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Supplier Selection by Using a Fuzzy Integrated Model for a Textile Company

Alptekin Ulutas

Cumhuriyet University
058140 Imaret, Merkez, Sivas, Turkey
E-mail. aulutas@cumhuriyet.edu.tr

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Supply chain management determining the competitive position of corporations in a rival and fast-changing environment is one of the favourite topics in engineering economics. Since the performance of suppliers affects the performance of the whole supply chain, the selection of a supplier is a significant problem in supply chain management. When solving a supplier selection problem, there are many criteria needed to be considered. Therefore, the supplier selection problem is a multi-criteria decision making (MCDM) problem. In the supplier selection process, most of the time, expert data is involved, and the judgement of experts includes ambiguous, imprecise and uncertain data. Thus, there are many methods to solve supplier selection issues by utilising fuzzy set theory, grey theory and rough theory to handle vagueness of a problem. This study also proposes a fuzzy model to solve this problem. In this study, an integrated fuzzy MCDM model including the Fuzzy Analytic Hierarchy Process (FAHP) and the Fuzzy Operational Competitiveness RAting (Fuzzy OCRA) will be proposed to solve supplier selection problem for a Turkish textile company. The FAHP is utilised to determine the weights of considered eight criteria and the fuzzy OCRA is used to rank five fabric suppliers concerning their performances on eight measures. This study is original and it contributes to the literature in two ways: first, this study proposes a fuzzy extension of the OCRA method and second, this study offers a new integrated fuzzy MCDM model consisting of the FAHP and the Fuzzy OCRA. By using a real case study of supplier selection problem, it is attempted to indicate the applicability of the new integrated fuzzy MCDM model for actual circumstances.

Keywords: *Supplier Selection; Fuzzy; AHP; OCRA; Textile.*

Introduction

Supply chain management (SCM), which determines the global competitive position of companies in a rival and fast-changing environment, is one of the crucial parts of engineering economics. Supplier selection is described as one of the significant problems in SCM as the supplier performance affects the entire supply chain performance. Due to many criteria involving choosing the most appropriate suppliers, supplier selection can be described as MCDM problem (Ho *et al.,* 2010). Choosing suitable suppliers may help to reduce purchasing cost and improve corporate competitiveness. However, working with an inappropriate supplier may lead to an increased risk in finance and operation (Omurca, 2013). Through the process of choosing the best suppliers, it is possible that the company can build a strategic and collaborative partnership with its suppliers. Thus, to achieve advance and development targets of corporations in a competitive market, corporations need to select the most appropriate suppliers and establish profitable and strategic partnerships with them (You *et al.,* 2015).

In supplier selection problem, experts' evaluations related to supplier performance are one of the critical parts of solving this problem. When a human judgement is involved in the evaluation process, uncertainty becomes an indispensable part of the information (Ghorabaee *et al.,* 2017). Any implemented project, its management techniques (Zavadskas *et al.,* 2009), and used technologies (Zavadskas *et al.,* 2013) have impact on risks and environment of projects and is a reason to change risk management strategy and suppliers. In the literature, there are many methods proposed to handle uncertainty in supplier selection problem. Most of the studies considered the fuzzy set theory, grey theory and rough theory to address the uncertainty issue. This paper also proposes a fuzzy integrated model. The aim of developing this fuzzy integrated model is to handle and address uncertainty issues in supplier selection problem. This paper contributes to the literature in two ways: first, this paper presents a fuzzy extension of Operational Competitiveness RAting (Fuzzy OCRA) and second, this paper also proposes a new fuzzy integrated model containing the Fuzzy Analytic Hierarchy Process (FAHP) and the Fuzzy OCRA.

The organization of the paper is as follows. First, a literature review about the application of the FAHP method to address supplier choice problems and an overview of the use of the OCRA method are provided. Next, basic definitions and operations related to fuzzy set theory, the FAHP and the Fuzzy OCRA are indicated in the methodology section. Then, the application of integrated model is presented. Finally, a brief conclusion and future directions are provided.

Literature Review

Selection among feasible options is a complicated and challenging task, which includes both qualitative and quantitative criteria (Sivilevicius *et al.,* 2008). The use of MCDM techniques can improve the overall sustainability of businesses and organisations, including SCMs (Zavadskas *et al.,* 2016). Recently, many studies have developed various integrated sustainability criteria using a variety of MCDM techniques. Dozens of MCDM techniques are available for decision-makers to solve different problems (Rajasekaran et al., 2016). Some of the classical MCDM techniques are as follows; ELECTRE (Benayoun et al., 1966), PROMETHEE (Brans *et al.,* 1986), SAW (MacCrimmon, 1968), REMBRANDT (Olson *et al.,* 1995), SMART (Edwards, 1977), SMARTER (Edwards and Barron, 1994) and QUALIFLEX (Paelinck, 1978). In addition to classical MCDM methods researcher developed dozens of novel methods and their extensions to solve MCDM problems as: COPRAS (Zavadskas & Kaklauskas, 1996), EDAS (Ghorabaee *et al.,* 2015), CoCoSo (Yazdani *et al.,* 2019), ARAS (Zavadskas & Turskis, 2010), CODAS (Ghorabaee *et al.,* 2016) and WASPAS (Zavadskas *et al.,* 2012). The extensions of these methods were used to solve MCDM problems (Turskis & Zavadskas, 2010a; Turskis & Zavadskas, 2010b; Turskis *et al.,* 2012; Turskis *et al.,* 2015; Zavadskas *et al.,* 2015; Ghorabaee *et al.,* 2016; Ghorabaee *et al.,* 2017). Different ranking results obtained when different MCDM methods applied. Therefore, scientists suggest using of integrated MCDM techniques (Multiplicative Exponential Weighting, Game Theory, SAW, AHP, EDAS, TOPSIS, ARAS, Laplace Rule, Full Multiplicative form, and Bayes Rule) to decide which option is the best (Turskis and Juodagalviene, 2016). Recently, many different MCDM methods are used to solve the supplier selection problem. For example, the best worst method (Rezaei *et al.,* 2016), linguistic MCDM method (Cid-Lopez *et al.,* 2016), fuzzy EDAS (Ghorabaee *et al.,* 2016), TOPSIS-MMD (Aouadni *et al.,* 2017), intuitionistic VIKOR (Zhao *et al.,* 2017), fuzzy Rasch based COPRAS-G (Chatterjee & Kar, 2018) and neutrosophic DEMATEL (Abdel-Basset *et al.,* 2018). The green supplier selection problem takes into account also environmental factors, unlike the common supplier selection problem. There are also many studies proposed MCDM techniques to solve green supplier selection problem (Hu *et al.,* 2015; Sang and Liu, 2016; Qin *et al.,* 2017; Banaeian *et al.,* 2018).

This section will be divided into two sub-sections, which are the FAHP in supplier selection and the applications of the OCRA method.

FAHP in Supplier Selection

The supplier selection problems aim to determine suppliers having the top capability to respond to the requirement of enterprises as supplier selection is a noteworthy problem in SCM for several companies (Shahmardan and Zadeh, 2014). Supplier selection problem as most of the MCDM problems depends on human judgment, including vagueness. Most of the authors in the literature proposed models, including fuzzy numbers, rough numbers, and grey numbers etc. to handle the uncertainty in the problem of supplier selection. This section will deal with using the FAHP to select the best supplier among available options. In general, the methods of identifying the attributes' weights divide into two classifications: subjective and objective methods (Li *et al.,* 2015). The first mentioned methods (subjective) are to identify characteristics' weights in terms of decision makers' subjective judgment or preference, comprising AHP (Saaty, 1977; Saaty, 1980; Peng *et al.,* 2011; Ergu *et al.,* 2013; Kou *et al.,* 2014), Delphi method, the direct rating method (Roberts & Goodwin, 2002) and others. However, both objective and subjective categories have their advantages and disadvantages. Objective methods have a robust theoretical and mathematical basis, and the results of assessment do not depend upon factors of humans, but they do not project decision-makers' subjective preferences and these methods disregard the accumulation of experts' experience and knowledge. To make scientific and accurate judgements, the decision makers are generally needed to assign quantitative or qualitative assessment scores for identifying the relative importance of the assessment criteria and the performance of alternatives. They always are subjective and to determine them, and stakeholders need to know their goals and help of experts. Systematic comparison and measurement of the importance of criteria is the basis for techniques, such as AHP (Saaty, 1977), ANP (Saaty, 1996), SWARA (Kersuliene *et al.,* 2010; Ruzgys *et al.,* 2014) and FARE (Ginevicius, 2011) to determine the relative importance of criteria. Researchers concern about weighting methods for more than fifty years. In 1965, Eckenrode compared efficiency of six methods (two types of Partial Paired Comparisons, Rating, Ranking, Successive Comparisons, and Complete Paired Comparisons) in collecting the judgment data and determined that the values computed by all of the methods correlate (Eckenrode, 1965). Recently, Turskis et al. extended the Eckenrode's rating technique and presented its fuzzy extension (Turskis *et al.,* 2019). The AHP method is the most widely used method among the MCDM methods (Zavadskas *et al.,* 2016). Therefore, the AHP method is verified in many studies and is one of the soundest mathematical techniques to determine criteria weights. The first overview of the AHP method applications presented by Zahedi (Zahedi, 1986). After this study, Vargas (1990) presented the overview of AHP. Also, Ishizaka and Labib (2011) presented the analysis of the main events in the AHP development. Van Laarhoven and Pedrycz published an article on the method's fuzzy extension (Van Laarhoven & Pedrycz, 1983). The paper by Buckley followed it (Buckley, 1985). FAHP has been preferred by many authors in the literature as it can address uncertainty. However, T. L. Saaty was against use of the fuzzy extension of the AHP and stated that the "Fuzzy set practice had become a self-defeating number crunching enterprise to publish papers."(Saaty, 2006). Contrary to Saaty's paper, scholars use the fuzzy extension of the AHP method. Buckley et al. (2001) and Fedrizzi & Krejci (2015) argue that the fuzzy extension of the AHP method is valid, and it should be used by decision-makers to solve real-life problems. For solving the problem of supplier selection, the FAHP has been used in the literature many times (Chan *et al.,* 2008; Aydin and Kahraman, 2010; Kilincci and Onal, 2011). Table 1 indicates some recent studies related to the FAHP and its types used to solve supplier selection problem.

Table 1

Recent Studies in Literature

Authors	Methods	Year
Ghorbani et al.	Fuzzy Kano Model, FAHP and Fuzzy TOPSIS (Technique for order preference by similarity to an ideal solution)	2013
Kannan et al.	FAHP, Fuzzy TOPSIS and Fuzzy Multi-objective Linear Programming (MOLP)	2013
Alinezad et al.	Quality Function Deployment (QFD) and FAHP	2013
Pitchipoo et al.	FAHP and Grey Relational Analysis (GRA)	2013
Li et al.	FAHP and Dynamic Programming	2013
Kaur	Intuitionistic FAHP	2014
Rezaei et al.	Conjunctive Screening Method and FAHP	2014
Junior et al.	FAHP and Fuzzy TOPSIS	2014
Kahraman et al.	Interval Type 2 FAHP	2014
Kar	FAHP and Fuzzy Goal Programming (FGP)	2014
Xu and Liao	Intuitionistic FAHP	2014
Azadnia et al.	FAHP and MOLP	2015
Lee et al.	FAHP and Fuzzy TOPSIS	2015
Gold and Awasthi	FAHP	2015
Plebankiewicz and Kubek	AHP and FAHP	2015
Sultana et al.	Fuzzy Delphi, FAHP and Fuzzy TOPSIS	2015
Oztaysi et al.	Hesitant FAHP	2015
Yadav and Sharma	FAHP	2015
Liao et al.	FAHP, Multi-segment goal programming and Fuzzy Additive Ratio Assessment (ARAS)	2016
Wang Chen et al.	FAHP and Fuzzy TOPSIS	2016
Deepika and Kannan	Intuitionistic FAHP	2016
Ulutas et al.	FAHP, Fuzzy Complex Proportional Assessment (Fuzzy COPRAS) and Fuzzy Linear Programming (FLP)	2016
Asgari et al.	FAHP, FGP and Adaptive neuro-fuzzy inference system (ANFIS)	2016
Secundo et al.	FAHP	2017
Kumar et al.	FAHP and Fuzzy MOLP	2017
Tooranloo and Iranpour	Interval-valued Intuitionistic FAHP	2017
Buyukozkan and Gocer	Intuitionistic FAHP and Intuitionistic Fuzzy Axiomatic Design (FAD)	2017
Zimmer et al.	Input-Output Analysis, Social Risk Assessment Model and FAHP	2017
Awasthi et al.	FAHP and Fuzzy VIKOR (visekriterijumska optimizacija i kompromisno resenje)	2018
Wang et al.	FAHP and Green Data Envelopment Analysis (DEA)	2018

The Applications of OCRA

By comparison with other MCDM methods, the OCRA method was less common used to solve MCDM problems in the literature (Stanujkic *et al.,* 2017). The OCRA method, which was developed by Parkan (1994), was used to address some types of MCDM problems. For instance, Parkan (1996) proposed the OCRA method to analyse the hotel operations' performance. In another attempt, Parkan et al. (1997) measured the performance of teams of software development of a bank by using the OCRA method. Additionally, Parkan and Wu (1998; 2000) proposed the OCRA method to select process in manufacturing sector. In another study, Parkan (2003) used the OCRA method to identify the impact of a point of sale system on drugstore's performance. Furthermore, Parkan (2005) proposed the OCRA method to compare two hotels' operational performances. Besides, the OCRA method was utilised to solve different types of MCDM problems such as hotel selection (Isik & Adali, 2016), material selection (Chatterjee & Chakraborty, 2012), and performance analysis of public banks (Ozbek, 2015). Additionally, Stanujkic et al. (2017) developed Improved Grey OCRA method to handle uncertainty in MCDM problems. The authors applied this method to contractor selection and capital investment project selection problems.

Methodology

In this study, the FAHP and the fuzzy OCRA will be utilised to solve supplier selection problem. This section consists of three sub-sections, which are basic definitions and operations, FAHP and fuzzy OCRA.

Basic Definitions and Operations

Fuzzy set theory has been used to handle information including uncertainty, vagueness and impreciseness in problems in the literature. Some basic concepts and definitions, which are used to develop fuzzy integrated model including the FAHP and the fuzzy OCRA, are stated as follows (Gani and Assarudeen, 2012):

Definition 1. A fuzzy set $\widetilde{D}$ is defined as following equation:

$$\widetilde{D} = \{(x, \mu_D(x)) : x \in D, \mu_D(x) \in [0,1]\} \quad (1)$$

In equation 1, $x \in D$ denotes that elements belonging to the classical set D and $\mu_D(x)$ indicates membership function and it belongs to $[0,1]$.

Definition 2. If $\widetilde{D} = (l_D, m_D, u_D)$ is a fuzzy triangular number, its membership function can be described as follows.

$$\mu_{\widetilde{D}}(x) = \begin{Bmatrix} 0, & for\ x < l_D \\ \frac{x-l_D}{m_D-l_D}, & for\ l_D < x < m_D \\ \frac{u_D-x}{u_D-m_D}, & for\ m_D < x < u_D \\ 0, & for\ x > u_D \end{Bmatrix} \quad (2)$$

Definition 3. Let us assume that $\widetilde{D} = (l_D, m_D, u_D)$ and $\tilde{E} = (l_E, m_E, u_E)$ are two positive triangular fuzzy numbers and z is a positive crisp number. The arithmetic operations using these fuzzy numbers and crisp number are indicated below (Van Laarhoven and Pedrycz, 1983).

i. Addition: $\widetilde{D} + \tilde{E} = (l_D + l_E, m_D + m_D, u_D + u_E)$
ii. Subtraction: $\widetilde{D} - \tilde{E} = (l_D - u_E, m_D - m_E, u_D - l_E)$
iii. Multiplication: $\widetilde{D} \times \tilde{E} = (l_D \times l_E, m_D \times m_E, u_D \times u_E)$
iv. Division: $\widetilde{D}/\tilde{E} = (l_D/u_D, m_D/m_E, u_D/l_E)$
v. Scalar Addition: $\tilde{E} + z = (l_E + z, m_E + z, u_E + z)$
vi. Scalar Division: $\tilde{E}/z = (l_E/z, m_E/z, u_E/z)$

Fuzzy AHP

In this study, the FAHP and the fuzzy OCRA will be used to solve supplier selection problem. The FAHP (Calabrese et al., 2013; Ulutas et al., 2016) will be utilised to identify the weights of criteria. Decision makers utilised terms in Table 2 to compare criteria. The FAHP's steps are as follows.

Step 1.1: First of all, the fuzzy judgements of decision makers are aggregated by following equations.

$$l_{ij} = \min_k(l_{ij}^1, l_{ij}^2, l_{ij}^3 \dots l_{ij}^k) \qquad i,j = 1, \dots n \quad (3)$$

$$m_{ij} = \frac{(m_{ij}^1 + m_{ij}^2 + m_{ij}^3 + \dots + m_{ij}^k)}{k} \qquad i,j = 1, \dots n \quad (4)$$

$$u_{ij} = \max_k(u_{ij}^1, u_{ij}^2, u_{ij}^3 \dots u_{ij}^k) \qquad i,j = 1, \dots n \quad (5)$$

After the aggregation process, comparison matrix ($\tilde{C}$) is structured to compare criteria.

$$\tilde{C} = (\tilde{c}_{ij})_{n \times n} \quad (6)$$

where

$$\tilde{c}_{ij} = (l_{ij}, m_{ij}, u_{ij}) \text{ and } \tilde{c}_{ij}^{-1} = \left(\frac{1}{u_{ij}}, \frac{1}{m_{ij}}, \frac{1}{l_{ij}}\right) \; i,j = 1, \dots n; i \neq j \quad (7)$$

and u_{ij}, m_{ij} and l_{ij} indicate the upper, medium and lower values of $\tilde{c}_{ij}$ respectively.

Table 2

Terms and Fuzzy Scores used in FAHP

Terms	Fuzzy Scores
Absolutely Importance	(8, 9, 10)
Intermediate	(7, 8, 9)
Very Strongly Importance	(6, 7, 8)
Intermediate	(5, 6, 7)
Strong Importance	(4, 5, 6)
Intermediate	(3, 4, 5)
Weakly Importance	(2, 3, 4)
Intermediate	(1, 2, 3)
Equally Importance	(1, 1, 1)

Source: Adapted from Chou and Cheng (2012)

Step 1.2: Comparison matrix ($\tilde{C}$)'s consistency index (CI) and the comparison matrix ($\tilde{C}$)'s consistency ratio (CR) are calculated by using Eqns. 9 and 10 respectively to analyse the consistency of $\tilde{C}$ (Saaty, 1990). If CR of $\tilde{C}$ is less than 0.1, $\tilde{C}$ will be accepted as a consistent comparison matrix. Otherwise, the judgements of decision makers will be collected to structure a new comparison matrix. Each element ($\tilde{c}_{ij}$) of $\tilde{C}$ need to be transformed into crisp numbers using the centre of gravity method to calculate CI of $\tilde{C}$ (Wang and Elhag, 2007):

$$c_{ij} = \frac{l_{ij} + m_{ij} + u_{ij}}{3} \qquad i,j = 1, \dots n \quad (8)$$

By using Eq. 9, CI of $\tilde{C}$ is calculated. In this equation, β_{max} denotes the largest eigenvalue of C. After calculating of CI value, CR of C can be computed by using equation 10. In this equation, RI represents a random index, which is based on the number of criteria (n). In this study, RI equals to 1,4 due to 8 criteria considered.

$$CI = \frac{(\beta_{max} - n)}{n-1} \quad (9)$$

$$CR = (CI/RI) \quad (10)$$

If comparison matrix ($\tilde{C}$) is consistent, the analysis of $\tilde{C}$ is continued by equation 11.

Step 1.3: For each row in $\tilde{C}$ is summed to obtain relative row sum ($\tilde{M}_i$) as:

$$\tilde{M}_i = \sum_{j=1}^{n} \tilde{c}_{ij} = \left(\sum_{j=1}^{n} l_{ij}, \sum_{j=1}^{n} m_{ij}, \sum_{j=1}^{n} u_{ij}\right) i,j = 1, \dots n \quad (11)$$

Step 1.4: To obtain fuzzy weights of i^{th} criterion ($\tilde{w}_i$), the normalisation formula of Wang et al. (2008) is used as:

$$\tilde{w}_i = \frac{\tilde{M}_i}{\sum_{j=1}^{n} \tilde{M}_i} = \left(\frac{\sum_{j=1}^{n} l_{ij}}{\sum_{j=1}^{n} l_{ij} + \sum_{q=1,q\neq j}^{n} \sum_{j=1}^{n} u_{ij}}, \frac{\sum_{j=1}^{n} m_{ij}}{\sum_{q=1}^{n} \sum_{j=1}^{n} m_{ij}}, \frac{\sum_{j=1}^{n} u_{ij}}{\sum_{j=1}^{n} u_{ij} + \sum_{q=1,q\neq j}^{n} \sum_{j=1}^{n} l_{ij}}\right) = (l_i, m_i, u_i) \quad i,j = 1, \dots n \quad (12)$$

Step 1.5: Fuzzy weights of i^{th} criterion ($\tilde{w}_i$) are transformed into crisp weight (w_i) of i^{th} criterion through defuzzification formula (equations 13-16) of Wu and Lee (2007):

$$l_e = m_i/(1 + m_i - l_i) \qquad i = 1,2, \dots .n \quad (13)$$

$$u_e = u_i/(1 + u_i - m_i) \qquad i = 1,2, \dots .n \quad (14)$$

$$z_e = \frac{(l_e \times (1 - l_e)) + (u_e \times u_e)}{(1 - l_e + u_e)} \qquad i = 1,2, \dots .n \quad (15)$$

$$w_i = \min l_e + z_e \times \Delta_{min}^{max} \qquad i = 1,2, \dots .n \quad (16)$$

where $\Delta_{min}^{max} = \max u_e - min l_e$.

Step 1.6: To normalise w_i, equation 17 is used as:

$$w_i^* = \frac{w_i}{\sum_{i=1}^{n} w_i} \qquad i = 1,2, \dots .n \quad (17)$$

After obtaining normalised crisp weight (w_i^*) of i^{th} criterion, these normalised weights are transferred into fuzzy OCRA.

Fuzzy OCRA

The Fuzzy OCRA method consisting of seven steps is used to rank alternatives. Decision makers used terms in Table 3 to identify the performance of alternatives with respect to considered criteria. The steps of the Fuzzy OCRA are presented as below.

Step 2.1: First, the fuzzy scores are aggregated by using equations 3-5 to structure decision matrix ($\tilde{X}$) shown in equation 18.

$$\tilde{X} = (\tilde{x}_{si})_{t \times n} \qquad i = 1,2, \dots .n \quad s = 1,2, \dots .t \quad (18)$$

In this equation, $\tilde{x}_{si}$ denotes fuzzy score of the s^{th} alternative with respect to the i^{th} criterion.

Table 3

Terms and Fuzzy Scores used in Fuzzy OCRA

Terms	Fuzzy Scores
Perfect	(8, 9, 10)
Very High	(7, 8, 9)
High	(6, 7, 8)
Medium High	(5, 6, 7)
Medium	(4, 5, 6)
Medium Low	(3, 4, 5)
Low	(2, 3, 4)
Very Low	(1, 2, 3)
Equal	(1, 1, 1)

Source: Adapted from Fouladgar et al. (2012)

Step 2.2: Fuzzy performance ratings in accordance with non-beneficial criteria are aggregated by following equation 19.

$$\tilde{\bar{I}}_s = \sum_{i \in \Omega_{min}} w_i^* \frac{max_i\, \tilde{x}_{si} - \tilde{x}_{si}}{min_i\, \tilde{x}_{si}} \quad (19)$$

where $\tilde{\bar{I}}_s$ represents the aggregate fuzzy performance rating of the s^{th} alternative calculated based on the non-beneficial criteria.

Step 2.3: Fuzzy linear performance rating of each alternative considered the non-beneficial criteria are evaluated by using following equation.

$$\bar{\tilde{\bar{I}}}_s = \tilde{\bar{I}}_s - min_s \tilde{\bar{I}}_s \quad (20)$$

where $\bar{\tilde{\bar{I}}}_s$ denotes the fuzzy linear performance rating of the s^{th} alternative, calculated based on the non-beneficial criteria.

Step 2.4: Fuzzy performance ratings for the beneficial criteria are aggregated by using following equation.

$$\tilde{\bar{O}}_s = \sum_{i \in \Omega_{max}} w_i^* \frac{\tilde{x}_{si} - min_i \tilde{x}_{si}}{min_i \tilde{x}_{si}} \quad (21)$$

where $\tilde{\bar{O}}_s$ is the aggregate fuzzy performance rating of the s^{th} alternative calculated based on the beneficial criteria.

Step 2.5: Fuzzy linear performance rating of each alternative in accordance with the beneficial criteria are calculated by equation 22.

$$\bar{\tilde{\bar{O}}}_s = \tilde{\bar{O}}_s - min_s \tilde{\bar{O}}_s \quad (22)$$

In equation 22, $\bar{\tilde{\bar{O}}}_s$ presents the fuzzy linear performance rating of the s^{th} alternative, calculated according to the beneficial criteria.

Step 2.6: Fuzzy overall performance rating for each alternative is obtained by using equation 23.

$$\tilde{P}_s = \bar{\tilde{\bar{I}}}_s + \bar{\tilde{\bar{O}}}_s - \min(\bar{\tilde{\bar{I}}}_s + \bar{\tilde{\bar{O}}}_s) \quad i = 1,2,\dots.n \quad s = 1,2,\dots.t \quad (23)$$

where $\tilde{P}_s$ denotes fuzzy overall performance rating of s^{th} alternative.

Step 2.7: In the last step, fuzzy overall performance ratings are converted into crisp overall performance ratings (P_s) by using equation 8. After obtaining crisp overall performance ratings, alternatives are ranked with respect to these ratings. Alternative having the highest rating is selected as the most appropriate alternative. Next section will present application of the fuzzy integrated model.

Application

The fuzzy integrated model applied into a Turkish textile company having more than 15 years of experience in shirt manufacturing market. All fuzzy data were collected by using questionnaires from four managers (factory manager, quality manager, purchasing manager and financial manager) of company. The criteria that were considered in the study were decided with the help of consultation conducted with the managers. After consultation, eight criteria were identified for the supplier selection process. These criteria are Quality (C1), Delivery (C2), Technological Capability (C3), Reputation (C4), Cost (C5), Communication Issues (C6), Technical Assistances (C7) and Volume Flexibility (C8). This company purchases fabric used for producing shirts from five suppliers. The aggregated fuzzy scores of criteria (for FAHP) obtained by using equations 3-5 are indicated in Table 4.

Table 4

Aggregated Fuzzy Scores of Criteria (FAHP)

Criteria \ Criteria	C1	C2	C3	C4
C1	(1, 1, 1)	(1.5, 2.25, 3)	(4, 5, 6)	(4.75, 5.75, 6.75)
C2	(0.333, 0.444, 0,667)	(1, 1, 1)	(3.5, 4.5, 5.5)	(4.5, 5.5, 6.5)
C3	(0.167, 0.2, 0.25)	(0.182, 0.222, 0.286)	(1, 1, 1)	(1.5, 2.5, 3,5)
C4	(0.148, 0.174, 0.211)	(0.154, 0.182, 0.222)	(0.286, 0.4, 0.667)	(1, 1, 1)
C5	(0.667, 0.8, 1)	(1, 1, 1)	(4.75, 5.75, 6.75)	(5.25, 6.25, 7.25)
C6	(0.138, 0.16, 0.19)	(0.16, 0.19, 0.235)	(0.2, 0.25, 0.333)	(0.182, 0.222, 0.286)
C7	(0.16, 0.19, 0.235)	(0.143, 0.167, 0.2)	(0.174, 0.211, 0.267)	(0.667, 0.8, 1)
C8	(0.154, 0.182, 0.222)	(0.133, 0.154, 0.182)	(0.222, 0.286, 0.4)	(0.5, 0.667, 1)
Criteria \ Criteria	**C5**	**C6**	**C7**	**C8**
C1	(1, 1.25, 1.5)	(5.25, 6.25, 7.25)	(4.25, 5.25, 6.25)	(4.5, 5.5, 6.5)
C2	(1, 1, 1)	(4.25, 5.25, 6.25)	(5, 6, 7)	(5.5, 6.5, 7.5)
C3	(0.148, 0.174, 0.211)	(3, 4, 5)	(3.75, 4.75, 5.75)	(2.5, 3.5, 4.5)
C4	(0.138, 0.16, 0.19)	(3.5, 4.5, 5.5)	(1, 1.25, 1.5)	(1, 1.5, 2)
C5	(1, 1, 1)	(5.5, 6.5, 7.5)	(5.5, 6.5, 7.5)	(5.25, 6.25, 7.25)
C6	(0.133, 0.154, 0.182)	(1, 1, 1)	(1, 1.25, 1.5)	(1, 2, 3)
C7	(0.133, 0.154, 0.182)	(0.667, 0.8, 1)	(1, 1, 1)	(2, 3, 4)
C8	(0.138, 0.16, 0.19)	(0.333, 0.5, 1)	(0.25, 0.333, 0.5)	(1, 1, 1)

Aggregated fuzzy scores are analysed with the FAHP to obtain normalised weights of criteria (w_i^*). Table 5 presents the normalised weights of criteria. According to Table 5, the order of criteria with respect to their weights are C5 > C1 > C2 > C3 > C4 > C7 > C6 >C8. After obtaining the weights of criteria, performance of suppliers are calculated by using the Fuzzy OCRA. Table 6 shows that the aggregated fuzzy scores for the Fuzzy OCRA.

Table 5

The Normalised Weights of Criteria

Criteria	Weights
C1	0.190
C2	0.182
C3	0.122
C4	0.091
C5	0.198
C6	0.074
C7	0.078
C8	0.065

Table 6

The Aggregated Fuzzy Scores for Fuzzy OCRA

Suppliers \ Criteria	C1	C2	C3	C4
S1	(4.75, 5.75, 6.75)	(5.5, 6.5, 7.5)	(5, 6, 7)	(3.75, 4.75, 5.75)
S2	(3.75, 4.75, 5.75)	(4.5, 5.5, 6.5)	(4.25, 5.25, 6.25)	(5.75, 6.75, 7.75)
S3	(4.5, 5.5, 6.5)	(4.75, 5.75, 6.75)	(4.75, 5.75, 6.75)	(4.25, 5.25, 6.25)
S4	(3, 4, 5)	(4.25, 5.25, 6.25)	(3.5, 4.5, 5.5)	(3, 4, 5)
S5	(5, 6, 7)	(3, 4, 5)	(4.5, 5.5, 6.5)	(3.25, 4.25, 5.25)
Suppliers \ Criteria	**C5**	**C6**	**C7**	**C8**
S1	(1.25, 2.25, 3.25)	(1, 2, 3)	(4.75, 5.75, 6.75)	(5, 6, 7)
S2	(1.5, 2.5, 3.5)	(1.75, 2.75, 3.75)	(4.5, 5.5, 6.5)	(5.25, 6.25, 7.25)
S3	(1, 2, 3)	(1.75, 2.75, 3.75)	(4, 5, 6)	(5.75, 6.75, 7.75)
S4	(2, 3, 4)	(1.5, 2.5, 3.5)	(4.75, 5.75, 6.75)	(5.25, 6.25, 7.25)
S5	(1.75, 2.75, 3.75)	(1.25, 2.25, 3.25)	(4.5, 5.5, 6.5)	(5.5, 6.5, 7.5)

Aggregated fuzzy scores are analysed with the Fuzzy OCRA to rank suppliers with respect to their performances in criteria. Table 7 presents the results of the Fuzzy OCRA. According to Table 7, S1 having the highest crisp overall performance rating (P_S) is the best supplier and this is followed by S3, S2, S5 and S4 respectively.

Table 7

The Results of Fuzzy OCRA

Suppliers \ Results	$\tilde{\bar{I}}_s$	$\tilde{\bar{\bar{I}}}_s$	$\tilde{\bar{O}}_s$
S1	(-0.060, 0.266, 0.796)	(-0.597, 0.195, 1.013)	(-0.113, 0.102, 0.748)
S2	(-0.115, 0.197, 0.705)	(-0.652, 0.126, 0.922)	(-0.148, 0.050, 0.643)
S3	(-0.096, 0.221, 0.736)	(-0.633, 0.150, 0.953)	(-0.115, 0.099, 0.742)
S4	(-0.217, 0.071, 0.537)	(-0.754, 0, 0.754)	(-0.175, 0.009, 0.563)
S5	(-0.160, 0.141, 0.629)	(-0.697, 0.070, 0.846)	(-0.152, 0.043, 0.631)
Suppliers \ Results	$\tilde{\bar{\bar{O}}}_s$	$\tilde{P}_s$	P_s
S1	(-0.676, 0.093, 0.923)	(-2.765, 0.288, 3.428)	0.317
S2	(-0.711, 0.041, 0.818)	(-2.855, 0.167, 3.232)	0.181
S3	(-0.678, 0.090, 0.917)	(-2.803, 0.240, 3.362)	0.266
S4	(-0.738, 0, 0.738)	(-2.984, 0, 2.984)	0
S5	(-0.715, 0.034, 0.806)	(-2.904, 0.104, 3.144)	0.115

Conclusion

Working with inappropriate suppliers can lead a decrease in the performance of entire supply chain as suppliers' performance affect entire supply chain performance. Thus, supplier selection is a significant problem. As several criteria are considered in the supplier selection, this problem is called an MCDM problem. In this study, a new integrated fuzzy MCDM model including the FAHP and the Fuzzy OCRA proposed to handle and solve supplier selection problem for a Turkish textile company. A real case study of this problem is utilised to indicate the practical applicability of integrated fuzzy MCDM model. The FAHP is utilised to obtain the weights of criteria considered and the Fuzzy OCRA is used to rank suppliers. Supplier 1 (S1) is selected as the most appropriate supplier according to the results of proposed model. This paper contributes the literature in two ways: first, this paper presents fuzzy extension of OCRA (Fuzzy OCRA) and second, this paper also proposes a new fuzzy integrated model including the FAHP and the Fuzzy OCRA. Future studies can use the Fuzzy OCRA to handle other MCDM problems, such as warehouse location selection, third party logistics provider selection and machine selection etc.

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