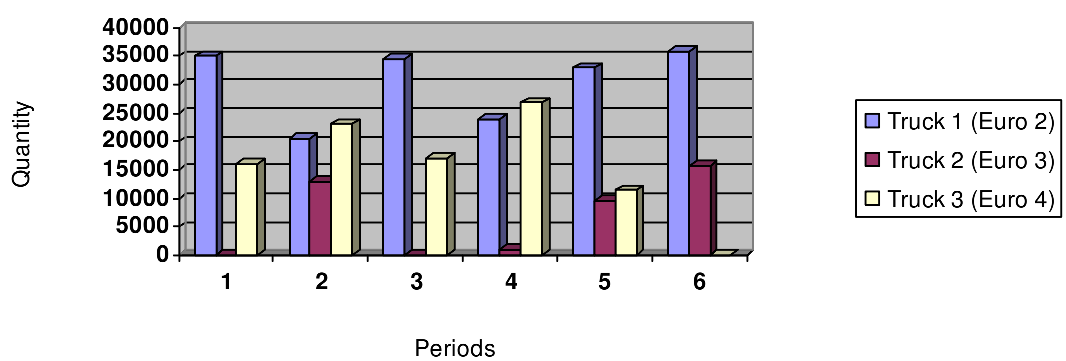

Figure 3. The transported amounts by each truck at the first echelon.

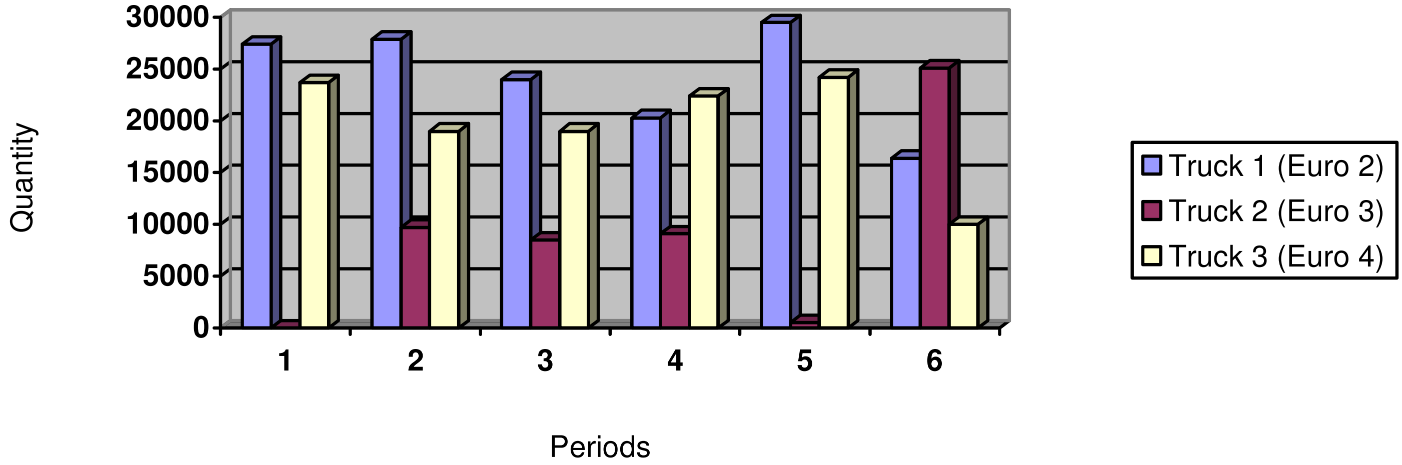

Figure 4. The transported amounts by each truck at the second echelon.

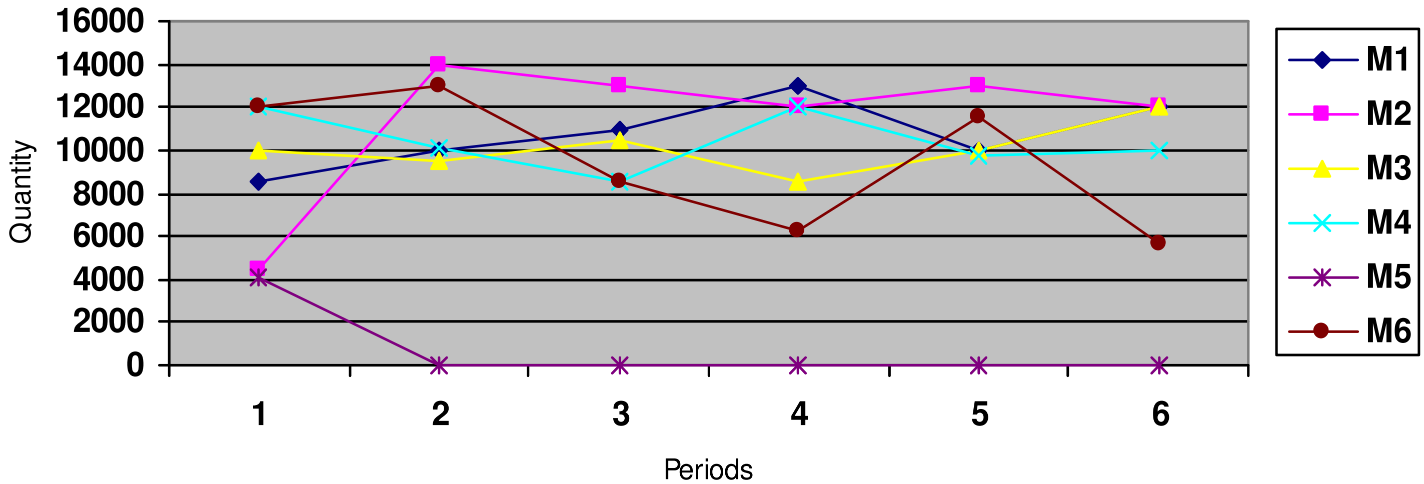

Figure 5. The manufactured amounts at all manufacturers' facility.

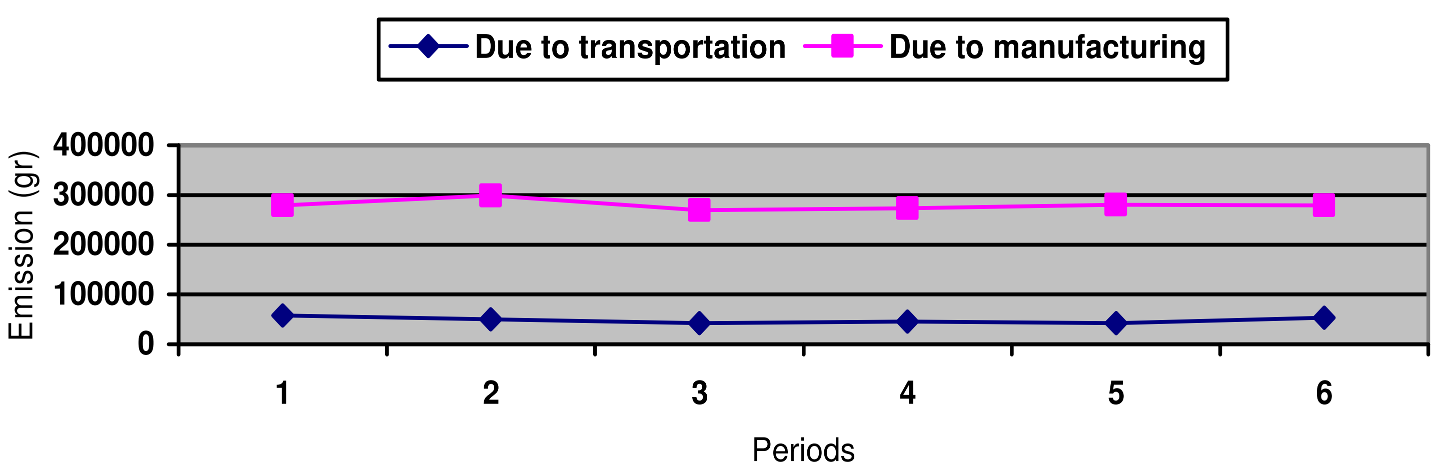

Figure 6. The emission amounts caused by transportation and manufacturing.

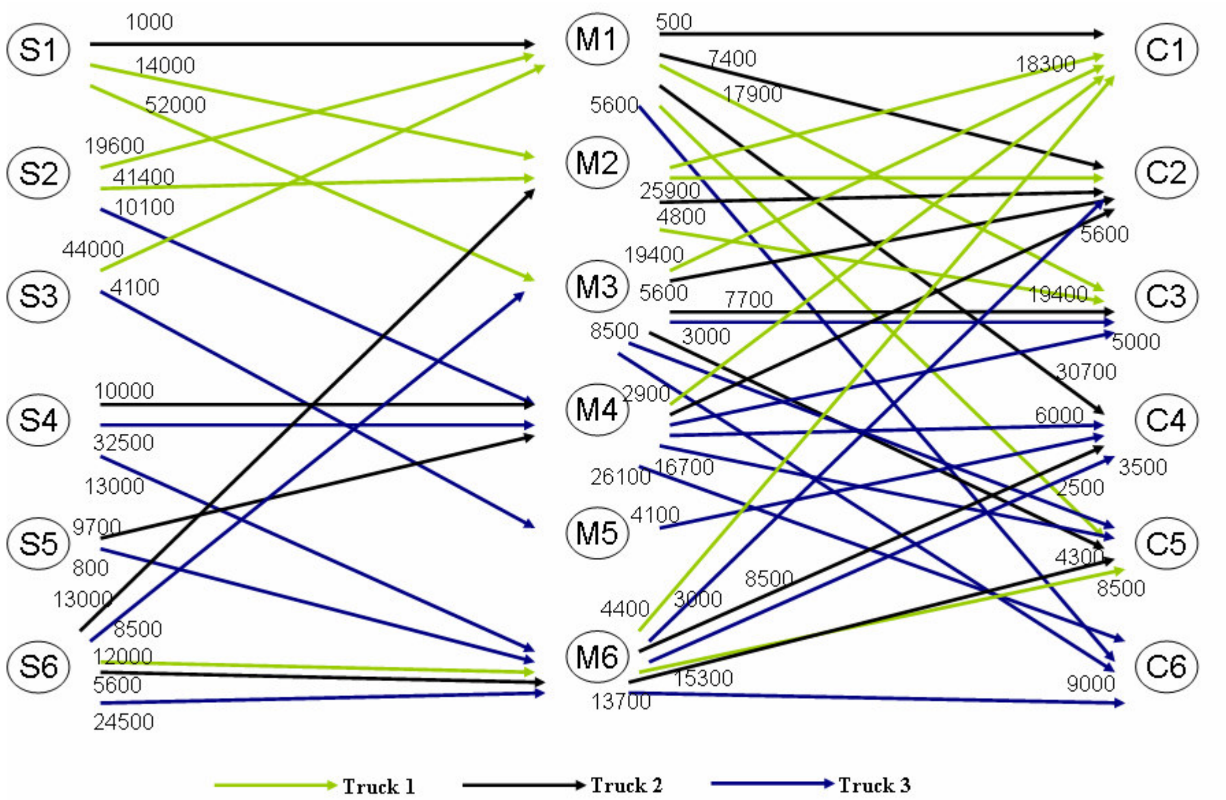

Figure 7. The optimal distribution.

increases. It is obvious that managing the supply chain network design problem is a comprehensive topic and there are additional variables and parameters which can be embedded to the model. This type of large sized models is NP-complete. However, approximate results can easily be obtained for complex problems by using various simulation techniques or heuristics, such as, simulated annealing, tabu search, genetic algorithms, etc.

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