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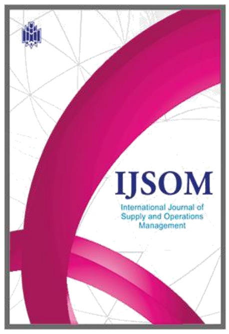

An Integrated Model of Fuzzy AHP/Fuzzy DEA for Measurement of Supplier Performance: A Case Study in Textile Sector

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Abstract

Competition between supply chains of businesses reveals the importance of supplier selection and performance evaluation when the current state of the international markets and the global economy are taken into consideration. As in many other sectors, it is also very important for companies in the textile sector to use their resources more efficiently and constantly evaluate their suppliers in order to compete with their competitors. In this study, the performance of 16 common fiber suppliers of five different companies that operate in one of subsector of textile sector namely the blanket sector has been measured and evaluated using fuzzy analytic hierarchy process (FAHP) and fuzzy data envelopment analysis (FDEA) methods. Criteria, which are weighted by FAHP method have been selected as the input and output variables to be used in FDEA. The fuzzy efficiency of supplier firms at different $\alpha -$cut levels has been measured by FDEA. Efficient and inefficient suppliers have been identified as a result of the efficiency measurement. Finally, a general discussion of the findings and directions for future research has been provided.

Keywords: Efficiency; Fuzzy AHP; Fuzzy DEA; Logistics; Supply Chain; Textile.

1. Introduction

There is a close competition between supply chains of businesses when the current state of the technological developments and the global economy are taken into consideration. It is possible to say that supply chain performance (SCP) has a direct impact on business success, depending on the competitions that are experienced. Supply chain management (SCM) provides sustainable competitive advantage to businesses in international markets and gains such as productivity and cost reduction (Fawcett et al., 2008; Tan et al., 1998). SCP evaluation has an important place in the literature of SCM (Jakhar & Barua 2014). Unnecessary resource use of businesses is reduced due to a good SCM and this resource saving can be directed towards investments in different areas where higher efficiency can be obtained (Gorcun 2013). The purpose of SCM is to achieve the level of product and service provided to the customer by using the least amount of resource and make strategic, tactical and operational decisions to optimize SCP (Cooper et al., 1997; Fox et al., 2000). Supplier selection is one of the most important decisions to be made for protecting long-term strategies of businesses. The main target of the supplier selection is to buy the product of right quality and quantity from the right resource at the reasonable price, at the right time (Bayhan 2011; Arıkan and Kucukce 2012; Zouggari and Benyoucef 2012). From this point of view, it can be said that supplier selection and performance evaluation are very important for all sectors. As a result of careful literature review, it is clear that the performance evaluation of SCM has become an increasingly popular multi-criteria decision making problem. It is argued that multi-criteria decision-making problems in terms of optimal decision making in both manufacturing and service sectors cannot be evaluated to a single criterion. For this reason, multi-criteria decision-making problems have been used for measurement and evaluation of efficiency in many studies (Jakhar & Barua 2014). AHP is a widely used method for multi-criteria analysis used in many decision making problems (Romeijn et al. 2016). AHP is also applied with other multi-criteria decision-making methods.

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AHP is an useful method based on mathematical and psychological basis to analyze complex decisions (Petrini et al., 2016). FAHP is a suitable method for solving problems of multi-criteria performance measurement and evaluation (Wichapa & Khokhajaikiat, 2017).

Efficiency which is an important aspect of the performance is a concept of how resources are used and usage rate. Data Envelopment Analysis (DEA) is a non-parametric method widely used for efficiency measurement (Dogan & Ersoy 2017). One of the most important reasons for the widespread use of DEA is that it allows analysis in multiple input and output environments (Charles & Kumar, 2012). DEA is a method developed to measure the relative efficiency of businesses called decision-making units that produce products or services (Fanchon 2003). Classic DEA models can only be applied in cases where input and output variables are certainly known. FDEA models are used for measurement of relative efficiency when the data are uncertain (Oruc & Gungor 2010).

The textile industry is a labour-intensive industry where competition is increasing day by day and waste of resources is too much. Companies in the textile industry need to use their resources more effectively and to continuously evaluate the performance of their supplier to achieve a sustainable competitive advantage in global markets and to be able to continue their existence. For this reason, a model in which FAHP and FDEA methods are used together for an optimal measurement of SCM in blanket sector is proposed. In this study, the performance of 16 common fiber suppliers of five different companies are located in Usak province and operate in one of subsector of textile sector namely the blanket sector, have been measured and evaluated using FAHP and FDEA methods. Firstly, a comprehensive literature review has been carried out to determine the criteria to be used in evaluating the performances of the suppliers. A 7-point Likert-type scale consisting of 26 items has been applied to purchasing experts of five different companies in order to determine the importance level of supplier selection criteria within the scope of FAHP application. The weights of the criteria which are in the top eight of the importance level ranking list have been calculated using FAHP method. Criteria which are weighted by FAHP method have been selected as the input and output variables to be used in FDEA. The efficiency of the suppliers at different $\alpha -$cut levels have been measured and ranked using FDEA model with three inputs and five output variables. When the literature is reviewed, no other study comparing different FDEA models and FAHP and FDEA methods used together in the blanket sector has been found.

When the study is evaluated from this point of view, the findings of the study can provide useful and important results for researchers, firms that are in supplier position and companies that are in the purchasing position. The rest of this paper is organized as follows. Section 2 presents a review of literature in supplier selection and evaluation. FAHP and FDEA methods are provided in Section 3. Section 4 provides the evaluation results of the application. Finally, in Section 5, concluding remarks and suggests directions for future research are provided.

2. Literature review

This section is divided into two sections, (i) supplier evaluation criteria and (ii) supplier evaluation methods, to provide a comprehensive overview of the current literature.

2.1. Supplier evaluation criteria

One of the earliest studies on supplier selection was conducted by Dickson (1966), in 1966, with 273 purchasing managers and a questionnaire survey. Dickson has put forward important ideas on supplier selection and has prepared a list of 23 criteria for supplier selection. Dempsey (1978) identified eight key criteria for supplier selection or supplier evaluation. Those criteria are delivery, quality, price, capacity, supplier performance history, communication system, geographical location, and service. Weber et al., (1991) examined a large number of studies on supplier selection and performance measurement, and found that the most used criteria for supplier selection was the price, followed by delivery and quality. In addition to these criteria, product capacity and localization were found to be important in supplier selection. Vokurga et al., (1996) used some of Dickson's criteria for supplier selection in their study and emphasized that the reliability of the supplier company, future production capabilities and development gap of the supplier company criteria were important. Ghodsypour and O'Brien (1998) used some of Dickson's criteria for supplier selection, and such as the ability to respond to changes of supplier and process flexibility of supplier criteria. Humphreys et al., (2001) concluded that in addition to the general criteria accepted in the literature for supplier selection in the study they conducted, the design capacity, problem-solving capacity and environmental awareness criteria became increasingly important. Tam and Tummala (2001) utilized the quality of the support services of the supplier company, openness to technology development, problem-solving capacity and quality system criteria in addition to some of Dickson's criteria for supplier selection in their study. Cheraghi et al., (2004) concluded that in the study they carried out, reliability, flexibility, consistency and long-term relationships criteria in supplier selection gain importance, and guarantee & policies, past performance, willingness for business continuity and educational supports criteria from Dickson's criteria lost importance.

When the literature is examined, it can be seen that price, quality and delivery criteria are considered the main criteria in the evaluation or selection of suppliers. In addition, flexibility, after-sales service and customer satisfaction criteria are widely used in evaluating suppliers (Akman & Alkan 2006). Ha, and Krishnan (2008) used new criteria such as ecommerce capability, eco-friendly products, just-in-time capability, product view, catalogue technology, the response to customer request, continuity and after-sales service technology in addition to Dickson's criteria for supplier selection in their study. Yildiz (2013) studied 89 different studies related to supplier selection criteria in the production, health, electricity-electronics, furniture and white goods, textile, agriculture, construction, automotive, transportation-logistics food and information sectors and as supplier selection criteria in the textile sector; quality, cost and delivery criteria are the most important criteria. Patil (2014) studied 27 different researchers between 1966 and 2012. In this study, 48 different supplier selection criteria were found in the literature. It is possible to see that the priorities of Dickson's 23 criteria have changed and that new criteria have been added depending on sector and market conditions in studies the researchers have made (Ordoobadi 2009; Sydani et al.,2011; Tezsurucu 2013; Tayyar and Arslan 2013; Shiraz 2014). The particular criteria used in supplier selection and the application areas of the textile and apparel sector are summarized in Table 1.

2.2. Supplier evaluation methods

Supplier performance management is a field where mathematical models such as linear and mixed integer programming are used (Baskaran et al., 2012; Marbini et al., 2017). There are many methods in the literature to evaluate supplier performance (Kuo et al., 2010). In recent years, many methods such as mathematical programming techniques and Multi Criteria Decision Making (MCDM) have been proposed to MCDM problems (Ho et al., 2010; Govindan et al., 2015; Wichapa & Khokhajaikiat 2017; Simic et al., 2017). The AHP method, which is easy to implement, is widely used for the solution of the MCDM problems. Some researcher have used AHP method alone or combination in other methods to solve MCDM problems because of the complexity of the decision making environment and the uncertainty of each problem (Wichapa & Khokhajaikiat 2017; Ho & Ma 2018). In the literature, there are various multi-criteria decision making methods used in supplier selection in different fields and their fuzzy versions. In the same way, DEA and FDEA are the methods that are used on this issue. Some studies using these methods in the literature are included in the following paragraphs.

It is possible to find out many studies in which the suppliers are evaluated using the AHP method. Tam, and Tummala (2001) in a telecommunication company, Muralihadran et al., (2002) in a bicycle manufacturing company, Kahraman et al., (2003) in a company operating in the production of white goods in Turkey, Liu, and Hai (2005) in a company operating in furniture-white goods sector, Hou and Su (2006) in a company operating in the electronics sector, Tahriri et al. (2008) in a company operation in the steel production in Malaysia, Bronja (2011) in a company that manufactures mechanical fittings for automotives, Cetin and Onder (2015) in a company producing automotive spare parts have used AHP method for supplier selection problem. It is possible to come across many studies in which suppliers are evaluated using the FAHP method in combination with other methods. In Haq and Kannan (2006) an integrated AHP and FAHP model, Ozturk et al., (2008) an integrated FAHP and Fuzzy TOPSIS(FTOPSIS) model, Zeydan et al., (2011) an integrated FAHP, FTOPSIS and DEA model, Zouggari and Benyoucef (2012) an integrated FAHP and FTOPSIS model, Tayyar (2012) an integrated FAHP and FTOPSIS model, Jonavic and Delibasic (2014) an integrated Quality Function Deployment (QFD) and FAHP model, Sultana et al., (2015) an integrated fuzzy DELPHI, FAHP and FTOPSIS model, Kumar et al., (2015) and integrated FAHP and DEA model, Stevic et al., (2016) an integrated FAHP and TOPSIS model, Awasthi et al., (2018) an integrated FAHP and VIKOR model have been used for supplier selection problem.

It is possible to find out in many studies that DEA and FDEA methods in combination with other methods have been used for supplier selection and evaluation of supplier performance. In Weber et al., (2000) an integrated Multi-Purpose Programming (MPP) Method and DEA model, Seydel (2005) an integrated SMART method and DEA model, Zhenhua (2009) an integrated AHP and DEA model, Kuo et al., (2010) an integrated FAHP and FDEA model, Raut (2011) an integrated AHP an DEA model, Shiraz (2014) an integrated FTOPSIS and FDEA model, Kumar et al., (2015) an integrated FAHP and DEA model, Alikhani et al., (2019) an integrated Fuzzy VIKOR and DEA model have been used for supplier selection and evaluation of supplier performance.

As in many other sectors, there are great many studies in the textile sector that have been carried on supplier selection and evaluation of supplier performance. Kahraman et al., (2004) have used FAHP in a company operating in the textile sector in Turkey, Ozturk et al., (2011) have used AHP in a textile company in Turkey, Chen (2011) have used an integrated SWOT analysis, DEA and TOPSIS model in a company operating in the textile sector in Taiwan, Gules et al., 2014) have used AHP in a company that produces apparel products in textile sector in Turkey for supplier selection and evaluation of supplier performance. Other studies in the textile sector on supplier selection and evaluation of supplier performance can be seen in Table 1.

3. Methodology

In this section of the study, an application has been carried out in 5 companies operating in the blanket sector for supplier selection and evaluation of supplier performance. Models used in this study have been identified as a result of a comprehensive literature review. The hierarchical structure of the study consists of three parts where the performance evaluations of the suppliers made can be seen in Figure 1.

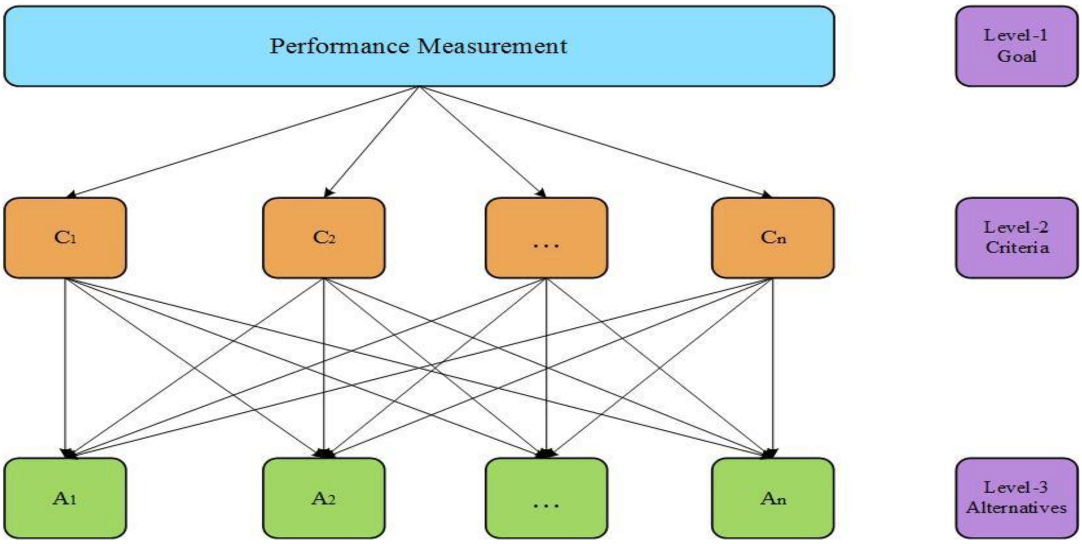

Figure1. Hierarchical structure for supplier performance measurement
(Source: Jakhar and Barua 2014; Cakir 2016; Wichapa and Khokhajaikiat. 2017)

In the first part of the hierarchical structure of this study, a 7-point Likert-type scale consisting of 26 criteria has been applied to purchasing experts of five different companies in order to determine the importance level of supplier selection criteria to be used in the application of FAHP. In the second part, the FAHP method has been applied to determine the weights of the criteria to be used in evaluating the performances of the suppliers. In the third part, the performances of suppliers have been evaluated with FDEA using criteria weights calculated with FAHP. The first 8 criteria in the ranking of importance levels have been compared by the purchasing specialist of 5 different firms according to the FAHP scale in Table 2 and the weights of the criteria have been determined. The weights of criteria obtained by FAHP will express the weights of input and output variables in FDEA.

In this study, each supplier has been evaluated by experts according to criteria to obtain data on input and output variables to be used in FDEA. These data have been multiplied by the weights of criteria obtained from the FAHP, and the criteria weights of input and output variables have been calculated for FDEA application. The collected data for input and output variables have been taken into FDEA and the performances of the suppliers have been measured. A total of 8 variables for 16 suppliers have been used to meet the restriction of the decision making unit (DMU) of the DEA. The efficiency ranking has been done according to the measurement of performance results of 16 fiber supplier companies. Efficient and inefficient suppliers have been identified as a result of the ranking. Steps of the research process can be seen in Figure 2.

3.1. Determination of supplier evaluation criteria

The supplier selection criteria that are in the 7-point Likert-type scale have been determined as a result of the literature review. Cost, price, quality, flexibility, delivery reliability, experience, reputation of the company, technology, continuous improvement program, geographical location, production capacity, technical capacity, inventory availability, customer service, reliability, guarantee policies, corporation, problem solving ability, financial situation, environmental management system, organizational management system, product range, logistics status, standards and certifications, after-sales service, compliance with the law, pollution rate of the raw material and specification of the raw material criteria have been determined as supplier selection criteria. Supplier selection is one of the most important decisions that must be made for businesses that are in the textile sector as well as in other sectors. Some criteria specific to the textile sector in supplier selection and the importance of these criteria in terms of the textile sector have been given in the following paragraphs.

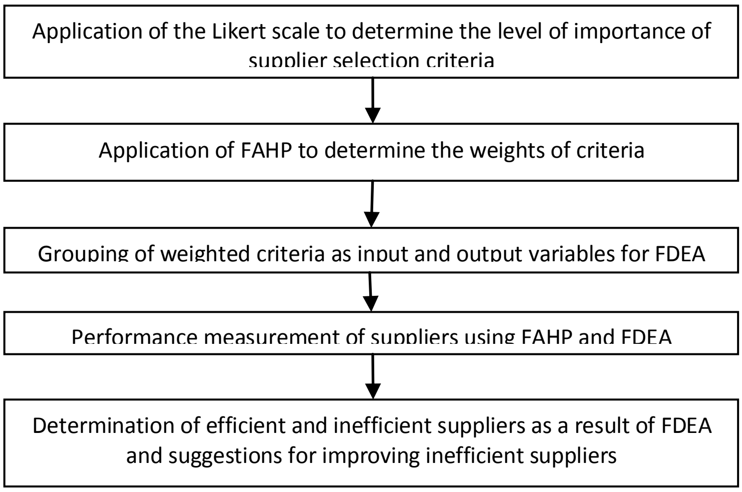

Figure2. Steps of the research process

Hazards from dust affect the defence system of the lungs. Dust accumulates in the lung for a long time and causes the lung disease known as pneumoconiosis. Dust in textile firms where ginning, recycled fiber (blanket, fabric, yarn etc.) yarn, apparels, woven and denim grinding are produced have negative effects (loss of performance at work and risk of accidents due to carelessness etc.) on the employees for a short period of time. In the long term, it causes the occupational disease, which is very common in the textile sector called byssinosis. The density of the dust in the environment, the production methods and the exposure times affect the frequency of appearance of byssinosis. One of the most important precautions to be taken is that these dusts are absorbed and removed from their source (Bakırcı & Tumerdem 2002; Mezarcioz & Ogulata 2014). Debris, dusts and foreign materials in cotton fibers have a significant negative impact on machine efficiency and yarn quality during yarn production in the open-end yarn production system (Ersoy 2014). Therefore, it is important for the supplier firm and the company to cooperate which makes foreign pollutants such as leaves, dust, sand and metal fragments causing pollution in the raw material removed from the raw material (minimization of the pollution rate) before the raw material is delivered to the supplier. Negative impacts of the pollution on businesses; the pollution-related occupational diseases cause high compensation for the employers, loss of skilled workers, damage to machinery and equipment, the decrease of product quality, the decrease of efficiency in the business and so on. Because of these reasons, it is essential to evaluate pollution rate of the raw material as a criteria in supplier selection.

According to Ozdemir and Gurcan (2013), it has been determined that composition of the raw material (the fiber blend ratio and properties of the fiber) significantly influences the physical properties of the yarn in 100 % yarns of wool carpet. In addition, it has been found that the physical properties of the yarn obtained from the quality fibers are better and the specific tensile strength of the yarns composed of fine fibers high. According to Oguz and Dayık (2014), it has been found that the yarn strength increases with the increase in fiber length and increase in yarn strength has a positive effect on yarn quality. According to Ersoy's (2014) research, it has been found that composition of the raw material has a direct effect on the yarn quality parameters. Additionally, the strength, elongation and Uster values of the yarn obtained from the mixture of 80% cotton and 20% polyester fibers have been determined to be better than yarns obtained from the mixture of 91% cotton and 9% polyester fibers.

The producer companies need to increase their responsibilities towards the environment for ensuring environmental integrity and sustainability in textile and apparel sector. Manufacturer companies need to use raw materials that are not harmful to nature, do not threaten bio-diversity, and are produced in a non-toxic sustainable way or recycled (Eser et al., 2016). According to Ersoy and Senol (2017), it has been pointed out that yarn producers, blanket producers, and other producers in the textile sector use products from recycled fibers because of problems such as resources used being limited in nature, increased awareness of the environment worldwide, the continuing rapid consumption of natural resources, and economic problems. Textile producers have emphasized the importance of producing raw materials from recycling to ensure that nature remains clean and resources are protected. In addition, it has been proposed that the production from recycling raw material in the future will have an important place. Furthermore, the raw material used also affects the operating efficiency. For these reasons, it is critical to evaluate the specification of the raw material as a criterion in supplier selection. Two different criteria not included in the literature and used in evaluating suppliers in the textile sector have been included in this study. This is because the firms in the sector have to specify that specifications of the raw material and pollution rate of the raw material criteria are determining factors in evaluating the suppliers in the textile sector.

3.2. Fuzzy AHP

There are many methods developed for the solution of the MCDM problems (Wichapa & Khokhajaikiat 2017; Zarghami et al., 2018). Some of these methods are Analytic Hierarchy Process (AHP) (Azimifard et al., 2018), Analytic Network Process (ANN) (Govindan et al., 2015), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

(Bianchini, 2018), Elimination and Choice Translating Reality (ELECTRE) (Eren & Ozder, 2016), Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) (Arıkan & Kucukce, 2012) and VlsKriterijumska Optimizacija I Kompromisno Resenje (VIKOR) (Awasthi et al., 2018) methods.

The AHP method, which is easy to implement for the solution of the MCDM problems, is widely used. Fuzzy logic, which was first introduced by Zadeh in 1965, is used for the control of complex processes and information in cases where uncertain. FAHP has been introduced by combining fuzzy logic and AHP because of the AHP is not fully suitable for decision making in case of uncertainty. FAHP is a method that facilitates decision making (Yacan, 2016; Wichapa & Khokhajaikiat 2017).

The triangular fuzzy numbers are used in studies of FAHP. The fuzzy triangular numbers are shown as (*l / m, m / u*) or (*1, m, u*). For a fuzzy case, *l*; the smallest possible value, m; the largest value that can be taken and u; the widest possible value represents (Başlıgil 2005). The linear representations of each triangular number can be defined as the left and right sides with the membership function in equation (1) (Kahraman et al., 2004; Ayag 2005).

$$\mu(x/\tilde{M}) = \begin{cases} 0, & x < 1, \\ (x-l)/(m-l), & l \le x \le m, \\ (u-x)/(u-m), & m \le x \le u, \\ 0, & x > u, \end{cases} \tag{1}$$

The first FAHP study was conducted by Van Laarhoven and Pedrycz (1983) with a comparison of fuzzy rates defined by triangular membership functions (Kahraman et al., 2004). In addition, different FAHP methods such as Buckley's FAHP method (Buckley 1985), Chang's Extended Analysis method (Chang 1996), Enea and Piazza's FAHP methods (Enea and Piazza 2004) and Ayag's FAHP (Ayag 2005) method are available in the literature. One of the most commonly used models in the literature is Chang's Expanded Analysis Method (Kahraman et al., 2015; Zarghami et al., 2018). There are different fuzzy AHP scales using triangular fuzzy numbers in FAHP applications in the literature (Chang, 1996; Kahraman et al., 2004; Do and Chen, 2014; Eskandari, 2017; Groselj and Stirn, 2017; Santis et al.,, 2017; Awasthi et al.,, 2018). In this study, the FAHP scale in Table 2 has been used in the binary comparisons of the criteria to determine the weight of each criterion. After the criteria to be used in the FAHP application have been determined, the steps of FAHP application have been applied to the extended analysis method of Chang (1996) as follows (Chang, 1992; Chang, 1996; Kahraman et al., 2004; Baslıgil 2005; Zarghami et al., 2018).

Let $X_n = (1, 2, ...,n)$ be an object set, and $U_m = (1, 2, ...,m)$ be a goal set. According to the extended analysis method of Chang, each object is taken and applied extended analysis for each goal, respectively. Hence, m extent analysis values are made for each subject, with the following symbols:

$$M_{gi}^1, M_{gi}^2, ..., M_{gi}^m, \quad i = 1, 2, ..., n \tag{2}$$

All these $M_{gi}^j (j = 1, 2, ..., m)$ are triangular fuzzy numbers.

Step 1: According to the *i*th object, the value of fuzzy synthetic extent is defined in equation (3) as follows:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \tag{3}$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$, fuzzy sum of synthetic extent value of *m* is applied as in equation (4).

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \tag{4}$$

To obtain $\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, fuzzy sum of $M_{gi}^j (j = 1, 2, ..., m)$ is applied as in equation (5).

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \tag{5}$$

and then compute the inverse of the vector as in equation (6).

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (6)$$

Step 2: The degree possibility for $M_2 = (l_2, m_2, u_2) \geq M_1 = (l_1, m_1, u_1)$ is defined as

$$V(M_2 \geq M_1) = \sup_{y \geq x} \left\lfloor \min(\mu_{M1}(x), \mu_{M2}(y)) \right\rfloor \quad (7)$$

and can be equivalently shown as in equation (8):

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) = \begin{cases} 1, & if, m_2 \geq m_1 \\ 0, & if, l_1 \geq u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (8)$$

Where *d* is the ordinate of the highest intersection point *D* between μ_{M1} and μ_{M2}.

To compare M_1 and M_2, we need both the values of $V(M_1 \geq M_2)$ and $V(M_2 \geq M_1)$.

Step 3: The degree possibility for a convex fuzzy number to be greater than k convex fuzzy numbers $M_i (i = 1, 2, ..., k)$ can be defined by

$$\begin{aligned} &V(M \geq M_1, M_2, ..., M_k) = V\left[(M \geq M_1) and (M \geq M_2) and ....and (M \geq M_k)\right] \\ &\min V(M \geq M_i), \quad i = 1, 2, 3, ..., k. \end{aligned} \quad (9)$$

Assume that $d'(A_i) = \min V(S_i \geq S_k)$ (10)

For $k = 1, 2, 3, ...n, \quad k \neq i$. Then the weight vector is given by $W' = (d'(A_1), d'(A_2'), ..., d'(A_n))^T$ (11)

Where $A_i (i = 1, 2, ..., n)$ are *n* elements.

Step 4: Via normalization, the normalized weight vectors are $W = (d(A_1), d(A_2), ..., d(A_n))^T$ (12)

Where *W* is a non-fuzzy number.

3.2.1. Validation of Results

Binary comparisons in the AHP method involve subjective perceptions of decision makers. There is a need to consider the Consistency Index (*CI*) and Consistency Ratio (*CR*) to ensure the consistency and relative weights of these perceptions. The largest value $(\lambda_{\max})$ must be equal to the matrix size (*n*) in order for a comparison matrix to be consistent. *CI* is calculated through equation (13) and *CR* is calculated through equation (14). *RI* is the Random Consistency Index value and takes the values in Table 4 according to the number of different elements. The acceptable upper limit for comparison is 0.10. Decision makers are asked to re-evaluate cases where the *CR* is greater than 0.10 (Iwaro et al., 2014; Cakır 2016; Oral 2016; Zarghami et al., 2018).

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (13)$$

$$CR = \frac{CI}{RI} \quad (14)$$

In order to calculate the Consistency Rate in this study, the experts compared the determined criteria according to the scale developed by Saaty (1990) and shown in Table 3.

3.3. Fuzzy DEA

DEA is a linear programming based nonparametric method developed to measure the relative activities of systems that produce goods or services called decision making units (DMUs) (Fanchon 2003; Yıldırım and Onder 2015). The basics of DEA are based on Farrell's study named "The Measurement of Productive Efficiency" in which description of technical efficiency and price efficiency in 1957 (Farrell 1957). Charnes Cooper and Rhodes (1978) have contributed DEA to the literature with the article entitled "Measuring the Efficiency of Decision Making Units"(Charnes et al., 1978). The CCR model based on the constant return to scale, which is the first DEA model named by the initials of the names of these authors, measurers total efficiency. Banker, Charnes and Cooper (1984) developed a BCC model based on the variable return to scale (Banker 1984; Banker et al., 1984; Cook and Seiford 2009). The DEA methodology is applied in fields of education, marketing, production, economy, health, insurance, information technology and many other fields. The main reason for the widespread use of DEA is to enable analysis in multiple input and multiple output environments (Charles & Kumar 2012).

The underlying assumption of the DEA is based on the principle that all data have specific numerical values. But in real life, some applications may not be accurate. Classic DEA models can only be applied in cases where input-output variables are clearly known. Fuzzy DEA models have been developed so that efficiency measurement can be performed when the data are uncertain (Oruc & Gungor 2010). Sengupta (1992) included for the first time fuzzy theory into DEA with the study where performance measurement was made using random observations in 1992.
Some researchers have used fuzzy theory to measure and evaluate the performance (Oruc & Gungor 2010; Wang & Chin 2011; Marbini et al., 2011; Shiraz 2014). Some of the fuzzy DEA models have been developed using fuzzy theory in the literature; Cook et al., (1996), Cooper et al., (1999), Kao and Liu (2000), Guo and Tanaka (2001), Despotis and Smirlis (2002), Saati et al., (2002), Lertworasirikul et al., (2003), Leon et al., (2003), Saati and Memariani (2005), Wang et al., (2005) and Wang-Chin (2011) models. There are 6 different approaches in the literature to solve the Fuzzy DEA model. These approaches are the tolerance approach, the $\alpha-$level based approach, the fuzzy ranking approach, the possibility approach, the fuzzy arithmetic, and the fuzzy random/type-2 fuzzy set. The $\alpha-$level based approach is one of the approaches widely used in the literature (Marbini et al., 2011; Emrouznejad and Tavana 2014; Wanke et al., 2016; Marbini et al., 2017).

In fuzzy DEA application section of the study, we aimed to measure the fuzzy efficiency of 16 companies operating in the fiber sector in Turkey for different $\alpha-$level ($\alpha = 0, 0.25, 0.5, 0.75, 1$). For this purpose, Saati-Memariani-Jahanshahloo (2002) and Lertworasirikul-Fang-Joines-Nuttle (2003) models, which are widely used in the literature (Marbini et al., 2011; Marbini et al., 2012; Chang and Lee 2012; Emrouznejad and Tavana 2014), have been used. The fuzzy CCR model based on the cut-level approach proposed by Saati, Memariani, and Jahanshahloo (2002) is as follows:

$$
\begin{aligned}
& E_z = \max \sum_{r=1}^{s} \bar{y}_{rz} \\
& \text{s.t}: \quad \sum_{i=1}^{m} \bar{x}_{iz} = 1 \\
& \sum_{r=1}^{s} \bar{y}_{rj} - \sum_{i=1}^{m} \bar{x}_{ij} \le 0 \quad \forall j \\
& v_i(ax_{ij}^{m} + (1-a)x_{ij}^{l}) \le \bar{x}_{ij} \le v_i(ax_{ij}^{m} + (1-a)x_{ij}^{u}) \quad \forall i,\ j \\
& u_r(ay_{rj}^{m} + (1-a)y_{rj}^{l}) \le \bar{y}_{rj} \le u_r(ay_{rj}^{m} + (1-a)y_{rj}^{u}) \quad \forall r,\ j \\
& u_r, v_i \ge 0 \quad \forall i,\ r
\end{aligned}
\tag{15}
$$

Where $\bar{x}_{ij} = (x_{ij}^{l}, x_{ij}^{m}, x_{ij}^{u})$ and $\bar{y}_{ij} = (y_{rj}^{l}, y_{rj}^{m}, y_{rj}^{u})$ are triangular fuzzy inputs and triangular fuzzy outputs. This model is equivalent to a parametric programming, while $\alpha \in (0, 1]$ is a parameter. It is noted that for each α we have an optimal solution. Thus, we can provide the decision maker a solution table with different α in (0, 1].
The fuzzy model based on the cut-level approach proposed by Lertworasirikul et al., (2003) is as follows:

$$
\begin{aligned}
& \left(\tilde{E}_o\right) = \max_{u,v,\bar{f}} \bar{f} \\
& \text{s.t}: \quad (1-\beta)\sum_{r=1}^{s} (u_r \tilde{y}_{ro})_0^U + \beta \sum_{r=1}^{s} (u_r \tilde{y}_{ro})_1^U \ge \tilde{f} \\
& (1-\alpha_0)\sum_{i}^{m} (v_i \tilde{x}_{io})_0^U + \alpha \sum_{i=1}^{m} (v_i \tilde{x}_{io})_1^U \ge 1 \\
& (1-\alpha_0)\sum_{i}^{m} (v_i \tilde{x}_{io})_0^L + \alpha \sum_{i=1}^{m} (v_i \tilde{x}_{io})_1^L \le 1 \\
& (1-\alpha)\left[\sum_{r=1}^{s} u_r (\tilde{Y}_{rj})_0^L - \sum_{r=1}^{s} u_r (\tilde{X})_0^L\right] + \alpha \left[\sum_{r=1}^{s} u_r (\tilde{Y}_{rj})_1^L - \sum_{i=1}^{m} v_i (\tilde{X}_{ij})_1^L\right] \le 0 \quad j = 1, 2, \ldots, n \\
& u_r, v_i \ge 0 \quad r = 1, 2, \ldots, s \quad i = 1, 2, \ldots, m \\
& \beta, \alpha_o, \alpha \in [0, 1]
\end{aligned}
\tag{16}
$$

$\bar{f} \geq 1$, the relevant decision-making unit is efficient, it is not efficient in other cases.

4. Empirical Illustration

Fuzzy AHP and fuzzy DEA methods have been used together to measure and evaluate the performance of suppliers in the research. Weights of 8 criteria have been calculated by fuzzy AHP method and the performances of 16 suppliers have been evaluated with fuzzy DEA methods.

4.1. Determination of Supplier Evaluation Indicators

A total of 26 criteria have been evaluated by expert of 5 different firms using a 7-point Likert type scale (1- very low, 2- low, 3- medium low, 4- middle, 5- medium high, 6- high, 7- very high) in order to determine the importance level of the criteria to be used in the supplier selection. The price, quality, pollution rate of the raw material, specification of the raw material, reliability, delivery, inventory availability and flexibility have been determined the first 8 criteria in the order of the importance level of the criteria. These 8 criteria will be used in fuzzy AHP approach.

4.2. Fuzzy AHP Approach

There are different criteria used in literature regarding supplier selection and evaluation. Two different criteria not included in the literature and used in evaluating suppliers in the textile sector have been included in this study. Fuzzy AHP has been applied to determine the weights of the criteria.

4.2.1. Calculation of The Relative Weightage of Decisions Levels with Respect to Each Criteria

Binary comparison matrices have been created based on the fuzzy AHP scale data given in Table 2, where each expert evaluated the selection criteria. Using the equation (3) for each criteria according to expert 1, the synthesis values have been calculated as follows:

$$S_1 = (5.64,\ 6.90,\ 8.66) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.06,\ 0.09,\ 0.14)$$
$$S_2 = (12.26,\ 15.46,\ 18.64) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.13,\ 0.20,\ 0.30)$$
$$S_3 = (7.28,\ 8.89,\ 10.77) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.08,\ 0.12,\ 0.18)$$
$$S_4 = (10.30,\ 12.92,\ 15.68) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.11,\ 0.17,\ 0.26)$$
$$S_5 = (4.84,\ 5.79,\ 7.21) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.05,\ 0.08,\ 0.12)$$
$$S_6 = (4.13,\ 4.84,\ 6.01) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.04,\ 0.06,\ 0.10)$$
$$S_7 = (6.74,\ 8.60,\ 10.73) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.07,\ 0.11,\ 0.18)$$
$$S_8 = (10.06,\ 12.87,\ 15.78) \otimes (1/93.48,\ 1/76.27,\ 1/61.25) = (0.11,\ 0.17,\ 0.26)$$

Based on the opinion of 5 experts, the average of the weights of the criteria has been taken and Table 5 has been formed. These criteria weights will be used as data in fuzzy DEA.

Table5. Arithmetic Mean of the Weights of The Criteria.

Criteria	Weight
Price	**0.036**
Quality	**0.302**
Delivery	**0.095**
Reliability	**0.226**
Inventory availability	**0.018**
Flexibility	**0.004**
Pollution rate of the raw material	**0.086**
Specification of the raw material	**0.233**

4.2.2. Check for CR values

Experts of five different firms have compared the identified criteria according to the scale developed by Saaty (1990) which can be seen in Table 3. Geometric averages of comparisons have been taken, using Equations (13) and (14), the Consistency Ratio has been calculated as follows:

$$CI = \frac{\lambda_{\max} - n}{n-1} = \frac{8.380-8}{8-1} = \frac{0.380}{7} = 0.054$$

$$CR = \frac{CI}{RI} = \frac{0.054}{1.40} = 0.039$$

If the Consistency Ratio is less than 0.10, it means that the results obtained are within acceptable limits.

4.3. Fuzzy DEA Approach

In the literature, price, quality and delivery criteria in some studies were used as output variables in DEA method for selecting and evaluating suppliers (Talluri and Narasimhan 2004; Ramanathan 2007; Tezsurucu 2013; Shiraz 2014; Radfar and Salahi 2014; Dotoli et al., 2016). Opinions of experts for supplier selection criteria; "quality", "price" and "delivery" were very important and should be used in the process of supplier selection and evaluation. For this reason, the criteria of "quality", "price" and "delivery" have been defined as output variables in fuzzy DEA. The criteria of "reliability", "inventory availability", "flexibility", " pollution rate of the raw material " and " specification of the raw material " in Table 5 have been defined as input variables to be used in fuzzy DEA. In the fuzzy DEA approach of the study, it was aimed to measure fuzzy efficiency of 16 companies operating in fiber sector in Turkey at different $\alpha-$cut levels. LINGO 17.0 package program has been used for the measurement of the efficiency.

4.3.1. The Step of Generating of the Data Set

In the literature, it is possible to come across different linguistic evaluation scales in which the triangular fuzzy numbers are used for fuzzy DEA applications (Loron et al., 2015; Hemmati et al., 2016; Tavakoli, et al., 2017; Dursun et al., 2017). At this stage of the Fuzzy DEA application, 16 different suppliers have been evaluated according to the linguistic evaluation scale (very low, low, medium low, high and very high), which has been calculated using the fuzzy triangular numbers as can be seen in Table 6. The same suppliers have been evaluated by experts according to 8 criteria and data related to the input and output variables to be used in fuzzy DEA have been obtained. The arithmetic averages of these obtained input and output data have been multiplied by the average of the weights of criteria obtained from the fuzzy AHP results in Table 5 for the relevant criteria and the final data (weighted data) have been obtained for fuzzy DEA application.

4.3.2. Implementation of Fuzzy DEA Models

The results of the fuzzy DEA application models in which the arithmetic averages have been treated as a data set and the LINGO program has been used are given in Table 7 and Table 8. Score of efficiency (ES), ranking of the efficiency (R) and decision-making units (T1, T2,...., T16) can be seen in Table 7 and Table 8.

Table7. Efficiency Score and Efficiency Ranking of Saati et al., Model at Different $\alpha-$cut Levels.

DMU	$\alpha=0$		$\alpha=0.25$		$\alpha=0.5$		$\alpha=0.75$		$\alpha=1$	
	ES	R	ES	R	ES	R	ES	R	ES	R
T1	1	1	1	1	1	1	1	1	1	1
T2	1	1	1	1	1	1	1	1	1	1
T3	1	1	1	1	1	1	1	1	0.976	13
T4	1	1	1	1	1	1	1	1	1	1
T5	1	1	1	1	1	1	1	1	1	1
T6	1	1	1	1	1	1	1	1	0.944	16
T7	1	1	1	1	1	1	1	1	0.987	12
T8	1	1	1	1	1	1	1	1	0.992	11
T9	1	1	1	1	1	1	1	1	1	1
T10	1	1	1	1	1	1	1	1	0.998	10
T11	1	1	1	1	1	1	1	1	1	1
T12	1	1	1	1	1	1	1	1	0.953	14
T13	1	1	1	1	1	1	1	1	0.952	15
T14	1	1	1	1	1	1	1	1	1	1
T15	1	1	1	1	1	1	1	1	1	1
T16	1	1	1	1	1	1	1	1	1	1

Table8. Efficiency Score and Efficiency Ranking of Lertworasirikul et al., Model at Different $\alpha-$cut Levels.

DMU	$\alpha=0$		$\alpha=0.25$		$\alpha=0.5$		$\alpha=0.75$		$\alpha=1$	
	ES	R	ES	R	ES	R	ES	R	ES	R
T1	2.530	1	1.957	2	1.550	2	1.242	2	1	1
T2	2.414	3	1.892	3	1.516	3	1.228	3	1	1
T3	1.946	7	1.623	8	1.363	8	1.154	9	0.976	13
T4	2.180	5	1.771	5	1.456	5	1.205	5	1	1
T5	1.846	11	1.577	9	1.353	9	1.164	8	1	1
T6	1.709	13	1.467	13	1.264	13	1.091	16	0.944	16
T7	1.850	10	1.568	10	1.339	10	1.148	11	0.987	12
T8	1.512	16	1.352	16	1.215	16	1.094	14	0.992	11
T9	1.627	15	1.432	16	1.267	14	1.124	12	1	1
T10	2.176	6	1.769	6	1.454	6	1.204	6	0.998	10
T11	2.334	4	1.858	4	1.500	4	1.222	4	1	1
T12	1.704	14	1.463	14	1.262	15	1.094	14	0.953	14
T13	1.855	9	1.559	11	1.319	12	1.120	13	0.952	15
T14	1.786	12	1.535	12	1.326	11	1.150	10	1	1
T15	2.522	2	1.968	1	1.576	1	1.261	1	1	1
T16	1.943	8	1.634	7	1.382	7	1.175	7	1	1

As observed in Table 7, the decision-making units T1, T2, T4, T5, T9, T11, T14, T15 and T16 are efficient in all $\alpha-$cut levels and have best performance. It can be said that the decision-making units T3, T6, T7, T8, T10, T12 and T13 are efficient in $\alpha-$cut $(\alpha=0, 0.25, 0.5, 0.75)$ levels. Efficiency scores of inefficient supplier firms decrease due to the increase in $\alpha-$cut levels. According to the efficiency score in Table 7, it is possible to rank the efficiency score of the firms as follows:

$$T1 = T2 = T4 = T5 = T9 = T11 = T14 = T15 = T16 > T10 > T8 > T7 > T3 > T12 > T13 > T6$$

Table 8 illustrates that all decision-making units are efficient in $\alpha-$cut $(\alpha = 0, 0.25, 0.5, 0.75)$ levels. Efficiency scores of all decision-making units decrease from "0" to "1". According to the efficiency score in $\alpha = 1$ cut level, the efficiency score of the firms ca n be ranked as follows:

$$T1 = T2 = T4 = T5 = T9 = T11 = T14 = T15 = T16 > T10 > T8 > T7 > T3 > T12 > T13 > T6$$

5. Conclusion

Nowadays there are intense competitions between supply chains of businesses. It can be said that the performance of supply chains directly affects business success in all sectors. The textile industry is a labour-intensive industry where the competition is rising daily and the resources are wasted too much. Businesses operating in the textile industry need to use their resources more effectively and to constantly measure the performance of their suppliers to maintain a sustainable competitive advantage in global markets and sustain their assets. Efficiency, an important aspect of performance, is a concept of how resources are used. As a nonparametric method, DEA is widely used in efficiency measurement. AHP is a method used to determine the weights of criteria in decision-making problems where there are one or more decision makers, more alternatives and criteria. Fuzzy AHP is a method that helps decision makers to evaluate them in case of uncertainty. It should be kept in mind that the efficiency measurement using the fuzzy DEA method is a relative measure of efficiency while evaluating the results of the efficiency. The suppliers have been evaluated using Fuzzy AHP and fuzzy DEA methods. As a result of fuzzy AHP application, as shown in Table 5, the criterion "quality" is placed in the first order with 0.302 weight and "flexibility" is placed in the last order with 0.004 weight. The Consistency Rate calculated whether the study was consistent or not. Consistency rates of less than 0.10 indicate that the comparisons are consistent. The efficiency scores obtained as a result of the efficiency measurement at the $\alpha = 1$ cut level using the two different fuzzy DEA models are the same. Decision making units T1, T2, T4, T5, T9, T11, T14, T15 and T16 were efficient in all $\alpha-$cut levels and both fuzzy DEA models.

At the end of the evaluations, the suppliers that are efficient / not efficient have been determined. In addition, suggestions are provided along with the improvements in areas where suppliers are not efficient as below:

- In the DEA efficiency measurement results, efficient decision-making units are a reference set for decision-making units that are inefficient. Comparable analyzes can be made based on these results. Overall, if the input-oriented DEA model is used, there is a case of reducing the inputs. Similarly, if the output-oriented DEA model is used, there is a case of increasing the outputs.
- It is believed that it would be useful for the inefficient suppliers to check their pricing policies. It is also considered useful to determine the net price by taking into account all the costs that may arise in the process up to the delivery of the product from the supplier to the firms; the price should not be changed showing a variety of reasons and should follow a stable price policy.
- It is considered beneficial for inefficient suppliers to give more importance to quality. Therefore, textile producers are advised to provide their suppliers with training and information support on quality systems. In addition, it may be useful to constantly monitor their suppliers by setting some conditions.
- It would be beneficial to keep in check the stock levels of inefficient suppliers. Additionally, it is suggested to create a more flexible structure and to avoid situations that might negatively affect the reliability of inefficient suppliers.
- The pollution rate of the raw material and specification of the raw material, which directly affect product quality, are known to be important for the textile industry. It is therefore recommended that inefficient suppliers develop procedures to assess the pollution rate of the raw material, group products according to raw material specifications and create identifier labels indicating the product properties.
- It is believed that inefficient suppliers should pay attention to on-time delivery of the products and to ensure that the packaging of the products is not deformed and that the products delivered are the same as the products ordered.
- As in the case of value stream mapping for quality, price, delivery, inventory availability, pollution rate of the raw material, specification of the raw material, reliability and flexibility criteria in the businesses of inefficient suppliers, current and future status maps can be created to determine value-added / non-value-added activities. In this way, suppliers can determine what improvements they can make about these criteria.

The study suggests that the criteria for the pollution rate of the raw materials and specification of the raw material are crucial in the textiles and apparel sector and especially the blanket sector where recycled raw materials are used heavily for the evaluation of suppliers. Production in the textile sector with raw materials with low prices often increases the unit cost of the products and affects companies negatively in subsequent processes because the raw material used in the textile industry and apparel industry directly affects the quality of the product, production efficiency, occupational health and safety and production costs. The results of the study reveal that companies operating in the blanket sector should feed the companies that supply raw materials with reliable, quality, low pollution rate of the raw material and specification of the raw material suitable for their production in the supplier lists processes rather than supplying low-cost raw materials. Firms that are suppliers for the textile and apparel sector, and especially the blanket sector, need to consider the following proposals in order to be included in the approved supplier lists of the producer companies.

- It is considered necessary that the documents showing pollution rate of the raw material and specification of the raw material be obtained from the universities or other competent authorities.
- They must have quality management system and environmental management system certificates. They must have documents from the universities or other authorized bodies showing that the raw materials they provide are not harmless to the environment and human health.
- They must create approved supplier lists and evaluate them according to supplier selection criteria.
- They should focus on delivery time, flexible work, co-operation, optimizing the stock level for the raw materials demanded constantly, and avoiding behaviours that would damage the reliability of their companies.
- Instead of offering only the price advantage for the raw materials, it is thought that they should offer advantages to the suppliers by taking the price criteria and other important criteria together to have an advantage over the competitors.

When the literature is examined, no other studies comparing the fuzzy AHP and fuzzy DEA methods and the different fuzzy DEA methods have been found in the textile sector. The study differs from other studies in the literature because it is carried out in the blanket sector. If the study is judged from this point of view, it provides some facilities to the business managers in the blanket sector and researcher who will do research on this issue. In future studies, performance evaluation can be performed by using different input and output variables. In addition, studies can be conducted by using Fuzzy AHP and Fuzzy DEA models together or multi-criteria decision-making methods in the textile industry or other sectors.

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References

Acar, A.Z., Onden İ., and Gurel O. (2016). Evaluation of the Parameters of the Green Supplier Selection Decision in Textile Industry. *FIBRES & TEXTILES in Eastern Europe*, Vol. 24(5), pp. 8-14.

Akman, G., and Alkan A. (2006). Measurement of Supplier Performance at Supply Chain Management by Using Fuzzy AHP Method: A Study at Automotive Subcontractor Industry. *İstanbul Ticaret University Journal of Science*, Vol. 5(9), pp. 23-46.

Alikhani, R., Torabi , R. and Altay N. (2019). Strategic Supplier Selection Under Sustainability and Risk Criteria. *International Journal of Production Economics*, Vol. 208, pp. 69-82.

Amindoust. A., and Saghafinia A. (2017). Textile Supplier Selection in Sustainable Supply Chain Using a Modular Fuzzy Inference System Model. *The Journal of the Textile Institute*, Vol. 108(7), pp. 1250-1258.

Arıkan, F., and Kucukce Y.S. (2012). A Supplier Selection-Evaluation Problem for the Purchase Action and Its Solution. *Journal of the Faculty of Engineering and Architecture of Gazi Universit*, Vol. 27(2), pp. 255-264.

Ayag, Z. (2005). A Fuzzy AHP-Based Simulation Approach to Concept Evaluation in A NPD Environment. *IIE Transactions*, Vol. 37(9), pp. 827-842.

Ayyıldız, G., and Demirel N.Ç. (2010). Fuzzy Choquet Integral Approach for Multi Criteria Supplier Evaluation Problem. *Journal of Engineering and Natural Sciences (Sigma)*, Vol. 28, pp. 214-223.

Azimifard, A., Moosavirad S.H., and Ariafar S. (2018). Selecting Sustainable Supplier Countries for Iran's Steel Industry at Three Levels by Using AHP and TOPSIS Methods. *Resources Policy*, Vol. 57, pp. 30-44.

Awasthi, A., Govindan K., and Gold S. (2018). Multi-Tier Sustainable Global Supplier Selection Using A Fuzzy AHP-VIKOR Based Approach. *International Journal of Production Economics*, Vol. 195(2), pp. 106-117.

Bakirci, N., and Tumerdem N. (2002). Pamuk İplik Uretimi ve İşçi Sağlığına Etkileri. *Turkish Journal of Occupational Health and Safety* Ocak, pp. 12-23.

Banker, R.D. (1984). Estimating Most Productive Scale Size Using Data Envelopment Analysis. *European Journal of Operational Research*, Vol. 17(1), pp. 35-44.

Banker, R.D., Charnes A., and Cooper W.W. (1984). Some Models for Estimating Technical and Scale Inefficiencies in Data Envelopment Analysis. *Management Scienc*, Vol. 30(9), pp. 1078-1092.

Baskaran, V., Nachiappan S., and Rahman S. (2012). Indian Textile Suppliers' Sustainability Evaluation Using The Grey Approach. *International Journal of Production Economics,* Vol. *1*35(2): 647-658.

Baslıgil, H. (2005). The Fuzzy Analytic Hierarchy Process for Software Selection Problems. *Journal of Engineering and Natural Sciences (Sigma),* Vol. 3, pp. 24-33.

Bayhan, M. (2011). An Empirical Study on Supplier Selection in Service Industry by Using Fuzzy Quality Function Deployment. PhD diss., University of SUleyman Demirel.

Bianchini, A. (2018). 3PL provider Selection by AHP and TOPSIS Methodology. *Benchmarking: An International Journal*, Vol. 25(1), pp. 235-252.

Bronja, H.(2011). Multi-Criteria Approach to Ranking Suppliers in the Supply Chains Concept. *Technical Gazette,* Vol. 18(3), pp. 393-401.

Buckley, J.J. (1985). Fuzzy Hierarchical Analysis. *Fuzzy Sets and Systems*, Vol. 17(3), pp. 233-247.

Buyukozkan, G., Feyzioglu O., and Nebol E. (2008). Selection of the Strategic Alliance Partner in Logistics Value Chain. *International Journal of Production Economic,* Vol. 113(1), pp. 148-158.

Cebeci, U. (2009). Fuzzy AHP-Based Decision Support System for Selecting ERP Systems in Textile Industry by Using Balanced Scorecard. *Expert Systems with Applications* Vol. 36(5), pp. 8900-8909.

Chan, F.T.S., and Chan H.K. (2010). An AHP Model for Selection of Suppliers in The Fast Changing Fashion Market. International Journal of Advanced Manufacturing Technology, Vol. 51(9-12), pp. 1195-1207.

Chang, D.Y. (1992). Extent Analysis and Synthetic Decision. *Optimization Techniques and Applications,* Vol. 1, pp. 352-355.

Chang, D.Y. (1996). Applications of The Extent Analysis Method on Fuzzy AHP. *European Journal of Operational Research,* Vol. 95(3), pp. 649-655.

Chang, P.T., and Lee J.H. (2012). A Fuzzy DEA and Knapsack Formulation Integrated Model for Project Selection. *Computers & Operations Research,* Vol. 39(1), pp. 112-125.

Charles, V., and Kumar M. (2012). *Data Envelopment Analysis and Its Application to Management*. Newcastle Upon Tyne: Cambridge Scholars Publishing.

Charnes, A., Cooper W.W., and Rhodes E. (1978). Measuring The Efficiency Of Decision Making Units. *European Journal of Operation Research,* Vol. 2(6), pp. 429-444.

Chen, Y.J. (2011). Structured Methodology for Supplier Selection and Evaluation in A Supply Chain. *Information Science,* Vol. 181(9), pp. 1651-1670.

Cheraghi, S,H,, Dadashzadeh M., and Subramanian M. (2004). Critical Success Factors for Supplier Selection: An Update. *Journal of Applied Business Research,* Vol. 20(2), pp. 91-108.

Cook, W.D., Kress M., and Seiford L.M. (1996). Data Envelopment Analysis in the Presence of Both Quantitative and Qualitative Factors. *The Journal of the Operational Research Society,* Vol. 47(7), pp. 945-953.

Cook, W.D., and Seiford L.M. (2009). Data Envelopment Analysis (DEA) – Thirty Years On. *European Journal of Operational Research,* Vol. 192(1), pp. 1-17.

Cooper, M.C, Lambert D.M., and Pagh J.D. (1997). Supply Chain Management: More Than a New Name for Logistics. *The International Journal of Logistics Management*, Vol. 8(1), pp. 1-14.

Cooper, W.W., Park K.S., and Yu G. (1999). IDEA and AR-IDEA: Models for Dealing with Imprecise Data in DEA. *Management Science*, Vol. 45(4), pp. 597-607.

Cakir, E. (2016). The Determination of Part-Time Students Using VIKOR Method Based on Analytic Hierarchy process. *International Journal of Management Economics and Business*, Vol. 12(29), pp. 195-224.

Cetin, O., and Onder E. (2015). Using Analytic Network Process Method for Supplier Selection. The Journal of *Kafkas University Economics and Administrative Sciences Faculty*, Vol. 6(10), pp. 335-354.

Dempsey, W.A. (1978). Vendor Selection and The Buying Process. *Industrial Marketing Management*, Vol. 7(4), pp. 257-267.

Despotis, D.K., and Smirlis Y.G. (2002). Data Envelopment Analysis with Imprecise Data. *European Journal of Operational Research*, Vol. 140(1), pp. 24-36.

Dickson, G.W. (1966). An Analysis of Vendor Selection Systems and Decisions. *Journal of Purchasing*, Vol. 2(1), pp. 5-17.

Do, Q.H., and Chen J.F. (2014). A Hybrid Fuzzy AHP-DEA Approach for Assessing University Performance. *WSEAS TRANSACTIONS on BUSINESS and ECONOMICS*, Vol. 11, pp. 386-397.

Dogan, N.O., and Ersoy Y. (2017). Efficiency Measurement: A Case Study of A Firm in the Textile Sector. *Hitit University Journal of Social Sciences Institute*, Vol. 10(1), pp. 35-44.

Dotoli, M., Epicoco N., Falagario M., and Sciancalepore F.. (2016). A Stochastic Cross-Efficiency Data Envelopment Analysis Approach for Supplier Selection Under Uncertainty. *International Transactions in Operational Research*, Vol. 23(4), pp. 725-748.

Dursun, M., Sener Z., and Cedolin M. (2017). Performance Evaluation of Medical Device Suppliers with Fuzzy DEA Technique. Proceedings of the World Congress on Engineering 2017 Vol. II, London/UK, July 5-7.

Emrouznejad, A., and Tavana M. (2014). *Performance Measurement with Fuzzy Data Envelopment Analysis*. Newyork: Springer.

Enea, M., and Piazza T. (2004). Project Selection by Constrained Fuzzy AHP." *Fuzzy Optimization and Decision Making*, Vol. 3(1), pp. 39-62.

Eren, T., and Ozder E.H. (2016). Supplier Selection for a Beverage Company with Multicriteria Decision Making Methods. 4th International Symposium on Innovative Technologies in Engineering and Science, Alanya/Antalya, November 3-5.

Ersoy, N. (2017). Supplier Selection by Using Fuzzy logic: The Case of Gaziantep. *Journal of Economics Business and Political Researches*, Vol. 2(3), pp. 11-29.

Ersoy, Y. (2014). A Study on Specifications of Regenerated Open-End Yarn Production. Msc. diss., Usak University.

Ersoy, Y., and Senol M.F. (2017). Type of Raw Material and Production Parameters Effect on Yarn Quality: An Application on Open-End Spinning. *The Journal of Graduate School of Natural and Applied Sciences of Mehmet Akif Ersoy University*, Vol. 8(1), pp. 96-107.

Eser, B., Çelik P., Çay A., and Akgumus D. (2016). Sustainability and Recycling Opportunities in the Textile and Apparel Sector. *Journal of Textile and Engineer*, Vol. 23(101), pp. 44-60.

Eskandari, S. (2017). A new Approach for Forest Fire Risk Modelling Using Fuzzy AHP and GIS in Hyrcanian Forests of Iran. *Arabian Journal of Geosciences*, Vol. 10(190), pp. 1-13.

Fanchon, P. (2003). Variable Selection for Dynamic Measures Efficiency in the Computer Industry. *International Advanced in Economic Research*, Vol. 9(3), pp. 175-188.

Farrell, M.J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society*, Vol. 120(3), pp. 253-290.

Fawcett, S.E., Magnan G.M., and McCarter M.W. (2008). Benefits, Barriers and Bridges to Effective Supply Chain Management. *Supply Chain Management: An International Journal*, Vol. 13(1), pp. 35-48.

Fox M.S., Barbuceanu M., and Teigen R. (2000). Agent- Oriented Supply- Chain Management. *The International Journal of Flexible Manufacturing Systems*, Vol. 12, pp. 165-188.

Ghodsypour, S.H., and O'Brien C. (1998). A Decision Support System for Supplier Selection Using an Integrated Analytic Hierarchy Process and Linear Programming. *International Journal of Production Management,* Vol. 56-57, pp. 199-212.

Govindan, K., Rajendran S., Sarkis J., and Murugesan P. (2015). Multi Criteria Decision Making Approaches for Green Supplier Evaluation and Selection: A Literature Review. *Journal of Cleaner Production,* Vol. 98(1), pp. 66-83.

Gorcun, O.F. (2013). *Ornek Olay ve Uygulamalarla Tedarik Zinciri Yonetimi*. İstanbul: Beta Publishing.

Groselj, P., and Stirn L.Z. (2017). Soft Consensus Model for The Group Fuzzy AHP Decision Making. *Croatian Operational Research Review,* Vol. 8(1), pp. 207-220.

Gungor, A., Coşkun S., Durur G., and Gören H.G. (2010). A Supplier Selection, Evaluation and Re-Evaluation Model for Textile Retail Organizations. *The Journal of Textile and Garment,* Vol. 3, pp. 181-187.

Guo, P., and Tanaka H. (2001). Fuzzy DEA: A Perceptual Evaluation Method. *Fuzzy Sets and Systems,* Vol. 119(1), pp. 149-160.

Gules, H.K., Caglıyan V., T. Sener. (2014). Supplier Selection Based on Analytic Hierarchy Process Methods in Garment Sektor. *Selçuk University Journal of Institute of Social Sciences* Dr. Mehmet YILDIZ Special Edition, pp. 159-170.

Guneri, A.F., Ertay T., and Yucel A. (2011). An Approach Based on ANFIS Input Selection and Modelling for Supplier Selection Problem. *Expert Systems with Applications,* Vol. 38(12), pp. 14907-14917.

Ha, S.H., and Krishnan R. (2008). A Hybrid Approach to Supplier Selection for The Maintenance of A Competitive Supply Chain. *Expert Systems with Applications*, Vol. 34(2), pp. 1303-1311.

Haq, A.N., and Kannan G. (2006). Fuzzy Analytical Hierarchy Process for Evaluating and Selecting A Vendor in A Supply Chain Model. *International Journal of Advanced Manufacturing Technology*, Vol. 29(7), pp. 826-835.

Hemmati, M., Feiz D., Jalilvand M.R., and Kholghi I. (2016). Development of Fuzzy Two-Stage DEA Model for Competitive Advantage Based on RBV and Strategic Agility as A Dynamic Capability. *Journal of Modelling in Management,* Vol. 11(1), pp. 288-308.

Ho, W., and Ma X. (2018). The State-of-The-Art Integrations and Applications of The Analytic Hierarchy Process. *European Journal of Operational Research,* Vol. 267(2), pp. 399-414.

Ho, W., Xu X., and Dey P.K. (2010). Multi-Criteria Decision Making Approaches for Supplier Evaluation and Selection: A Literature Review. *European Journal of Operational Research,* Vol. 202(1), pp. 16-24.

Hou, J., and Su. D. (2006). Integration of Web Services Technology with Business Models within The Total Product Design Process for Supplier Selection. *Computers in Industry,* Vol. 57(8-9), pp. 797-808.

Humphreys, P.K., Shiu W.K., and Chan F.T.S. (2001). Collaborative Buyer-Supplier Relationships in Hong Kong Manufacturing Firms. *Supply Chain Management: An International Journal,* Vol. 6(4), pp. 152-162.

Iwaro, J., Mwasha A., Williams R.G., and Zico R. (2014). An Integrated Criteria Weighting Framework for The Sustainable Performance Assessment and Design of Building Envelope. *Renewable and Sustainable Energy Reviews,* Vol. 29, pp. 417-434.

Jakhar, S.K., and Barua M.K. (2014). An Integrated Model of Supply Chain Performance Evaluation and Decision-Making Using Structural Equation Modelling and Fuzzy AHP. *Production Planning & Control*, Vol. 25(11), pp. 38-957.

Jonavic, B., and Delibasic B.. (2014). Application of Integrated QFD and Fuzzy AHP Approach in Selection of Suppliers. *Management,* Vol. 19(72), pp. 25-35.

Kahraman, C., Cebeci U., and Ruan D.. (2004). Multi-Attribute Comparison of Catering Service Companies Using Fuzzy AHP: The Case of Turkey. *International Journal of Production Economics,* Vol. 87(2), pp. 171-184.

Kahraman, C., Cebeci U., and Ulukan Z.. (2003). Multi-Criteria Supplier Selection Using Fuzzy AHP. *Logistics Information Management,* Vol. 16(6), pp. 382-394.

Kahraman, C., Onar S.C., and Oztaysi B. (2015). Fuzzy Multicriteria Decision-Making: A Literature Review. *International Journal of Computational Intelligence Systems,* Vol. 8(4), pp. 637-666.

Kao, C., and Liu S.T. (2000). Fuzzy Efficiency Measures in Data Envelopment Analysis. *Fuzzy Sets and Systems,* Vol. 113(3), pp. 427-437.

Kara, I., and Ecer. F. (2016). Supplier Selection with AHP-VIKOR Integrated Method: Textile Industry Application. *Dokuz Eylul University The Journal of Graduate School of Social Sciences,* Vol. 18(2), pp. 255-272.

Kara, K., Koleoglu N., and GUrol P. (2016). Analytic Network Process (ANP) in Supplier Selection: A Case Study in Textile Sector. *International Journal of Business and Social Science*, Vol. 7(5), pp. 241-257.

Koprulu, A., and Albayrakoglu M. (2007). Supply Chain Management in the Textile Industry: A Supplier Selection Model with The Analytic Hierarchy Process. International Symposium on the Analytic Hierarchy Process 2007(ISAHP 2007), Viña Del Mar/Chile, August 3-6.

Kumar, A., Shankar R., and Debnath R.M. (2015). Analyzing Customer Preference and Measuring Relative Efficiency in Telecom Sector: A Hybrid Fuzzy AHP/DEA Study. *Telematics and Informatics*, Vol. 32(3), pp. 447-462.

Kumar, D., Singh J., Singh O.P., and Darshan S. (2013). A Fuzzy Logic Based Decision Support System for Evaluation of Suppliers in Supply Chain Management Practices. *Mathematical and Computer Modelling,* Vol. 57(11-12), pp. 2945-2960.

Kuo, R.J., Lee L.Y., and Hu T.L. (2010). Developing A Supplier Selection System Through Integrating Fuzzy AHP and Fuzzy DEA: A Case Study on An Auto Lighting System Company in Taiwan. *Production Planning & Control,* Vol. 21(5), pp. 468-484.

Leon, T., Liern V., Ruiz J.L., Sirvent I. (2003). A Fuzzy Mathematical Programming Approach to the Assessment of Efficiency with DEA Models. *Fuzzy Sets and Systems,* Vol. 139(2), pp. 407-419.

Lertworasirikul, S., Fang S.C., Joines J.A., and Nuttle H.L.W. (2003). Fuzzy Data Envelopment Analysis (DEA): A Possibility Approach. *Fuzzy Sets and Systems*, Vol. 139(2), pp. 379-394.

Liu, F.H.F., and Hai H.L. (2005). The Voting Analytic Hierarchy Process Method for Selecting Supplier. *International Journal of Production Economics*, Vol. 97(3), pp. 308-317.

Loron, A.S., Loron M.S., and Peyvandi G. (2015). An Integrated Fuzzy Analytic Hierarchy Process-Fuzzy Data Envelopment Analysis (FAHP-FDEA) Method for Intelligent Building Assessment. *Technical Gazette,* Vol. 22(2), pp. 383-389.

Marbini, A.D., Agrell P.J., Tavana M., and Khoshnevis P. (2017). A Flexible Cross-Efficiency Fuzzy Data Envelopment Analysis Model for Sustainable Sourcing. *Journal of Cleaner Production,* Vol. 142(4), pp. 2761-2779.

Marbini, A.D., Emrouznejad A., and Tavana M. (2011). A Taxonomy and Review of The Fuzzy Data Envelopment Analysis Literature: Two Decades in The Making. *European Journal of Operational Research,* Vol. 214(3), pp. 452-472.

Marbini, A.D., Tavana M., and Emrouznejad A. (2012). Productivity Growth and Efficiency Measurement in Fuzzy Environments with an Application to Health Care. *International Journal of Fuzzy System Applications,* Vol. 2(2), pp. 1-35.

Mezarcıoz, S., and Ogulata R.T. (2014). The Law on Occupational Health and Safety No.6331 Difficulties of Occupational Health and Safety in Textile Industry. *Engineer and Machine,* Vol. 55(655), pp. 72-79.

Mokhtari, M., Javanshir H., Dolatabati M.K., Tashakori L., and Madanchi F. (2013). Supplier Selection in Textile Industry Using Fuzzy MADM. *Research Journal of Applied Sciences, Engineering and Technology,* Vol. 6(3), pp. 400-411.

Muralihadran, C., Anantharaman N., and Deshmukh S.G. (2002). A Multi-Criteria Group Decisionmaking Model for Supplier Rating. *Journal of Supply Chain Management,* Vol. 38(4), pp. 22-33.

Ofluoglu, P., and Miran B. (2014). Supplier Selection Through Fuzzy Pair-Wise Comparison Method: A Case Study for Turkish Clothing Companies. *Journal of Textiles and Engineer,* Vol. 21(96), pp. 1-9.

Oguz, N.S., and Dayik M. (2014). Determination of Factors Affecting Strength in Cotton Yarn with Fuzzy Logic Method. *Electronic Journal of Textile Technologies,* Vol. 8(2), pp. 12-18.

Oral, C. (2016). Analytical Hierarchy Process as a Tool for Investment Appraisal. *International Journal of Economics and Finance,* Vol. 8(4), pp. 306-311.

Ordoobadi, S.M. (2009). Development of A Supplier Selection Model Using Fuzzy Logic. *Supply Chain Management: An International Journal,* Vol. 14(4), pp. 314-327.

Oruç, K.O., and Gungor I. (2010). Comparison of Fuzzy Data Envelopment Analysis Models: For Interval Data. *Suleyman Demirel University Journal of Faculty of Economics and Administrative Sciences,* Vol. 15(2), pp. 417-442.

Ozdemir, H., and Gurcan H.A. (2013). A Study on The Effects of Different Components in Woollen Blend, The Dye and Carding Intensity on The Physical Properties of Carpet Yarns. *Electronic Journal of Textile Technologies,* Vol. 7(1), pp. 18-32.

Ozfırat, P.M., Tasoglu G.T, and Memis G.T. (2014). A Fuzzy Analytic Hierarchy Process Methodology for the Supplier Selection Problem. *Journal of Enterprise Information Management*, Vol. 27(3), pp. 292-301.

Ozkok, B.A., and Tiryaki F. (2011). A Compensatory Fuzzy Approach to Multi-Objective Linear Supplier Selection Problem with Multiple-Item. *Expert Systems with Applications,* Vol. 38(9), pp. 11363-11368.

Ozturk, A., Ertugrul İ., and Karakaşoğlu N. (2008). Comparison of FUZZY AHP and FUZZY TOPSIS Methods in Transportation Firm Selection. *Marmara University Journal of Economics and Administrative Sciences,* Vol. 15(2), pp. 785-824.

Ozturk, A., Erdogmus S. and Arıkan V.S. (2011). Evaluation The Suppliers Using Analytic Hierarchy Process (AHP): An Application in The Textile Firm. *Dokuz Eylul University Faculty of Economics and Administrative Sciences Journal*, Vol. 26(1), pp. 93-112.

Paksoy, T., and Gules H.K. (2006). Analytic Hierarchy Process for Supplier Selection Problem in Supply Chain Management: Case Study of A Textile Manufacturer Firm. *Sigma, Journal of Engineering and Natural Science,* Vol. 4, pp. 100-109.

Patil, A.N. (2014). Modern Evulation in Supplier Selection Criteria and Methods. *International Journal of Management Research & Revie,* Vol. 4(5), pp. 616-623.

Petrini, M.A, Rocha J.V., Brown J.C., and Bispo R.C. (2016). Using an Analytic Hierarchy Process Approach to Prioritize Public Policies Addressing Family Farming in Brazil. *Land Use Policy,* Vol. 51, pp. 85-94.

Radfar, R., and Salahi F. (2014). Evaluation and Ranking of Suppliers with Fuzzy DEA and PROMETHEE Approach. *International Journal of Industrial Mathematics,* Vol. 6(3), pp. 189-197.

Ramanathan, R. (2007). Supplier Selection Problem: Integrating DEA with The Approaches of Total Cost of Ownership and AHP. *Supply Chain Management: An International Journal,* Vol. 12(4), pp. 258-261.

Raut, R.D. (2011). Environmental Performance: A Hybrid Method for Supplier Selection using AHP-DEA. *International Journal of Business Insights & Transformation,* Vol. 5(1), pp. 16-29.

Romeijn, H., Faggian R., Diogo V., and Sposito V. (2016). Evaluation of Deterministic and Complex Analytical Hierarchy Process Methods for Agricultural Land Suitability Analysis in a Changing Climate. *International Journal of Geo-Information,* Vol. 5(6), pp. 1-16.

Saati, S., and Memariani A. (2005). Reducing Weight Flexibility in Fuzzy DEA. *Applied Mathematics and Computation,* Vol. 161(2), pp. 611-622.

Saati, S., Memariani A., and Jahanshahloo G.R.. (2002). Efficiency Analysis and Ranking of DMUs with Fuzzy Data. *Fuzzy Optimization and Decision Making,* Vol. 1(3), pp. 255-267.

Saaty, T.L. (1990). How to Make A Decision: The Analytic Hierarchy Process. *European Journal of Operational Research*, Vol. 48, pp. 9-26.

Saaty, T.L. (1994). How to Make A Decision: The Analytic Hierarchy Process. *INTERFACES,* Vol. 24(6), pp. 19-43.

Santis, R.B.D., Golliat R., and Aguiar E.P.D. (2017). Multi-Criteria Supplier Selection Using Fuzzy Analytic Hierarchy Process: Case Study From a Brazilian Railway Operator. *Brazilian Journal of Operations & Production Management,* Vol. 14(3), pp. 428-437.

Sengupta, J.K. (1992). A fuzzy Systems Approach in Data Envelopment Analysis. *Computers & Mathematics with Applications,* Vol. 24(8-9), pp. 259-266.

Seydel, J. (2005). Supporting the Paradigm Shift in Vendor Selection: Multi criteria Methods for Sole-Sourcing. *Managerial Finance,* Vol. 31(3), pp. 49-66.

Shaw, K., Shankar R., Yadav S.S, and Thakur L.S. (2012). Supplier Selection Using Fuzzy AHP and Fuzzy Multi-Objective Linear Programming for Developing Low Carbon Supply Chain. *Expert Systems with Applications,* Vol. 39(9), pp. 8182-8192.

Shiraz, S.E. (2014). An Integrated Fuzzy TOPSIS-Fuzzy DEA Approach for Supplier Criteria and Supplier Selection." PhD diss., AtatUrk University.

Shukla, M.K. (2016). Supplier Evaluation and Selection Criteria in Business Performance of Small and Medium Scale Enterprise. *International Research Journal of Engineering and Technology (IRJET),* Vol. 3(6), pp. 70-76.

Simic, D., Kovacevic I., Sivircevic V., and Simic S. (2017). 50 Years of Fuzzy Set Theory and Models for Supplier Assessment and Selection: A Literature Review. *Journal of Applied Logic,* Vol. 24(Part A), pp. 85-96.

Stevic, Z., Tanackov I., Vasilevic M., Novarlic B., and Stojic G. (2016). An Integrated Fuzzy AHP and TOPSIS Model for Supplier Evaulation. *Serbian Journal of Management,* Vol. 11(1), pp. 15-27.

Stojanov, T., and Ding X. (2015). Supplier Selection for Mixed-Model Production: A Case Study from the Apparel Industry. *FIBRES & TEXTILES in Eastern Europe,* Vol. 23(1), pp. 8-12.

Su, J., Dyer C.L. and Gargeya V.B. (2009). Strategic Sourcing and Supplier Selection in the U.S. Textile– Apparel–Retail Supply Network. *Clothing & Textile Research Journal,* Vol. 27(2), pp. 83-97.

Sultana, I., Ahmed I., and Azeem A. (2015). An Integrated Approach for Multiple Criteria Supplier Selection Combining Fuzzy Delphi, Fuzzy AHP & Fuzzy TOPSIS. *Journal of Intelligent & Fuzzy Systems,* Vol. 29, pp. 1273-1287.

Sydani, A.Z., Karbasi, A. and Yekta E.A. (2011). Evaluating and Selecting Supplier in Textile Industry Using Hierarchical Fuzzy TOPSIS." *Indian Journal of Science and Technology,* Vol. 4(10), pp. 1322-1334.

Tahriri, F,, Osman M.R., Ali A., Yusuff R.M., and Esfandiary A.. (2008). AHP Approach for Supplier Evaluation and Selection in A Steel Manufacturing Company. *Journal of Industrial Engineering and Management,* Vol. 1(2), pp. 54-76.

Talluri, S., and R. Narasimhan. (2004). A Methodology for Strategic Sourcing. *European Journal of Operational Research*, Vol. 154(1), pp. 236-250.

Tam, M.C.Y., and Tummala V.M.R. (2001). An Application of The AHP in Vendor Selection of A Telecommunications System. *Omega,* Vol. 29(2), pp. 171-182.

Tan, K.C., Kannan V.R., and Handfield R.B. (1998). Supply Chain Management: Supplier Performance and Firm Performance. *International Journal of Purchasing and Materials Management*, Vol. 34(3), pp. 1-9.

Tavakoli, M.M., Molavi B., and Shirouyehzad H. (2017). Organizational Performance Evaluation Considering Human Capital Management Approach by Fuzzy-DEA: A Case Study. *International Journal of Research in Industrial Engineering*, Vol. 6(1), pp. 1-16.

Tayyar, N. (2012). Fuzzy AHP and Fuzzy TOPSIS Approach to Pet Bottle Supplier Selection. *Suleyman Demirel University The Journal of Faculty of Economics and Administrative Sciences*, Vol. 17(3), pp. 351-371.

Tayyar, N, and Arslan P. (2013). Selection of The Best Sub-Contractor in Clothing Sector Using AHP and VIKOR Methods. *Celal Bayar University Journal of Institute of Social Sciences*, Vol. 11(1), pp. 340-358.

Teng, S.G., and Jaramillo H. (2005). A Model for Evaluation and Selection of Suppliers in Global Textile and Apparel Supply Chains. *International Journal of Physical Distribution & Logistics Management*, Vol. 35(7), pp. 503-523.

Tezsurucu, D. (2013). Measuring The Effectiveness of Supplier Performance by Using Data Envelopment Analysis and An Industrial Application. PhD diss., University of Celal Bayar.

Unal, C., and Guner M.G. (2009). Selection of ERP Suppliers Using AHP Tools in The Clothing Industry. *International Journal of Clothing Science and Technology*, Vol. 21(4), pp. 239-251.

Van Laarhoven, P.J.M., and Pedrcyz W. (1983). A Fuzzy Extension of Saaty's Priority Theory. *Fuzzy Sets and System*, Vol. 11(1-3), pp. 229-241.

Vokurka, R.J, Choobineh J., and Vadi L. (1996). A Prototype Expert System for The Evaluation and Eelection of Potential Suppliers. *International Journal of Operations & Production Management*, Vol. 16(12), pp. 106-127.

Yacan, I. (2016). Evaluation Factors That Affect The Determination of Quality in The Education with Fuzzy AHP and Fuzzy TOPSIS. Mss diss., Pamukkale University.

Yayla, A.Y., Yildiz A., and Ozbek A. (2012). Fuzzy TOPSIS Method in Supplier Selection and Application in the Garment Industry. *FIBRES & TEXTILES in Eastern Europe*, Vol. 20(4), pp. 20-23.

Yıldırım, B.F., and Onder E. (2015). *Multi Criteria Decision Making Methods.* Bursa: Dora Publishing.

Yildiz, A. (2013). Selection of Suppliers Using Fuzzy Multi-Criteria Decision Making Methods and Determination of Economic Order Quantity: An Application in Automotive Industry. PhD diss., Marmara University.

Yilmaz, O., Gulsun B., Guneri A.F., and Ozgurler S. (2011). Supplier Selection of a Textile Company with ANP. *15th International Research/Expert Conference: Trends in the Development of Machinery and Associated Technology (TMT 2011), Prague/ Czech Republic, September 12-18.*

Yucenur, G.N., Vayvay O., Demirel N.Ç. (2011). Supplier Selection Problem in Global Supply Chains by AHP and ANP Approaches Under Fuzzy Environment. *International Journal of Advanced Manufacturing Technology, Vol. 56(5), pp. 823-833.*

Zadeh, L.A. (1965). Fuzzy Sets. *Information and Control*, Vol. 8, pp. 338-353.

Zarghami, E., Azemati H., Fatourehchi D., and Karamloo M. (2018). Customizing Well-Known Sustainability Assessment Tools for Iranian Residential Buildings Using Fuzzy Analytic Hierarchy Process. *Building and Environment*, Vol. 128, pp. 107-128.

Zhenhua, G. (2009). The Application of DEA/AHP Method to Supplier Selection. *International Conference on Information Management, Innovation Management and Industrial Engineering, Xi'an/China, December 26-27.*

Zeydan, M., Çolpan C. and Çobanoğlu C. (2011). A Combined Methodology for Supplier Selection and Performance Evaluation. *Expert Systems with Applications*, Vol. 38(3), pp. 2741-2751.

Zouggari, A., and Benyoucef L. (2012). Simulation Based Fuzzy TOPSIS Approach for Group Multi-Criteria Supplier Selection Problem. *Engineering Applications of Artificial Intelligence*, Vol. 25(3) pp. 507-519.

Wang, Y.M., Greatbanks R., and Yang J.B. (2005). Interval Efficiency Assessment Using Data Envelopment Analysis. *Fuzzy Set and Systems*, Vol. 153(3), pp. 347-370.

Wang, Y.M., and Chin K.S. (2011). Fuzzy Data Envelopment Analysis: A Fuzzy Expected Value Approach. *Expert Systems with Applications*, Vol. 38(9), pp. 11678-11685.

Wanke P., Barros C.P. and Nwaogbe O.R. (2016). Assessing Productive Efficiency in Nigerian Airports Using Fuzzy-DEA. *Transport Policy*, Vol. 49, pp. 9-16.

Wichapa, N., and Khokhajaikiat P. (2017). Solving Multi-Objective Facility Location Problem Using The Fuzzy Analytical Hierarchy Process and Goal Programming: A Case Study on Infectious Waste Disposal Centers. *Operations Research Perspectives,* Vol. 4, pp. 39-48.

Weber C.A., Current J.R. and Benton W.C. (1991). Vendor Selection Criteria and Methods. *European Journal of Operational Research,* Vol. 50(1), pp. 2-18.

Weber, C.A., Current J. and Desai A. (2000). An Optimization Approach to Determining The Number of Vendors to Employ. *Supply Chain Management: An International Journa,* Vol. 5(2), pp. 90-98.

Appendix

Table1. Supplier selection criteria and supplier evaluation methods in textile and apparel sector in the term of supplier evaluation

Author	**Year**	**Supplier selection criteria**	**Sector**	**Method**
Teng and Jaramillo	2005	Geographical location, freight terms, trade restrictions, total order lead time, capacity, inventory availability, information sharing, negotiability, customization, supplier's selling price, internal cost, ordering and invoicing, continuous improving programs, customer service, certifications, % of on time shipments, feeling of trust, country's political situation, currency exchange situation, warranty policies	Textile and apparel	AHP and multiple attribute utility theory
Paksoy and Gules	2006	Quality, supply performance, cost, compromise ability, technology, colour procurement, distance	Apparel	AHP
Koprulu and Albayrakoglu	2007	Cost, quality, delivery, flexibility, innovation, trust	Apparel	AHP
Su et al.,	2009	Product cost, product quality, delivery dependability, delivery speed	Textile and apparel	Structural equation model
Unal and Guner	2009	Functionality, implementation approach, support, costs, organizational credibility, experience, flexibility, customer focused, future strategy	Apparel	AHP
Cebeci	2009	Total cost, implementation, functionality, flexibility, systems reliability, user friendliness, research and development capability, better fit with company's business processes, ability for upgrade in-house, compatibility with other systems, after sales service, vendor reputation, terms and period of guarantee	Apparel	Fuzzy AHP and balanced scorecard method
Ayyıldız and Demirel	2010	Price, geographical location, quality, financial status, flexibility, place in the textile sector, past performance, meet customer needs, delivery performance, packaging, the closeness of relations, solution of disputes, colour working process	Knitting	Fuzzy ANP
Chan and Chan	2010	Total order lead time, geographical location, trade restriction, certifications, customer service, commitment to quality, continuous improvement program, shipment accuracy (on time), shipment accuracy (on quantity), warranty policies, capacity, inventory availability, customization, negotiability, information sharing, availability of raw material, supplier's selling price, logistic cost, value-added cost, management outlook of the future, company's financial situation, company past record/reputation in the field, political stability/government policy, legal system, stable workforce, technical capability, innovation capability, environmental management plan, environmental certifications	Apparel	AHP
Gungor et al.,	2010	Product quality level, technical capability, production capacity, management system, product range, logistics position, financial position	General textile	AHP and ANP
Chen	2011	Quality, cost, technology and production, organizational management	General textile	SWOT Analysis, DEA and TOPSIS
Guneri et al.,	2011	Quality, cost, delivery, relationship closeness, conflict resolution	Dyeing-printing	Adaptive neuro-fuzzy inference system
Sydani et al.,	2011	Geographical location, shipment conditions, lead time, trade restrictions, capacity, inventory availability, meet the unexpected need, make to order, selling cost, internal cost, billing and ordering, continuous improvement plans customer services, standards and certificates, defect rate, feeling of trust, pricing and payment policies, warranty policies	Yarn	Fuzzy TOPSIS
Yılmaz et al.,	2011	Production capacity, technical capability, packing capability, quality of products, variety of products, price appropriateness, financial condition, ease in payment, amount per delivery, shortness of delivery time, delivery quality, references, flexibility, experience, after sales service, communication capability, problem solving capability, installation capability	Apparel	ANP

Table1. Continued

Author	Year	Supplier selection criteria	Sector	Method
Yucenur et al.,	2011	Reliability, just in time delivery, supply capacity, innovative properties, quality of transport place, flexibility and agility, non-damaged transport, communication easiness, product price, lead cost, shipping and distribution costs, quality cost, tariff and custom duties, delay cost, order delays, political stability, economy, costumer complaints, geographical structure, terrorism, climate conditions, cultural differences, management and organizational structure, financial status, reputation, experience, relationship closeness, legality	Apparel	Fuzzy AHP and Fuzzy ANP
Ozkok and Tiryaki	2011	Total purchase cost, service quality, item quality	Dyeing-printing	Fuzzy multi-objective linear programming
Ozturk et al.,	2011	Quality, supply performance, technical capacity, options/promotions, cost, financial capacity, experience and willingness	Apparel	AHP
Baskaran et al.,	2012	Discrimination, abuse of human rights, child labour, long working hours, unfair competition, pollution	Apparel	Grey approach
Yayla et al.,	2012	Quality, delivery time, cost, flexibility, geographical location	Apparel	Fuzzy TOPSIS
Shaw et al.,	2012	Cost, quality, lead time, demand, green house gas emission	Apparel	Fuzzy AHP and Fuzzy multi-objective linear programming
Mokhtari et al.,	2013	Quality, cost, location, delivery, trust	Yarn	Fuzzy AHP and Fuzzy VIKOR
Kumar et al.,	2013	Consistency in product quality, improvement in incoming components, reduction in damaged components in transit, inventory level reduction, lot size reduction, reduction in plant stoppage due to shortage of material, on-time delivery, reduction on order lead time, reduction in product development cycle time	General textile	Mamdani fuzzy inference system
Ofluoglu and Miran	2014	Quality, price, flexibility, customer satisfaction, lead time, service	Apparel	Fuzzy comparison method
Ozfirat et al.,	2014	Quality, lead time, delivery performance, capacity	Apparel	Fuzzy AHP
Stojanov and Ding	2015	Production quality level, production flexibility, product range, technical capability, production capacity, management system, logistics position, financial position	Apparel	AHP and cluster analysis
Kara et al.,	2016	Honesty and truth, price, service performance, quality, mutual trust, customer relations, risk factor, after sales service, customer response speed, delivery reliability, delivery speed, being the current supplier, flexibility, geographical location, problem solving, capacity, guarantee, product range, design, brand name, supplier profile, prestige, background, certificates, R&D skills, market expertise, green production	General textile	ANP
Shukla	2016	Cost, quality, delivery, flexibility, reliability	Apparel	AHP
Kara and Ecer	2016	Unit cost, delivery cost, defect rate, solving quality problem, product quality, delivery (on time), delivery (on quantity), supplier's financial structure, supplier's image, ability and capacity, guarantee, after sales services	Yarn	AHP and VIKOR
Acar et al.,	2016	Quality, pollution control, environmental management, green product, delivery, service, cost, strategic alliance	General textile	Fuzzy AHP
Ersoy	2017	Quality, delivery, procedural compliance, performance history, technical capability	Weaving-dyeing	Fuzzy TOPSIS
Amindoust and Saghafinia	2017	Cost, quality, delivery, inventory level reduction, pollution control, environmental management system, social equities, labour health and work safety	Apparel	Fuzzy inference system

Table2. Triangular fuzzy conversion scale

Linguistic scale for importance degrees	Triangular fuzzy scale	Triangular fuzzy reciprocal scale
Equally important	(1/2, 1, 3/2)	(2/3, 1, 2)
Weakly more important	(1, 3/2, 2)	(1/2, 2/3, 1)
Strongly more important	(3/2, 2, 5/2	(2/5, 1/2, 2/3)
Very strongly more important	(2, 5/2, 3)	(1/3, 2/5, 1/2)
Absolutely more important	(5/2, 3, 7/2)	(2/7, 1/3, 2/5)

Source: Buyukozkan et al., 2008.

Table3. The fundamental scale

Intensity of importance on an absulate scale	**Definition**	**Explanation**
1	Equal importance	Two activities contribute equally to the objective
3	Modarete importance of one over another	Experience and judgment strongly favor one activity over another
5	Essential of strong importance	Experience and judgment strongly favor one activity over another
7	Very strong importance	An activity is strongly favored and its dominance demonstrated in practice
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between the two adjacent judgments	When compromise is needed
Reciprocals	If activity i has one of the above numbers assigned to it when compared with activity j, then j has the reciprocal value when compared with i	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining *n* numerical values to span the matrix

Source: Saaty 1990.

Table4. Random consistency index (R.I)

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,52	0,89	1,11	1,25	1,35	1,40	1,45	1,49

Source: Saaty, 1994.

Table6. Linguistic ratings and fuzzy triangular numbers

Linguistic rating	**Fuzzy triangular numbers**
Very low	(1, 1, 3)
Low	(1, 3, 5)
Medium	(3, 5, 7)
High	(5, 7, 9)
Very high	(7, 9, 9)

Source: Emrouznejad and Tavana 2014