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A Two-Phase Approach for Supply Chain Network Design: A Real-World Case Study from Automotive Industry

S. Tunali[1*], G. Oztuzcu[2]
[1]Department of Business Administration, İzmir University of Economics, İzmir, Turkey.
[2]Opet Fuchs Oil Company, 35600 Cigli-Izmir, Turkey.

A B S T R A C T
Effective design and management of Supply Chain Networks (SCN) support the production and delivery of products at low cost, high quality, high variety, and short lead times. In this study, a SCN is designed for an automotive company by integrating various approaches. The study has been carried out in two phases: The first phase involves selecting suppliers and distributors by using Data Envelopment Analysis (DEA) and integer-programming model. In the second phase, first the priority ranking of selected suppliers and distributors is determined using the Analytical Hierarchy Process (AHP) and then these priority rankings are integrated into the transportation models developed to identify the optimal routing decisions for all members of the supply chain.

Keywords: Supply chain management, Data envelopment analysis, Integer programming, Analytical hierarchy process, Transportation problem.

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1. Introduction

The competition has imposed pressure on product and service providers to emphasize short delivery lead times, flexibility, low cost and high quality. Companies are responding to this pressure in various ways: One such strategy utilized by the companies is to integrate purchasing and supply management with other key business functions such as production, distribution, and finance. In recent years, to gain competitive advantage, the companies have placed considerable emphasis on Supply Chain Networks (SCNs), which are considered as a solution for effectively meeting customer requirements [1, 2, 4, 6, 12, 18, 24, 26]. Designing a SCN involves creating a network that brings together many facilities including production sites, suppliers, distributors, storage warehouses, and retail stores. The success of SCNs depends on a large extent how effectively they are designed and operated. The reader can refer to a recent survey study by

* Corresponding author
E-mail address: semra.tunali@ieu.edu.tr
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Farahani et al., which classified the published literature based on models and solution techniques used in designing competitive SCNs [13]. An emerging research direction is the sustainable supply chain network design [3].

There are many strategic, tactical, and operational aspects that must be considered in designing and operating SCNs. While strategic issues deal with long-term decisions involving the selection of suppliers and distributors and selection of sites for production and distribution [19, 21, 22, 25], operational issues focus on activities over a day-to-day basis such as production scheduling, inventory planning and warehouse operations [5, 11, 14, 16, 17, 20]. During the survey of current relative research it has been noted that majority of the studies dealt with operational issues using various quantitative models. Geoffrion and Graves conducted one of the pioneer works in this area [15]. They proposed a multi-commodity logistics network design model for optimizing annualized finished product flows through the supply chain. Later, Cohen and Lee [8] proposed a pair of models for the network design problem, which is based on Geoffrion and Graves' work [15]. They proposed a multi-commodity manufacturing network design model that optimized the product flows from raw material vendors to end customers. In another study, Cohen and Lee proposed a set of approximate stochastic sub-models and heuristic methods to develop a stationary long-term operational policy for supply chains [9]. Subsequently, Cohen and Lee proposed a deterministic model for a global manufacturing and distribution network [10]. This model included value markups and costs, exchange effects, and before and after tax profitability estimation. All of these models concentrate on the operational issues of SCN design more.

Talluri and Baker [24] addressed both strategic issues and also operational aspects by incorporating capacity and location constraints into the decision making process. Moreover, they proposed a multi-phase mathematical programming approach to design the entire SCN with several nodes at each value-added stage. This paper also focuses on both strategic issues in SCN design including supplier and distributor selection and some operational issues that involve sourcing and deployment plans. Originating from a real-world industrial problem, this study not only deals with various aspects of SCN design in a realistic way, but also serves as a guideline for practitioners to solve their industrial problems in a systematic way. The rest of the paper is organized as follows: The next section presents the proposed methodology to design a SCN. A real-world case study is given in Section 3 to illustrate the steps of the proposed methodology. In the last section, the concluding remarks and future research directions are presented.

2. Proposed Methodology

As mentioned earlier, a two-phase procedure is employed in designing a SCN. The first phase, which involves selecting suppliers and distributors, exclusively concentrates on the operating efficiencies of candidate suppliers and distributors. The second phase deals with operational issues. Particularly, based on the given demand and capacity constraints of all supply chain members, a transportation model is constructed to identify the optimal routing decisions.

2.1. Phase 1: Supplie*r and Distributor Selection

The first phase is carried out in three steps: First, the relative efficiency scores for each candidate supplier and distributor are obtained using the CCR model, which is the basic DEA model developed by Charnes et al. [7]. One of the limitations of the CCR model is its unrestricted weight flexibility. To deal with this issue, in the second step, the PEG (pair-wise efficiency game) model is employed [23]. The outputs of CCR and PEG models are used to calculate an aggregated mean efficiency score for each candidate supplier and distributor. Lastly, an integer-programming model is constructed to select the suppliers and distributors optimally.

2.1.1. Step 1: Application of CCR Model

Charnes et al. [7] initially introduced the CCR model to measure the relative efficiency of DMUs using multiple inputs to produce multiple outputs. For a given DMU, this model maximizes the output-to-input ratio. They addressed Constant Returns-to-Scale (CRS). An increase in a unit's inputs leads to a proportionate increase in its outputs, i.e. there is a one-to-one linear relationship between inputs and outputs, and then the unit exhibits CRS. For example, if a 10% increase in inputs yields a 10% increase in outputs, the unit is operating at constant returns to scale. This means that no matter what scale the unit operates at, assuming its current operating practices, its efficiency will remain unchanged. The CRS efficiency represents technical efficiency, which measures inefficiencies due to input/output configuration and size of operation. In this step, firstly, the key input/output measures for candidate suppliers and distributors are identified and data on all these measures are collected. Next, the relative efficiency score of each candidate supplier and distributor is calculated using the CCR model. It must be noted that the candidate suppliers and distributors were referred as Decision-Making Units (DMUs) henceforth. The CCR model in its purest form allows flexibility in the selection of weights, especially if fewer DMUs are included in the analysis. This is known as weight flexibility; however, the weight flexibility is often discussed as a main weakness of traditional CCR model.

Weight flexibility allows each DMU to achieve the maximum feasible efficiency score with its existing levels of inputs and outputs. An argument in favor of the weight flexibility is that if a DMU is identified as inefficient in spite of using a favorable set of weights; it is a strong statement about the inefficiency of that DMU. Another argument in favor of the flexibility is that the efficiency of different DMUs that is evaluated using different sets of weights allowing DMUs to express their different circumstances and different objectives. So, the relative efficiency scores obtained from the CCR model may not accurately determine the performance of some DMUs because the input and output weights are unrestricted. Therefore, to deal with the unrestricted weight flexibility of the CCR model, in the second step, the Pair-Wise Efficiency Game formulation (PEG) model is used and a pair-wise comparison of DMUs is carried out.

2.1.2. Step 2: Pair-Wise Efficiency Game Formulation

This section explains the PEG formulation, which is utilized in combination with the CCR model to carry out the pair-wise comparison of DMUs. Using the terminology of DEA, the unit whose efficiency is being evaluated is referred as the test DMU. The test DMU is compared to all of the other DMUs which are called the target DMUs in this study. In the following PEG model, the test DMU is represented as DMU_j and the target DMU is represented as DMU_o.

$$\forall j=o, \quad j=0,1,.....n$$

$$\min \left[\sum_{r=1}^{s} u_r y_{rj} / \sum_{i=1}^{m} v_i x_{ij}\right] \tag{1}$$

S.t.

$$\left[\sum_{r=1}^{s} u_r y_{ro} / \left[\sum_{i=1}^{m} v_i x_{io}\right]\right] = \theta, \tag{2}$$

$$\left[\sum_{r=1}^{s} u_r y_{rj} / \left[\sum_{i=1}^{m} v_i x_{ij}\right]\right] \leq 1, \tag{3}$$

$$u_r, v_i \geq 0, \ \forall r,i, \tag{4}$$

where $\boldsymbol{\theta}$ is the efficiency score of the target DMU obtained from the CCR model; **n** is the number of DMUs; **s** is the number of outputs; **m** is the number of inputs; $\mathbf{y_{rj}}$ is the amount of output r produced by DMU_j; $\mathbf{y_{ro}}$ is the amount of output r produced by the target DMU (DMU_o); $\mathbf{x_{ij}}$ is the amount of input i used by DMU_j; $\mathbf{x_{io}}$ is the amount of input i utilized by the target DMU (DMU_o); $\mathbf{u_r}$ is the weight given to output r and $\mathbf{v_i}$ is the weight given to input i.

The objective function (1) tries to minimize the ratio of the total weighted output to the total weighted input, which gives the efficiency score of a test DMU. Constraint (2) prevents the efficiency score of the target DMU (DMU_o) from being either higher or lower than the DMU_o's maximum value, which is the CCR score. Constraint (3) which is a normalization constraint assures that the efficiency score of the test DMU is not larger than 1. To convert the above non-linear problem into a linear program, the following transformation is carried out:

$$\sum_{i=1}^{m} V_i X_{ij} = 1 \tag{5}$$

The above constraint assures that the weighted input of the test DMU in the objective function is equal to 1. The two original constraints of general formulation are transformed into linear constraints. The new formulation named as "model 1" is as follows:

$$\forall j \neq o,$$

$$\min \left[\sum_{r=1}^{s} u_r y_{rj}\right] \tag{6}$$

S.t.

$$\left[\sum_{i=1}^{m} v_i x_{ij}\right] = 1, \tag{7}$$

$$[\sum_{r=1}^{s} u_r y_{ro}] - \theta[\sum_{i=1}^{m} v_i x_{io}] = 0, \quad (8)$$

$$[\sum_{r=1}^{s} u_r y_{rj}] - [\sum_{i=1}^{m} v_i x_{ij}] \leq 0, \quad (9)$$

$$u_r, v_i \geq 0. \ \forall r,i, \quad (10)$$

By changing the target DMU, the PEG formulation is rerun "n-1" times, which results in exactly "n-1" efficiency scores for each DMU. The results of PEG and CCR models are used to obtain an aggregated mean efficiency (M_EFF) score for each DMU. These aggregated mean efficiency scores are utilized as an index to differentiate between the good and poor performers, where high score indicates good operating practices. The aggregated mean efficiency score of each DMU_j is

$$M\_EFF_j = [\sum_{o=1}^{n} e_{jo}]/n, \quad (11)$$

calculated as follows:

where $\mathbf{e_{jo}}$ shows the efficiency score of a test DMU that is obtained by PEG model and **n** is the number of DMUs. As mentioned earlier, in addition to the CCR scores obtained for each DMU in the Step 1, the PEG formulation generates exactly "n-1" efficiency scores for each DMU. The CCR and PEG models provide a productivity index that represents the efficiency of various DMUs based on multiple performance criteria. In summary, this step results in the aggregated mean efficiency score, M_EFF score for each candidate supplier and distributor.

2.1.3. Step 3: Selection of Suppliers and Distributors

This step involves using the following integer-programming model, named as "model 2", to identify the optimal suppliers by taking into consideration the M_EFF score calculated above, and also the demand, capacity and location constraints:

$$\min [\sum_{i=1}^{n} x_i] \quad (12)$$

S.t.

$$[\sum_{i=1}^{n} E_i x_i] - E_{avg}[\sum_{i=1}^{n} x_i] \geq 0, \quad (13)$$

$$[\sum_{i=1}^{n} L_i x_i] - L_{avg}[\sum_{i=1}^{n} x_i] \geq 0, \quad (14)$$

$$\sum_{i=1}^{n} C_i x_i \geq \sum_{j=1}^{q} D_j, \quad (15)$$

$$x_i = 0 \text{ or } 1, \quad (16)$$

where $\mathbf{x_i}$ is the binary variable that indicates the selection of supplier i; **n** is the number of DMUs; **q** is the number of manufacturers; $\mathbf{E_i}$ is the M_EFF score of supplier i; $\mathbf{E_{avg}}$ is "the required lowest M_EFF score"; $\mathbf{L_i}$ is the location rating of supplier i; $\mathbf{L_{avg}}$ is "the required lowest location rating";

C_i is the annual production capacity of each supplier; **D_j** is the demand of manufacturer j that must be satisfied.

The objective function (12) aims at minimizing the number of selected suppliers. Constraint (13) states that the M_EFF score of selected supplier should be equal to or higher than the required lowest M_EFF score. Constraint (14) states that the location rating of selected supplier should be equal to or higher than the required lowest location rating. Constraint (15) assures that the total capacity of selected suppliers is sufficient to satisfy the total demand of three manufacturers.

Likewise, the following integer-programming model, named as "model 3", is utilized to identify the optimal distributors:

$$\min \left[\sum_{i=1}^{n} x_i\right] \tag{17}$$

S.t.

$$\left[\sum_{i=1}^{n} E_i x_i\right] - E_{avg}\left[\sum_{i=1}^{n} x_i\right] \geq 0, \tag{18}$$

$$\left[\sum_{i=1}^{n} L_i x_i\right] - L_{avg}\left[\sum_{i=1}^{n} x_i\right] \geq 0, \tag{19}$$

$$\sum_{i=1}^{n} D_i x_i \geq \sum_{j=1}^{q} C_j, \tag{20}$$

$$x_i = 0 \text{ or } 1, \tag{21}$$

$$i = 1,.....,n.$$
$$j = 1,.....,q.$$

where **x_i** is the binary variable that indicates the selection of distributor i; **n** is the number of DMUs; **q** is the number of manufacturers; **E_i** is the M_EFF score of distributor i; **E_{avg}** is "the required lowest M_EFF score"; **L_i** is the location rating of distributor i; **L_{avg}** is "the required lowest location rating"; **D_i** is the demand of distributor i that must be satisfied; **C_j** is the annual production capacity of manufacturer j.

The objective function (17) in Model 3 aims at minimizing the number of selected distributors. Constraint (18) states that the M_EFF score of selected distributor should be equal to or higher than the required lowest M_EFF score. Constraint (19) states that the location rating of selected distributor should be equal to or higher than the required lowest location rating. Constraint (20) states that the degree of satisfying the demand of selected distributors will be limited by the capacity of the manufacturers.

2.2. Phase 2: Optimal Route Planning

Phase 2 involves two steps. First, the priorities of selected suppliers and distributors are determined. Next, these priorities are integrated into the transportation models developed in this study to identify the optimal routing decisions for all members in the network.

2.2.1. Step 1: Determination of Priority Rankings

This step involves analyzing the capabilities and characteristics of selected suppliers and distributors by a management team. A solution to this multi-criteria decision problem is obtained by using the AHP software, "Expert Choice." First, various main, and sub-criteria are identified based on this management team members' opinions. Next, these criteria are structured into a hierarchical form and the team members are required to perform pair-wise comparisons among all main criteria and sub-criteria by using the Saaty's 1-9 scale. As a result of these pair-wise comparisons, a weight is assigned to each sub-criterion using AHP. Following, the team evaluates the performance levels of selected suppliers and distributors during the audits and assigns a rating to each supplier and distributor. These ratings describe how well a certain supplier or distributor is expected to satisfy the group preferences based on the predetermined criteria and sub-criteria. Ratings are the performance values of selected suppliers and distributors on a scale of 0-100 where higher values represent better performance. Finally, the priorities of selected suppliers and distributors are calculated by multiplying these ratings with the weight of each sub-criterion.

2.2.2. Step 2: Transportation Problem

This step identifies the optimal routing decisions related to the supply of raw materials and shipment of finished goods. The transportation model for supply of raw materials takes into consideration the capacities of suppliers, demand of three manufacturers and the priorities of selected suppliers. Likewise, the transportation model for shipment of finished products takes into consideration the capacities of manufacturers, demand of selected distributors and the priorities of selected distributors. Assuming that the p suppliers are selected in Phase 1 of the proposed methodology, the following transportation model, named as "Model 4" is developed to express the routing between p suppliers and q manufacturers under given demand and capacity constraints:

$$\min \left[\sum_{i=1}^{p}\sum_{j=1}^{q}(1/t_i)x_{ij}\right] \tag{22}$$

S.t.

$$\sum_{j=1}^{q} x_{ij} \le C_i, \ \forall i, \tag{23}$$

$$\sum_{i=1}^{p} x_{ij} = D_j, \ \forall j, \tag{24}$$

$$x_{ij} \ge 0, \forall i, j, \tag{25}$$

where $\mathbf{t_i}$ is the priority of supplier i; $\mathbf{x_{ij}}$ is the number of units shipped from supplier i to manufacturer j; $\mathbf{C_i}$ is the capacity of supplier i; $\mathbf{D_j}$ is the demand of the manufacturer j. The objective function (22) aims at minimizing the quantity of raw materials to be shipped from selected "p" suppliers to "q" manufacturers. Constraint (23) assures that the sum of the shipments from a supplier cannot exceed the annual production capacity of this supplier. Constraint (24) makes sure that the demand of a manufacturer is satisfied. Likewise, assuming that the r distributors are selected in phase 1, the transportation model named as “model 5,” expressing the routing between q manufacturers and r distributors, is constructed as follows:

$$\min \left[\sum_{j=1}^{q}\sum_{k=1}^{r}(1/t_k)x_{jk}\right] \tag{26}$$

S.t.

$$\sum_{k=1}^{r} x_{jk} \le C_j, \ \forall j, \tag{27}$$

$$\sum_{j=1}^{q} x_{jk} = D_k, \ \forall k \ne h, \tag{28}$$

$$\sum_{j=1}^{q} x_{jh} = \sum_{j=1}^{q} C_j - \sum_{k=1}^{r} D_k, \ \forall k \ne h, \tag{29}$$

$$x_{jk}, x_{jh} \ge 0, \ \forall j, k \tag{30}$$

where **h** denotes the distributor with the minimum priority; $\mathbf{t_k}$ is the priority of distributor k; $\mathbf{x_{jk}}$ is the number of finished products to be shipped from manufacturer j to distributor k; $\mathbf{x_{jh}}$ is the number of finished products to be shipped from manufacturer j to distributor h; $\mathbf{C_j}$ is the capacity of manufacturer j; $\mathbf{D_k}$ is the demand of the distributor k; $\mathbf{D_h}$ is the demand of the distributor h.

The objective function (26) aims at minimizing the quantity of finished products to be shipped from “q” manufacturers to selected “r” distributors. It must be noted that using the reciprocals of the priorities assures that the demand of the distributor with maximum priority is satisfied primarily. Constraint (27) states that the sum of the shipments from a manufacturer cannot exceed the annual production capacity of this manufacturer. Constraint (28) states that the sum of the shipments to a distributor (except for the distributor h with minimum priority) is equal to the demand of this distributor. Constraint (29) states that the sum of the shipments to the distributor h that has minimum priority, is equal to “the total capacity of three manufacturers minus the total demand of distributors with higher priority”. It must be noted that to reflect the company’s desire to minimize the level of inventory, the objective functions in models 4 and 5 are expressed as minimization functions.

3. Implementation

This section presents a real-world case study to illustrate the steps of the proposed methodology. The study has been conducted at an automotive company located in Izmir, Turkey. The objective is to develop a supply chain network for one of its recently introduced new products, a light commercial vehicle.

3.1. Phase 1: Supplier and Distributor Selection

This light commercial vehicle is assembled from many purchased components besides manufactured ones. Purchased components are procured from a large number of suppliers (i.e. 156 suppliers). As presented below, we placed these suppliers into nine groups based on the type of the component purchased.

1. Air Systems (6 suppliers).
2. Auto Tyres (5 suppliers).
3. Chemical Materials (6 suppliers).
4. Electric Materials (17 suppliers).
5. Plastic and Polyester and Glass Materials (18 suppliers).
6. Radiator and Intercooler (5 suppliers).
7. Miscellaneous Parts (50 suppliers).
8. Sheet Iron and Welded Assemblies (30 suppliers).
9. Trim & Rubber Materials (19 suppliers).

All suppliers in each group are assumed to be shipping identical components. To evaluate these nine groups of suppliers, two input and four output measures are used.

The Input measures are:

1. **Total Cost (TC):** The total logistics and procurement cost of the raw materials.
2. **Experience (EX):** Working experience of supplier with the company regarding responsiveness, access, courtesy, communication, and trust.

The output measures are:

1. **Percentage of On-Time Deliveries (OTD):** The timely transfer or exchange of the raw materials and the ability to deliver to the manufacturers according to the target schedule.
2. **Acceptance Rate (AR):** The percentage of accepted units during quality control of incoming parts.
3. **Post Transaction Service Level (SL):** Commitment of the resources to offer the desired level of service after sale.
4. **Defect Rate (DR):** The percentage of rejected units during quality control of incoming parts.

Data on these input and output measures are based on the audits performed by the company. To reflect the performance of the suppliers, numerical values based on a scale of 0-100 are given. High values indicate good performance. Likewise, all candidate distributors (i.e. 64 distributors) for the shipment of finished products are placed into six groups based on the region:

1. Adana (10 distributors).
2. Ankara (9 distributors).
3. Diyarbakır (7 distributors).
4. İstanbul (10 distributors).
5. İzmir (22 distributors).

6. Samsun (6 distributors).

To evaluate these six groups of distributors, one input and three output measures are used. Input measure is:

Operating Costs per Dollar Revenue (OC): This measure demonstrates how much it costs to generate a dollar of revenue from a particular distributor. It compares activity expense to per dollar revenue received.

The output measures are:

1. **Percentage of On-Time Deliveries (OTD):** It measures the timely transfer or exchange of the finished products to the ultimate customers.
2. **Service level (SL):** It measures percentage of time without stockouts.
3. **Percentage of Accurately Handled Customer Orders (AHO):** It measures conformity of the finished products to requirements of customer orders.

It must be noted that because of the limited space the implementation of the proposed methodology is illustrated only for electric materials suppliers and the distributors in Ankara region.

3.1.1. Step 1: Application of CCR Model

This step generates a relative efficiency score for each candidate supplier by taking into consideration the input and output measures given in earlier section. First, numerical values based on a scale of 0-100 are given to these input and output measures to reflect that supplier's performance. Next, the relative efficiency scores of candidate electric materials suppliers are calculated using the DEA software, Efficiency Measurement System (EMS). As can be seen in Table 1, among 17 suppliers, eight of them (i.e. 1, 4, 9, 11, 13, 14, 15 and 17) with a relative efficiency score of 1 are identified to be efficient. The last two columns in Table 1 present Location Ratings (LOC) and Annual Production Capacities (CAP) of these 17 suppliers.

As mentioned in detail in Section 2.1.1, the relative efficiency scores obtained from the CCR model may not accurately determine the performance of some suppliers because the input and output weights are unrestricted. To overcome this problem of the CCR model, the cross-evaluations are conducted to discriminate between good and poor performers by utilizing the PEG formulation.

Table 1. Electric materials suppliers' data and efficiency scores.

Suppliers	Location	Inputs		Outputs				Relative Efficiency Scores	M_EFF Scores	Loc	Cap
		TC	EX	OTD	AR	SL	DR				
1	İstanbul	90	75	100	100	89	98	1.000	0,835	87	641239
2	Ankara	80	95	58	100	80	49	0,873	0,635	86	573952
3	İstanbul	80	90	59	95	79	86	0,963	0,722	87	571631
4	İstanbul	80	90	94	97	91	72	1.000	0,787	87	656240
5	İstanbul	80	66	44	95	67	1	0,942	0,210	87	482339
6	İstanbul	80	90	70	65	71	78	0,872	0,587	87	511219
7	Sakarya	80	90	73	94	83	22	0,910	0,494	87	595960
8	Bursa	70	95	24	96	76	1	0,881	0,155	91	543930
9	İstanbul	80	90	34	84	71	95	1.000	0,515	87	514159
10	Kırklareli	80	90	40	96	76	1	0,859	0,194	86	547157
11	İzmir	81	60	54	99	67	90	1.000	0,685	100	613920
12	İstanbul	90	76	51	95	72	30	0,861	0,497	87	521662
13	İstanbul	60	95	81	78	79	66	1.000	0,678	87	571696
14	Bursa	70	90	83	100	85	5	1.000	0,321	91	484608
15	İstanbul	60	90	72	98	80	24	1.000	0,563	87	578192
16	İstanbul	80	75	29	79	64	1	0,792	0,176	87	458358
17	İstanbul	60	84	41	95	71	40	1.000	0,606	87	509666

3.1.2. Step 2: Pair-Wise Efficiency Game (PEG) Formulation

In this step, the PEG formulation, given as model 1 in Section 2.1.2, is utilized to evaluate the cross-efficiency scores of the candidate suppliers by taking into consideration both input and output measures and relative efficiency scores calculated in earlier step. The PEG formulation is solved using Lindo. The CCR score and the PEG results for each supplier are used to calculate the M_EFF score of that supplier. It is interesting to note that the supplier 3, which was found to be inefficient as a result of applying the CCR model in earlier step, now it was found to have a better performance (i.e. M_EFF score for supplier 3 is 0.772) than the suppliers 9, 11, 13, 14, 15 and 17, which were identified as efficient in earlier step. This result clearly demonstrates the usefulness of the PEG model in differentiating between good and bad performers.

3.1.3. Step 3. Selection of Suppliers

This step employs the integer-programming model given as model 2 in Section 2.1.3 to identify the optimal suppliers by taking into consideration the capacities, location ratings and the aggregated mean efficiency scores, M_EFF scores of candidate suppliers and the demand of three manufacturers. In order to represent the closeness of each supplier to the company, a location rating (L_i) on a scale of 0-100 is given to each candidate supplier. The higher the location rating the closer the supplier to the manufacturing site. The required lowest M_EFF scores and the required lowest location ratings of supplier groups and the forecasted demand values of three manufactures for each supplier group are given in Table 2. It must be noted that, all data on demand for raw materials are based on the forecasted values, since this case study focuses on designing a SCN for a recently introduced product of the company.

As seen in Table 2, the required lowest M_EFF score and the location rating for electric materials are calculated as 0.51 and 88 respectively. These two values will serve as critical values in evaluation of 17 suppliers. Another requirement is that the total capacity of selected suppliers must be sufficient to meet the estimated demand for electric suppliers (i.e. 1897632 units). It must be noted that if a supplier does not meet the minimum performance requirement, it is not taken into consideration during the evaluation process. The integer-programming model constructed to select the suppliers is solved using Lindo. As seen in Table 3, the electric materials suppliers 1, 4, and 11 are selected to take place in the SCN for this new product of the company. These suppliers are not only good performers with respect to their internal operating practices, but also, as a group, satisfy the required lowest M_EFF scores, location and capacity constraints. Table 3 also presents the supplier selection decisions taken for other material groups.

As for the distributor selection, only the second group, Ankara, has been taken into consideration. The calculated efficiency scores, evaluation of distributors and distributor selection decisions are presented in tables 4, 5 and 6 respectively.

Table 2. Evaluation of suppliers.

No	**Supplier Groups**	**The Required Lowest M_EFF Scores**	**The Required Lowest Location Ratings**	**Demand of Manufacturer 1**	**Demand of Manufacturer 2**	**Demand of Manufacturer 3**	**Total Demand**
1	Air Systems	0,60	90	44664	71462	17866	133992
2	Auto Tyres	0,74	90	31332	50131	12533	93996
3	Chemical Materials	0,79	98	162852	260563	65141	488556
4	**Electrical Materials**	**0,51**	**88**	**632544**	**1012070**	**253018**	**1897632**
5	Plastic & Polyester & Glass	0,38	92	759960	1215936	303984	2279880
6	Radiator & Intercooler	0,72	92	7200	11520	2880	21600
7	Miscellaneous Parts	0,45	92	2778180	4445088	1111272	8334540
8	Sheet Iron & Welded Assemblies	0,50	92	2129160	3406656	851664	6387480
9	Trim & Rubber Materials	0,54	91	1034136	1654618	413654	3102408

Table 3. Supplier selection decisions.

No	Supplier Groups	Selected Suppliers
1	Air Systems	2, 5, 6
2	Auto Tyres	3, 4, 5
3	Chemical Materials	2, 4, 5
4	**Electrical Materials**	**1, 4,11**
5	Plastic & Polyester & Glass	3, 5, 7,15
6	Radiator & Intercooler	3, 4, 5
7	Miscellaneous Parts	4, 7,17, 20, 40, 43, 48
8	Sheet Iron & Welded Assemblies	1, 9, 17, 22
9	Trim & Rubber Materials	2, 6, 8,16

Table 4. Distributors' data and efficiency scores for Ankara region.

Distributors	Location	Inputs	Outputs			Relative efficiency scores	M_EFF Scores	Loc	Dem
		OC	OTD	SL	AHO				
1	Ankara	60	25	90	90	1.000	0,514	86	1878
2	Ankara	80	92	90	95	1.000	0,912	86	1495
3	Konya	80	63	88	85	0,877	0,765	86	1355
4	Bolu	80	30	50	75	0,654	0,409	86	1322
5	Eskişehir	80	36	45	26	0,462	0,291	89	688
6	Karabük	100	77	71	45	0,669	0,410	82	1237
7	Ankara	90	68	95	97	0,841	0,746	86	1892
8	Yozgat	90	78	79	88	0,803	0,719	80	1828
9	Zonguldak	80	66	75	87	0,857	0,745	62	1697

Table 5. Evaluation of distributors.

No	Distributor Groups	Required Lowest M_EFF Scores	Required Lowest Location Ratings	Capacity of First Manufacturer	Capacity of Second Manufacturer	Capacity of Third Manufacturer	Total Capacity
1	Adana	0,63	77	876	1402	350	2628
2	Ankara	0,61	83	872	1395	349	2616
3	Diyarbakır	0,77	66	296	474	118	888
4	İstanbul	0,69	88	2164	3462	866	6492
5	İzmir	0,50	94	1276	2042	510	3828
6	Samsun	0,81	72	456	730	182	1368

Table 6. Distributor Selection Decisions.

No	Distributor Groups	Selected Distributors
1	Adana	8, 10
2	Ankara	2, 3
3	Diyarbakır	1, 2
4	İstanbul	2, 4
5	İzmir	8, 13
6	Samsun	2, 6

As seen in Table 6, the distributors 2 and 3 are selected to take place in the SCN for the region of Ankara. Table 6 also lists the decisions taken for the remaining distributor groups.

3.2. Phase 2: Optimal Route Planning

In this phase, first, priorities of selected suppliers and distributors are determined by taking into consideration the preferences of management team on performance of these suppliers and distributors. Next, optimal routing decisions for all members of SCN are identified.

3.2.1. Transportation from Selected Suppliers to Manufacturers

As explained above, the procedure employed involves two steps:

Step 1: Determination of the Priority Rankings Using AHP

The priorities of selected suppliers are determined by taking into consideration the group preferences on performance of these suppliers. In this study, the insights of a group of 10 employees whose decisions are effective on management of the company are utilized to determine the priorities of selected suppliers. Firstly, the decision making criteria to include in this analysis are organized into the hierarchical structure (see Figure 1). The overall goal for the analysis, which is located at the highest level of the hierarchy is to evaluate the selected suppliers on four main criteria, reliability, flexibility, discipline, and cost. As seen in Figure 1, in order to reach an adequate level of detail in the analysis, each of the three main criteria is further divided into two sub-criteria.

Reliability: Reliability including "quality" and "on time delivery" aspects refers to the ability to deliver raw materials to the manufacturers to meet the target schedule and pre-specified quality standards.
Flexibility: Flexibility refers to the ability of a supplier to respond to unpredictable demand changes (i.e. capacity adjustments) and to any special requests set by the manufacturers (i.e. special requests).
Discipline: This criterion consists of the working experience of supplier with the company as discussed in Section 3.1 (i.e. experience) and the ability of the supplier to obey the procedures of the company (i.e. procedural compliance).

Cost: As discussed in Section 3.1, it refers to the cost total logistics and procurement of raw materials.

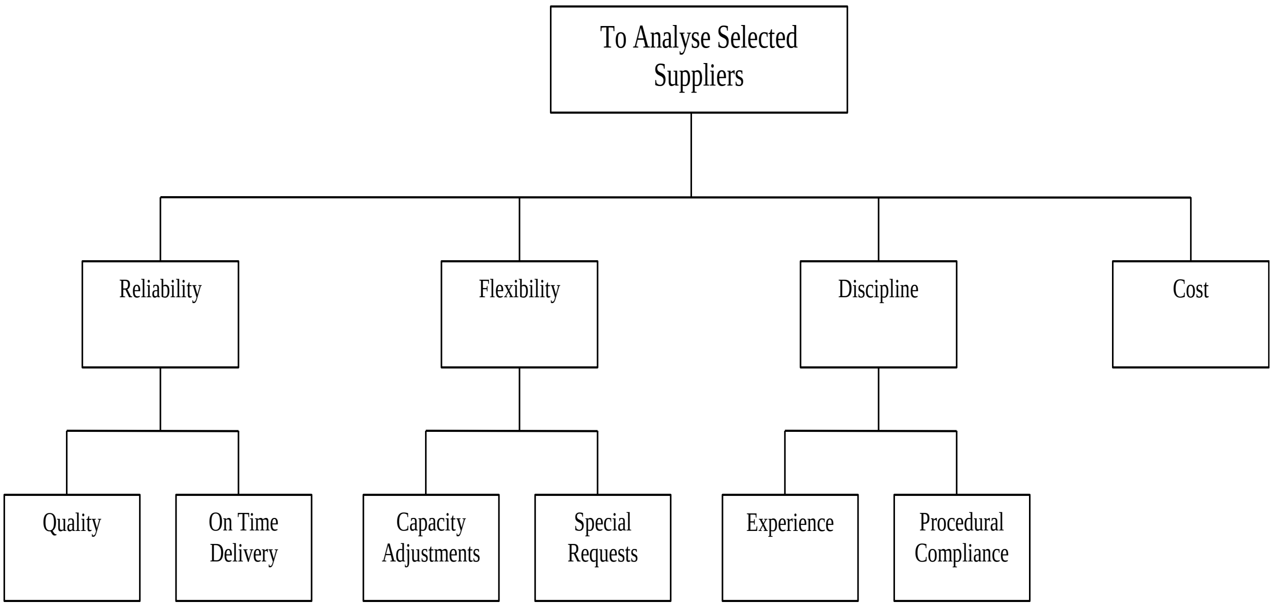

Figure 1. The hierarchy for analyzing selected suppliers.

First, all pairwise comparisons for main and sub-criterion are done using the Saaty's 1-9 scale in order to derive priorities (weights) for each criterion. Next, based on these sub-criteria, the performance levels of selected suppliers are evaluated by the management team during the audits on a scale of 0-100 where higher values represent better performance. Finally, the weights of each criterion and the ratings of each supplier with respect to these criteria are used to obtain the priorities of the suppliers. As given in Table 7, the management team gives more importance to quality criterion (0,451), followed by cost (0,261).

Table 7. Analysis of selected suppliers of electric materials.

Electric Materials									
Subcriteria	**Quality**	**On Time Delivery**	**Capacity Adjust.**	**Special Requests**	**Exper.**	**Proc. Compl.**	**Cost**	**Total**	**Priority**
Score / Suppliers	0,451	0,113	0,094	0,031	0,044	0,006	0,261	1.000	
1	95	100	82	95	75	94	90	92	**0,3608**
4	81	94	84	92	90	69	80	83	0,3255
11	91	54	62	94	60	86	81	80	0,3137

The priorities represent the overall preference of a certain supplier to the manufacturer. As given in Table 7, the supplier 1 has the highest priority.

Step 2: Transportation Problem

The transportation route selection is based on the priorities calculated in Step 1. These priorities make it possible to take into account the group member's preferences on selected suppliers. To identify the optimal routing decisions for supply of raw materials, these priorities are integrated into the transportation model given in Section 3.2.2 and the results given in Table 8 are obtained.

Table 8. Optimal routing decisions for the supply of electric materials.

Electric Materials				
From \ To	**Manufacturer 1**	**Manufacturer 2**	**Manufacturer 3**	**The Reciprocal of Priority**
Supplier 1	632544	-	8695	2.772
Supplier 4	-	656240	-	3.072
Supplier 11	-	355830	244323	3.188

3.2.2. Transportation from Manufacturers to Selected Distributors

Optimal routing decisions related to the shipment of finished products from manufacturers to distributors are made using the same two-step procedure given in earlier section. It must be noted that to determine the priority ranking of selected distributors, the same set of criteria used for suppliers (see Figure 1) are taken into consideration. First, as given in Table 9, the priorities of selected distributors are identified, next these priorities are integrated into the transportation model given as model 5 in Section 3.2.2 to obtain optimal routing decisions (see Table 10).

Table 9. Analysis of selected distributors at Ankara.

Ankara									
Subcriteria	**Quality**	**On Time Delivery**	**Capacity Adjust.**	**Special Requests**	**Exper.**	**Proc. Compl.**	**Cost**	**Total**	**Priority**
Weight	0,451	0,113	0,094	0,031	0,044	0,006	0,261	1.000	
Distributor 2	89	92	89	86	89	95	80	87	0,5210
3	83	63	80	84	79	92	80	80	0,4790

Table 10. Optimal routing decisions for Ankara.

Ankara		
From \ To	**Distributor 2**	**Distributor 3**
Manufacturer 1	100	772
Manufacturer 2	1395	-
Manufacturer 3	-	349
The Reciprocal of Priority	1.920	2.088

It must be noted that the same two-step procedure has been applied to all selected suppliers and distributors to identify optimal routing decisions. However, owing to the limited space, only the results for electric materials suppliers and the distributors in the region of Ankara are presented here.

4. Conclusion

The main interest of this study was to design an efficient SCN for an automotive company by integrating various approaches. The study has been carried out in two phases: The first phase employs a number of multi-criteria efficiency models, CCR and PEG to evaluate the performance of candidate suppliers and distributors. Following, an integer-programming model is developed to optimally solve supplier and distributor selection problem under the given efficiency, capacity, demand, and location constraints. In the second phase, two transportation problems are solved in order to identify the optimal routing decisions for supply of raw materials and shipment of finished products. The preferences of the company on selected suppliers and distributors are determined by using the AHP and these preferences are reflected in transportation models. This approach provides a systematic and flexible framework for determining the priority of each node within the network by taking into account the preferences of the company. Compared to the traditional transportation models, mainly cost oriented approaches, the utilization of the AHP enables the inclusion of both quantitative and qualitative factors in the decision process.

Originating from a real-world industrial problem, we hope that this study will serve as a guideline for practitioners to design their SCN in a systematic way to reap the benefits of meeting the constantly changing needs of the customer at low cost, high quality and in short lead times. As a future work, a decision support system, which automates the steps of the suggested procedure for designing a SCN, can be developed. Such a system not only can be used for new products to shorten the time required to design a SCN but also for existing products to test the efficacy of supply chain decision making at the strategic, tactical and operational levels. Especially, since the analyses in phase 2 are expected to be carried out more frequently due to changes in demand and capacity constraints, employing a decision support system to deal with the operational issues will certainly help to obtain solutions in much shorter time.

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