Supplier Selection for Automotive Industry Using Multi-Criteria Decision Making Techniques

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Abstract: This paper is aimed to suggest an approach for evaluating and selecting suppliers for an automotive manufacturing company, based on multi-criteria decision making methods. As an initial step, main criteria and sub-criteria which affect the evaluation and selection process of a supplier are identified. Secondly, DEMATEL approach is implemented to the main criteria in order to expose cause and affect interrelationship among them which is required by Analytic Network Process (ANP) method. At the third step, ANP methodology is applied for calculating the weights of each sub-criterion. After obtaining the weights of the sub-criteria, alternative suppliers are evaluated and ranked using TOPSIS method. At the end, the supplier with the highest performance indices is selected as the best supplier.

Key words: Supplier selection, multi-criteria decision making, DEMATEL, ANP, TOPSIS.

Introduction

An automotive manufacturing corporation is a global organization. It requires various technologies to produce a vehicle such as electronics, mechanics, engine technology, tire technology and so on. Each of these technologies is an industry in itself which needs special expertise. It is almost impossible for a main manufacturer to own all the technologies needed to produce such vehicle. Thus, as Razmi et al. (2009) indicated, these organizations must concentrate on their main operations and organizational goals, and outsource all non-strategic operations. To be competitive in a global marketplace, especially in automotive industry, supplier evaluation and selection is a vital process. Proper purchasing strategies, and especially proper suppliers, can play a key role in management of successful organizations and it is worthwhile to invest on making appropriate decision on supplier selection (Razmi et al., 2009).

The studies on supplier selection have begun in 1960s. Dickson (1966) has made an analysis of vendor selection and identified 23 different factors such as quality, delivery, price, performance history, warranties, technical capability, etc. His study showed that quality is the most important criteria and it is followed by delivery and then performance history.

There are several approaches for supplier evaluation and selection. Some of these approaches are data envelopment analysis (Wu et al., 2007; Saen, 2007; Ross et al., 2006), mathematical programming (Ng, 2008; Karpak et al., 2001; Wadhwa and Ravindran, 2007) such as linear programming, goal programming, multi-objective programming, analytic hierarchy process (Hou and Su, 2007), analytic network process (Gencer and Gürpinar, 2007), case-based reasoning (Choy and Lee, 2002) and genetic algorithms (Ding et al., 2005). Ho et al. (2010) mentions that there are several articles reviewing the literature about supplier evaluation and selection models up to 2000 and they have extended them by surveying the multi-criteria supplier evaluation and selection approaches from 2000 to 2008.

The selection process mainly involves evaluation of different alternative suppliers based on different criteria. This process is essentially considered as a multiple criteria decision-making (MCDM) problem which is affected by different tangible and intangible criteria (Önüt et al., 2009).

In this study, hybrid multi-criteria decision making approach is proposed and implemented for evaluating and selecting the most suitable supplier in automotive industry. This approach includes DEMATEL technique for revealing cause and effect interaction among criteria, analytic network process for obtaining the weights of the sub-criteria based on the result of the DEMATEL method, and TOPSIS method for evaluating and ranking the alternative suppliers according to the sub-criteria and the weights. Main criteria and their related sub-criteria are investigated and determined as given in Fig. 1.

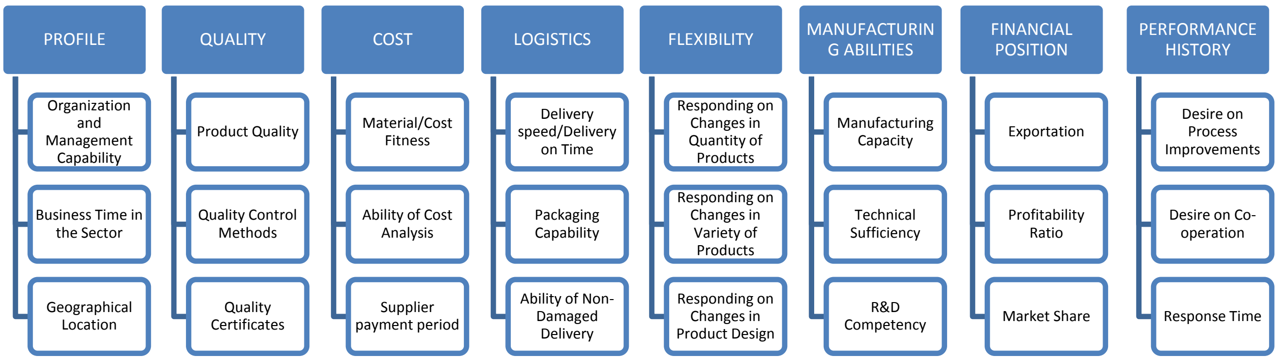

Fig. 1. Main criteria and related sub-criteria for supplier selection model.

Literature Review

A number of alternative approaches have been proposed for supplier evaluation and selection, called mathematical programming models, multiple attribute decision aid methods, cost-based methods, statistical and probabilistic methods, combined methodologies and other methods (Önüt et al., 2009). However, supplier selection process mainly involves evaluation of several alternatives based on different criteria. For that reason, multi-criteria decision-making (MCDM) approaches are used to deal with the selection process.

Extensive multi-criteria decision making approaches have been proposed for supplier selection, such as the analytic hierarchy process (AHP), analytic network process (ANP), case-based reasoning (CBR), data envelopment analysis (DEA), fuzzy set theory, genetic algorithm (GA), mathematical programming, simple multi-attribute rating technique (SMART), and their hybrids (Ho et al., 2010).

Gencer and Gürpinar (2007) developed a model aiming the usage of ANP in supplier selection owning to the evaluation of the relations between supplier selection criteria in a feedback systematic. The proposed model was implemented in an electronic company. Demirtas and Üstün (2008) proposed an integrated approach of ANP and multi-objective mixed integer linear programming for considering both quantitative and qualitative factors in choosing the best suppliers and defining the optimum quantities among selected suppliers to maximize the total value of purchasing and minimize the budget and defect rate. They evaluated four different plastic molding firms working with a refrigerator plant according to fourteen criteria that are involved in the four clusters: benefits, opportunities, costs and risks (BOCR).

Ming-Lang et al. (2009) proposed a novel hierarchical evaluation framework to assist the expert group to select the optimum supplier with ANP and choquet integral with reference to multiple conflicting criteria in supply chain management system (SCMS).

Dalalah et al. (2011) proposed a hybrid fuzzy model for group multi-criteria decision making. A modified fuzzy DEMATEL model was presented to deal with the influential relationship between the evaluation criteria. In addition, a modified TOPSIS model was proposed to evaluate the alternatives according to each criterion. Hsu and Hu (2009) presented an ANP approach to incorporate the issue of hazardous substance management (HSM) into supplier selection. In their study they proposed a multi-criteria decision model in which identification of criteria of HSM competence is categorized into four dimensions.

There are also studies concerning fuzzy set theory integrated with multi-criteria decision making methods. Some of the literature review about fuzzy multi-criteria decision making applications is given in the following part of this section.

Kilincci and Onal (2011), investigated the supplier selection problem of a washing machine company in Turkey, and a fuzzy AHP based methodology was used to select the best supplier firm providing the most customer satisfaction for the criteria determined. Lee (2009) also proposed fuzzy AHP to evaluate various aspects of suppliers and selecting them under fuzzy environment which incorporates the BOCR concept. A case study of backlight unit supplier selection was presented for a TFT-LCD manufacturer in Taiwan. Vinodh et al. (2011) used fuzzy ANP approach for the supplier selection process and the case study has been carried out in an Indian electronics switches manufacturing company. Razmi et al. (2009) aimed to develop a fuzzy ANP model to evaluate the potential suppliers and select the best one(s) with respect to the vendor important factors. They have augmented the model with a non linear programming model to elicit eigenvectors from fuzzy comparison matrices.

Chang et al., (2011) claims that their study pioneers in using the fuzzy decision-making trial and evaluation laboratory (DEMATEL) method to find influential factors in selecting suppliers. They designed a fuzzy DEMATEL questionnaire which is sent to seventeen professional purchasing personnel in the electronic industry.

Önüt et al, (2009) developed a supplier evaluation approach based on the ANP and TOPSIS methods to help a telecommunication company in the GSM sector in Turkey under the fuzzy environment. Boran et al. (2009) proposed TOPSIS method combined with intuitionistic fuzzy set to select appropriate supplier in group decision making environment. Intuitionistic fuzzy weighted averaging (IFWA) operator is utilized to aggregate individual opinions of decision makers for rating the importance of criteria and alternatives. They have given a numerical example for supplier selection to illustrate application of intuitionistic fuzzy TOPSIS method. Wang et al. (2009) simplified the complicated metric distance method which was introduced by Chen and Chang (2005) and they proposed an algorithm to modify Chen's (2000) Fuzzy TOPSIS. From experimental verification, Chen directly assigned the fuzzy numbers $\tilde{1}$and $\tilde{0}$ as fuzzy positive ideal solution (PIS) and negative ideal solution (NIS). They claimed that Chen's method sometimes violates the basic concepts of traditional TOPSIS. Thus their study proposed fuzzy hierarchical TOPSIS, which can provide more objective and accurate criterion weights, while simultaneously avoiding the problem of Chen's Fuzzy TOPSIS.

Methodology

In this study, hybrid DEMATEL, ANP and TOPSIS methods are implemented in a combined way. Thus these methods are explained in this section.

DEMATEL Method

The Battelle Geneva Institute created DEMATEL in order to solve difficult problems that mainly involve interactive man model techniques as well as to measure qualitative and factor linked aspects of societal problems. (Gabus and Fontela, 1972). It analyzes the influential status and strength between the factors and convert them into an explicit structural mode of a system (Lin and Wu, 2008). The mathematical concepts are then evolved and adapted in many academic fields, such as industrial strategy analysis, competence evaluation, solution analysis, selection, and etc. It has been proven as a useful method to solve complicated problems.

The DEMATEL methodology construction process is described below;

Step 1: Generating the direct-relation matrix.

A group of experts is asked to make pairwise comparisons in terms of influence between criteria. An evaluation scale of 0, 1, 2, 3, and 4 is used for comparison, representing "no influence", "low influence", "medium influence", "high influence" and "very high influence", respectively. The results of these evaluations form an $n \times n$ matrix for each respondent expert where the x_{ij}^{k} is the score given by the *k*th expert indicating the influential level that factor *i* has on factor *j*. To incorporate all opinions from *K* experts, the direct-relation matrix *A* is calculated using Eq. (1) by averaging each expert's scores.

$$a_{ij} = \frac{1}{K}\sum_{k=1}^{K} x_{ij}^{k} \qquad (1)$$

Step 2: Normalizing the direct-relation matrix.

The normalized direct-relation matrix *M* can be obtained by normalizing *A* using Eqs. (2) and (3).

$$M = k.A \qquad (2)$$

$$k = Min\left(\frac{1}{\max_{1\le i\le n}\sum_{j=1}^{n} a_{ij}}, \frac{1}{\max_{1\le j\le n}\sum_{i=1}^{n} a_{ij}}\right) \tag{3}$$

Step 3: Obtaining the total-relation matrix.

The total-relation matrix *T* can be obtained by using Eq. (4), where *I* denotes the identity matrix.

$$\mathrm{T} = \mathrm{M} + \mathrm{M}^2 + \mathrm{M}^3 + \ \ldots = \sum_{\mathrm{i}=1}^{\infty} \mathrm{M}^{\mathrm{i}} = \mathrm{M}(\mathrm{I} - \mathrm{M})^{-1} \tag{4}$$

where $T = \left[t_{ij}\right]_{n\times n}, i, j = 1, 2, \ldots, n.$

Step 4: Compute the dispatcher group and receiver group.

The vectors *D* and *R* represent the sum of rows and columns of matrix *T* respectively, as shown in Eqs. (5) and (6). *D* + *R* value indicates the degree of importance that the corresponding criterion plays in the entire system. The factor having greater value of *D* + *R* has more interrelationships with other factors. On the other hand, criteria having positive values of *D* – *R* are on the cause group and dispatches effects to the other criteria. On the contrary, criteria having negative values of *D* – *R* are on the effect group and receive effects from the other criteria.

$$D = \sum_{j=1}^{n} t_{ij} \tag{5}$$

$$R = \sum_{i=1}^{n} t_{ij} \tag{6}$$

Step 5: Set up a threshold value to obtain the causal diagram.

Since the total-relation matrix *T* provides the information on how one criterion affects another, decision maker group should set up a threshold value in order to filter out some negligible relationships. This way enables the decision maker to choose only the relationships greater than the threshold value and to map the cause-effect relationship accordingly. The causal diagram can be acquired by mapping the dataset of the (*D* + *R*, *D* – *R)* where the horizontal axis *D* + *R* and the vertical axis *D* – *R*.

ANP Method

Analytic network process (ANP) is the general form of analytic hierarchy process (AHP) and was proposed by Saaty (1996) to overcome the problem of interrelation among criteria or factors. It provides measurements to derive ratio scale priorities for the distribution of influence between factors and groups of factors in the decision (Saaty, 2001). The feedback structure does not have the top to bottom form of a hierarchy but looks more like a network, with cycles connecting its components of elements, which we can no longer call levels, and with loops that connect a component to itself (Saaty, 2005).

Through a supermatrix, whose entries are themselves matrices of column priorities, the ANP synthesizes the outcome of dependence and feedback within and between clusters of elements (Yang and Chang, 2012). The initial supermatrix must be transformed to a matrix in which each of its columns sums to unity. For this reason, this matrix must be normalized by the cluster’s weight to get the column sums to unity. Hence, the weighted supermatrix is obtained (Saaty and Vargas, 1998). The supermatrix representation is given in Fig. 2.

$$W = \begin{array}{cc} & \begin{array}{cccc} C_1 & C_2 & \cdots & C_m \\ e_{11} \cdots e_{1n_1} & e_{21} \cdots e_{2n_2} & \cdots & e_{m1} \cdots e_{mn_m} \end{array} \\ \begin{array}{cc} C_1 & \begin{array}{c} e_{11} \\ \vdots \\ e_{1n_1} \end{array} \\ C_2 & \begin{array}{c} e_{21} \\ \vdots \\ e_{2n_2} \end{array} \\ \vdots & \vdots \\ C_m & \begin{array}{c} e_{m1} \\ \vdots \\ e_{mn_m} \end{array} \end{array} & \begin{pmatrix} W_{11} & W_{12} & \cdots & W_{1m} \\ W_{21} & W_{22} & \cdots & W_{2m} \\ \vdots & \vdots & \ddots & \vdots \\ W_{m1} & W_{m2} & \cdots & W_{mm} \end{pmatrix} \end{array}$$

Fig. 2. The supermatrix representation

Pairwise comparisons between the criteria can be implemented according to dependency relationships which are obtained from DEMATEL approach in order to generate local weights assessing relative importance value using a scale of 1 (equal importance) to 9 (extreme importance).

TOPSIS Method

The technique for order preference by similarity to an ideal solution (TOPSIS) was proposed by Hwang and Yoon (1981) and expanded by Chen and Hwang (1992). The main principle in TOPSIS method is that, in a graph, any chosen alternative should have the shortest distance from the ideal solution and the farthest distance from the negative-ideal solution (Opricovic and Tzeng, 2004).

The TOPSIS technique is implemented using the following steps (Triantaphyllou, 2000; Opricovic and Tzeng, 2004):

Step 1. Calculate the normalized decision matrix. D is the decision matrix which refers to *n* alternatives that are evaluated in terms of *m* criteria.

$$D = \begin{bmatrix} x_{11} & \cdots & x_{1n} \\ \vdots & \ddots & \vdots \\ x_{m1} & \cdots & x_{mn} \end{bmatrix}$$

R is the normalized decision matrix and r_{ij} is an element of *R*. The normalized value r_{ij} is calculated as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{j=1}^{m} x_{ij}^2}}, \qquad i = 1, \dots, m; \quad j = 1, \dots, n \tag{7}$$

Then the *R* matrix is formed as follows:

$$R = \begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix}$$

Step 2. Calculate the weighted normalized decision matrix. V is the weighted normalized decision matrix and v_{ij} is an element of *V*. The weighted normalized value v_{ij} is calculated as:

$$v_{ij} = w_i r_{ij}, \qquad i = 1, \dots, m; \quad j = 1, \dots, n \tag{8}$$

where w_i is the weight of the *i*th criterion and $\sum_{i=1}^{m} w_i = 1$. Then the *V* matrix is formed as follows:

$$V = \begin{bmatrix} v_{11} & \cdots & v_{1n} \\ \vdots & \ddots & \vdots \\ v_{m1} & \cdots & v_{mn} \end{bmatrix}$$

Step 3. Determine the positive-ideal and the negative-ideal solutions. The positive-ideal donated as A^* and the negative-ideal donated as A^- alternatives are defined as:

$$A^* = \{v_1^*, \dots, v_m^*\} = \left\{\left(\max_j v_{ij} | i \in I'\right), \left(\min_j v_{ij} | i \in I''\right)\right\} \tag{9}$$

$$A^- = \{v_1^-, \dots, v_m^-\} = \left\{\left(\min_j v_{ij} | i \in I'\right), \left(\max_j v_{ij} | i \in I''\right)\right\} \tag{10}$$

where I' is associated with benefit criteria, and I'' is associated with cost criteria.

A^* indicates the most preferable solution and similarly A^- indicates the least preferable solution.

Step 4. Calculate the separation measure. The separation of each alternative from the positive-ideal solution and negative-ideal solution are calculated using *n*-dimensional Euclidean distance method. The distances from the positive-ideal solution and negative-ideal solution can be calculated as follows:

$$D_j^* = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^*\right)^2}, \qquad j = 1, \dots, n, \tag{11}$$

$$D_j^- = \sqrt{\sum_{i=1}^{m} \left(v_{ij} - v_i^-\right)^2}, \qquad j = 1, \dots, n. \tag{12}$$

Step 5. Calculate the relative closeness to the ideal solution. The relative closeness of alternative A_j with respect to A^* is calculated as follows:

$$C_j^* = D_j^- / \left(D_j^* + D_j^-\right), \qquad j = 1, \dots, n \tag{13}$$

where $0 \leq C_j^* \leq 1$.

If $A_j = A^*$ then C_j^* is equal to 1 and if $A_j = A^-$ then C_j^* is equal to 0.

Step 6. Rank the preference order. The best alternative can be now decided according to the preference rank order of C_j^*. Therefore, the best alternative is the one that has the shortest distance to the ideal solution.

Implementation

The case study is implemented in an automotive factory in Bursa, Turkey. First, interactions among the main criteria are obtained asking experts working for the company and using DEMATEL approach. Then ANP method is implemented according to the experts' opinions in order to calculate the local weights of the sub-criteria. After determining the weights, four SMEs are investigated and graded according to each sub-criterion. As a result, each SME is scored implementing TOPSIS method.

The evaluation of one of the experts in terms of the effect between the main criteria is given in Table 1. Similarly, all of the evaluations from the rest of the experts are obtained and then averages of numbers are calculated using Eq. (1). The average values are given in Table 2. The normalized direct-relation matrix is obtained using Eqs. (2 and 3). After calculating the normalized direct-relation matrix, the total-relation matrix is obtained using Eqs. (4, 5, and 6). The total-relation matrix is shown in Table 3. Then (D + R) and (D – R) values are calculated and also shown in Table 3. The threshold value is determined as 0.51 according to the experts' opinions. The values above the threshold are represented in bold in the table which gives the cause and effect relationship among the main criteria.

Table 1. Evaluation of an expert in terms of effect among the criteria

	C1	C2	C3	C4	C5	C6	C7	C8
C1	0	3	2	2	2	3	4	4
C2	3	0	4	2	1	3	3	2
C3	1	4	0	2	2	2	4	1
C4	3	1	3	0	1	1	3	2
C5	2	3	4	2	0	4	2	2
C6	3	3	4	1	4	0	3	2
C7	3	1	1	2	1	4	0	2
C8	3	3	2	4	2	3	2	0

Table 2. The initial direct-relation matrix (average values of the evaluations of the experts)

	C1	C2	C3	C4	C5	C6	C7	C8
C1	0.00	3.33	2.33	2.33	2.33	3.33	3.33	4.00
C2	2.67	0.00	3.00	1.67	1.67	1.67	3.67	2.00
C3	1.33	3.33	0.00	1.33	1.67	1.67	3.67	1.33
C4	2.67	1.33	2.67	0.00	1.00	1.00	3.00	1.67
C5	1.67	2.33	3.00	1.33	0.00	3.33	2.00	1.33
C6	2.33	2.33	4.00	1.33	4.00	0.00	3.00	1.67
C7	2.67	1.33	1.00	2.00	1.00	4.00	0.00	1.67
C8	3.67	2.67	2.67	4.00	2.67	2.67	2.33	0.00

Table 3. The total-relation matrix

	C1	C2	C3	C4	C5	C6	C7	C8	D	D+R	D-R
C1	0.485	**0.613**	**0.620**	0.504	**0.517**	**0.650**	**0.728**	**0.563**	4.679	8.467	0.892
C2	0.489	0.372	**0.527**	0.387	0.394	0.477	**0.615**	0.400	3.660	7.407	-0.086
C3	0.390	0.461	0.351	0.331	0.353	0.426	**0.557**	0.331	3.199	7.294	-0.896
C4	0.426	0.371	0.445	0.262	0.312	0.382	**0.512**	0.336	3.046	6.192	-0.101
C5	0.418	0.446	0.505	0.344	0.304	0.508	**0.517**	0.346	3.388	6.648	0.127
C6	**0.513**	**0.518**	**0.617**	0.403	**0.526**	0.449	**0.641**	0.418	4.086	8.102	0.069
C7	0.446	0.388	0.410	0.362	0.340	**0.518**	0.407	0.351	3.221	7.873	-1.431
C8	**0.620**	**0.576**	**0.620**	**0.555**	**0.515**	**0.607**	**0.677**	0.391	4.559	7.693	1.425
R	3.788	3.746	4.095	3.147	3.260	4.016	4.652	3.134			
Threshold value = 0.51											

According to the cause and effect relationship extracted from the DEMATEL method, the weights of the sub-criteria are calculated following ANP approach in order to form the supermatrix. For example, since “C1: Profile” effects “C2: Quality”, the evaluation of importance of sub-criteria of C2 (C21, C22 and C23) in terms of C11 is given in Table 4. Then geometric average is taken after obtaining evaluations of the rest of the experts in order to calculate the local weights. The result is shown in Table 5.

The rest of the local weights are calculated in the same way based on the interaction obtained from the DEMATEL. The supermatrix is formed for the sub-criteria and the local weights calculated are placed into the matrix accordingly. The unweighted supermatrix is presented in Table 6. Then, unweighted supermatrix is normalized to transform it to the weighted supermatrix in which each of its columns sums to 1. The power of the weighted supermatrix is taken until the values of each column are stabilized and equal. These calculations are implemented using MATLAB software and the limit supermatrix is obtained which is given in Table 7. Any column of the matrix shows the weights of corresponding sub-criteria.

Table 4. Pairwise comparison matrix of an expert in terms of C11: Organization and Management Capability

	K21	K22	K23
K21	1.00	0.33	0.20
K22	3.00	1.00	0.33
K23	5.00	3.00	1.00

Table 5. Geometric average of all the expert evaluations, and the weights

	K21	K22	K23	**Wi**
K21	1.00	0.26	0.17	**0.089**
K22	3.87	1.00	0.33	**0.272**
K23	5.92	3.00	1.00	**0.639**

Table 6. The unweighted supermatrix

	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43	C51	C52	C53	C61	C62	C63	C71	C72	C73	C81	C82	C83
C11	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.705	.677	.534	.000	.000	.000	.694	.509	.516
C12	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.145	.180	.341	.000	.000	.000	.219	.307	.325
C13	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.150	.143	.125	.000	.000	.000	.088	.185	.158
C21	.089	.686	.623	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.443	.534	.000	.000	.000	.106	.724	.633
C22	.272	.079	.147	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.443	.341	.000	.000	.000	.260	.083	.106
C23	.639	.235	.230	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.114	.125	.000	.000	.000	.633	.193	.260
C31	.114	.357	.720	.680	.443	.659	.000	.000	.000	.000	.000	.000	.000	.000	.000	.680	.452	.150	.000	.000	.000	.552	.443	.235
C32	.364	.149	.088	.225	.443	.170	.000	.000	.000	.000	.000	.000	.000	.000	.000	.094	.458	.705	.000	.000	.000	.332	.114	.407
C33	.522	.493	.192	.094	.114	.170	.000	.000	.000	.000	.000	.000	.000	.000	.000	.225	.089	.145	.000	.000	.000	.116	.443	.358
C41	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.659	.623	.652
C42	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.170	.147	.097
C43	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.170	.230	.252
C51	.092	.111	.623	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.671	.114	.073	.000	.000	.000	.623	.089	.698
C52	.341	.328	.230	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.130	.299	.228	.000	.000	.000	.147	.272	.216
C53	.567	.561	.147	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.198	.587	.699	.000	.000	.000	.230	.639	.086
C61	.116	.213	.292	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.125	.680	.213	.105	.633
C62	.332	.418	.511	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.534	.094	.418	.540	.260
C63	.552	.369	.197	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.333	.341	.225	.369	.355	.106
C71	.193	.213	.333	.321	.690	.680	.097	.098	.300	.434	.677	.659	.225	.252	.341	.106	.448	.190	.000	.000	.000	.213	.341	.330
C72	.178	.369	.333	.104	.134	.094	.652	.413	.427	.106	.143	.170	.094	.097	.125	.260	.282	.449	.000	.000	.000	.418	.125	.168
C73	.629	.418	.333	.575	.176	.225	.252	.489	.272	.459	.180	.170	.680	.652	.534	.633	.270	.361	.000	.000	.000	.369	.534	.502
C81	.199	.199	.106	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C82	.312	.489	.260	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C83	.489	.312	.633	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000

Table 6. The limit supermatrix

	C11	C12	C13	C21	C22	C23	C31	C32	C33	C41	C42	C43	C51	C52	C53	C61	C62	C63	C71	C72	C73	C81	C82	C83
C11	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043	.043
C12	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014	.014
C13	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009	.009
C21	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032	.032
C22	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027	.027
C23	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020	.020
C31	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057	.057
C32	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040	.040
C33	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021	.021
C41	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001	.001
C42	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C43	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
C51	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024	.024
C52	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018	.018
C53	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036	.036
C61	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135	.135
C62	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097
C63	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097	.097
C71	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078	.078
C72	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100	.100
C73	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138	.138
C81	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002	.002
C82	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004	.004
C83	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005	.005

After calculating the weights of the sub-criteria, TOPSIS method is implemented, which is going to score the suppliers investigated. Four suppliers are investigated and assigned a score to each supplier for each criterion. The scores are given in Table 7.

Tablo 7. Evaluation of the suppliers in terms of the sub-criteria

	A	B	C	D
C11	85	90	75	87
C12	17	21	5	9
C13	350	120	540	40
C21	90	65	83	77
C22	85	72	74	75
C23	5	3	6	4
C31	91	92	79	81
C32	75	57	61	86
C33	60	60	30	45
C41	88	92	83	78
C42	80	88	91	85
C43	83	90	95	87
C51	86	93	67	78
C52	75	87	65	80
C53	55	59	63	68
C61	80	90	65	70
C62	74	85	65	78
C63	52	50	58	65
C71	40	55	70	80
C72	25	37	30	43
C73	17	10	20	15
C81	70	63	88	76
C82	80	90	75	72
C83	5	6	7	9

Table 7 is normalized by using Eq. (7) and multiplied by the weights obtained from ANP calculations, by using Eq. (8). The new table is called as the weighted normalized decision matrix. Then, the positive-ideal A^* and the negative-ideal A^- values are calculated by using Eq. (9 and 10). See Table 8 for the weighted normalized decision matrix, and for the values A^* and A^-. Minimum value of sub-criterion C13: Geographic location is selected as the positive-ideal A^* value and maximum value of related row is selected as the negative-ideal A^- value since the closer supplier location is better for the company.

The separation or distances of each alternative from the positive-ideal solution and negative-ideal solution are calculated using Eq. (11 and 12). Then, the relative closeness of alternative A_j with respect to A^* is calculated as Eq. (13). Table 9 shows the results and the rank of each supplier.

It is found out that, alternative D is the best supplier among the alternative suppliers. The rest of the alternatives are ranked as C, A and B.

Tablo 8. The weighted normalized decision matrix and positive and negative ideal solutions

	A	B	C	D	A^*	A^-
C11	.0218	.0231	.0193	.0223	.0231	.0193
C12	.0085	.0105	.0025	.0045	.0105	.0025
C13	.0051	.0017	.0078	.0006	.0006	.0078
C21	.0182	.0132	.0168	.0156	.0182	.0132
C22	.0148	.0126	.0129	.0131	.0148	.0126
C23	.0106	.0064	.0127	.0085	.0127	.0064
C31	.0301	.0304	.0261	.0268	.0304	.0261
C32	.0212	.0161	.0172	.0243	.0243	.0161
C33	.0126	.0126	.0063	.0095	.0126	.0063
C41	.0005	.0006	.0005	.0005	.0006	.0005
C42	.0001	.0001	.0001	.0001	.0001	.0001
C43	.0002	.0002	.0002	.0002	.0002	.0002
C51	.0129	.0139	.0100	.0117	.0139	.0100
C52	.0086	.0100	.0075	.0092	.0100	.0075
C53	.0163	.0175	.0187	.0202	.0202	.0163
C61	.0701	.0789	.0570	.0614	.0789	.0570
C62	.0475	.0545	.0417	.0500	.0545	.0417
C63	.0445	.0428	.0496	.0556	.0556	.0428
C71	.0248	.0341	.0434	.0496	.0496	.0248
C72	.0363	.0537	.0435	.0624	.0624	.0363
C73	.0735	.0433	.0865	.0649	.0865	.0433
C81	.0010	.0009	.0012	.0011	.0012	.0009
C82	.0019	.0022	.0018	.0017	.0022	.0017
C83	.0019	.0023	.0027	.0034	.0034	.0019

Tablo 9. Final performance indices of supplier alternatives.

	D_j^*	D_j^-	C_j^*	Rank
A	.0422	.0363	.4626	3
B	.0500	.0351	.4125	4
C	.0367	.0488	.5708	2
D	.0298	.0469	.6111	1

Conclusion

The purpose of this paper is to suggest an approach for evaluating and selecting suppliers for an automotive company, based on hybrid multi-criteria decision making methods. First, main and sub-criteria that affect the evaluation and selection process of a supplier are identified. Then, DEMATEL approach is implemented to the main criteria in order to obtain cause and affect interaction among them which is required by ANP method. After deriving cause and effect interrelationship, ANP methodology is applied for calculating the weights of each sub-criterion. And then, as far as obtaining the weights of the sub-criteria, alternative suppliers are evaluated and ranked using TOPSIS method. At the end, the supplier with the highest performance indices is selected as the best supplier. The proposed approach can be implemented in different multi-criteria decision making problems.

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