Journal of Mathematical Extension
Vol. 16, No. 4, (2022) (3)1-26
URL: https://doi.org/10.30495/JME.2022.1315
ISSN: 1735-8299
Original Research Paper

A New Method for Selecting the Most Appropriate Suppliers in the Supply Chain using DEA

H. Ghamgosar
Central Tehran Branch, Islamic Azad University

M. Rostamy-Malkhalifeh*
Tehran Science and Research Branch, Islamic Azad University

M. Sanei
Central Tehran Branch, Islamic Azad University

F. Hosseinzadeh Lotfi
Tehran Science and Research Branch, Islamic Azad University

G. Tohidi
Central Tehran Branch, Islamic Azad University

Abstract. Evaluation and selection of efficient suppliers is accepted as one of the key issues in supply chain management (SCM). The research problem here is a specific mode of suppliers in a supply chain with a multistage system, consisting of several components. Each component is also regarded as a phase in a supply-chain network (SCN) with a number of inputs and outputs that are being produced independently and simultaneously. Moreover, each input is generated from different modes and there are many output indicators. The main purpose of this study is to propose a new method for selecting the most appropriate

Received: December 2019; Accepted: February 2020
*Corresponding Author

suppliers in a SCN using data envelopment analysis (DEA) strategies. The premise is that, a SCN space can be transformed into a DEA one considering the occurrence of input/output mode in each phase in the SCN as a decision-making unit (DMU), and the relative efficiency of each possible mode in each phase of the given network can be obtained via DMUs. Finally, the component endowed with the highest efficiency can be selected as the most appropriate supplier.

AMS Subject Classification: 47N10
Keywords and Phrases: Supply chain, Data envelopment analysis(DEA), supply chain network design, Efficiency.

1 Introduction

With respect to globalization and increasingly tough competitions in global markets and business environments as well as great importance of improving productivity, reducing costs, reaching ultimate desirability of goods, applying customer feedback in final products, and the like; companies and organizations are struggling more than ever before to maintain their survival, and this issue has led to the emergence of the philosophy of supply chain management (SCM). In fact, SCM refers to integration of organizational units throughout a supply chain and harmonizing flow of materials, information, and finance. Moreover, SCM has turned into one of the substantial issues for companies and organizations, as it covers all activities from stages of procurement to production of final products and their delivery to customers [4].

Evaluating the efficiency of a supply-chain network (SCN) encompasses a wide range of performance evaluations throughout the supply chain processes in independent companies and organizations. So, one of the most important issues in decision-making is adopting an appropriate strategy that allows for long-term effective operations throughout the entire SCN. Since marketing, distribution, planning, manufacturing, and procurement in companies and organizations are generally independent from others in terms of their SCN; supply chain efficiency assessment implies evaluating efficiency of marketing, distribution, planning, production, and purchasing within companies and organizations.

The rising trend in purchasing problems has also redoubled the significance of purchasing decisions. Therefore, decisions related to strategies and purchasing operations can play a determining role in profitability. Also, selection of suppliers is taken into account as one of the most important issues in the field of purchasing management. Hence, in response to increasing competitions, shortening product lifecycles, and rapid changes in customer taste, most companies and organizations have focused on development of suppliers' long-term capabilities, highlighting the importance of their evaluation and selection. So far, various studies have been carried out on decision-making issues and selection of appropriate suppliers, as follows.

For example, Basent and Leung [1] focused on determining the size of periodic batch order along with choice of suppliers, in which only few factors were considered and then an innovative count-based exploration algorithm was provided to solve this problem. The given model could help decision-makers to know they needed to supply how much of what products, in which period, and from which supplier. Hong et al. [20] also presented a mixed-integer programming (MIP) model for selection of suppliers, which could finalize the optimal number of suppliers, elevate order quantity, and maximize revenues. As well, Fazipour [16] developed a data analysis method to select efficient suppliers in the presence of two undesirable outputs. Narasimahan et al. [36] similarly suggested a multi-objective programming model for selecting the most appropriate suppliers and determining economic order quantity. Also, Biazit [3] proposed an analytic network process (ANP) model for supplier selection which included ten evaluation indicators categorized based on suppliers' performances and capabilities. To formulate interactions between all indicators, each one was considered as a control one for paired comparison matrices. Using a case-based argument, Choy and Lee [8] also put forward a general model to select suppliers in which different categorization criteria had been divided into three groups of technical capabilities, quality systems, and organizational characteristics. Moreover, Kull and Talluri [29] offered a hybrid goal programming and analytic hierarchy process (AHP) to evaluate existing suppliers based on relevant indicators and index weighting. Ifeyinwa and Sun [21] correspondingly took advantage of a simulation model of a fuzzy dynamical system to select suppliers. In addition, Chen et al. [6] suggested a hierarchical model based on fuzzy set theory to do so. To this end, linguistic variables were employed to determine index weighting, expressed by triangular or trapezoidal fuzzy numbers. Fikri et al. [17] also utilized AHP to select suppliers in the automotive industry in Pakistan and Rahiminezhad et al. [37] proposed a hybrid model of fuzzy AHP and balanced scorecard for selecting suppliers in the same industry.

Data envelopment analysis (DEA) is known as one of the most powerful tools based on math planning to evaluate performance and to compute efficiency of a set of decision-maker units (DMUs), which was first investigated for input-output [15]. Then, the model developed by Charnes, Cooper, and Rhodes (CCR) was introduced to measure performance through multiple inputs and outputs [5]. Numerous works have been also done on SCM; however, use of DEA in this field has been recently considered [11, 42]. On account of successful case studies and applications, DEA has been widely used by business researchers and academics in various fields e.g. data warehousing [35], selection of flexible production systems [33], performance appraisal of bank branches [18], analysis of financial statements of institutions [12], efficiency assessment of higher education institutions [23], and problem-solving in designing how to deploy facilities [13]. Garfamy [19] also used DEA to evaluate efficiency of suppliers according to characteristics and performance indices of suppliers and purchasers. In this approach, three sensitivity analysis had been performed. The first analysis calculated suppliers' performance without considering the assessment team weight, the second analysis preferred assessment of evaluation team to suppliers but took no input into account, and the third analysis singled out buyers instead of suppliers. In addition, Seydel [38] employed DEA to select suppliers but with no inputs. In this model, a seven-point scale had been proposed to rank qualitative indices. As well, Liu et al. [31] proposed a simplified DEA model to evaluate efficiency of suppliers with three and two input and output indicators; respectively. Korhonen and Syrjanen also devised a method based on DEA and multi-criteria decision-making (MCDM) for centralized resource allocation [28]. Furthermore, Talluri et al. [39] presented a DEA model with random constraints to evaluate efficiency of suppliers. In this model, price was considered as an input parameter and quality and delivery were selected as output ones. Wu et al. [44] similarly introduced a DEA method for selecting suppliers in uncertain

situations. As well, Wu and Olson [43] proposed a hybrid DEA model and a fuzzy grey relational analysis (GRA) to rank problems.
While the standard DEA reflects on a simple process, network DEA considers a sequence of processes in which their own sets of inputs are utilized to produce a collection of outputs. To measure such systems, network DEA was presented [7, 46]. Charens et al. and Liu and Zhou [34] also presented a two-stage network with moderate input and undesirable output. Then, the researchers invented various models of the network such as parallel, series, and relational ones. Moreover, Kao [26] introduced a model to measure efficiency of a parallel network. Also, Kaffash and Marra [24] presented a model to quantify efficiency of a series network. Fare and Grosskopf [14], Kao [27], and Tone and Tsutsui [41] additionally provided radial and non-radial models for analyzing efficiency of a relational network. Ultimately, Liu and Lu [32] provided a non-radial network DEA model.
Now, a mode of a commodity production chain, consisting of various components for construction, is considered in this study; so that each one has different conditions and is produced separately and independently. Then, a new solution is provided for selecting suppliers in a SCN. To this end, each chain component will be turned into a phase in a parallel network and the supply chain will be considered as a multi-stage DMU by choosing each mode as a DMU. Taking advantage of DEA methods, the optimal paths will be identified. The study is structured as follows: DEA and its introductory models are presented in Section 2. In Section 3, supply chain, its types, and details of the proposed method are mentioned. Section 4 includes a numerical example and a case study to manufacture auto parts, and conclusions regarding the proposed method are made in Section 5.

2 DEA and Basic Models

In this section, DEA and its basic models are reviewed. It should be noted that DEA is a mathematical programming method for measuring efficiency of DMUs, defined as units using a number of inputs to generate various outputs [5].
Assume that (DMUj) $j = 1, \ldots, n$, where, consumption of m input leads

to s output, and input and output vectors are as follows, respectively:

$$X_j = (x_{1j}, x_{2j}, \dots, x_{mj}), Y_j = (y_{1j}, y_{2j}, \dots, y_{sj})$$

Provided that these two vectors are non-negative and non-zero, production possibility set (T_C) will be as follows:

$$T_C = \{(X,Y) : X \geq \sum_{j=1}^{n} \lambda_j X_j, Y \leq \sum_{j=1}^{n} \lambda_j Y_j, \lambda_j \geq 0 (j = 1, \dots, n)\} \quad (1)$$

With regard to the above definition, the CCR model in input identity will be as follows:

$$\begin{array}{ll} \text{Min} & \theta \\ \text{s.t.} & \sum_{j=1}^{n} \lambda_j X_j \leq \theta X_p \\ & \sum_{j=1}^{n} \lambda_j Y_j \geq Y_p \\ & \lambda_j \geq 0, \quad (j = 1, \dots, n), \end{array}$$

Where, $\lambda = (\lambda_1, \lambda_2, \dots, \lambda_n)$ is a non-negative vector of variables and θ refers to a real number. In this model, the optimal solution applies to the condition of $0 < \theta^* \leq 1$. If $\theta^* = 1$, the given unit is efficient and considered as inefficient if $\theta^* < 1$.
In addition, the production possibility set T_V is as follows:

$$T_V = \{(X,Y) : X \geq \sum_{j=1}^{n} \lambda_j X_j, Y \leq \sum_{j=1}^{n} \lambda_j Y_j, \sum_{j=1}^{n} \lambda_j = 1, \lambda_j \geq 0 (j = 1, \dots, n)\} \quad (2)$$

In spite of this set, the model by Banker, Chames, and Cooper (BCC) will be as follows in terms of input identity:

$$\begin{array}{ll} \text{Min} & \theta \\ \text{s.t.} & \sum_{j=1}^{n} \lambda_j X_j \leq \theta X_p \\ & \sum_{j=1}^{n} \lambda_j Y_j \geq Y_p \\ & \sum_{j=1}^{n} \lambda_j = 1, \\ & \lambda_j \geq 0, \quad (j = 1, \dots, n) \end{array}$$

Note that CCR and BCC models are provided to measure the performance of radial models [2]. More information is also presented in [10, 40], illustrating how DEA formulas can reflect on performance in the presence of slack-based measures (i.e. non-radial models).

3 Supply Chan and Statement of the Problem

3.1 Supply Chain

In this section, SCN and SCM definitions are initially reviewed, and then the importance of decision-making by suppliers as well as the need to adopt specific strategies and techniques for certain SCNs under specific conditions are highlighted.

A supply chain refers to a network of facilities and distribution choices, providing customers with material preparation, converting these materials into intermediate or final products, and distributing these products among customers. A supply chain is not merely related to manufacturers and suppliers but to transportation lines, warehouses, retailers, and even customers themselves [22].

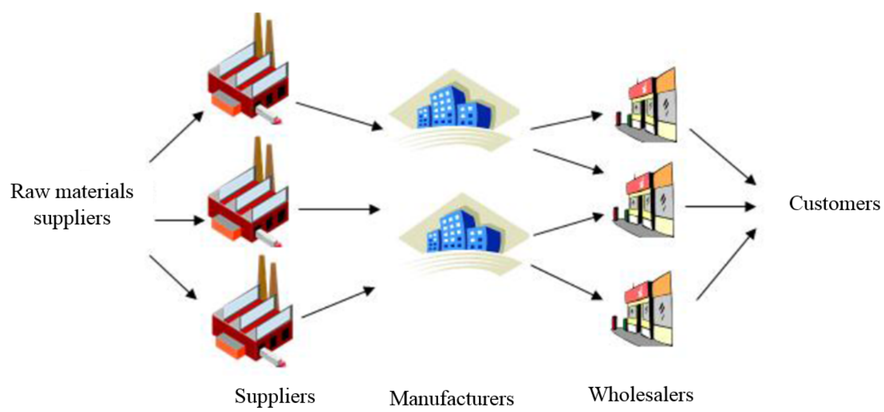

Figure 1: Supply Chain.

Design and management of a SCN helps to produce and deliver various products at low cost, high quality, and short delivery times. Global competitions are also putting pressure on product and service providers

to improve their operations and practices. However, the success rate of a SCN depends to a large extent on its design and implementation, identification of effective combinations of suppliers, manufacturers, and distributors, as well as supply chain performance monitoring [4].
Independent companies and organizations correspondingly have their own goals throughout a SCN which are frequently in conflict. Moreover, companies have found out that increased performance of one member in a SCN may not have a significant impact on overall performance. Beside these two important criteria for companies and organizations i.e. minimizing costs and maximizing profits and quality, other new criteria such as accelerating market access and offering products at reasonable prices and costs are further considered. Albeit there are many potential opportunities in SCNs for companies and organizations to reduce their costs and to increase levels of their services, the fact that which approach and technique should be utilized for each certain chain, depends on the conditions of that chain.
Network models are one of the supply chains, among others, that were developed to solve problems of real life and to represent and to solve many problems of operations research (OR) easily and as networks [25, 30]. A SCN, or the logistics network, includes suppliers, warehouses, as well as distributors and retailers, and the network model is displayed using some indicators such as factories, warehouses, transportation lines, etc. Therefore, these models are proper and accurate responses to assess performance of network supply chains [9].
Today, deciding on the most appropriate suppliers is of utmost importance but complicated, so that the greater the dependency of companies and organizations on suppliers, the more harmful the direct and indirect results of their wrong decisions. Also, achieving customer satisfaction and meeting their needs and priorities require prompt and appropriate selection and evaluation of suppliers. Many of the issues facing companies and organizations and occurring in everyday life are also associated with MCDM whose goals are to select among several choices. There are various methods such as simple additive weighting (SAW), the technique for order of preference by similarity to ideal solution (TOPSIS), AHP, and DEA to deal with the MCDM problems [45, 47, 48, 49].

3.2 Statement of the Problem and the Proposed Method

In this study, a mode of a SCN is firstly reviewed in which suppliers exposed to specific conditions are of importance. Then, a model is presented.
Assume a SCN wherein suppliers have a multi-stage system.
The system consists of several components with a number of inputs and outputs that are being produced independently. Also, each input is supplied from several different places and outputs also have several indicators, as shown in Figure 2. As observed in Figure 2, suppliers in the SCN

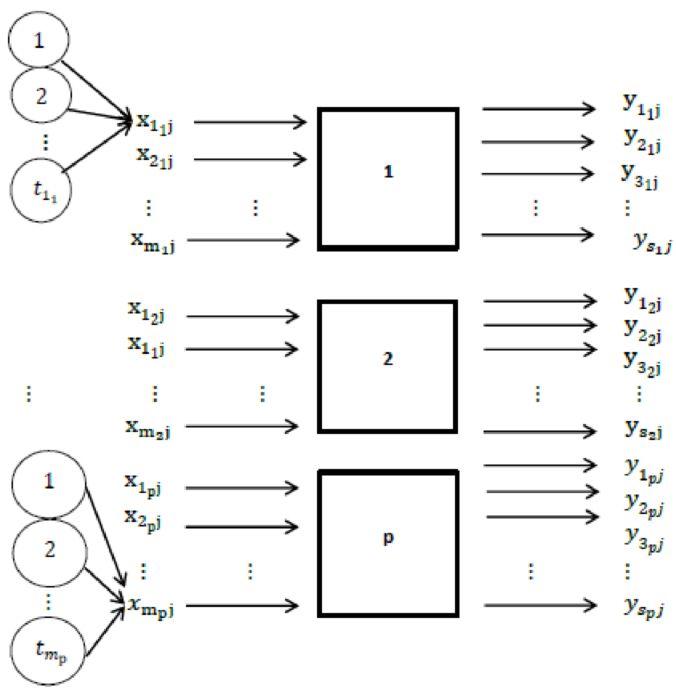

Figure 2: The network of supply chain in general.

consist of a set of $1, 2, \ldots, p$ components. Each of these p-components is considered as a supply chain phase with a number of inputs and outputs that are being produced independently and simultaneously. Each of these phases in the given network is also made up of $1, 2, \ldots, m_p$ input components and $1, 2, \ldots, s_p$ output ones. In other words, the first phase

is comprised of $x_{1_1}, x_{2_1}, \ldots, x_{m_1}$ inputs and $y_{1_1}, y_{2_1}, \ldots, y_{s_1}$ outputs, the second phase consists of $x_{1_2}, x_{2_2}, \ldots, x_{m_2}$ inputs and $y_{1_2}, y_{2_2}, \ldots, y_{s_2}$ outputs, ... , and the pth phase is made up of $x_{1_p}, x_{2_p}, \ldots, x_{m_p}$ inputs and $y_{1_p}, y_{2_p}, \ldots, y_{s_p}$ is outputs.
Moreover, each of the inputs in each phase is generated from several different modes. For example, the first input x_{1_1j} in the first phase is the number of t_{1_1} in different places, and the second input x_{2_1j} in the first phase refers to the number of t_{2_1} in various places, ... , and the input x_{m_1j} in the first phase represents the number of t_{m_1} supplied by different places (thus, the inputs in each phase are supplied by different t_{m_p}). Now, in the proposed SCN, the right choices are searched to achieve the optimal conditions and the shortest paths (i.e. the lowest costs). To find the most appropriate and the best suppliers in the SCN, the occurrence of each mode of the inputs and outputs in each SCN phase is considered as a DMU and an optimal response θ is obtained for each one. In other words, the relative efficiency (θ_i) of each mode for each SCN phase is calculated. The number of these DMUs is the product of the multiplication of various possible modes in the input, calculated according to the following equation:

$$\begin{aligned} n \;&=\; t_{1_1} \times t_{2_1} \times \cdots \times t_{m_1} \times t_{1_2} \times t_{2_2} \times \cdots \times t_{m_2} \times \cdots \\ &\quad \times t_{1_p} \times t_{2_p} \times \cdots \times t_{m_p} \quad \text{for } j = 1, 2, \ldots, n \end{aligned} \tag{3}$$

Given the problem conditions, the proposed model for the above SCN is expressed in (4), where in, $i = 1, 2, \ldots, m_1$ are the first component inputs, $i = 1, 2, \ldots, m_2$ denote the second component inputs, ... , and $i = 1, 2, \ldots, m_p$ represent the pth component inputs. As well, $r = 1, 2, ..., s_1$ are the first outputs, ... , and $r = 1, 2, \ldots, s_p$ refer to s_p outputs which can be regarded as different indicators. In the first phase (the first component), there are $t_{1_1} \times t_{2_1} \times \ldots \times t_{m_1}$ choices, in the second phase (the second component), there are $t_{1_2} \times t_{2_2} \times \ldots \times t_{m_2}$ choices, ... , and in the pth phase (pth component), there are $t_{1_p} \times t_{2_p} \times \ldots \times t_{m_p}$ choices for outputs. Thus, taking into account the occurrence of input/output modes in each phase in the SCN as DMUs, the SCN space is converted into a DEA one and θ_i is calculated with DMUs and the model (6) and various efficiencies are obtained for each SCN phase. Finally, the component with the highest efficiency (θ_i) is considered as the best and the most appropriate one.

$$
\begin{array}{lll}
\text{Min} & \sum_{i=1}^{m_p} \theta_{i_p} & \\
\text{s.t.} & \sum_{j=1}^{n} \lambda_j x_{i_1 j} \leq \theta_{i_1} x_{i_1 0} & i = 1, 2, \ldots, m_1 \\
& \sum_{j=1}^{n} \lambda_j x_{i_2 j} \leq \theta_{i_2} x_{i_2 0} & i = 1, 2, \ldots, m_2 \\
& \vdots & \\
& \sum_{j=1}^{n} \lambda_j x_{i_p j} \leq \theta_{i_p} x_{i_p 0} & i = 1, 2, \ldots, m_p \\
& \sum_{j=1}^{n} \lambda_j y_{r_1 j} \geq y_{r_1 0} & r = 1, 2, \ldots, s_1 \\
& \sum_{j=1}^{n} \lambda_j y_{r_2 j} \geq y_{r_2 0} & r = 1, 2, \ldots, s_2 \\
& \vdots & \\
& \sum_{j=1}^{n} \lambda_j y_{r_p j} \geq y_{r_p 0} & r = 1, 2, \ldots, s_p \\
\lambda_j \geq 0, & (p = 1, \ldots, P), & j = 1, 2, \ldots, n
\end{array}
\tag{4}
$$

$$
\begin{aligned}
n \ &= \ t_{1_1} \times t_{2_1} \times \ldots \times t_{m_1} \times t_{1_2} \times t_{2_2} \times \ldots \times t_{m_2} \times \ldots \\
& \quad \times t_{1_p} \times t_{2_p} \times \ldots \times t_{m_p}
\end{aligned}
$$

4 Numerical Example

The SCN of SAIPA Automobile Manufacturing Company has more than a dozen auto part manufactures and suppliers. In the present study, the main objective is to evaluate and select efficient auto part manufactures through the proposed method. To illustrate the issue, it is assumed that three auto parts i.e. car seat, bumper, and engine are required to be manufactured for a certain kind of car and each part will be manufactured separately and independently. Each part consists of different components. The first part consists of spring, cover, and foam; the second part is made up of rear and front bumper; and the third part is comprised of crankshaft and cylinder head as presented in Table 1.

Table 1: List of manufactured parts of the car.

Car	Parts		
Seat	Spring	Cover	Foam
Engine	Crankshaft	Cylinder head	
Bumper	Rear bumper	Front bumper	

The components of the seats, bumpers, and engines will be supplied from two different companies.
The prices of the purchased parts are also listed in Tables 2, 3, and 4.

Table 2: Price list of the seats parts

Seat					
Foam		Cover		Spring	
Type 1	Type 2	Type 1	Type 2	Type 1	Type 2
200000	120000	290000	130000	60000	110000

Table 3: Price list of the bumper parts

Bumper			
Front bumper		Rear bumper	
Type 1	Type 2	Type 1	Type 2
900000	1400000	800000	1250000

Table 4: Price list of the engine parts

Engine			
Cylinder head		Crankshaft	
Type 1	Type 2	Type 1	Type 2
900000	400000	400000	900000

Also, there are several output indicators for each part, as requested by managers. For example, two output indicators i.e. comfort and price for car seat; three output indicators, that is, weight, quality, and price for bumper; and two indicators, namely, price and volume are considered. Each one of these indicators takes various values according to the inputs of each part and the sum of these outputs produce the car part. The output indicators for each part and their values are presented in Tables 5, 6, and 7.

Table 5: Output indicators and their values for seat parts

Index / Seat	Price y_{1_1j}	Comfort y_{2_1j}	For Inputs x_{1_1j}	x_{2_1j}	x_{3_1j}
1	700000	7	x_{1_11}	x_{2_11}	x_{3_11}
2	450000	3	x_{1_11}	x_{1_12}	x_{3_11}
3	500000	4	x_{1_11}	x_{2_11}	x_{1_12}
4	600000	5	x_{1_12}	x_{2_11}	x_{3_11}
5	1000000	9	x_{1_12}	x_{1_12}	x_{3_11}
6	740000	6	x_{1_12}	x_{1_11}	x_{1_12}
7	400000	3	x_{1_11}	x_{1_12}	x_{1_12}
8	720000	7	x_{1_12}	x_{1_12}	x_{1_12}

Table 6: Output indicators and their values for bumper parts.

Index / Bumper	Price y_{1_2j}	Weight y_{2_2j}	Quality y_{3_2j}	For inputs x_{1_2j}	x_{2_2j}
1	2000000	7 kg	3	x_{1_21}	x_{2_21}
2	3500000	8/9 kg	6	x_{1_21}	x_{2_22}
3	4000000	10 kg	9	x_{1_22}	x_{2_21}
4	2500000	8/5 kg	7	x_{1_22}	x_{2_22}

Table 7: Output indicators and their values for engine parts

Engine \ Index	Price y_{1_3j}	Weight y_{2_3j}	For inputs x_{1_3j} x_{2_3j}
1	2200000	1400	x_{1_31} x_{2_31}
2	1600000	2000	x_{1_31} x_{2_32}
3	1000000	1400	x_{1_32} x_{2_31}
4	1300000	1600	x_{1_32} x_{2_32}

According to the above-mentioned issues, as well as the inputs and outputs, the problem chain will be as follows:

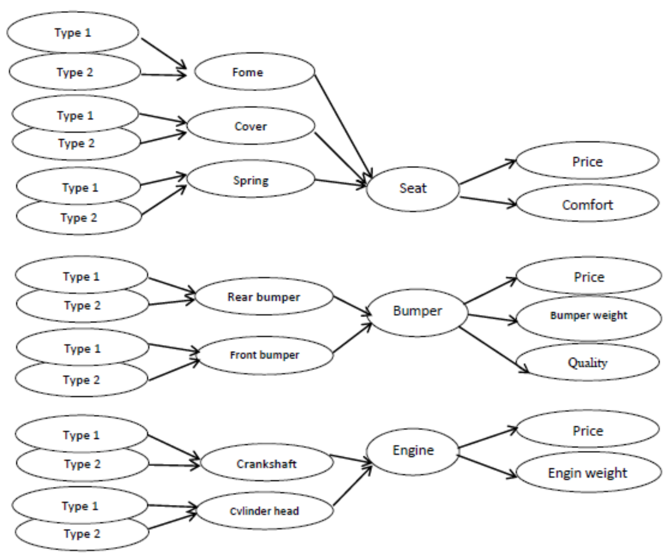

Figure 3: SCN of SAIPA Automobile Manufacturing Company

According to the SCN, how the appropriate choices will be possible to reach optimal conditions and the shortest paths (the lowest costs)? In other words, how one should choose the seat, bumper, and engine parts according to the output indicators, to be the best and the most appropriate choices with the lowest costs to produce the auto parts?
The SCN consists of three parts: chair, bumper, and engine, which are being produced independently and simultaneously. Therefore, each of

these parts is considered as a supply chain phase. Thus, the first phase (i.e. seat) is comprised of three inputs of foam, cover, spring and two outputs i.e. price and comfort; the second phase (that is, bumper) is made up of rear bumper and front bumper as inputs and three outputs of bumper price, weight, and quality; and the third phase (namely, engine) consists of two inputs as crankshaft and cylinder head and two outputs of price and engine volume. Each input is also provided by two different companies. The parallel network is illustrated as follows:

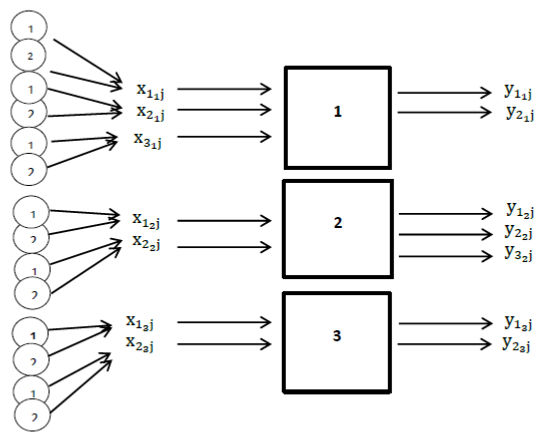

Figure 4: SCN of SAIPA Automobile Manufacturing Company

To select the best and the most appropriate suppliers at the lowest possible costs, each occurrence of input/output mode in each phase of SCN is considered as a DMU. Therefore, different choices create a variety of $\mathrm{DMU_s}$.

For example, in the first phase, if the first-type foam, cover, and spring are chosen, the first-type chair (DMU_1) is produced and if the first-type foam and cover and the second-type spring are chosen, the second-type chair is produced (DMU_2), and so on. The number of these choices will be $2\times2\times2$ modes in the first phase, 2×2 modes in the second phase, and 2×2 modes in the third phase. Similarly, different choices make different phases for the $\mathrm{DMU_s}$. So, depending on the network, there will be 128 $\mathrm{DMU_s}$, which can be utilized to calculate the relative performance of each mode in the SCN, so the model is measured based on different θ_i

and various efficiencies ultimately are obtained.
After coding and entering the data into the model using the General Algebraic Modeling System (GAMS) software, a total of 128 $\mathrm{DMU_s}$ was obtained based on the proposed 20 $\mathrm{DMU_s}$ which are very useful in terms of finding the most appropriate suppliers. The results are shown in Table 8.

5 Conclusion

Given the growing significance of supplier performance with respect to companies and organizations as well as their internal and external competitive conditions, evaluation and selection of efficient suppliers is of utmost importance to achieve strategic goals and to maintain their survival. In this regard, this study proposes a new method for selecting the best suppliers in a SCN via DEA. This model is able to evaluate SCN efficiency in a mode in which its suppliers have a multi-stage system. Accordingly, the network system consists of several components that are being produced independently and simultaneously. Each part also contains a number of inputs and outputs. As well, each input is comprised of several places and has numerous output indicators. In this method, each occurrence of input/output mode in the entire SCN was considered as a DMU. Therefore, the problem converted from SCN space into DEA one and different efficiencies were obtained for the DMUs and through calculation of θ_i for each model phase. The component endowed with the highest efficiency was ultimately selected as the best and the most appropriate one at the lowest possible cost. Therefore, the proposed model transforms each SCN problem into n black box models and optimal solutions are accordingly obtained. With regard to the structure of this method for selecting the most appropriate suppliers, it is suggested to use ranking methods in DEA, MCDM, and so on in future studies to find the best suppliers among the most efficient ones. It should be also evaluated if the data in the SCN are qualitative and quantitative.

Table 8: Results of model (4)

DMUS	efficiency	Reference DMUS				
DMU001	1.00000000	DMU001				
DMU002	1.00000000	DMU001				
DMU003	1.00000000	DMU001				
DMU004	1.00000000	DMU004				
DMU005	1.00000000	DMU005				
DMU006	1.00000000	DMU006				
DMU007	1.00000000	DMU007				
DMU008	1.00000000	DMU004	DMU005			
DMU009	1.00000000	DMU009				
DMU010	1.00000000	DMU009				
DMU011	1.00000000	DMU009				
DMU012	1.00000000	DMU012				
DMU013	1.00000000	DMU013				
DMU014	1.00000000	DMU014				
DMU015	1.00000000	DMU009				
DMU016	1.00000000	DMU012	DMU013			
DMU017	1.00000000	DMU017				
DMU018	1.00000000	DMU017				
DMU019	1.00000000	DMU019				
DMU020	1.00000000	DMU020				
DMU021	1.00000000	DMU021				
DMU022	1.00000000	DMU022				
DMU023	1.00000000	DMU017				
DMU024	1.00000000	DMU020	DMU021	DMU025	1.00000000	DMU017
DMU026	1.00000000	DMU028				
DMU027	1.00000000	DMU001	DMU017			
DMU028	1.00000000	DMU004	DMU020			
DMU029	1.00000000	DMU005	DMU021			
DMU030	1.00000000	DMU006	DMU022			
DMU031	1.00000000	DMU004	DMU017			
DMU032	1.00000000	DMU008	DMU020	DMU021		
DMU033	1.00000000	DMU033				
DMU034	1.00000000	DMU037				
DMU035	1.00000000	DMU033				
DMU036	1.00000000	DMU036				
DMU037	1.00000000	DMU037				
DMU038	1.00000000	DMU038				
DMU039	1.00000000	DMU037				
DMU040	1.00000000	DMU037				

Table 9: Continue the table 8

DMU041	1.00000000	DMU041				
DMU042	1.00000000	DMU041				
DMU043	1.00000000	DMU044				
DMU044	1.00000000	DMU044				
DMU045	1.00000000	DMU045				
DMU046	1.00000000	DMU046				
DMU047	1.00000000	DMU041				
DMU048	1.00000000	DMU044	DMU045			
DMU049	1.00000000	DMU049				
DMU050	1.00000000	DMU049				
DMU051	1.00000000	DMU049				
DMU052	1.00000000	DMU052				
DMU053	1.00000000	DMU053				
DMU054	1.00000000	DMU054				
DMU055	1.00000000	DMU054				
DMU056	1.00000000	DMU052	DMU053			
DMU057	1.00000000	DMU049				
DMU058	1.00000000	DMU036	DMU049			
DMU059	1.00000000	DMU033	DMU049			
DMU060	1.00000000	DMU036	DMU052			
DMU061	1.00000000	DMU037	DMU053			
DMU062	1.00000000	DMU038	DMU054			
DMU063	1.00000000	DMU042	DMU049			
DMU064	1.00000000	DMU048	DMU053			
DMU065	1.00000000	DMU001				
DMU066	0.94812282	DMU009	DMU041	DMU053		
DMU067	0.94812282	DMU017	DMU041	DMU047	DMU049	
DMU068	0.98009050	DMU041	DMU053	DMU054	DMU078	DMU081
DMU069	1.00000000	DMU037				
DMU070	1.00000000	DMU038				
DMU071	0.94812282	DMU021	DMU041	DMU054		
DMU072	0.95548786	DMU005	DMU045	DMU053	DMU077	
DMU073	1.00000000	DMU009				
DMU074	1.00000000	DMU045				
DMU075	1.00000000	DMU009				
DMU076	1.00000000	DMU012				
DMU077	1.00000000	DMU013				
DMU078	1.00000000	DMU014				
DMU079	1.00000000	DMU078				
DMU080	1.00000000	DMU013				

Table 10: Continue the table 8

DMU081	1.00000000	DMU017				
DMU082	1.00000000	DMU017				
DMU083	1.00000000	DMU017				
DMU084	1.00000000	DMU052				
DMU085	1.00000000	DMU021				
DMU086	1.00000000	DMU022				
DMU087	1.00000000	DMU083				
DMU088	1.00000000	DMU021	DMU052			
DMU089	1.00000000	DMU081				
DMU090	0.85000000	DMU021	DMU049			
DMU091	0.85000000	DMU017	DMU049			
DMU092	0.98740458	DMU017	DMU020	DMU052	DMU053	DMU054
DMU093	1.00000000	DMU117				
DMU094	1.00000000	DMU022				
DMU095	0.76539278	DMU013	DMU021	DMU045	DMU118	
DMU096	0.85000000	DMU020	DMU053			
DMU097	1.00000000	DMU033				
DMU098	0.96105187	DMU001	DMU033	DMU041	DMU049	
DMU099	0.96105187	DMU001	DMU033	DMU041	DMU049	
DMU100	0.98367260	DMU022	DMU038	DMU044	DMU045	DMU049
DMU052						
DMU101	1.00000000	DMU037				
DMU102	1.00000000	DMU038				
DMU103	0.96105187	DMU009	DMU033	DMU041	DMU054	
DMU104	0.96105187	DMU005	DMU033	DMU037	DMU045	DMU053
DMU105	1.00000000	DMU041				
DMU106	1.00000000	DMU041				
DMU107	1.00000000	DMU041				
DMU108	1.00000000	DMU044				
DMU109	1.00000000	DMU045				
DMU110	1.00000000	DMU046				
DMU111	1.00000000	DMU107				
DMU112	1.00000000	DMU048				
DMU113	1.00000000	DMU049				
DMU114	1.00000000	DMU049				
DMU115	1.00000000	DMU049				
DMU116	1.00000000	DMU052				
DMU117	1.00000000	DMU053				
DMU118	1.00000000	DMU054				
DMU119	1.00000000	DMU116				
DMU120	1.00000000	DMU052	DMU053			

Table 11: Continue the table 8

DMU121	1.00000000	DMU049			
DMU122	0.85000000	DMU049			
DMU123	0.85000000	DMU049			
DMU124	0.98740458	DMU049	DMU052	DMU053	DMU054
DMU125	1.00000000	DMU053			
DMU126	1.00000000	DMU110	DMU118		
DMU127	0.85000000	DMU053			
DMU128	0.85000000	DMU053			

Acknowledgements
The authors would like to express their sincerest gratitude to the anonymous referees and honorable editors for their valuable comments which helped them in improving this study.

References

[1] C. Basent and J. M. Y. Leung, Inventory Lot – sizing with Supplier Selection,*Computers & Operation Research*, 32 (1) (2005), 1-14.

[2] R. D. Banker, A. Charnes and W. W. Cooper, Some models for estimating technical and scale efficiencies in data envelopment analysis, *Management science*, 30(1984) , 1078-109.

[3] O. Bayazit, Use of Analytic Network Process in Vendor Selection Decisions, *Benchmarking: An International Journal*, 13 (5) (2006), 566-579.

[4] M. Birasnav, Implementation of Supply Chain Management Practices: The Role of Transformational Leadership,*Global Business Review*, 14 (2013), 239-342.

[5] A. Charnes, W. Cooper and E. Rhodes, Measuring the efficiency of decision making units,*European Journal of Operation Research*, 2 (6) (1978), 429-444.

[6] C. Chen, C. Lin and S. Huang, A Fuzzy Approach for Supplier Evaluation and Selection in Supply Chain Management, *International Journal of Production Economics*, vol.102 (2006), 289-301.

[7] C. chen, Y. Hong, Network DEA model for supply chain performance evaluation, 213 (2011), 147-155.

[8] K. Choy, W. Lee, H. Lau, D. Lu and V. Lo, Design of an Intelligent Supplier Relationship Management System for New Product Development, *International Journal of Computer Integrated Manufacturing*, vol. 17 (2004), 692-715.

[9] M. L. Christopher,*Logistics and Supply Chain Management*, London: Pitman Publishing, (1992).

[10] W.W. Cooper, L. M. Seiford and J. Zhu, Data Envelopement Analysis: Models and Interpretations-Handbook on Data Envelopment Analysis, *Kluwer, Academic Publisher, Boston*, (2004).

[11] L. Easton, D. J. Murphy and J. N. Pearson, Purchasing performance evaluation: with data envelopment analysis,*European Journal of Purchasing* & *Supply Management*, 8 (2012), 123–134.

[12] N. C. P. Edirisinghe and X. Zhang, Generalized DEA model of fundamental analysis and its application to portfolio optimization, *Journal of Banking and Finance*, 31 (11) (2007), 11-25.

[13] T. Ertay, D. Ruan and U. R. Tuzkaya, Integating data envelopment ananlysis and analytic hierarchy for the facility layout design in manufacturing systems, *Information Sciences*, 176 (2006), 237-262.

[14] R. Färe and S. Grosskopf, Network DEA,*Socio-Economic Planning Sciences*, 34 (2000), 35-49.

[15] J.Farrel, The Measurement of Productivity Efficiency, *The Royal Statistical Society, Series A*, 120 (1957), 253-290.

[16] R. Farzipoor Saen, Developing a New Data Envelopment Analysis Methodology for Supplier Selection in the Presence of Both Undesirable Outputs and Imprecise Data,*International Journal of Advanced Manufacturing Technology*, vol. 51 (2010), 1243-1250.

[17] D. Fikri, K. Sameer, A. K. Sharfuddin and J. Vipul, Designing an Integrated AHP based Decision Support System for Supplier Selection in Automotive Industry, *Expert Systems with Applications*, vol. 62 (2015), 273-283.

[18] H. Fukuyama and R. Matousek, Modelling Bank Performance: A Network DEA Approach, *European Journal of Operational Research*, 259 (2) (2017), 721-732.

[19] R. M. Garfamy, A Data Envelopment Analysis Approach Based on Total Cost of Ownership for Supplier Selection,*Journal of Enterprise Information Management*, 19 (6) (2006), 662-678.

[20] G. H. Hong, S. C. Park, D. S. Jang and H. M. Rho, An Effective Supplier Selection Method for Constructing A Competitive Supply-relationship, *Expert Systems with Applications*, vol. 28 (4) (2005), 629-639.

[21] J. O. Ifeyinwa and W. Sun, An Innovative Integration of Fuzzy-logic and Systems Dynamics in Sustainable Supplier Selection: A Case on Manufacturing Industry,*Computers & Industrial Engineering*, vol. 88 (2015), 1-12.

[22] K. Ishii, K. Takahashi and R. Muramatsu. Integrated production, inventory and distribution systems.*International Journal of Production Research*, 26(3) (1988), 473-482.

[23] J. Johnes, Measuring Teaching Efficiency in Higher Education: Appliction of Data Envelopment Analysis to Economics Graduates from UK Universities1993,*European Journal of Operational Reseach*, 174 (1) (2006), 443-456.

[24] S. Kaffash and M. Marra, Data envelopment analysis in financial services: a citations network analysis of banks, insurance companies and money market funds,*annals operations research*, 253 (1) (2017), 307-344..

[25] C. Kao, Efficiency decomposition in network data envelopment analysis: A relational model, *European Journal of Operational Reseach*, 192 (3) (2009), 949-962.

[26] C. Kao, Efficiency measurement for parallel production systems, *European Journal of Operational Research*, 196 (3) (2009), 1107-1112.

[27] C. Kao and S. Hwang, Efficiency measurement for network systems: IT impact on firm performance, 48 (2010), 437-446.

[28] P. Korhonen and M. Syrjänen, Resource allocation based on efficiency analysis, 50 (8) (2004), 1134-1144.

[29] T. J. Kull and S. Talluri, A Supply-risk Reduction Model Using Integrated Multicriteria Decision Making,*IEEE Transactions on Engineering Management*, vol. 55 (3) (2008), 409-419.

[30] L. Liang, F. Yang, W. D. Cook and J. Zhu, DEA models for supply chain efficiency evaluation, *Annuals of Operational Research* 145 (1) (2006), 35-49.

[31] J. Liu, F. Ding and V. Lall, Using Data Envelopment Analysis To Compare Suppliers for Supplier Selection and Performance Improvement,*Supply Chain Management: An International Journal*,vol. 5 (2000), 143-150.

[32] J. S. Liu and W. M. Lu, Network-based method for ranking of efficient units in two-stage DEA models, *Journal of the Operational Research Society*, 63 (2012), 1153-1164.

[33] S. T. Liu, A fuzzy DEA/AR approach to the selection of flexible manufacturing systems, *Computers & Industrial Engineering*, 54 (2008), 66-79.

[34] W. Liu, Z. Zhou, C. Ma, D. Liu and W. Shen, Two-stage DEA models with undesirable input-intermediate-outputs. *Omega*, 56 (2015), 74-87.

[35] M. Mannino, S. Hong and I. Choi, Efficiency evalution of data warehouse operations, *Decision Suport System*, 44 (2008), 883-898.

[36] R. Narasimhan, S. Talluri and S. K. Mahapatra, Multiproduct, Multicriteria Model for Supplier Selection with Product Life-Cycle Considerations, *Decision Sciences*, vol. 37 (4) (2006), 577-603.

[37] M. Rahiminezhad Galankashi, S. A. Helmi and P. Hashemzahi, Supplier Selection in Automobile Industry: A Mixed Balanced Scorecard–fuzzy AHP Approach,*Alexandria Engineering Journal*, vol. 55 (2016), 93-100.

[38] J. Seydel, Data Envelopment Analysis for Decision Support, *Industrial Management & Data Systems*, vol. 106 (2006), 81-95.

[39] S. Talluri, R. Narasimhan and A. Nair, Vendor Performance with Supply Risk: A Chance-constrained DEA Approach, *International Journal of Production Economics*, vol. 100 (2) (2006), 212-222.

[40] K .Tone, A slack-based measure of efficiency in data envelopment analysis,*European Journal of Operational Research*, 130 (2001), 498-509.

[41] K. Tone and M. Tsutsui, Dynamic DEA: A slacks-based measure approach,*Omega*, 38 (2010), 145-156.

[42] M. Troutt, P. Ambrose and C. Chan, Multi-stage efficiency tools for goal setting and monitoring in supply chains. Successful strategies in supply chain management Hershey: *Idea Group Publishing Co*, (2004).

[43] D. Wu and D. L. Olson, Fuzzy Multiattribute Grey Related Analysis Using DEA, *Computers and Mathematics with Applications*,vol. 60 (2010), 166-174.

[44] T. Wu, D. Shunk, J. Blackhurst and R. Appalla, AIDEA: A Methodology for Supplier Evaluation and Selection in a Supplier-based Manufacturing Environment, *International Journal of Manufacturing Technology and Management*, vol. 11(2) (2007), 174-192.

[45] C.C. Yang and B.S. Chen, Supplier Selection Using Combined Analytical Hierarchy Process and Grey Relational Analysis, *Journal of Manufacturing Technology Management*, vol. 17, no. 7, pp. (2006), 926-941.

[46] F. Yang, D. Wu, L. Liang and G. Bi , Supply chain DEA: production po ssibility set and performance evaluation model, *Annals of operation res earch*, DOI: 10.1007/s10479-008-0511-2, (2010).

[47] K. Yoon and C. L. Hwang, Multiple Attribute Decision Making,*An Introduction California*, Sage, (1995).

[48] T. Yang, M. C. Chen and C. C. Hung, Multiple Attribute Decision-making Methods for the Dynamic Operator Allocation Problem,*Mathematics and Computers in Simulation*, vol. 73, pp(2007). 285-299.

[49] T. Yang and C. C. Hung, Multiple-attribute Decision Making Methods for Plant Layout Design Problem,*Robotics and Computer Integrated Manufacturing*, vol. 23, pp (2007),126-137.

Haniyeh Ghamgosar
PHD candidate
Department of Mathematics
Centeral Tehran Branch, Islamic Azad University
Tehran, Iran
E-mail: haniye.ghamgosar@gmail.com

Mohsen Rostamy-Malkhalifeh
Associate Professor of Mathematics
Department of Mathematics
Science and Research Branch, Islamic Azad University
Tehran, Iran
E-mail: mohsen_rostamy@yahoo.com

Masoud Sanei
Associate Professor of Mathematics
Departement of Mathematics
Centeral Tehran Branch, Islamic Azad University
Tehran, Iran
E-mail: masoudsanei49@yahoo.com

Farhad Hosseinzadeh Lotfi
Professor of Mathematics
Departement of Mathematics
Tehran Science and Research Branch, Islamic Azad University
Tehran, Iran
E-mail: hosseinzadeh_lotfi@yahoo.com

Ghasem Tohidi
Associate Professor of Mathematics
Departement of Mathematics
Centeral Tehran Branch, Islamic Azad University
Tehran, Iran
E-mail: ghatohidu@yahoo.com