Fuzzy Multicriteria Model for Ranking Suppliers in Manufacturing Company

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Abstract
By using the methods of multi-criteria analysis it is possible to make decisions which have significant influence on companies' business. The aim of this paper is to evaluate different suppliers using the integrated model that recognizes a combination of fuzzy AHP (Analytical Hierarchy Process) and the COPRAS method. Based on six criteria, the expert team was formed to compare them, so determination of their significance is being done with fuzzy AHP method. Expert team also compares suppliers according to each criterion and on the base of triangular fuzzy numbers. Based on their inputs, COPRAS method is used to estimate potential solutions. Suggested model accomplishes certain advantages in comparison with previously used traditional models which were used to make decisions about evaluation and choice of supplier. It is vital to make the right decision when selecting a supplier, because the optimal choice ensures lower cost and higher quality of the product itself, and therefore more competitiveness in the market.

Keywords: Multi-criteria decision making, supplier evaluation, Fuzzy AHP, COPRAS, procurement, research, decision support systems
JEL classification: C44, C52, C61, D22, D81, M11, L6

Introduction
Company today must strive to enlarge the quality of product itself, so the end user is satisfied with provides services, what would make him a loyal user. Due to above mentioned it is necessary, during the first phase of logistics, i.e. purchasing logistics, to commit good evaluation and choice of supplier, what can largely influence the forming of product's final price and in that way accomplish significant effect in complete supply chain. It is possible to accomplish the above mentioned if evaluation is being done based on multi-criteria decision making that includes large number of criteria and expert's estimation of their relative significance.

Multi-criteria analysis is rapidly expanding, especially during the past several years, and therefore, big number of problems is being solved nowadays using methods from that area. The AHP method was previously used to address the problem of supplier selection, whether in the conventional form or in a combination with fuzzy logic, for example in Chen et al.(2006), supplier selection for the textile company

Ertugrul and Karakasoglu (2006), the area of production Chan and Kumar(2007), the area of production TFT-LCD Lee (2009), electronic procurement Benyoucef and Canbolat (2007), in washing machine company Kilincci and Onal (2011), in a gear motor company Ayhan (2013).

For the purpose of suppliers' evaluation, this paper uses the combination of these methods of multi-criteria analysis. Fuzzy AHP (FAHP) had been used for determination of significance of criteria, while COPRAS method was used for suppliers ranking.

This paper is structured as follows. Section 2 shows the fundamentals of conventional analytic hierarchy process, FAHP and Copras method. Section 3 describes main part of this paper: practical example. Section 4 show results of multicriteria model. Section 5 is discussion and section 6 sets out the conclusions and the paper concludes with the references.

Methodology

Conventional AHP method

Analytic hierarchy process is created by Thomas Saaty (Saaty, 1980) and according to him (Saaty, 2008) AHP is a measurement theory which is dealing with pairs comparing and which relies on expert opinion in order to perform the priority scale. Parts of AHP method are problem decomposition, where the goal is located at the top, followed by criteria and sub-criteria, and at the end of the hierarchy are potential solutions. More details on the AHP are found in the book of Saaty and Vargas (2012).Some key and basic steps in the AHP Methodology are: define the problem, expand the problem taking all the actors into account, the objective and the outcome, identificate criteria with influence on the outcome, structure problem in already explained hierarchy, compare each element with each other at the appropriate level, calculate the maximum value of its own vector, index and degree of consistency.

Chang's extent analysis

The theory of fuzzy sets was first introduced by Zadeh (1965), whose application enables decision makers to effectively deal with the uncertainties. Fuzzy sets used generally triangular, trapezoidal and Gaussian fuzzy numbers, which convert uncertain fuzzy numbers. Triangular fuzzy numbers (TFN), which were used in this work are marked as (l_{ij}, m_{ij}, u_{ij}). The parameters (l_{ij}, m_{ij}, u_{ij}) are the smallest possible value, the most promising value and highest possible value that describes a fuzzy event, respectively. Let's assume that X={x_1, x_2,...,x_n} is number of objects, and U={u_1, u_2,...,u_m} is number of aims.

According to the methodology of extended analysis set up by Chang (1996), for each object an extended goal analysis is made. Values of the extended analysis "m" for each object can be represented as follows:

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

where $M_{g,}^{j}\ j = 1,2, \dots m.,$ are TFN.

Chang's expanded analysis includes following steps:

Step 1: Values of fuzzy extension for the i-ti object are given by the equation:

$$S_i = \sum_{j=1}^{n} M_{gi}^{j} \times \left[\sum_{\mathrm{i}=1}^{\mathrm{n}} \sum_{\mathrm{j}=1}^{\mathrm{m}} M_{gi}^{j} \right]^{-1} \tag{2}$$

In order to obtain expression

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (3)$$

it is necessary to perform additional fuzzy operations with "m" values of the extended analysis, which is represented by the following expressions:

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

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

Then it is necessary to calculate the inverse vector:

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

Step 2: Possibility degree $S_b > S_a$ is defined:

$$V(S_b \geq S_a) = \begin{cases} 1, & ako\ je\ m_b \geq m_a \\ 0, & ako\ je\ \ l_a \geq u_b \\ \dfrac{l_a - u_b}{(m_b - u_b) - (m_a - l_a)}, & otherwise \end{cases} \quad (7)$$

where „d“ ordinate of a largest cross-section in point D between μ_{Sa} and $i\mu_{Sb}$.

To compare S_1 and S_2, both values $V(S_1 \geq S_2)$ i $V(S_2 \geq S_1)$ are needed.

Step 3: Level of possibility for convex fuzzy number to be greater than „k“ convex number S_i (i =1,2,...,k) can be defined as follows:

$$V(S_i \geq S_1, S_2, \ldots, S_k) = \min V(S_i \geq S_k), \quad = w'(S_i) \quad (8)$$

$$d'(A_i) = \min V(S_i \geq S_k), k \neq i, k = 1,2,\ldots,n \quad (9)$$

The weight vector is given by the following expression:

$$W' = (\mathrm{d}'(A_1), \mathrm{d}'(A_2), \ldots., \mathrm{d}'(A_n))^T, \quad (10)$$

Step 4: Through normalization, the weight vector is reduced to the phrase:

$$W = (\mathrm{d}(A_1), \mathrm{d}(A_2), \ldots., \mathrm{d}(A_n))^T, \quad (11)$$

where W does not represent fuzzy number.

COPRAS method

The COPRAS (Complex Proportional ASsessment) method is presented by Zavadskas et al.(1994). Description of COPRAS methods and possibilities of its application are published in a large number of papers Zavadskas et al. (2001), Kaklauskaset al. (2006). The determination of significance and priority of alternatives, by using COPRAS method, can be expressed concisely using next steps:

Step 1: Set the initial decision matrix,

$$X = [x_{ij}] \quad (12)$$

where x_{ij} is the assessment value of i-th alternative in respect to j-th criterion.

Step 2: Normalize the decision matrix using linear normalization procedure.

About normalization procedures can found in Ginevičius (2007). For normalization in COPRAS method the following formula is used:

$$R = [r_{ij}] = \frac{x_{ij}}{\sum_{i=1}^{m} x_{ij}} \quad (13)$$

Step 3: Determine the weighted normalized decision matrix D, by using the following equation:

$$D = [x_{ij}] = r_{ij} \cdot w_{j,} \quad i = 1, \dots, m, \quad j = 1, \dots., n \quad (14)$$

wherer_{ij} is the normalized performance value of i-th alternative on j-th criterion and w_j is the weight of j-th criterion. The sum of weighted normalized values of each criterion is always equal to the weight for that criterion:

$$\sum_{i=1}^{m} y_{ij} = w_j \; (15)$$

Step 4: In this step the sums of weighted normalized values are calculated for both the beneficial and non-beneficial criteria by using the following equations:

$$S_{+i} = \sum_{j=1}^{n} y_{+ij} \quad (16)$$

$$S_{-i} = \sum_{j=1}^{n} y_{-ij} \quad (17)$$

where y_{+ij} and y-ij are the weighted normalized values for the beneficial and non-beneficial criteria, respectively.

Step 5: The relative weight of i-th alternative is calculated as follows:

$$Q_i = S_{+i} + \frac{\min_i S_{-i} \sum_{i=1}^{m} S_{-i}}{S_{-i} \sum_{i=1}^{m} \frac{\min_i S_{-i}}{S_{-i}}} \; (18)$$

Step 6: Determine the priority order of alternatives. The priority order of compared alternatives is determined on the basis of their relative weight.

$$A^* = \left\{ A_i \middle| \max_i Q_i \right\} (19)$$

Numerical example

Criteria applied in this study are: price of materials, pipe length, delivery time, way of payment, mode of delivery and quality hat are still in operation are marked with C_1-C_6 respectively. Therefore, there are three criteria, quantitatively expressed and three criteria which are qualitative.Upon criteria establishing, the expert team comprised of three members compared them on the base of triangular fuzzy scale.

Table 1
Comparison criteria by three experts

		C_1	C_2	C_3	C_4	C_5	C_6
C_1	E_1	(1,1,1)	(2/3,1,2)	(1/2,2/3,1)	(1/2,1,3/2)	(1/2,1,3/2)	(2/3,1,2)
	E_2	(1,1,1)	(2/3,1,2)	(2/3,1,2)	(1,3/2,2)	(1/2,1,3/2)	(2/3,1,2)
	E_3	(1,1,1)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1/2,1,3/2)	(1/2,1,3/2)	(2/7,1/3,2/5)
C_2	E_1	(1/2,1,3/2)	(1,1,1)	(2/3,1,2)	(1,3/2,2)	(1,3/2,2)	(1,1,1)
	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)
	E_3	(1,3/2,2)	(1,1,1)	(2/3,1,2)	(3/2,2,5/2)	(3/2,2,5/2)	(2/5,1/2,2/3)
C_3	E_1	(1,3/2,2)	(1/2,1,3/2)	(1,1,1)	(3/2,2,5/2)	(3/2,2,5/2)	(1/2,1,3/2)
	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)
	E_3	(3/2,2,5/2)	(1/2,1,3/2)	(1,1,1)	(2,5/2,3)	(2,5/2,3)	(1/2,2/3,1)
C_4	E_1	(2/3,1,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(2/3,1,2)
	E_2	(1/2,2/3,1)	(2/5,1/2,2/3)	(2/5,1/2,2/3)	(1,1,1)	(1/2,1,3/2)	(2/5,1/2,2/3)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)
C_5	E_1	(2/3,1,2)	(1/2,2/3,1)	(2/5,1/2,2/3)	(1,1,1)	(1,1,1)	(1/2,2/3,1)
	E_2	(2/3,1,2)	(1/2,2/3,1)	(1/2,2/3,1)	(2/3,1,2)	(1,1,1)	(1/2,2/3,1)
	E_3	(2/3,1,2)	(2/5,1/2,2/3)	(1/3,2/5,1/2)	(1,1,1)	(1,1,1)	(2/7,1/3,2/5)
C_6	E_1	(1/2,1,3/2)	(1,1,1)	(2/3,1,2)	(1/2,1,3/2)	(1,3/2,2)	(1,1,1)
	E_2	(1/2,1,3/2)	(1,1,1)	(1,1,1)	(3/2,2,5/2)	(1,3/2,2)	(1,1,1)
	E_3	(5/2,3,7/2)	(3/2,2,5/2)	(1,3/2,2)	(5/2,3,7/2)	(5/2,3,7/2)	(1,1,1)

Source: Authors

Results

After previous describes methodology this section show results of research and their calculation. Fuzzy important weight of the criteria is calculated by taking geometric mean of the responses of the experts Lee (2009), this is shown in Table 2.

Table 2
Fuzzy important weight of the criteria calculated by taking geometric mean

	C_1	C_2	C_3	C_4	C_5	C_6
C_1	(1,1,1)	(0.606,0.874, 1.587)	(0.511,0.693, 1.817)	(0.630,1.145, 1.651)	(0.5,1,1.5)	(0.503,0.694, 1.170)
C_2	(0.630,1.145 1.651)	(1,1,1)	(0.763,1,1.587)	(1.310,1.817, 2.31)	(1.145,1.651, 2.154)	(0.737,0.794, 0.874)
C_3	(0.909,1.442, 1.957)	(0.630,1,1.31)	(1,1,1)	(1.651,2.154, 2.657)	(1.442,1.957, 2.466)	(0.630,0.874, 1.145)
C_4	(0.606,0.784, 1.587)	(0.431,0.550, 0.763)	(0.376,0.464, 0.606)	(1,1,1)	(0.794,1, 1.145)	(0.424,0.550, 0.811)
C_5	(0.667,1,2)	(0.464,0.606, 0.874)	(0.405,0.511, 0.693)	(0.874,1,1.26)	(1,1,1)	(0.415,0.529, 0.737)
C_6	(0.855,1.442, 1.990)	(1.145,1.260, 1.357)	(0.874,1.145, 1.587)	(1.233,1.817, 2.359)	(1.357,1.890, 2.41)	(1,1,1)

Source: Authors

Example calculation of geometric mean for C_{12} is:
n-= (2/3x2/3x1/2)1/3=0,606;
n=(1x1x2/3) 1/3=0,874;
n+=(2x2x1) 1/3=1,587

To determine Fuzzy combination expansion for each one of the criteria, first we calculate $\sum_{j=1}^{n} M_{gi}^{j}$ value for each row of the matrix.

C1=(1+0.606+0.511+0.630+0.5+0.503; 1+0.874+0.693+1.145+1+0.694; 1+1.587+1.817 +1.651+1.5+1.17)=(3.75; 5.406; 8.725) etc.

The $\sum_{i=1}^{n}\sum_{j=1}^{n} M_{gi}^{j}$ value is calculated as:
(3.75; 5.406; 8.725)+(5.585; 7.407; 9.576) +(6.262; 8.427; 10.535)+(3.631; 4.348; 5.912)+(3.825; 4.646; 6.564)+(6.464; 8.554; 10.703)=(29.517; 38.788; 52.015)

Then, $S_i = \sum_{j=1}^{n} M_{gi}^{j} \times \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$

S_1=(3.75; 5.406; 8.725)x(1/52.015;1/38.788; 1/29.517)=(0.072; 0.139; 0.296) etc.

Now, the V values (preference order) are calculated using these vectors.

$$V(S_1 \geq S_2) = \frac{0.107 - 0.296}{(0.139 - 0.296) - (0.191 - 0.107)} = 0.784$$

$$V(S_1 \geq S_3) = \frac{0.12 - 0.296}{-0.157 - 0.097} = 0.693$$

$$V(S_1 \geq S_4) = 1;$$

$$V(S_1 \geq S_5) = 1$$

$$V(S_1 \geq S_6) = \frac{0.124 - 0.296}{-0.157 - 0.097} = 0.677$$

The priorities of weights are calculated using:
d'=(C_1)min(0.784; 0.693; 1; 1; 0.677)=0.677;
d'=(C_2)min(1; 0.887; 1; 1; 0.870)=0.870
d'=(C_3)min(1; 1; 1; 1; 0.983)=0.983;
d'=(C_4)min(0.826; 0.541; 0.432; 0.941; 0.411)=0.411
d'=(C_5)min(0.888; 0.618; 0.513; 1; 0.492)= 0.492;
d'=(C_6)min(1; 1; 1; 1; 1; 1)=1

After the equation is applied (10), weight values are obtained, and from the equation (11) normalized weights of criteria are received:
W'=(0.677; 0.870; 0.983; 0.411; 0.492; 1);
W=(0.15; 0.20; 0.22; 0.09; 0.11; 0.23)

By applying previously described steps of COPRAS method, results represented by the following table were obtained.

Table 3
Ranking of alternatives

	S_+	S_-	Q_i	Rank
S_1	0.111	0.031	0.226	2
S_2	0.138	0.035	0.240	1
S_3	0.143	0.062	0.200	3
S_4	0.107	0.047	0.183	4
S_5	0.131	0.193	0.149	5

Source: Authors

Discussion

After determination of criteria, it is clear that the third and the sixth criteria are almost equally relevant, i.e. for the company which is subject of research, delivery time and material quality represents the most important criteria during the evaluation of potential suppliers. In table 3, it is visible that the supplier no. 2 has the highest value and represents the best solution according to previously conducted steps.

Conclusion

In its work, expert team which is integral part of the company where the research was done chose suppliers which are competing for the job of securing the purchase system, out of which supplier 2 is most suitable solution. The primary objective and the contribution of this paper the possibility of establishing the long-term cooperation with selected supplier, which will enable the realization of additional benefits.

The evaluation of suppliers may be based on different criteria not only in this, which we used in this paper. Further research will include more criterions for evaluation and combination fuzzy AHP and COPRAS-G methods.

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