Environment, Development and Sustainability (2023) 25:12791–12827
https://doi.org/10.1007/s10668-022-02590-2

A sustainable supplier selection method using integrated Fuzzy DEMATEL–ANP–DEA approach (case study: Petroleum Industry)

Seyed Amir Nasri[1] · Behdad Ehsani[1] · Seyed Javad Hosseininezhad[1] · Nasser Safaie[1]

Received: 6 February 2021 / Accepted: 20 July 2022 / Published online: 8 August 2022

Abstract
Petroleum is an important strategic material connected with the national economy's safety. Sustainable supplier performance evaluation plays a considerable role in establishing an effective, sustainable supply chain management (SSCM) and is related to the safety of petroleum production and supply. Social responsibility, governmental regulations, and public consciousness of environmental aspects are enforcing the companies to make their supply chains more sustainable. This paper presents a method for sustainable supplier selection problems by combining fuzzy decision-making trial and evaluation laboratory (DEMATEL), analytic network process (ANP), data envelopment analysis (DEA) methods, and Anderson-Peterson rating model. This method proposes a novel procedure for solving the sustainable supplier selection problem. It allows decision-makers to minimize the negative environmental effects and maximize the social impact of the supply chain while maximizing its business performance. At first, the effects between selection criteria are computed by Fuzzy DEMATEL. Then the weights of each criterion-related with to the petroleum supplier selection are derived by the ANP method. Results of this stage are inputs for the next stage, where DEA is applied to select the best suppliers. Finally, 15 petroleum supplier companies in Iran are evaluated and prioritized as a case study to show the capabilities of the proposed model.

Keywords Analytical network process · Data envelopment analysis · Fuzzy DEMATEL · Supplier selection and evaluation · Performance measurement · Petroleum

1 Introduction

In the economic and political equations of the world, the oil and gas industry is of strategic importance and plays an important role in international relations. Iran, with its large oil and gas reserves and its position in the Middle East, has a great opportunity to develop these industries, and on the other hand, it is close to consumer markets. Oil and gas are two

✉ Seyed Javad Hosseininezhad
Hosseininezhad@kntu.ac.ir

[1] Department of Industrial Engineering, K. N. Toosi University of Technology, P.O. Box 19991-43344, Tehran, Iran

important elements in the petrochemical industry to supply the required feedstock. The oil, gas, and petroleum industries play an essential role in economic sectors for oil-dependent economies. The oil, gas, and petroleum industries supply a significant portion of Iran's foreign exchange earnings and are undeniably crucial to the national economy. This requires appropriate methods to provide reliable and sufficient financial resources for exploration of field development, optimal extraction over the reservoir's life, and operation with maximum technical and economic efficiency. According to the Iranian Ministry of Petroleum, the petrochemical industry in Iran generates more than 100% value-added, turning a total of $ 7 billion in food and fuel into $ 14.5 billion in petrochemical products. Therefore, if this industry did not develop, Iran's public and private sectors would be deprived of a total of $ 7.5 billion in gross profit and would be doomed to sell the same $ 7 billion feed of this industry. On the other hand, other industries in the country, which use the products of the petrochemical industry, were forced to import raw materials, which exported $ 5 billion in foreign currency annually. Among the top 10 petrochemical companies in the Middle East and Africa, three companies are assigned to Iran. Privatization of the oil and petrochemical sector in Iran has led to the creation of three new players that have been included in the ranking of the top petrochemical companies in the Middle East. Among the 100 economic enterprises of Iran, the position of petrochemical companies is among the leading companies in Iran. According to this ranking, the petrochemical group ranks first in profitability index, total factor productivity, and exports. In terms of sales, value-added assets are in second place. The development of the petrochemical industry, in addition to creating added value and preventing imports, has created about one million direct and indirect jobs for the country. Nowadays, due to joining the World Trade Organization with the challenges of increasing productivity in this dynamic environment, the country's petroleum industries need to face the situation of new suppliers, such as the arrival of foreign suppliers and an increase in the activities of domestic suppliers. Therefore, the oil and gas industries of their country, which is one of their main pillars, should pay more attention; it is the performance of the suppliers of any organization that can lead to the survival or destruction of that organization. Nowadays, identifying customer needs and trying to gain their satisfaction is the company's priority competitive environment. So that successful and leading companies develop these needs to the extent of their strategic plans, and by implementing them, they lead all their capabilities to achieve them. Since a large volume of the factory's essentials is supplied by suppliers. Outside the organization, one of the conditions for providing quality products and reliable production is the purchase of materials and spare parts with appropriate and desired quality. So that the supply of materials and parts of inappropriate quality will cause the production of standard products, and the costs of supplying inappropriate goods will be much higher and, in some cases, will cause the loss of the market and loyal customers. Therefore, in recent decades, by applying the concept of the supply chain in industries, the issue of supplier selection has attracted a lot of attention and various identification methods, which result in partnerships with suppliers and the company's close relationship with them, the organization. Still, as members of a core chain called the supply chain, which aims to maximize profits and enhance the overall productivity of the supply chain. So far, many methods have been proposed for evaluating and ranking suppliers, most of which have their own advantages and limitations. For years, researchers and analysts have been looking for methods that have as few limitations as possible and cover a wider range of suppliers' performance, which is why analysts are moving toward those methods of measuring performance and ranking. Suppliers have a desire to be able to integrate existing information and the effects of all of them into the analysis. One of the most widely used procedures in evaluating the performance of organizations today is

DEA. This method compares and assessing the relative efficiency of decision-making units that have many similar inputs and outputs, such as schools, universities, hospitals, banks.

In each organization, an integrated management system can enable managers to implement the organization's mission and strategy by making their activities transparent, but this method also has a general deficiency that only divides the units into efficient and inefficient categories and does not perform a perfect ranking. In the meantime, combining the DEA method with some multi-criteria decision-making techniques, including AHP, with its own characteristics, can eliminate this deficiency. However, since many decision-making issues cannot have a hierarchical structure due to interdependence or feedback, it is more appropriate to combine Fuzzy DEMATEL, ANP, with DEA to address this deficiency. The combined Fuzzy DEMATEL-ANP-DEA-AP method, unlike the DEA method, divides units into two parts. Efficient–inefficient does not divide but performs complete ranking. This research investigates the problem of selecting suitable suppliers in the oil and petroleum industry in Iran. The oil and petroleum supplier selection issue is introduced as a hierarchical model with five key criteria. The main criteria include (1) financial aspect, (2) environmental aspect, (3) technical power, (4) supplier features and capabilities, and (5) supplier services. These main criteria consist of 34 sub-criteria, and the individual pairwise comparisons are carried out using expert judgment. Additionally, we incorporated a DEA For the aggregation of the ANP global priorities. The results indicated that the DEA model is helpful in finding global ranking among the candidate suppliers.

Undoubtedly, there are general standards and a fundamental framework for selecting suppliers. Nevertheless, factors' degree of importance and prioritization vary in different industries. For instance, the main criteria influencing the selection of suppliers in the pharmaceutical industry differ from the criteria for selecting suppliers in the oil and gas industry or heavy industries. In this research, after checking the previous study on supplier selection in different industries, we choose and categorize these factors and customize them with the situation of the selected industry. These criteria were finalized and confirmed by the Petroleum Standards Process Machines Group and National Standards Organization of Iran, and the Technical Inspection Unit of General Petroleum Equipment.

To the best of our knowledge, there is no hybrid approach including Fuzzy DEMATEL, ANP, DEA, and Anderson–Peterson rating method in order to assess the performance of Oil and Petroleum Companies in order to maximize their business performance. This research highlights several quantitative and qualitative factors that should be considered in this problem. Oil and Petroleum Companies' performance evaluation is a demanding and intriguing process. Since several factors are used in this assessment, furthermore, it is presumed that these criteria interact in complicated ways and in a fuzzy environment in multiple periods of planning that can handle the interdependencies among several criteria. Nonetheless, neither the literature nor Iran has a study combining these approaches for the Oil and Petroleum Companies' selection problem. This research is unique not only in its assessment method but also in its application to a real case study in Iran.

The remained of this research is further organized as follows; Sect. 2 reviews the relevant research on supplier selection methods and parameters for the considered problem. Section 3 presents the procedure of the proposed method for sustainable supplier selection using integrated fuzzy DEMATEL analytic network process and DEA approaches in the gas, oil, and petroleum industry. In Sect. 4, the proposed method is applied in a real case of petroleum, gas, and oil suppliers to evaluate 15 suppliers. Finally, in Sect. 5, the managerial preference of this research is described, and the conclusions and direction for future research are presented.

2 Literature review

Numerous investigations have so far been published in the supplier selection area. Varma et al. (2008) reported that product purity, market share, steady supply of raw material, and the application of information technology are the essential criteria for supplier selection in the petroleum industry and suggested that the combination method of the analytical hierarchy process (AHP) and balanced scored (BSC) to assess the efficiency of suppliers in this industry. Vanteddu et al. (2011) considered cost and responsiveness as the most significant factor of supplier selection by proposing dimensionless quantity, called the CIR, to improve and simplify the interpretation of the results. Their model included two key elements: inventory-related costs and responsiveness. They attempted to include parameters associated with supply chain responsiveness in their model. They did not consider order splitting, buyer collaboration, and other qualitative factors such as quality, financial stability, cultural match, staying power, volume, and quantity discounts mostly presented by suppliers. Amiri (2010) used six criteria with AHP and the fuzzy Topsis technique to rank alternative projects to choose the best ones. He showed that calculating the criteria weight could influence the final ranking. His case study was project selection in the National Iranian Oil Company. They analyzed the defects of previous methods used in supplier selection and proposed case-based reasoning methods for Chinese petroleum enterprises to improve the accuracy of decision-making in petroleum supplier selection. He has evaluated the importance of multi-attributes objectively in supplier selection. Masi et al. (2013) considered a set of typical purchasing situations to specify EPC firms and maximize effectiveness according to the amount of human, technological and economic resources. They offered a new classification based on the concept of the optimal supplier selection techniques oriented to procurement. They offered an optimum selection method based on the impact of procurement and the degree of difficulty in purchase management. They attempted to propose strategies to bridge the gap with the supplier selection technique and diverse buying scenarios. Igoualalene et al. (2015) used two novel approaches and computed the criteria weighed by each approach, and compared the combination of fuzzy consensus-based probability measures with fuzzy Topsis methods for strategic supplier selection a novel approach. Chen and Baddam (2015) investigated the social dimension of supplier selections, such as child labor and the use of unsafe processes. They analyzed social irresponsibility and its effects on the firm's sourcing strategy and then compared the buying company's sourcing decision on supplier selection between ethical and unethical suppliers. Chen and Zou (2017) have presented two-phase supplier selections using GIFSS and GRA method to choose the proper supplier considering the risk aversion. GIFSS eliminates decision-makers bias and the possibility of errors in alternative assessments. Amorim et al. (2016) presented a two-stage stochastic MIP model to evaluate suppliers in the food industry under uncertainties related to the supplier's spot market prices, lead time, the availability of raw materials, and the demand for final goods. For large instances, they developed the multi-cut Benders' decomposition algorithm. Rajabi (2017) introduced the costumer-oriented technique according to the dynamic of customer's needs by integrating ANP, QFD, and Markov chain to affect the alteration priority of customer's needs. Kannan (2018) provided a decision support system according to the sustainability view of several stakeholders. The outcome indicated that the first four influential CFS are divided as a social issue, and the fifth factor is an environmental dimension. Yu et al. (2018) to maximize profits and environmental factors while minimizing CO2 emissions, the carbon footprint-based incentive method to maximize profits and environmental factors while minimizing CO_2 emissions. Wood (2016) identified

30 criteria to assess supplier selection for the petroleum industry, including eight MCDM scoring methods using an intuitionistic fuzzy analysis of decision metrics, and proved the use of entropy weightings on the results of the fuzzy set in more consistent bidder selection. Manello and Calabrese (2019) investigated supplier selection in the automobile industry and suggested that classical criteria play a less essential role than reputational factors. Jain and Singh (2020) proposed a supplier selection model in a two-phase decision-making model using a FIS with a fuzzy Kano philosophy for a sustainable environment to assess the suppliers' sustainability performance and choose the best one in the industry in India. Stević et al. (2019) used multi-criteria analysis and Marco's methods for ranking sustainable real-world business problems. They considered environmental standards and corporate social responsibility and compared Marco's approach with other methods. The results confirmed the robustness and stability of Marco's method in a dynamic environment. Olanrewaju et al. (2020) proposed integrated supplier selection using multi-stage stochastic programming, taking into account the relief agency's commitment quantity, a quantity discount, and supplier reserve capacity, which consider natural disasters to establish a flexible contract before a disaster event occurs. They carried out a sensitivity analysis to determine the effects of changes in the cost parameters.

2.1 Sustainable supplier selection

In recent years, pressures from the international community and government laws to address environmental issues reduce environmental pollution and pay attention to employee health, customer expectations, and pressures and expand the concept of social and moral responsibility created an approach called sustainable development. For years, researchers and analysts have been looking for methods that have as few limitations as possible and cover a wider range of suppliers' performance, which is why analysts are moving toward those methods of measuring performance and ranking. Suppliers have a desire to be able to integrate existing information and the effects of all of them into the analysis. Because human health depends on a healthy and risk-free environment and social environment, a concept called sustainability to focus on improving environmental and social issues, along with economic perspectives, is a very influential issue in the future of humanity. Supply chains can be used as a suitable platform for sustainable development by creating responsible behavior at all stages and among chain members. Research in the field of social responsibility rarely leads to an insight into each other about social issues, supply chain actions, and performance outcomes. Many companies are beginning to consider new types of metrics such as carbon emissions and adapting social responsibility for supplier selection. In fact, sustainable development is defined as the process of change in the use of resources, investment guidance, technology development, and orientations that adapt to current and future needs. Nowadays, sustainable development receives plenty of attention in many areas. Also, in SCM, both practitioners and academics consider the issues of sustainability in their work, Buyukozkan and Cifci (2012). Furthermore, to achieve a potent economic basis, social responsibilities and environmental legislation enhance pressure and employ demands on an organization's stakeholders. Sustainability has become compulsive and binding for companies to improve the performance of SCM (Seuring & Gold, 2013; Seuring & Muller, 2008; Heikkurinen & Forsman-Hugg, 2011). For several years, the conventional approach has only considered the economic dimension. It is no longer sufficient due to commerce globalization, competitive market situations, and transforming customer demands. To remain in a sustainable supply chain, organizations should add environmental/ecological and social dimensions to conventional supplier selection criteria like cost, quality, service, and delivery (Amindoust et al., 2012). In this research, we considered social factors such as the responsibility to the customer (costumer-oriented), knowledge training after-sales product use and on time delivery of goods/services. Furthermore, four new factors in finance and economic dimension based on expert' opinion have been considered. Environmental dimension has been considered by six factors and social factors have been seen as supplier feature and capacity and supplier services. The main difference between this paper in comparison with previous research is integrating Fuzzy DEMATEL, ANP and DEA for the petroleum supplier selection. The significant purpose is to aid the decision-makers efficiently in specifying the most suitable petroleum supplier. First of all, fuzzy DEMATEL is utilized to compute the effects of selection criteria. Next the weights of each criterion related to the petroleum supplier selection problem were calculated using ANP. Eventually, DEA is utilized to propose a mathematical model to calculate the relative efficiency scores and prioritizing the petroleum suppliers. Factors that are defined as input and output in DEA do not all have the same weight and effect. Some factors have more weight than others, after determination of effects among selection criteria and therefore in the second stage using network analysis method, quantitative factors and qualitatively ranked. Then, in the DEA model, the best suppliers are selected considering the input and output weights. In fact, for the first time in the selection of suppliers of oil and petrochemical industry, a combined method of fuzzy DEMATEL, ANP, DEA and Anderson–Peterson rating model is used, which simultaneously examines the quantitative and qualitative factors and provides proper information to the decision-makers to effectively take managerial preference and subjective data into consideration. Supplier selection is a difficult problem involving the evaluation of both qualitative and quantitative characteristics. Hence, a comprehensive literature review was done to obtain and categorize the indicators given in Table 1:

3 Research methodology

This paper employs a three-step solution methodology to unravel the considered problem. This hybrid approach is based on DEA and MCDM. First of all, considering the reviewed paper and experts' opinions, we determined and categorized the criteria. The interaction between several criteria is recognized using the DEMATEL method in the form of a network in this hybrid approach. The transactions and interactions among parameters involved in the assessment process can be explained using this network structure. Then, the network structure and interaction criteria used to evaluate the performance of companies are modeled using ANP, and the relative importance of the criteria is calculated. The first outcome of this hybrid approach is determining the relative importance of criteria in terms of their mutual relationships. In the final section of the proposed hybrid approach, this relative importance is considered a restriction. A DEA model is provided in the final section of this hybrid approach to measure the performance of petroleum companies. The proposed hybrid approach is very practical and remarkable in terms of combining two types of commonly used decision-making tools, network modeling of cause and effect criteria, modeling qualitative and quantitative criteria simultaneously, and considering the relative importance of the different criteria in DEA modeling. This approach can also be used in management and engineering sciences to evaluate the performance of various systems in similar situations. This approach is used to compare 15 different oil and petroleum companies in order to provide a clear picture of the

Table 1 Overview of criteria and sub-criteria used for sustainable supplier selection

References	Sub-criteria	Criteria
Kannan (2018)	(1) Environmental certifications like ISO 14000, EMAS	Environmental dimension
	(2) Pollution control initiatives	
	(3) Carbon and hazardous substance management	
	(4) Checking and evaluation of environmental activities	
	(5) Design of products for reduced consumption of material and energy	
	(6) Use of environmentally friendly technology	
Fallahi and Motadel (2014)	(1) Competitive price	Financial and Economic dimension
Experts' opinion (This research)	(2) Average tax for the last five years	
	(3) Possession of office, warehouse, etc	
	(4) Fixed assets as per official statement	
	(5) Last year sales	
Fallahi and Motadel (2014)	(1) To-order production (Compliance with customer's technical standard)	Technology capability
	(2) Maintenance and repair of machinery	
Experts' opinion (This research)	(3) Standard quality certificates like ISO/IM	
	(4) Number of R&D projects in the last three years and their effectiveness	
	(5) Installation instructions/test and inspection	
Varma et al. (2008)	(6) proper product performance	
	(7) Packing and shipping quality	
Minooie and Mohsenikabir (2017)	(8) Equipment power and production capacity	
Varma et al. (2008)	(1) Executive record and good reputation	Supplier feature and capacity
	(2) Level of technical knowledge of engineers	
Experts' opinion (This research)	(3) Foreign exchange rate (import and export)	
	(4) Quality of raw materials and component in manufacturing	
	(5) Having quality system	
	(6) Product warranty	
	(7) Domestic production of products	
	(8) Human resource and management capability	

Table 1 (continued)

References	Sub-criteria	Criteria
Varma et al. (2008)	(1) On-time delivery of goods/services	Supplier services
Masi et al. (2013)	(2) After sales service	
Kannan (2018)	(3) Responsibility to the costumer(costumer-oriented)	
Fallahi and Motadel (2014)	(4) Knowledge training after-sales product use	
Experts's opinion (This research)	(5) Representation of internal and external offices	
	(6) Shipping costs, insurance	

performance of the proposed hybrid approach. The parts of the proposed hybrid approach are presented as follows.

3.1 Fuzzy DEMATEL

Considering Gabus and Fontela (1972, 1973), firstly, we generated a fuzzy direct relationship matrix. Experts create a set of $n * n$ pairwise comparisons in order to impact the necessary criteria of Matrix A, which $\widetilde{a_{ij}} = \left(l_{ij}, m_{ij}, u_{ij}\right)$ indicates the degree to which criterion i influence criterion j of experts. Afterward, we normalized the primary direct-relation matrix. We can normalize the direct relationship matrix after generating it in the previous step. According to the direct relationship matrix A, $\tilde{X}$ can be used to generate the normalized direct-relation matrix as follows:

$$s = \frac{1}{\max_{1 \le i \le n} \sum_{J=1}^{n} U_{iJ}} \tag{1}$$

$$\widetilde{a_{ij}} = \left(l_{ij}, m_{ij}, u_{ij}\right) \tag{2}$$

$$\widetilde{X} = s \times \widetilde{A} \tag{3}$$

Next, we generated the fuzzy total-relation matrix. X is generated when the direct-relation matrix is normalized. The following equations, in which I represent the unit matrix, can be used to create the total relation matrix T, Find $\widetilde{\mathrm{X}} = \left(l_{ij}, m_{ij}, u_{ij}\right)$ and define three definite matrices with the following elements extracted from X:

$$T_z = \begin{bmatrix} t_{11} & \cdots & t_{1j} & \cdots & t_{1n} \\ \vdots & & \vdots & & \vdots \\ t_{i1} & \cdots & t_{ij} & \cdots & t_{in} \\ \vdots & & \vdots & & \vdots \\ t_{n1} & \cdots & t_{nj} & \cdots & t_{nn} \end{bmatrix} X_2 = \begin{bmatrix} 0 & m_{12} & \cdots & m_{1n} \\ m_{21} & 0 & \cdots & m_{21} \\ \vdots & & & \vdots \\ m_{n1} & m_{n2} & \cdots & 0 \end{bmatrix} X_3 = \begin{bmatrix} 0 & u_{12} & \cdots & u_{1n} \\ u_{21} & 0 & \cdots & u_{21} \\ \vdots & & & \vdots \\ u_{n1} & u_{n2} & \cdots & 0 \end{bmatrix} \tag{4}$$

The fuzzy total-relation matrix between each pair of system factors is obtained as follows:

$$\widetilde{T} = \widetilde{X}\left(1 - \widetilde{X}\right)^{-1} \tag{5}$$

$$\widetilde{T} = \begin{bmatrix} \widetilde{t}_{11} & \widetilde{t}_{12} & \cdots & \widetilde{t}_{1n} \\ \widetilde{t}_{21} & \widetilde{t}_{22} & \cdots & \widetilde{t}_{2n} \\ \vdots & & & \vdots \\ \widetilde{t}_{n1} & \widetilde{t}_{n2} & \cdots & \widetilde{t}_{nn} \end{bmatrix} \tag{6}$$

$$\widetilde{t_{ij}} = \left(l'_{ij}, m'_{ij}, u'_{ij}\right) \tag{7}$$

$$\mathrm{matrix}\left[L'_{ij}\right] = X_l\left(1 - X_l\right)^{-1} \tag{8}$$

$$\text{matrix}\left[m_{ij}'\right] = X_m\left(1 - X_m\right)^{-1} \tag{9}$$

$$\text{matrix}\left[u_{ij}'\right] = X_u\left(1 - X_u\right)^{-1} \tag{10}$$

Eventually, we established an internal dependency matrix. After defuzzification of T using Eq. (11), the normalization method will make the aggregate of each column in the total relation matrix equivalent to one.

$$F\left(\tilde{t}_i\right) = \frac{1}{2} \times \int_0^1 \left(\inf \tilde{t}_{ij}^{\alpha} + \sup_{x \in R} \tilde{t}_{ij}^{\alpha}\right) \mathrm{d}\alpha \tag{11}$$

where D_1 is the sum of the first criterion's direct and indirect impacts on other criteria, and R_1 is the sum of the first criterion's direct and indirect impacts on other criteria. Then, for each criterion, we calculated D_i+R_i and D_i-R_i values. The strength of relationships with criteria and the strength of impacts among criteria are indicated by D_i+R_i and D_i-R_i, respectively. If there is a negative value for D_i-R_i, then the criterion is in the effect group, and the net receiver is called. If D_i-R_i is positive, the criterion is in the cause group and is referred to as the net causer.

3.2 ANP (analytical network process)

The AHP considers a single-direction hierarchy of elements. Saaty (1980). AHP is one of the fundamental techniques of Multi-Criteria Decision Making and is well suited to solving the most complex problems. Many decision problems cannot be categorized in a hierarchical structure due to the interactions between different factors, which cause top-level factors to be related to lower-level factors at times. A network of elements, rather than a hierarchy, is required by ANP. The elements are regarded as nodes in this network, and a level of elements can both overcome and be dominated in comparison with the others (Partovi, 2001). The main advantage of ANP compared to other MCDM tools, like the model for Order Preference by the resemblance to Ideal Solution (TOPSIS) or AHP, is considering the interdependence between criteria. The interdependencies between elements are not addressed by these tools. Since all real-life issues are interlinked, a methodology that addresses interdependencies is important to use (Wu & Barnes, 2016). Following such a scheme, we have the following algorithm:

- Determining the weight of each criterion assuming that there is no dependency between the criteria. The resulting matrix is called $\mathbf{W_1}$.
- Determining the weight of sub-criteria relative to each criterion, assuming that there is no dependence between the criteria. The resulting matrix is called $\mathbf{W_2}$
- Determining the interdependency matrix of the criteria relative to each criterion. The resulting matrix is called $\mathbf{W_3}$.
- Determining the interdependency matrix of the sub-criteria relative to each sub-criterion. The resulting matrix is called $\mathbf{W_4}$.
- Determining the priorities related to the main criteria by multiplying matrix $\mathbf{W_1}$by matrix $\mathbf{W_3}$. The resulting matrix is called $\mathbf{W_A}$:

Table 2 Saaty's scale

Judgement	Definition	Scale
Equal	Preference with equal importance and desirability	1
Moderate	The importance of A is a little more preferred than that of B	2–3
Strong	The importance of A is stronger than that of B	4–5
Very strong	The importance of A is much stronger than that of B	6–7
Extreme	The importance of A is absolutely preferred than that of B	8–9

Table 3 Values of the random index (RI)

m	3	4	5	6	7	8	9	10	11	12	13	14
RI	0.59	0.82	1.11	1.25	1.35	1.40	1.45	1.49	1.52	1.54	1.56	1.58

$$\mathbf{W_A} = \mathbf{W_1} \times \mathbf{W_3} \tag{12}$$

Determining the interdependent priorities of the sub-criteria by multiplying matrix $\mathbf{W_2}$ by matrix $\mathbf{W_4}$. The resulting matrix is called $\mathbf{W_B}$:

$$\mathbf{W_B} = \mathbf{W_2} \times \mathbf{W_4} \tag{13}$$

Determining the overall priorities (weights) of the sub-criteria by multiplying matrix $\mathbf{W_A}$ by a matrix $\mathbf{W_B}$. The resulting matrix is called $\mathbf{W_{AB}}$:

$$\mathbf{W_{AB}} = \mathbf{W_A} \times \mathbf{W_B} \tag{14}$$

Table 2 shows the judgment scores that can be used according to the criteria utilized in pairwise comparisons (Saaty & Sodenkamp, 2008).

Therefore, the values represented in Table 3 for the calculation of the Random Index (RI) (Saaty & Sodenkamp, 2008) can be utilized by means of Eqs. (15)–(16) to confirm the consistency of each pairwise comparison matrix consisting of m elements:

$$\text{Cons. Ind} = \frac{\lambda_{\max} - m}{m - 1} \tag{15}$$

$$\text{cons. Ratio} = \frac{\text{Cons. Ind}}{\text{RI}} \tag{16}$$

where $\lambda_{\max}$ is the pairwise comparison matrix's largest eigenvalue, while Cons. Ind. is the consistency index. To guarantee the consistency of the responses, a pairwise comparison matrix's consistency ratio must be less than 0.1. (Quezada et al., 2018).

3.3 DEA

DEA is one of the leading non-parametric performance measurement methods using multiple inputs to generate multiple efficiency measurement outputs and rank homogeneous decision-making units (DMUs). The use of DEA also dominates some of the problems with the conventional performance measurement techniques, like regression models and simple ratio analysis. Analysts used DEA in other applications to obtain new insights into business methods and also to assess their activities. The capability to provide conduction for how non-efficient units can become more efficient is one of the main reasons that DEA is considered an essential management tool for diagnosing DMUs. Charnes et al. (1978) first proposed this method based on the idea of Farrell (1957) and the assumption of Constant Returns to Scale (CRS) and called it the CCR model. The weights are selected in such a way that the assessed DMU attains its most appropriate efficiency when evaluating DMUs using DEA models. DMU_j ($j=1,\ldots, n$), which converts m inputs, x_{ij}($i=1, \ldots\ n$), into S outputs, y_{rj} ($r=1, \ldots, s$), and DMU0 is a DMU under-evaluated, are n homogenous. The non-negative weights v_i ($i=1, \ldots, m$) and u_r ($r=1, \ldots, s$), respectively, are assigned as inputs and outputs. Table 4 lists and explains the related notations of the model. Equations (17)–(20) is the input-oriented multiplier CCR (CCR-IO) model:

$$\text{Max}Z_0 = \sum_{r=1}^{s} U_r Y_{r0} \tag{17}$$

$$\sum_{i=1}^{m} V_i X_{i0} = 1 \quad i = 1, 2, \ldots, m \tag{18}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0 \quad j = 1, 2, \ldots, n \tag{19}$$

$$u_r, v_i \geq 0 \quad r = 1, 2, \ldots, s \tag{20}$$

A CCR model based on the VRS assumption was improved by Banker et al. (1984) and called it the BCC model. The BCC (BCC-IO) model of the Input-Oriented Multiplier is as follows:

Table 4 DEA related notations

Notations	Definitions
r	Index of outputs
i	Index of inputs
k	indexes of all efficient units
S_r^+	Output slack
S_i^-	Input slack
λ_k	coefficient of kth artificial DMU
Y_{rj}	Amount of the rth output produced by unit j
U_r	Weight given to rth output
X_{ij}	The amount of the ith input consumed by unit j
V_i	The weight given to the ith input
α_i	The relative importance of i-th input achieved by ANP method
β_r	The relative importance of r-th output achieved by ANP method

$$\mathrm{Max}Z_0 = \sum_{r=1}^{s} u_r y_{r0} + w_0 \tag{21}$$

$$\sum_{i=1}^{m} V_i X_{i0} = 1 \tag{22}$$

$$\sum_{r=1}^{m} U_r Y_{rj} - \sum_{i=1}^{s} V_i X_{ij} + w_0 \leq 0 \tag{23}$$

$$u_r, v_i \geq 0 \tag{24}$$

In output-oriented (BCC-OO) model, the general form will be as follows:

$$\mathrm{Min}Z_0 = \sum_{i=1}^{m} V_i X_{ij} + V \tag{25}$$

$$\sum_{r=1}^{s} U_r Y_{rj} = 1 \quad r = 1, 2, , \ldots, s \tag{26}$$

$$\sum_{r=1}^{s} U_r Y_{rj} \leq \sum_{i=1}^{m} V_i X_{ij} + V \quad i = 1, 2, , \ldots, m \tag{27}$$

$$u_r, v_i \geq 0 \tag{28}$$

The distinction between this model and the CCR is that we were loyal to the output and agreed to change the inputs to the CCR results.

3.3.1 Additive model

In this model, we subtract the inputs from the outputs, and then apply comparison to the inputs and outputs; however, since there are two free variables in the objective function, we only consider them for the outputs or inputs. Accordingly, the additive model will be as follows:

$$\mathrm{Max}Z_0 = \sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} V_i X_{ij} - V \tag{29}$$

$$\sum_{r=1}^{s} U_r \leq \sum_{i=1}^{m} V_i X_{ij} + V \tag{30}$$

$$u_r, v_i \geq 0, \quad V \text{ is unsigned variable} \tag{31}$$

3.3.2 Output-oriented AP model

In this method, in linear programming model is related to DMU efficiency. The smaller or equal zero constraints of that decision-making unit removed this constraint causes the maximum value of the objective function to be one. By removing this constraint, the unit efficiency coefficient under consideration may be larger than one. The procedure establishes a framework for ranking efficient units and allows for comparison with parametric rankings (Anderson & Peterson, 1993). The presented model is as follows:

$$\mathrm{MAX}y_i = \theta \tag{32}$$

$$\sum_{k=1}^{n} \lambda_k x_{ik} + s_i^- = x_{ij} \quad i = 1, 2, \dots, m,\ k \neq \dot{J} \tag{33}$$

$$S\theta \sum_{k=1}^{n} \lambda_k y_{rk} + S_r^+ = y_{rj} \quad r = 1, 2, \dots,\ , k \neq \dot{J} \tag{34}$$

$$\sum_{k=1}^{n} \lambda k = 1 \quad k = 1, 2, \dots, n,\ k \neq j \tag{35}$$

3.3.3 AP-CCR Model

In this method, the decision maker unit (DMU_0) is removed from the possibility of production and run the DEA model for the other DMUs. The complete ranking mathematical model with AP theory using the CCR multiplicative model by removing the decision-making unit from evaluation of the zero units is as Eqs. (36)–(39):

$$\mathrm{MAX} \sum_{r=1}^{s} u_r y_{r0} \tag{36}$$

$$\sum_{i=1}^{m} V_i x_{i0} = 1 \quad i = 1, 2, ..., m \tag{37}$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i=1}^{m} v_i x_{ij} \leq 0, \quad j = 1, 2, ..., n,\ j \neq 0,\ r = 1, 2, \dots, m \tag{38}$$

$$u_i, v_i \geq 0 \tag{39}$$

3.4 DEA model in presence of weight restrictions

The ability to distinguish the performance of DMUs in DEA models is improved by weight restrictions. Models are divided into four categories based on whether they are homogeneous

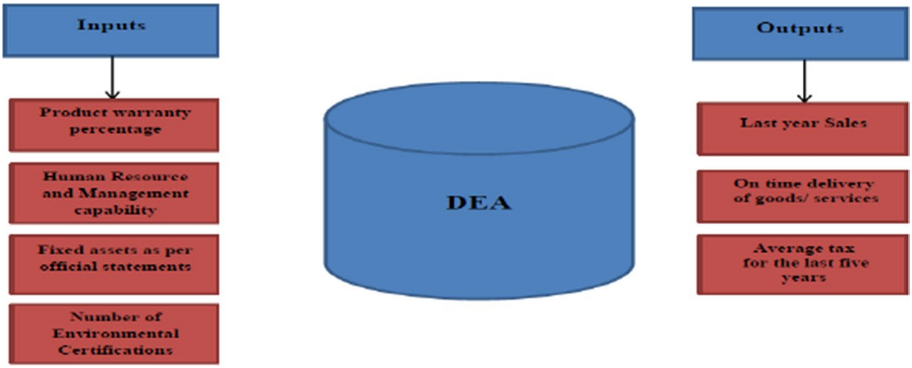


Fig. 1 Inputs and Outputs of the DEA model

or non-homogeneous, linked or unlinked, and weight restrictions are added to the multiplier form. Due to the weight of some inputs or outputs may be considered so small that they cannot affect the assessment, this freedom to choose weights leads to the achievement of inefficient efficiency measures. (Thanassoulis, 1995). One of the suggestions for troubleshooting is to consider weight restriction. For a review of some weight restriction methods in the DEA, can refer to Allen et al. (1997), Thanassoulis et al. (2004), Cooper et al. (2011), and Razipour et al. (2019). Podinovski (1999) has widely investigated relative efficiency in the presence of weight restrictions. Based on this method, the weight of quantitative criteria obtained from the Analytic Network Process is used in DEA models as inputs and outputs and added as a weight restriction in the above-mentioned DEA models in the previous section (Fig. 1). The relative importance of inputs and outputs which have been calculated by the ANP method is added to models (40)–(41) in the form of extra constraints as follows:

$$\sum_{j=1}^{n} \alpha_i x_{ij} \geq 0 \quad \forall i \tag{40}$$

$$\sum_{j=1}^{n} \beta_r y_{rj} \geq 0 \quad \forall r \tag{41}$$

where α_i is the relative importance of i-th input achieved by ANP method, and β_r is the relative importance of r-th output achieved by ANP method.

The conceptual flow of the proposed methods is shown in Fig. 2. As seen the three-stage framework requires these techniques to be employed in each stage.

4 Case study

The National Iranian Oil Company (NIOC) is a state-owned national oil and natural gas producer and distributor overseen by Iran's Ministry of Petroleum. The Consortium Agreement of 1954 restructured NIOC, which was founded in 1948. National Iranian Oil Company (NIOC) is the world's second-largest oil company, following Saudi

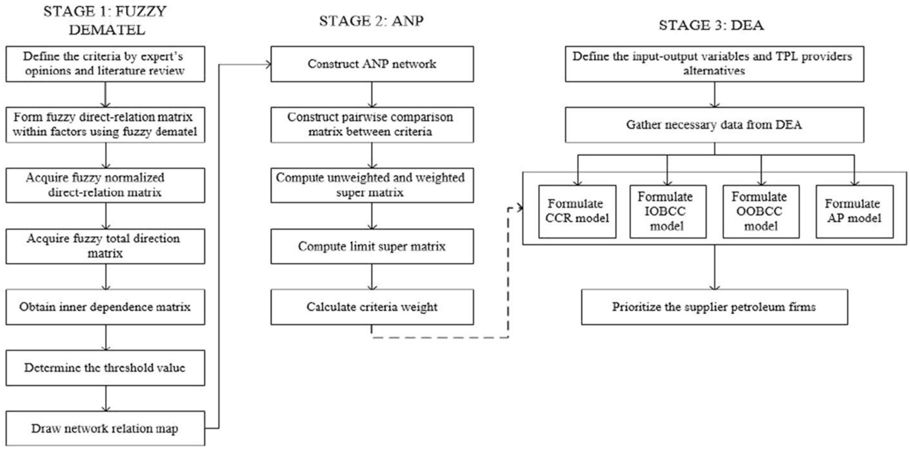


Fig. 2 The hybridization of fuzzy DEMATEL, ANP and DEA

Arabia's Aramco. The NIOC is solely responsible for crude oil exploration, drilling, production, distribution, and export, as well as natural gas and liquefied natural gas exploration, extraction, and sales (LNG). NIOC exports its excess production following OPEC commercial considerations and at market prices in international markets. Meanwhile, Iranian—Gas Engineering and Development Company is the pioneer company in managing and implementing gas industry plans and projects (including gas transmission pipelines, gas compression stations, refineries, and related buildings) in the Middle East. Engineering and Development Co. is a National Iranian Gas Company subsidiary, which has been established in line with the system to implement oil industry plans. It is in charge of all studies, including economic, technical, and feasibility, for all projects ordered by the National Iranian Gas Company, as well as implementing all engineering operations, including basic and detailed operations on the ordered projects. Design, supervision, and implementation of all engineering and construction operations, including construction and development of gas production, collection, and transmission systems; wellhead installations; refineries and dehumidification installations; transmission pipelines; gas feeding and distribution; gas compression and pressure reduction stations; telecommunication systems; pumping stations; construction and infrastructural operations; as well as the construction of offshore structures and related facilities inside and outside the country and undertaking logistics and procurement of articles needed for plans and projects from within and without the country. To verify the model, the combination of fuzzy DEMATEL, ANP, DEA, and AP methods was implemented to select petroleum, oil, and gas suppliers in Iran. Because of the rising demand for oil and gas, these companies are increasing their investment and improving their supply chains. In order to carry out this task, first, a committee of decision-makers was formed. By studying the identified criteria and sub-criteria of different researchers in evaluating the quality level of suppliers and their comparative comparison with each other and according to the opinions and experiences of experts, 34 sub-criteria were identified in five critical criteria. To construct the network structure, the problem is decomposed into three stages categories. This method consists of three stages, with the topmost level indicating the problem's goal of recognizing CSF priorities. The next stage indicates the dimensions employed in the paper. The lowest stage contains the CSFs. A schematic representation of the used network hierarchy is shown in Fig. 3. After computing effects between selection criteria, in the second stage, by means of ANP were derived the weights of each quantitative and qualitative criterion related to petroleum supplier selection. Based on recent research and experts' opinions, seven quantitative factors were prioritized and selected for evaluation of 15 petroleum suppliers by the DEA method. These companies supply steel products by centrifugal casting and molding, refractory materials used in petrochemical furnaces. Tubes, steam turbines and industrial gearboxes, compressors (air and gas-reciprocating and screw), tube tool, instrumentation, drilling equipment, power transformers, distribution, cathode protection and special, air, oil and gas switches, single-phase and three-phase contactors, cable trays, cable ladders, trucking and galvanized pipes, power and industrial electric motors at low and medium voltage levels, drives and soft starters, earthling and lightning arresting systems, cables, wires, cable washers, overhead cables, wire washers in low, medium and special use voltage levels, MCB and MCCB (miniature and suffering fuses), explosion-proof equipment, including socket plugs, lighting, measuring equipment, air brake filters, motor oil filters, hydraulic steering filters, hydraulic jack filters, and diesel fuel filters alarms and so on are the equipment that petroleum suppliers produce them for oil and gas and petrochemical products.

4.1 Fuzzy DEMATEL application

Many companies have used group decisions to detect a suitable solution to real-world decision-making problems. This method is to reach consensus through interaction with many experts, and afterward, an admitted determination can be derived (Cheng & Lin,

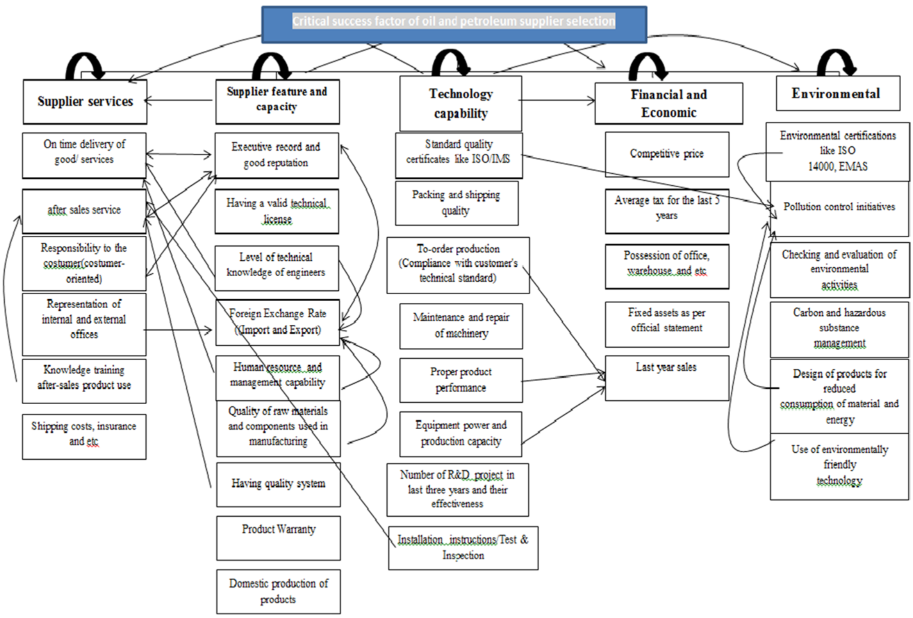


Fig. 3 Criteria and sub-criteria of petroleum supplier selection

2002). However, in complex system decision-making problems, decision-makers or experts always assess the qualitative criteria of a specific object using lingual expressions rather than crisp values based on experience and expertise. The fuzzy set theory can be used to quantify vague concepts related to the subjective judgments of human beings. Zhou et al. (2011). Table 5 presents the relationship between linguistic terms and fuzzy sets.

Total relation matrix (T) is shown in Table 6. According to the experts' opinion. Threshold value was determined to be 0.2 by the decision makers. Table 7 shows the matrix of significant relationships between the research factors. The priorities of criteria based on D_i+R_i and D_i-R_i values are presented in Table 8.

4.2 ANP application

To evaluate the quality level of oil and petrochemical industry suppliers, using the experts' opinions, variables, and sub-criteria and their relationships, they were identified, modeled, and ranked according to the ANP method. Fifteen companies were compared as samples according to the results obtained using the DEA method. The criteria used in this method are quantitative criteria, which were tax (in a million Rial) and the number of personnel (per person) as inputs. In addition, gross sales (in billion Rial), current assets (in billion Rial), and net sales (in billion Rial) were taken as model outputs, and thus, supplier companies were ranked accordingly. According to the explanations given in Sect. 3.1, the W_1 and W_2 to W_4 matrices were determined similarly, as presented in Tables 9, 10, 11 and 12. Based on Eqs. (1–3) W_A, W_B, W_{AB} were obtained, and the results are represented in Tables 13, 14 and 15.

After determining the experts' judgement form the pairwise comparisons of the criteria explained in Sect. 3.1, the priority of criteria was completed as shown in Table 16.

Considering the results obtained in this paper, we can say that competitive price is the most significant factor in oil and petroleum supplier selection. Equipment power and production capacity are the following ranks. This finding is similar to the findings of Minooie and Mohsenikabir (2017) and Kannan (2018). Also, among the top 10 factors, financial, economic, and environmental factors have the highest quota. Environmental certifications like ISO 14000, EMAS, using environmentally friendly technology, packing and shipping quality, carbon and hazardous substance management, fixed assets as per the official statement, average tax for the last 5 years, quality of raw materials and components used in manufacturing and responsibility to the customer (customer-oriented) are the most critical factors obtained in this research. The results indicated that decision makers must pay special attention to both financial and environmental indicators in choosing petroleum suppliers to succeed.

Table 5 relationship with linguistic terms and fuzzy numbers

Definition	Score
No influence	(0, 0, 0.25)
Very low influence	(0, 0.25, 0.5)
Low influence	(0.25, 0.5, 0.75)
High influence	(0.5, 0.75, 1)
Very high influence	(0.75, 1, 1)

Table 6 Total relation matrix

*W*4	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	*F*1	*F*2	*F*3	*F*4	*F*5
*E*1	0.091	0.201	0.084	0.152	0.134	0.164	0.092	0.021	0.011	0.016	0.018
*E*2	0.023	0.052	0.134	0.132	0.136	0.076	0.021	0.012	0.014	0.017	0.023
*E*3	0.120	0.143	0.086	0.137	0.148	0.186	0.078	0.078	0.065	0.056	0.088
*E*4	0.124	0.178	0.114	0.096	0.189	0.156	0.078	0.067	0.065	0.088	0.124
*E*5	0.128	0.234	0.124	0.165	0.067	0.164	0.187	0.075	0.065	0.057	0.113
*E*6	0.135	0.249	0.124	0.186	0.121	0.087	0.145	0.067	0.085	0.098	0.129
*F*1	0.114	0.087	0.065	0.076	0.112	0.096	0.076	0.081	0.068	0.081	0.149
*F*2	0.072	0.066	0.082	0.091	0.079	0.087	0.179	0.088	0.146	0.134	0.132
*F*3	0.087	0.079	0.087	0.076	0.098	0.074	0.135	0.167	0.096	0.166	0.129
*F*4	0.076	0.066	0.083	0.071	0.086	0.065	0.147	0.157	0.169	0.086	0.118
*F*5	0.086	0.078	0.067	0.098	0.101	0.109	0.142	0.176	0.119	0.125	0.051
*T*1	0.167	0.227	0.127	0.144	0.165	0.134	0.103	0.087	0.076	0.087	0.115
*T*2	0.087	0.112	0.157	0.087	0.075	0.078	0.091	0.123	0.067	0.076	0.067
*T*3	0.124	0.098	0.143	0.122	0.089	0.119	0.134	0.129	0.109	0.115	0.111
*T*4	0.129	0.134	0.083	0.072	0.132	0.089	0.113	0.124	0.081	0.074	0.092
*T*5	0.098	0.073	0.069	0.079	0.156	0.189	0.176	0.089	0.098	0.183	0.121
*T*6	0.089	0.104	0.114	0.078	0.156	0.178	0.187	0.167	0.126	0.167	0.118
*T*7	0.078	0.125	0.115	0.132	0.156	0.176	0.135	0.109	0.078	0.096	0.178
*T*8	0.112	0.098	0.087	0.078	0.087	0.112	0.108	0.091	0.067	0.083	0.094
*C*1	0.086	0.093	0.076	0.102	0.117	0.112	0.143	0.092	0.084	0.119	0.185
*C*2	0.123	0.134	0.143	0.143	0.103	0.135	0.094	0.082	0.078	0.119	0.112
*C*3	0.087	0.128	0.103	0.132	0.176	0.132	0.111	0.076	0.065	0.083	0.114
*C*4	0.187	0.123	0.127	0.109	0.154	0.123	0.156	0.123	0.134	0.132	0.167
*C*5	0.099	0.091	0.087	0.103	0.089	0.133	0.098	0.065	0.079	0.089	0.069
*C*6	0.114	0.132	0.109	0.124	0.107	0.113	0.178	0.134	0.074	0.089	0.167
*C*7	0.134	0.085	0.123	0.092	0.112	0.131	0.178	0.129	0.089	0.078	0.143
*C*8	0.123	0.091	0.119	0.079	0.122	0.139	0.146	0.117	0.920	0.710	0.135
*C*9	0.092	0.078	0.103	0.081	0.088	0.092	0.147	0.146	0.089	0.146	0.152
*S*1	0.087	0.072	0.069	0.104	0.114	0.125	0.179	0.159	0.108	0.117	0.089
*S*2	0.083	0.113	0.097	0.134	0.149	0.087	0.112	0.124	0.125	0.145	0.112
*S*3	0.078	0.095	0.120	0.072	0.076	0.116	0.145	0.176	0.107	0.114	0.152
*S*4	0.089	0.104	0.076	0.081	0.103	0.090	0.109	0.117	0.187	0.078	0.091
*S*5	0.081	0.119	0.119	0.072	0.066	0.079	0.143	0.125	0.137	0.088	0.111
*S*6	0.098	0.089	0.076	0.067	0.089	0.086	0.167	0.178	0.072	0.083	0.153

*W*4	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8	*C*1	*C*2	*C*3
*E*1	0.121	0.083	0.056	0.113	0.134	0.084	0.063	0.091	0.135	0.146	0.023
*E*2	0.146	0.065	0.083	0.136	0.083	0.034	0.023	0.134	0.123	0.134	0.023
*E*3	0.154	0.089	0.127	0.176	0.189	0.112	0.078	0.124	0.178	0.186	0.057
*E*4	0.186	0.143	0.147	0.168	0.165	0.089	0.097	0.105	0.168	0.156	0.078
*E*5	0.169	0.117	0.174	0.171	0.149	0.129	0.146	0.126	0.155	0.169	0.097
*E*6	0.189	0.120	0.117	0.184	0.164	0.076	0.098	0.119	0.165	0.139	0.076
*F*1	0.076	0.048	0.128	0.079	0.097	0.076	0.089	0.097	0.120	0.079	0.065
*F*2	0.097	0.086	0.084	0.091	0.093	0.072	0.068	0.087	0.112	0.076	0.071
*F*3	0.087	0.087	0.124	0.088	0.098	0.076	0.068	0.079	0.146	0.097	0.079

Table 6 (continued)

*W*4	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8	*C*1	*C*2	*C*3
*F*4	0.067	0.098	0.111	0.091	0.076	0.089	0.098	0.089	0.111	0.087	0.076
*F*5	0.068	0.098	0.119	0.088	0.129	0.098	0.121	0.067	0.183	0.076	0.087
*T*1	0.063	0.113	0.124	0.091	0.146	0.134	0.098	0.166	0.156	0.145	0.089
*T*2	0.134	0.076	0.132	0.086	0.091	0.074	0.093	0.118	0.146	0.092	0.067
*T*3	0.147	0.123	0.098	0.138	0.189	0.156	0.178	0.093	0.178	0.143	0.079
*T*4	0.127	0.123	0.154	0.078	0.143	0.132	0.091	0.146	0.174	0.138	0.171
*T*5	0.126	0.167	0.154	0.087	0.078	0.089	0.123	0.143	0.196	0.132	0.097
*T*6	0.145	0.111	0.187	0.086	0.076	0.098	0.156	0.143	0.125	0.176	0.091
*T*7	0.081	0.102	0.189	0.123	0.192	0.092	0.087	0.109	0.188	0.165	0.119
*T*8	0.087	0.109	0.129	0.154	0.189	0.123	0.089	0.118	0.129	0.219	0.093
*C*1	0.112	0.117	0.135	0.108	0.132	0.098	0.136	0.112	0.087	0.245	0.124
*C*2	0.165	0.127	0.109	0.134	0.143	0.098	0.123	0.116	0.154	0.087	0.087
*C*3	0.123	0.098	0.156	0.164	0.169	0.094	0.092	0.145	0.173	0.168	0.082
*C*4	0.139	0.098	0.133	0.139	0.144	0.118	0.172	0.088	0.131	0.123	0.081
*C*5	0.109	0.111	0.103	0.098	0.086	0.077	0.142	0.108	0.134	0.245	0.094
*C*6	0.155	0.103	0.124	0.129	0.146	0.092	0.089	0.078	0.153	0.092	0.099
*C*7	0.132	0.123	0.109	0.155	0.123	0.098	0.133	0.109	0.189	0.119	0.123
*C*8	0.146	0.102	0.092	0.128	0.131	0.650	0.132	0.116	0.134	0.112	0.142
*C*9	0.092	0.113	0.159	0.092	0.111	0.091	0.167	0.187	0.161	0.134	0.189
*S*1	0.092	0.174	0.870	0.065	0.097	0.081	0.760	0.076	0.261	0.096	0.087
*S*2	0.123	0.154	0.134	0.067	0.082	0.103	0.071	0.167	0.254	0.077	0.145
*S*3	0.145	0.156	0.189	0.132	0.148	0.096	0.106	0.139	0.257	0.087	0.091
*S*4	0.112	0.106	0.076	0.087	0.094	0.118	0.067	0.081	0.132	0.071	0.093
*S*5	0.121	0.139	0.083	0.127	0.119	0.072	0.069	0.137	0.105	0.116	0.109
*S*6	0.116	0.177	0.082	0.095	0.073	0.066	0.135	0.061	0.149	0.129	0.118

*W*4	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6
*E*1	0.149	0.056	0.074	0.148	0.136	0.049	0.074	0.056	0.075	0.023	0.033	0.093
*E*2	0.034	0.045	0.034	0.023	0.031	0.053	0.031	0.025	0.032	0.072	0.083	0.054
*E*3	0.112	0.086	0.098	0.167	0.640	0.067	0.078	0.089	0.145	0.098	0.089	0.116
*E*4	0.113	0.098	0.189	0.165	0.145	0.087	0.067	0.085	0.127	0.074	0.068	0.117
*E*5	0.122	0.071	0.134	0.126	0.087	0.089	0.086	0.087	0.098	0.076	0.069	0.09
*E*6	0.147	0.098	0.176	0.167	0.156	0.097	0.107	0.112	0.129	0.076	0.089	0.101
*F*1	0.069	0.071	0.089	0.083	0.069	0.096	0.111	0.131	0.132	0.087	0.069	0.127
*F*2	0.139	0.089	0.112	0.078	0.156	0.123	0.078	0.119	0.087	0.097	0.068	0.134
*F*3	0.129	0.098	0.089	0.078	0.139	0.115	0.097	0.107	0.079	0.147	0.079	0.123
*F*4	0.124	0.093	0.112	0.111	0.126	0.056	0.088	0.104	0.109	0.135	0.087	0.101
*F*5	0.116	0.091	0.088	0.109	0.089	0.081	0.067	0.125	0.118	0.098	0.113	0.108
*T*1	0.167	0.098	0.076	0.135	0.079	0.112	0.110	0.103	0.098	0.89	0.087	0.131
*T*2	0.135	0.066	0.085	0.076	0.089	0.113	0.086	0.113	0.129	0.136	0.078	0.143
*T*3	0.185	0.098	0.112	0.184	0.156	0.156	0.111	0.165	0.195	0.132	0.107	0.121
*T*4	0.127	0.089	0.079	0.113	0.189	0.102	0.121	0.186	0.178	0.072	0.076	0.119
*T*5	0.178	0.067	0.087	0.143	0.081	0.091	0.154	0.137	0.143	0.109	0.087	0.107
*T*6	0.165	0.076	0.129	0.173	0.179	0.147	0.124	0.187	0.176	0.154	0.074	0.132
*T*7	0.184	0.074	0.083	0.119	0.128	0.134	0.102	0.116	0.134	0.087	0.139	0.065

Table 6 (continued)

W4	C4	C5	C6	C7	C8	C9	S1	S2	S3	S4	S5	S6
T8	0.128	0.089	0.078	0.072	0.143	0.132	0.112	0.167	0.153	0.135	0.136	0.091
C1	0.245	0.089	0.113	0.136	0.145	0.087	0.246	0.134	0.145	0.119	0.132	0.092
C2	0.143	0.091	0.132	0.061	0.092	0.112	0.109	0.115	0.081	0.112	0.132	0.102
C3	0.139	0.165	0.067	0.098	0.069	0.176	0.253	0.111	0.132	0.69	0.092	0.117
C4	0.067	0.076	0.092	0.132	0.155	0.109	0.143	0.134	0.154	0.189	0.133	0.194
C5	0.221	0.082	0.104	0.114	0.146	0.123	0.235	0.097	0.111	0.078	0.98	0.071
C6	0.219	0.079	0.051	0.141	0.157	0.133	0.087	0.102	0.087	0.078	0.069	0.082
C7	0.172	0.092	0.115	0.165	0.079	0.134	0.124	0.231	0.089	0.078	0.067	0.082
C8	0.136	0.105	0.123	0.142	0.095	0.129	0.114	0.103	0.076	0.078	0.092	0.107
C9	0.176	0.098	0.087	0.112	0.102	0.079	0.113	0.154	0.132	0.101	0.148	0.123
S1	0.138	0.076	0.097	0.084	0.157	0.087	0.065	0.179	0.187	0.078	0.067	0.071
S2	0.091	0.169	0.067	0.103	0.147	0.098	0.123	0.092	0.167	0.087	0.077	0.139
S3	0.128	0.076	0.087	0.073	0.167	0.118	0.245	0.132	0.065	0.114	0.136	0.098
S4	0.254	0.107	0.071	0.082	0.103	0.116	0.133	0.143	0.152	0.078	0.103	0.098
S5	0.118	0.127	0.139	0.098	0.920	0.081	0.142	0.243	0.076	0.72	0.089	0.104
S6	0.136	0.105	0.092	0.082	0.078	0.092	0.163	0.132	0.116	0.074	0.082	0.095

4.3 DEA application

At this level, firstly, we determine the relative weight of each criterion and then analyze the relative efficiency scores of oil and petroleum companies' suppliers through various DEA models. Afterward, seven inputs and outputs criteria are determined into two categories. Human resource and management capability indicates the number of educated employees of the companies, and on-time delivery of goods/services is related to the social aspect of supplier selection. The numbers of environmental certifications Like ISO 1400, EMAS, etc., are related to the environmental aspect of supplier selection. Product warranty percentage, fixed assets as per the official statement, last year's sales, and average tax for the last 5 years are factors related to the economic aspect of supplier selection. Tables 17 and 18 represent the inputs and outputs of alternatives.

After comparison of the 15 selected petroleum suppliers by the CCR, BCC-IO, BCC-OO and ADDITIVE methods, the weight of each DMU was obtained and suppliers were ranked and prioritized in Table 19.

Before using the proposed approaches, the results of DEA method without considering the weight constrained are represented in Fig. 4.

Furthermore, the comparison results of petroleum suppliers by using the proposed method and a comparative study of supplier performance using different methods of BCC-IO, BCC-OO, CCR and ADDITIVE are presented in Fig. 5.

According to the tender laws in Iran, after reviewing the companies' qualifications, three companies are selected for the final review. By applying proposed method, instead of eight companies, only three companies were selected for the final review, which naturally increases the accuracy and quality of the decision-making. By the same token, three companies DM7, DM11 and DM12 were introduced as efficient suppliers based on the four methods BCC-IO, BCC-OO, CCR and ADDITIVE. To select the top company, the inputs and outputs data were also applied on the AP-BCC and AP-CCR methods, the results of

Table 7 Significant relationships between the research factors

W4	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	*F*1	*F*2	*F*3	*F*4	*F*5
*E*1	0	1	0	0	0	0	0	0	0	0	0
*E*2	0	0	0	0	0	0	0	0	0	0	0
*E*3	0	0	0	0	0	0	0	0	0	0	0
*E*4	0	0	0	0	0	0	0	0	0	0	0
*E*5	0	1	0	0	0	0	0	0	0	0	0
*E*6	0	1	0	0	0	0	0	0	0	0	0
*F*1	0	0	0	0	0	0	0	0	0	0	0
*F*2	0	0	0	0	0	0	0	0	0	0	0
*F*3	0	0	0	0	0	0	0	0	0	0	0
*F*4	0	0	0	0	0	0	0	0	0	0	0
*F*5	0	0	0	0	0	0	0	0	0	0	0
*T*1	0	1	0	0	0	0	0	0	0	0	0
*T*2	0	0	0	0	0	0	0	0	0	0	0
*T*3	0	0	0	0	0	0	0	0	0	0	1
*T*4	0	0	0	0	0	0	0	0	0	0	0
*T*5	0	0	0	0	0	0	0	0	0	0	1
*T*6	0	0	0	0	0	0	0	0	0	1	0
*T*7	0	0	0	0	0	0	0	0	0	0	0.233
*T*8	0	0	0	0	0	0	0	0	0	0	0.089
*C*1	0	0	0	0	0	0	0	0	0	0	0
*C*2	0	0	0	0	0	0	0	0	0	0	0
*C*3	0	0	0	0	0	0	0	0	0	0	0
*C*4	0	0	0	0	0	0	0	0	0	0	0
*C*5	0	0	0	0	0	0	0	0	0	0	0
*C*6	0	0	0	0	0	0	0	0	0	0	0
*C*7	0	0	0	0	0	0	0	0	0	0	0
*C*8	0	0	0	0	0	0	0	0	0	0	0.156
*C*9	0	0	0	0	0	0	0	0	0	0	0
*S*1	0	0	0	0	0	0	0	0	0	0	0
*S*2	0	0	0	0	0	0	0	0	0	0	0
*S*3	0	0	0	0	0	0	0	0	0	0	0
*S*4	0	0	0	0	0	0	0	0	0	0	0
*S*5	0	0	0	0	0	0	0	0	0	0	0
*S*6	0	0	0	0	0	0	0	0	0	0	0

W4	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8	*C*1	*C*2	*C*3
*E*1	0	0	0	0	0	0	0	0	0	0	0
*E*2	0	0	0	0	0	0	0	0	0	0	0
*E*3	0	0	0	0	0	0	0	0	0	0	0
*E*4	0	0	0	0	0	0	0	0	0	0	0
*E*5	0	0	0	0	0	0	0	0	0	0	0
*E*6	0	0	0	0	0	0	0	0	0	0	0
*F*1	0	0	0	0	0	0	0	0	0	0	0
*F*2	0	0	0	0	0	0	0	0	0	0	0
*F*3	0	0	0	0	0	0	0	0	0	0	0

Table 7 (continued)

*W*4	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8	*C*1	*C*2	*C*3
*F*4	0	0	0	0	0	0	0	0	0	0	0
*F*5	0	0	0	0	0	0	0	0	0	0	0
*T*1	0	0	0	0	0	0	0	0	0	0	0
*T*2	0	0	0	0	0	0	0	0	0	0	0
*T*3	0	0	0	0	0	0	0	0	0	0	0
*T*4	0	0	0	0	0	0	0	0	0	0	0
*T*5	0	0	0	0	0	0	0	0	0	0	0
*T*6	0	0	0	0	0	0	0	0	0	0	0
*T*7	0	0	0	0	0	0	0	0	0	0	0
*T*8	0	0	0	0	0	0	0	0	0	0	0
*C*1	0	0	0	0	0	0	0	0	0	1	0
*C*2	0	0	0	0	0	0	0	0	0	0	0
*C*3	0	0	0	0	0	0	0	0	0	0	0
*C*4	0	0	0	0	0	0	0	0	0	0	0
*C*5	0	0	0	0	0	0	0	0	0	0	0
*C*6	0	0	0	0	0	0	0	0	0	0	0
*C*7	0	0	0	0	0	0	0	0	0	0	0
*C*8	0	0	0	0	0	0	0	0	0	0	0
*C*9	0	0	0	0	0	0	0	0	0	0	0
*S*1	0	0	0	0	0	0	0	0	1	0	1
*S*2	0	0	0.104	0	0	0	0	0	1	0	0
*S*3	0	0	0	0	0	0	0	0	0.121	0	0
*S*4	0	0	0	0	0	0	0	0	0	0	0
*S*5	0	0	0	0	0	0	0	0	0	0	0
*S*6	0	0	0	0	0	0	0	0	0	0	0

*W*4	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6
*E*1	0	0	0	0	0	0	0	0	0	0	0	0
*E*2	0	0	0	0	0	0	0	0	0	0	0	0
*E*3	0	0	0	0	0	0	0	0	0	0	0	0
*E*4	0	0	0	0	0	0	0	0	0	0	0	0
*E*5	0	0	0	0	0	0	0	0	0	0	0	0
*E*6	0	0	0	0	0	0	0	0	0	0	0	0
*F*1	0	0	0	0	0	0	0	0	0	0	0	0
*F*2	0	0	0	0	0	0	0	0	0	0	0	0
*F*3	0	0	0	0	0	0	0	0	0	0	0	0
*F*4	0	0	0	0	0	0	0	0	0	0	0	0
*F*5	0	0	0	0	0	0	0	0	0	0	0	0
*T*1	0	0	0	0	0	0	0	0	0	0	0	0
*T*2	0	0	0	0	0	0	0	0	0	0	0	0
*T*3	0	0	0	0	0	0	0	0	0	0	0	0
*T*4	0	0	0	0	0	0	0	0	0	0	0	0
*T*5	0	0	0	0	0	0	0	0	0	0	0	0
*T*6	0	0	0	0	0	0	0	0	0	0	0	0
*T*7	0	0	0	0	0	0	0	0	0	0	0	0

Table 7 (continued)

*W*4	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6
*T*8	0	0	0	0	0	0	0	0	0	0	0	0
*C*1	0	1	0	0	0	1	0	0	0	0	0	0
*C*2	0	0	0	0	0	0	0	0	0	0	0	0
*C*3	1	0	0	0	0	0.390	0	0	0	0	0	0
*C*4	0	0	0	0	0	0	0	0	0	0	0	0
*C*5	1	0	0	0	0	0.285	0	0	0	0	0	0
*C*6	1	0	0	0	0	0	0	0	0	0	0	0
*C*7	0.126	0	0	0	0	0	0.134	0	0	0	0	0
*C*8	0	0	0	0	0	0	0.244	0	0	0	0	0
*C*9	0	0	0	0	0	0	0	0	0	0	0	0
*S*1	0	0	0	0	0	0	0	0	0	0	0	0
*S*2	0	0	0	0	0	0	0	0	0	0	0	0
*S*3	0	0	0	0	0	1	0	0	0	0	0	0
*S*4	0.308	0	0	0	0	0	0	0	0	0	0	0
*S*5	0	0	0	0	0	0	0.238	0	0	0	0	0
*S*6	0	0	0	0	0	0	0.090	0	0	0	0	0

which can be seen in Figs. 6 and 7, respectively. According to the calculations, the supplier company DMU11 was selected as the best and most efficient oil and petroleum supplier. Moreover, the comparison of the two AP methods showed the similarly of the results obtained from the application of these two methods.

As illustrated, eventually, the number of efficient companies for the final selection was reduced from 7 to 3 companies, showing that this method can highlight the possible differences between suppliers. Using this method, the final decision maker can make a low-risk and optimal decision in the company's interests by having the necessary information.

5 Conclusions

Supplier selection applying MCDM is a critical activity in the gas, oil, and petroleum industries that has significant financial and performance outcomes for constructing large facilities and other project types. Environmental certifications like ISO 14000, EMAS, using environmentally friendly technology, packing and shipping quality, carbon and hazardous substance management, fixed assets as per the official statement, average tax for the last 5 years, quality of raw materials and components used in manufacturing and responsibility to the customer (customer-oriented) were identified as the most important factors in the present research. The presented approach has various benefits for decision-makers. Fuzzy DEMATEL analyzed the criteria, and interdependencies among them were obtained. Then fuzzy DEMATEL was prepared as initial inputs for ANP to construct a network relation map. By implementation of ANP is probable to incorporate the managerial implication into the performance evaluation process these resulting in more practical model for DEA. Finally, the obtained results were used to evaluate 15 oil and petroleum supplier companies to select the best supplier. These companies supply the Boiler, heat Exchangers, compressors, distillation towers, cavitations, pumps, separators, pipes,

Table 8 The scores of each criteria and relevant value for cause and effect groups

Factors	R_i	C_i	$R_i + C_i$	$R_i - C_i$
Environmental certifications like ISO 14000, EMAS	1.5258	1.1111	2.8369	0.41475
Pollution control initiatives	2.1455	3.2771	5.5226	−0.6316
Carbon and hazardous substances	2.1593	2.0393	4.1986	0.12
Checking and evaluation of environmental activities	1.5495	1.4221	2.9716	0.1271
Design of products to reduce the consumption of material and energy	1.6158	1.1021	2.7179	0.5137
Use of environmentally friendly technology	2.2125	3.3672	5.5797	−1.1545
Competitive price	3.3015	3.3295	6.631	−0.028
Average tax for the last five years	1.5186	1.7206	3.2391	−0.202
Possession of office, warehouse. Etc	2.4335	2.3873	4.6308	0.0462
Fixed assets as per official statement	2.5176	2.4398	4.9574	0.0778
Last year sales	2.0405	2.7281	4.7686	−0.7077
To-order production (compliance with the customer's technical standard)	2.3669	2.495	4.8619	−0.128
Maintenance and repair of machinery	1.5697	1.4823	3.052	0.08744
Standard quality certificates like ISO/IM	2.5637	2.6831	5.2504	−0.1158
Number of R&D projects in the last three years and their effectiveness	1.5263	1.3467	2.8736	0.1802
Installation instructions/test & inspection	2.3471	2.2934	4.6405	0.0537
Proper product performance	3.5125	3.2931	6.8056	0.2194
Packing and shipping quality	2.7387	2.6738	5.4125	0.649
Equipment power and production capacity	2.8654	2.7378	5.6032	0.1276
Executive record and good reputation	2.2136	2.7873	5.0009	−0.5737
Level of technical knowledge of engineers	3.1238	2.1454	5.2692	0.9784
Having a valid technical license	2.6543	2.9873	5.6416	−0.333
Foreign Exchange Rate (Import and Export)	1.4533	2.9213	4.3746	−1.4668
Quality of raw materials and components in manufacturing	2.3567	1.9893	4.346	0.3674
Having quality system	3.1654	3.5466	6.712	−0.3812
Product warranty	3.1127	2.3834	5.4961	0.7293
Domestic production of products	2.5431	3.4782	6.0213	−0.9351
Human resource and management capability	3.7289	2.8736	6.6025	0.8553
On-time delivery of goods/services	2.1342	3.2341	5.3683	−1.0999
After-sales services	2.0257	3.2214	5.2471	−1.1916
Responsibility to the costumer (costumer-oriented)	2.2461	2.3573	4.6034	−0.1112
Knowledge training after-sales product use	2.3545	2.1465	4.501	0.208
Representation of internal and external offices	3.2821	2.8763	6.1584	0.4058
Shipping costs, insurance	2.2226	2.5371	4.7597	−0.3144

Table 9 W_1 matrix

*W*1	*E*	*T*	*C*	*F*	*S*
W	0.303	0.228	0.124	0.161	0.181

Table 10 W_2 matrix

W2	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5
E	0.234	0.145	0.151	0.161	0.100	0.204	0	0	0	0	0
F	0	0	0	0	0	0	0.466	0.167	0.069	0.175	0.410
T	0	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0

W2	T1	T2	T3	T4	T5	T6	T7	T8	C1	C2	C3
E	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0
T	0.073	0.115	0.132	0.095	0.118	0.140	0.161	0.163	0	0	0
C	0	0	0	0	0	0	0	0	0.053	0.105	0.117
S	0	0	0	0	0	0	0	0	0	0	0

W2	C4	C5	C6	C7	C8	C9	S1	S2	S3	S4	S5	S6
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	0	0	0	0	0	0	0	0	0
C	0.076	0.087	0.164	0.141	0.151	0.102	0	0	0	0	0	0
S	0	0	0	0	0	0	0.174	0.166	0.135	0.110	0.226	0.185

Table 11 W_3 matrix

W3	E	T	C	F	S
E	0.753	0	0	0	0
T	0.107	1	0	0.351	0.431
C	0.139	1	1	0.262	0.237
F	0	0	0	0.386	0
S	0	0	0	0	0.330

heaters, tanks, cooling towers, burners, and so on. By using this method, decision-makers can prioritize the large number of alternatives considering criteria data, which leads to a more accurate answer. DEA allows the decision-makers to analyze and rank the significant number of alternatives. For instance, investigating and prioritizing the proposed method requires fewer pairwise comparisons and computations. The results indicated that the hybrid method prepares the decision-makers to take the benefit of using it in a single framework. Investigating uncertainty in DEA and applying the proposed method to other industries could be considered for future research.

Table 12 W_4 matrix

W4	E1	E2	E3	E4	E5	E6	F1	F2	F3	F4	F5
*E*1	1	0.165	0	0	0	0	0	0	0	0	0
*E*2	0	0.139	0	0	0	0	0	0	0	0	0
*E*3	0	0	1	0	0	0	0	0	0	0	0
*E*4	0	0	0	1	0	0	0	0	0	0	0
*E*5	0	0.302	0	0	1	0	0	0	0	0	0
*E*6	0	0.251	0	0	0	1	0	0	0	0	0
*F*1	0	0	0	0	0	0	1	0	0	0	0.203
*F*2	0	0	0	0	0	0	0	1	0	0	0
*F*3	0	0	0	0	0	0	0	0	1	0	0
*F*4	0	0	0	0	0	0	0	0	0	1	0
*F*5	0	0	0	0	0	0	0	0	0	0	0.048
*T*1	0	0.106	0	0	0	0	0	0	0	0	0
*T*2	0	0	0	0	0	0	0	0	0	0	0
*T*3	0	0.035	0	0	0	0	0	0	0	0	0
*T*4	0	0	0	0	0	0	0	0	0	0	0
*T*5	0	0	0	0	0	0	0	0	0	0	0.189
*T*6	0	0	0	0	0	0	0	0	0	0	0
*T*7	0	0	0	0	0	0	0	0	0	0	0.233
*T*8	0	0	0	0	0	0	0	0	0	0	0.089
*C*1	0	0	0	0	0	0	0	0	0	0	0.078
*C*2	0	0	0	0	0	0	0	0	0	0	0
*C*3	0	0	0	0	0	0	0	0	0	0	0
*C*4	0	0	0	0	0	0	0	0	0	0	0
*C*5	0	0	0	0	0	0	0	0	0	0	0
*C*6	0	0	0	0	0	0	0	0	0	0	0
*C*7	0	0	0	0	0	0	0	0	0	0	0
*C*8	0	0	0	0	0	0	0	0	0	0	0.156
*C*9	0	0	0	0	0	0	0	0	0	0	0
*S*1	0	0	0	0	0	0	0	0	0	0	0
*S*2	0	0	0	0	0	0	0	0	0	0	0
*S*3	0	0	0	0	0	0	0	0	0	0	0
*S*4	0	0	0	0	0	0	0	0	0	0	0
*S*5	0	0	0	0	0	0	0	0	0	0	0
*S*6	0	0	0	0	0	0	0	0	0	0	0

*W*4	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8	*C*1	*C*2	*C*3
*E*1	0	0	0	0	0	0	0	0	0	0	0
*E*2	0	0	0	0	0	0	0	0	0	0	0
*E*3	0	0	0	0	0	0	0	0	0	0	0
*E*4	0	0	0	0	0	0	0	0	0	0	0
*E*5	0	0	0	0	0	0	0	0	0	0	0
*E*6	0	0	0	0	0	0	0	0	0	0	0
*F*1	0	0	0	0	0	0	0	0	0	0	0
*F*2	0	0	0	0	0	0	0	0	0	0	0
*F*3	0	0	0	0	0	0	0	0	0	0	0

Table 12 (continued)

W4	T1	T2	T3	T4	T5	T6	T7	T8	C1	C2	C3
F4	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	0	0	0	0	0	0	0	0
T1	1	0	0	0	0	0	0	0	0	0	0
T2	0	1	0	0	0	0	0	0	0	0	0
T3	0	0	1	0	0	0	0	0	0	0	0
T4	0	0	0	1	0	0	0	0	0	0	0
T5	0	0	0	0	1	0	0	0	0	0	0
T6	0	0	0	0	0	1	0	0	0	0	0
T7	0	0	0	0	0	0	1	0	0	0	0
T8	0	0	0	0	0	0	0	1	0	0	0
C1	0	0	0	0	0	0	0	0	0.104	0	0
C2	0	0	0	0	0	0	0	0	0	1	0
C3	0	0	0	0	0	0	0	0	0	0	1
C4	0	0	0	0	0	0	0	0	0	0	0
C5	0	0	0	0	0	0	0	0	0	0	0
C6	0	0	0	0	0	0	0	0	0	0	0
C7	0	0	0	0	0	0	0	0	0	0	0
C8	0	0	0	0	0	0	0	0	0	0	0
C9	0	0	0	0	0	0	0	0	0	0	0
S1	0	0	0	0	0	0	0	0	0.419	0	0
S2	0	0	0.104	0	0	0	0	0	0.353	0	0
S3	0	0	0	0	0	0	0	0	0.121	0	0
S4	0	0	0	0	0	0	0	0	0	0	0
S5	0	0	0	0	0	0	0	0	0	0	0
S6	0	0	0	0	0	0	0	0	0	0	0

W4	C4	C5	C6	C7	C8	C9	S1	S2	S3	S4	S5	S6
E1	0	0	0	0	0	0	0	0	0	0	0	0
E2	0	0	0	0	0	0	0	0	0	0	0	0
E3	0	0	0	0	0	0	0	0	0	0	0	0
E4	0	0	0	0	0	0	0	0	0	0	0	0
E5	0	0	0	0	0	0	0	0	0	0	0	0
E6	0	0	0	0	0	0	0	0	0	0	0	0
F1	0	0	0	0	0	0	0	0	0	0	0	0
F2	0	0	0	0	0	0	0	0	0	0	0	0
F3	0	0	0	0	0	0	0	0	0	0	0	0
F4	0	0	0	0	0	0	0	0	0	0	0	0
F5	0	0	0	0	0	0	0	0	0	0	0	0
T1	0	0	0	0	0	0	0	0	0	0	0	0
T2	0	0	0	0	0	0	0	0	0	0	0	0
T3	0	0	0	0	0	0	0	0	0	0	0	0
T4	0	0	0	0	0	0	0	0	0	0	0	0
T5	0	0	0	0	0	0	0	0	0	0	0	0
T6	0	0	0	0	0	0	0	0	0	0	0	0
T7	0	0	0	0	0	0	0	0	0	0	0	0

Table 12 (continued)

*W*4	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6
*T*8	0	0	0	0	0	0	0	0	0	0	0	0
*C*1	0.308	0	0	0	0	0	0.118	0.051	0	0	0	0
*C*2	0	0	0	0	0	0	0	0	0	0	0	0
*C*3	0.180	0	0	0	0	0	0.39	0	0	0	0	0
*C*4	0.146	0	0	0	0	0	0	0	0	0	0	0
*C*5	0.235	1	0	0	0	0	0.285	0	0	0	0	0
*C*6	0	0	1	0	0	0	0	0	0	0	0	0
*C*7	0.126	0	0	1	0	0	0	0.134	0	0	0	0
*C*8	0	0	0	0	1	0	0	0.244	0	0	0	0
*C*9	0	0	0	0	0	1	0	0	0	0	0	0
*S*1	0	0	0	0	0	0	0.205	0	0	0	0	0
*S*2	0	0	0	0	0	0	0	0.136	0	0	0	0
*S*3	0	0	0	0	0	0	0	0	1	0	0	0
*S*4	0.308	0	0	0	0	0	0	0	0	1	0	0
*S*5	0	0	0	0	0	0	0	0.238	0	0	1	0
*S*6	0	0	0	0	0	0	0	0.090	0	0	0	1

Table 13 W_A matrix

WA	*E*	*F*	*T*	*C*	*S*
WA	0.269	0.228	0.124	0.173	0.212

Table 14 W_B matrix

WB	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	*F*1	*F*2	*F*3	*F*4	*F*5
E	0.243	0.053	0.151	0.161	0.100	0.204	0	0	0	0	0
F	0	0	0	0	0	0	0.474	0.167	0.069	0.175	0.096
T	0	0	0	0	0	0	0	0	0	0	0
C	0	0	0	0	0	0	0	0	0	0	0
S	0	0	0	0	0	0	0	0	0	0	0

WB	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8	*C*1	*C*2	*C*3
E	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0
T	0.073	0.115	0.132	0.095	0.118	0.140	0.161	0.163	0	0	0
C	0	0	0	0	0	0	0	0	0.005	0.105	0.117
S	0	0	0	0	0	0	0	0	0	0	0

WB	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6
E	0	0	0	0	0	0	0	0	0	0	0	0
F	0	0	0	0	0	0	0	0	0	0	0	0
T	0	0	0	0	0	0	0	0	0	0	0	0
C	0.099	0.087	0.164	0.141	0.151	0.102	0	0	0	0	0	0
S	0	0	0	0	0	0	0.035	0.022	0.135	0.110	0.226	0.186

Table 15 W_{AB} matrix

WAB	*E*1	*E*2	*E*3	*E*4	*E*5	*E*6	*F*1	*F*2	*F*3	*F*4	*F*5
E	0.062	0.014	0.040	0.043	0.026	0.054	0.108	0.038	0.015	0.039	0.021
WAB	*T*1	*T*2	*T*3	*T*4	*T*5	*T*6	*T*7	*T*8	*C*1	*C*2	*C*3
E	0.009	0.014	0.016	0.011	0.014	0.017	0.019	0.202	0.009	0.018	0.020
WAB	*C*4	*C*5	*C*6	*C*7	*C*8	*C*9	*S*1	*S*2	*S*3	*S*4	*S*5	*S*6
E	0.017	0.015	0.028	0.024	0.026	0.017	0.007	0.004	0.028	0.023	0.047	0.039

Table 16 Priority of criteria

Dimension	Factor	Weight	Rank
Financial and Economic	Competitive price	0.108	1
Technology capability	Equipment power and production capacity	0.082	2
Environmental dimension	Environmental certifications like ISO 14000, EMAS	0.063	3
Environmental dimension	Use of environmentally friendly technology	0.054	4
Technology capability	Packing and shipping quality	0.047	5
Environmental dimension	Carbon and hazardous substance management	0.043	6
Financial and Economic	Fixed assets as per official statement	0.0392	7
Financial and Economic	Average tax for the last five years	0.0381	8
Supplier feature and capacity	Quality of raw materials and components used in manufacturing	0.0288	9
Supplier services	Responsibility to the costumer (costumer-oriented)	0.0283	10
Environmental dimension	Design of products for reducing the consumption of material and energy	0.0267	11
Supplier feature and capacity	Product warranty	0.0262	12
Supplier feature and capacity	Having quality system	0.0243	13
Supplier services	Representation of internal and external offices	0.233	14
Financial and Economic	Last year sales	0.214	15
Supplier feature and capacity	Level of technical knowledge of engineers	0.0201	16
Technology capability	Proper product performance	0.019	17
Supplier feature and capacity	Having a valid technical license	0.018	18
Technology capability	To-order production (compliance with customer's standard	0.176	19
Supplier feature and capacity	Domestic production of products	0.173	20
Supplier feature and capacity	Foreign Exchange Rate (Import and Export)	0.171	21
Supplier services	On time delivery of good/services	0.164	23
Supplier feature and capacity	Human resource and management capability	0.0158	24
Financial and Economic dimension	Possession of office, warehouse, etc	0.0152	25
Supplier feature and capacity	Installation instructions/test and inspection	0.0146	26
Environmental dimension	Pollution control initiatives	0.143	27
Technologycapability	Number of R&D projects in the last three years and their effectiveness	0.140	28

Table 16 (continued)

Dimension	Factor	Weight	Rank
Environmental dimension	Checking and evaluation of environmental activities	0.011	29
Supplier feature and capacity	Executive record and good reputation	0.0098	30
Technology capability	Standard quality certificates like ISO/IMS	0.0091	31
Supplier services	On time delivery of goods/services	0.007	32
Supplier services	After-sales service	0.005	33
Supplier services	Knowledge training after-sales products use	0.003	34

Table 17 Inputs of 15 companies

No	Companies	Product warranty percentage (V_1)	Human resource and management capability (V_2)	Fixed assets as per official statement (V_3)	Number of environmental certifications (V_4)
1	DMU 1	80	22	18.8832073	3
2	DMU 2	66	18	88.1989582	2
3	DMU 3	57	50	75.9261792	3
4	DMU 4	43	68	91.6622053	3
5	DMU 5	73	21	52.0320151	3
6	DMU 6	82	67	256.259365	3
7	DMU 7	23	11	18.8832073	2
8	DMU 8	75	65	42.1989584	2
9	DMU 9	68	117	163.327624	2
10	DMU 10	35	31	64.621231	3
11	DMU 11	15	135	382.621231	1
12	DMU 12	76	18	18.2972612	3
13	DMU 13	78	14	30.2203764	3
14	DMU 14	76	217	222.327531	2
15	DMU 15	45	22	73.2002176	3

Table 18 Outputs of 15 companies

No	Companies	Last year sales (U_1)	On time delivery of goods/services (U_2)	Average tax for the last 5 years (U_3)
1	DMU1	20.019797	18	1.5416921
2	DMU2	27.574532	33	1.0446022
3	DMU3	57.592552	68	0
4	DMU4	22.680886	56	0
5	DMU5	7.3176917	30	1.9869733
6	DMU6	73.119811	53	1.4457186
7	DMU7	19.381528	46	1.422853
8	DMU8	7.574532	15	1.5216064
9	DMU9	37.201082	43	1.503446
10	DMU10	49.743973	23	10.241643
11	DMU11	598.74397	31	60.996153
12	DMU12	41.186502	28	8.2373004
13	DMU13	3.9484053	20	0.7896811
14	DMU14	126.60897	39	2.8042586
15	DMU15	36.242573	59	1.2485147

Table 19 Ranking of DMUs by CCR, BCC-IO, BCC-OO and ADDITIVE methods

Companies	CCR	IO-BCC	OO-BCC	Additive
Company1	0.5438	0.9716	0.5519	0.4673
Company2	0.7107	0.9737	0.7127	0.3171
Company3	1	1	1	1
Company4	0.7959	0.8943	0.9501	0.7171
Company5	0.4447	0.659	0.5901	0.2276
Company6	0.7349	0.7537	0.8062	0.5486
Company7	1	1	1	1
Company8	0.3226	0.9697	0.3241	0.1173
Company9	1	1	1	1
Company10	1	1	1	1
Company11	1	1	1	1
Company12	1	1	1	1
Company13	0.3604	0.7857	0.4173	0.1759
Company14	0.7744	0.7858	0.7897	0.4234
Company15	1	1	1	1

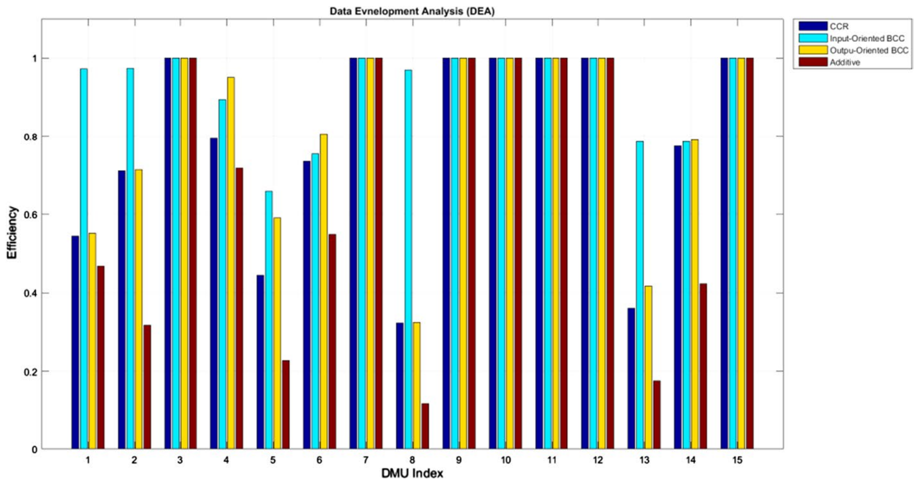


Fig. 4 Ranking of suppliers by traditional DEA method

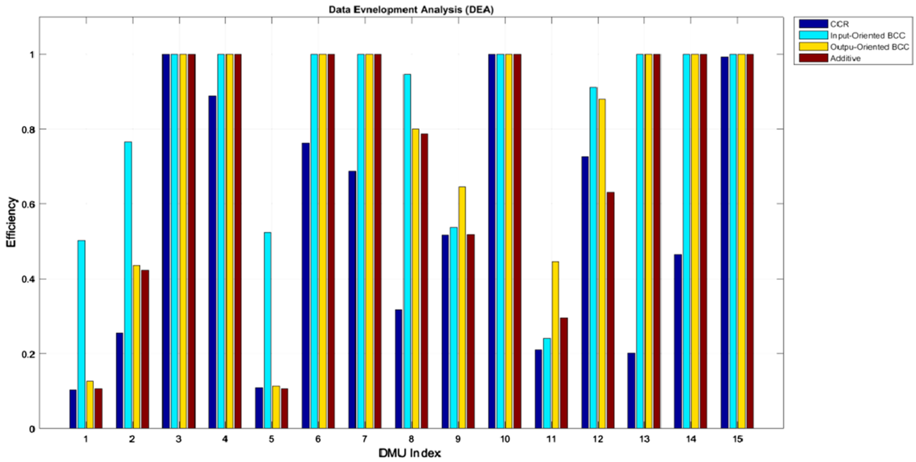


Fig. 5 Ranking of suppliers by the presented method

Fig. 6 Final ranking of efficient suppliers by output oriented AP model

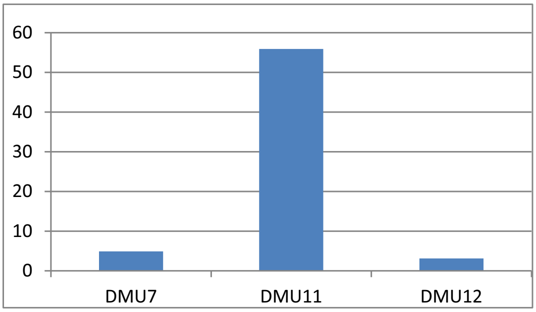
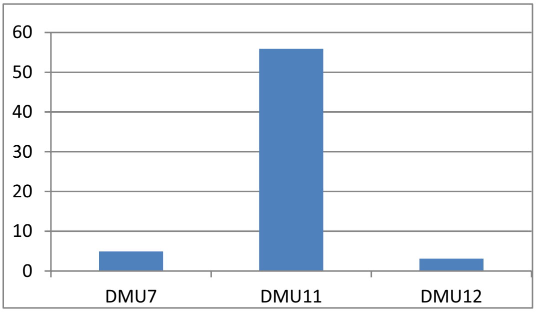


Fig. 7 Final ranking of efficient suppliers by AP-CCR model



Acknowledgements I would like to acknowledge Managing Director of Iranian – Gas Engineering & Development company, Technical and Commercial Working Group on Compressor Manufacturing of the National Oil Company, Secretary of Petroleum Standards Process Machines Group and National Standards Organization of Iran and Technical Inspection Unit of General Petroleum Equipment for their guidance in all stage of the study specially in implementing and testing the proposed model.

Data availability Data sharing not applicable to this article as no datasets were generated or analyzed during the current study.

References

Allen, R., Athanassopoulos, A., Dyson, R. G., & Thanassoulis, E. (1997). Weights restrictions and value judgments in DEA: Evolution, development and future directions. *Annals of Operation Research, 73*, 13–34.

Amindoust, A., Ahmed, Saghafinia, A., & Bahreininejad, A. (2012). Sustainable supplier selection: A ranking model based on fuzzy inference system. *Applied Soft Computing*, *12*, 1668–1677.

Amiri, M. P. (2010). Project selection for oil-fields development by using the AHP and fuzzy TOPSIS methods. *Expert Systems with Applications., 37*(9), 6218–6224.

Amorim, P., Curcio, E., Almada-Lobo, B., Barbosa-Póvoa, A. P., & Grossmann, I. E. (2016). Supplier selection in the processed food industry under uncertainty. *European Journal of Operational Research., 252*(3), 801–814.

Anderson, P., & Petersen, N. C. (1993). A procedure for ranking efficient units in data envelopment analysis. *Management Science*, *39*(10), 1261–1264.

Banker, R. D., Charnes. A., & Cooper, W. W. (1984). Some models for estimating technical and scale efficiencies in data envelopment analysis. *Management Science Sept*, *17*(25), 1078–1092.

Buyukozkan, G., & Cifci, G. (2012). A novel hybrid MCDM approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy TOPSIS to evaluate green suppliers. *Expert Systems with Applications*, *39*(3), 3000–3011.

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision making units. *European Journal of Operational Research, 2*(6), 429–444.

Chen, J. Y., & Baddam, S. R. (2015). The effect of unethical behavior and learning on strategic supplier selection. *International Journal of Production Economics, 167*, 74–87.

Chen, W., & Zou, Y. (2017). An integrated method for supplier selection from the perspective of risk aversion. *Applied Soft Computing, 54*, 449–455.

Cheng, C. H., & Lin, Y. (2002). Evaluating the best main battle tank using fuzzy decision theory with linguistic criteria evaluation. *European Journal of Operational Research, 142*, 174–186.

Cooper, W. W., Ruiz, J. L., & Sirvent, I. (2011). Choices and uses of DEA weights. In W. W. Cooper, L. W. Seiford, & J. Zhu (Eds.), *Handbook on data envelopment analysis* (pp. 93–126). Springer.

Fallahi, H., & Motadel, M. (2014). Quality level appraisal of machinery and related spare part's suppliers in Lavan oil refining company by Analytic Network Process method. In *International conference on management*. Iran: Tehran. https://civilica.com/doc/344239

Farrell, M. J. (1957). The measurement of productive efficiency. *Journal of the Royal Statistical Society. Series A (General)*, *121*, 231–253.

Gabus, A., & Fontela, E. (1972). *World problems, an invitation to further thought within the framework of DEMATEL*. Battelle Geneva Research Centre.

Gabus, A., & Fontela, E. (1973). *Perceptions of the world problematique: Communication procedure, communicating with those bearing collective responsibility*. Battelle Geneva Research Centre.

Heikkurinen, P., & Forsman-Hugg, S. (2011). Strategic corporate responsibility in the food chain. *Corporate Social Responsibility and Environmental Management*, *18*(5), 306–316.

Igoulalene, I., Benyoucef, L., & Tiwari, K. M. (2015). Novel fuzzy hybrid multi-criteria group decision making approaches for the strategic supplier selection problem. *Expert Systems with Applications, 42*(7), 3342–3356.

Jain, N., & Singh, A. R. (2020). Sustainable supplier selection under must-be criteria through Fuzzy inference system. *Journal of Cleaner Production*, *248*, 119275.

Kannan, D. (2018). Role of multiple stakeholders and the critical success factor theory for the sustainable supplier selection process. *International Journal of Production Economics, 195*, 391–418.

Manello, A., & Calabrese, G. (2019). The influence of reputation on supplier selection: An empirical study of the European automotive industry. *Journal of Purchasing and Supply Management, 25*(1), 69–77.
Masi, D., Micheli, G., & Cagno, E. (2013). A meta-model for choosing a supplier selection technique within an EPC company. *Journal of Purchasing & Supply Management*, *19*, 5–15.
Minouei, M., & Mohsenikabir, Z. (2017). Evaluation and prioritization of financiers of plans and projects of Iran gas engineering and development company. In *10th International conference on economics and management*. Iran: Rasht. https://civilica.com/doc/650458
Olanrewaju, A., Min, C. S., Sanmargaraja, S., & Ponniah, V. (2020). What is stopping the adoption of sustainable residential buildings in malaysia? In Z. Gou (Ed.), *Green building in developing countries. Green energy and technology*. Cham: Springer. https://doi.org/10.1007/978-3-030-24650-1_10
Partovi, F. Y. (2001). An analytic model to quantify strategic service vision. *International Journal of Service Industry Management, 12*(5), 476–499.
Podinovski, V. V. (1999). Side effects of absolute weight bounds in DEA models. *European Journal of Operational Research, 115*, 583–595.
Quezada, L., López-Ospina, H., Palominos, & Oddershede, A. (2018). Identifying causal relationships in strategy maps using ANP and DEMATEL. *Computers & Industrial Engineering, 118*, 70–79.
Rajabi, M. (2017). A customer based supplier selection process that combines quality function deployment, the analytic network process and a markov chain. *European Journal of Operational Research*, *263*, 1049–1062.
Razipour, S., Hosseinzadeh Lotfi, F., Jahanshahloo, G., Rostamy, M., & Sharafi, M. (2019). Finding closest target for bank branches in the presence of weight restrictions using data envelopment analysis. *Annals of Operations Research, 288*, 755–787.
Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw Hill.
Saaty, T., & Sodenkamp, M. (2008). Making decisions in hierarchic and network systems. *International Journal of Applied Decision Sciences*, *1*, 24–79.
Seuring, S., & Gold, S. (2013). Sustainability management beyond corporate boundaries: from stakeholders to performance. *Journal of Cleaner Production*, *56*, 1–6.
Seuring, S., & Muller, M. (2008). From a literature review to a conceptual framework for sustainable supply chain management. *Journal of Cleaner Production*, *16*(15), 1699–1710.
Stević, Ž., Vasiljević, M., Puška, A., Tanackov, I., Junevičius, R., & Vesković, S. (2019). Evaluation of suppliers under uncertainty: A multiphase approach based on fuzzy AHP and fuzzy EDAS. *Transport*, *34*(1), 52–66.
Thanassoulis, E. (1995). Assessing police forces in England and Wales using data envelopment analysis. *European Journal of Operational Research*, *87*, 641–657.
Thanassoulis, E., Portela, M. C., & Allen, R. (2004). Incorporating value judgments in DEA. In W. W. Cooper, L. M. Seiford, & J. Zhu (Eds.), *Handbook on data envelopment analysis. International series in operations research and management science* (2nd ed., Vol. 71, pp. 99–138). Norwell: Kluwer.
Vanteddu, G., Chinnam, R. B., & Gushikin, O. (2011). Supply chain focus dependent supplier selection problem. *International Journal of Production Economics, 129*(1), 204–216.
Varma, S., Wadhwa, S., & Deshmukh, S. G. (2008). Evaluating petroleum supply chain performance: Application of analytical hierarchy process to balanced scorecard. *Asia Pacific Journal of Marketing and Logistics*, *20*(3), 343–356.
Wood, D. A. (2016). Supplier selection for development of petroleum industry facilities, applying multi-criteria decision making techniques including fuzzy and intuitionistic fuzzy TOPSIS with flexible entropy weighting. *Journal of Natural Gas Science & Engineering*, *28*, 594–612.
Wu, C., & Barnes, D. (2016). An integrated model for green partner selection and supply chain construction. *Journal of Cleaner Production*, *112*, 2114–2132.
Yu, F., Yang, Y., & Chang, D. (2018). Carbon footprint based green supplier selection under dynamic environment. *Journal of Cleaner Production, 170*, 880–889.
Zhou, Q., Huang, W., & Zhang, Y. (2011). Identifying critical success factors in emergency management using a fuzzy DEMATEL method. *Safety Science, 49*, 243–252.