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Full Length Research Paper

A hybrid fuzzy multiple criteria decision making (MCDM) approach to combination of materials selection

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The selection of the appropriate combination of materials for a manufacturing company is one of the important points to achieving high competitiveness in the market. Besides, an appropriate choice of materials is very important as it helps to reach optimum production rate and efficiency. Today's market offers many more choices for materials alternatives. There are also many factors one should consider as part of the appropriate combination of materials selection process, including productivity, wastage, cost, style, etc., consequently, evaluation procedures involve several objectives and it is often necessary to compromise among possibly conflicting tangible and intangible factors. For dealing with these problems, multiple criteria decision making (MCDM) has been found to be a useful approach to solve this kind of problem. Most of the MCDM models are basically mathematical and disregard qualitative and subjective considerations. The application of fuzzy set theory allows incorporating the vague and imprecise linguistic terms and qualitative information into the decision process. This paper devises a fuzzy hybrid analytical hierarchy process (AHP) and technique for order preference by similarity to ideal solution (TOPSIS) approach to the problem of thesis subject selection. Fuzzy AHP is used to formulate and calculate the weight of each criterion, and fuzzy TOPSIS is proposed to prioritize combination material alternatives from the best to the worst ones. A case study on Kaach Company was put forward to illustrate the performance of the proposed methodology.

Key words: Combination of material, material selection, fuzzy analytical hierarchy process (AHP), fuzzy technique for order preference by similarity to ideal solution (TOPSIS).

INTRODUCTION

Selecting an appropriate combination of materials is one of the most complicated and time consuming problems for manufacturing companies, due to many feasible alternatives and conflicting objectives. The determination and evaluation of positive and negative characteristics of one alternative relative to others is a complex task. Selection process of suitable combination of materials has to begin with a critical evaluation of processes on the shop floor by considering an array of quantitative, qualitative and economic concerns. Therefore, the decision maker (engineer or manager) needs a lot of criteria to be considered and a large amount of data to be analyzed for a suitable and effective evaluation. Consequently, using proper combination of materials in a manufacturing facility can improve the production process, provide effective utilization of resources, increase productivity and enhance system flexibility, repeatability, reliability and satisfying more customers.

Many potential criteria, such as productivity, wastage, cost, style and compatibility with machines must be considered in the selection procedure of a combination of material. Therefore, combination of material selection can be viewed as a multiple criteria decision making (MCDM) problem in the presence of many quantitative and

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qualitative criteria. The MCDM methods deal with the process of making decisions in the presence of multiple criteria or objectives (Aghdaie and Behzadian, 2010). A decision maker (DM) is required to select among quantifiable or non-quantifiable and multiple criteria.

The DM's evaluations on qualitative criteria are always subjective and thus, vague. Besides, it is precisely a very difficult task to describe the preference of one criterion over another. The evaluation data of the combination of material alternatives suitability for various subjective criteria and the weights of the criteria are usually expressed in linguistic terms .This makes fuzzy logic a more useful approach to solve this kind of problems.

MCDM methods were used by many researchers for selection problems. One of the well-known MCDM methods is analytical hierarchy process (AHP) that was developed by Saaty (1980). AHP is a simple decision-making tool to cope with complex, unstructured and multi-attributed problems, and AHP is essential for the formalization of a complex problem using a hierarchical structure and utilizes pair-wise comparisons (Güngör et al., 2009). Besides, AHP is one of the best weight calculation procedures. The technique for order preference by similarity to ideal solution (TOPSIS) is one of the famous classical MCDM methods, and was first proposed in by Hwang and Yoon (1981). This technique is based on the concept that the ideal alternative has the best level for all criteria, whereas the negative ideal is the one with all the worst criteria values (Önüt et al., 2008). In fuzzy TOPSIS, criteria values are represented by fuzzy numbers (Chen, 2000).

Although, there were a number of publications that have looked into the combination of materials, but there are no studies that used MCDM methods for this selection .This study aims at filling this gap. Our study proposes a combined fuzzy AHP and fuzzy TOPSIS methodology for evaluating and selecting most suitable combination of material alternatives for a manufacturing company as a real world application. Fuzzy TOPSIS is used to select a combination of material alternative and the fuzzy AHP is applied to calculate criteria weights.

The rest of the paper is organized as follows. The proposed model is described under "the proposed model". The theoretic descriptions for the fuzzy AHP and fuzzy TOPSIS methods are presented in "fuzzy AHP procedure" and "fuzzy TOPSIS", respectively. In "case study", a real-world case study is given to prove the applicability of the proposed method on a medium sized manufacturing enterprise in Amol, Iran. The obtained results and discussion are also discussed, and finally, the paper was concluded.

THE PROPOSED MODEL

In this paper, we proposed a combined fuzzy AHP and TOPSIS approach for the combination of materials selection problem. After determining the necessity of the new combination of materials in the facility, candidate combinations of material alternatives for the related manufacturing process are identified. Then, the evaluation criteria of the specified combination of materials that the related managers and engineers consider most important are determined. Based on these criteria, the required data utilized in the comparisons are collected from the related DMs again. After constructing the evaluation criteria hierarchy, the criteria weights are calculated by applying the fuzzy AHP method. The performances of the alternatives corresponding to the criteria are performed using fuzzy set theory. Finally, fuzzy TOPSIS is employed to achieve the final ranking results. The detailed descriptions of the major steps are elaborated in the following.

Fuzzy AHP procedure

In the proposed methodology, AHP with its fuzzy extension, namely fuzzy AHP, is applied to obtain more decisive judgments by prioritizing the machine tool selection criteria and weighting them in the presence of vagueness. There are various fuzzy AHP applications in the literature that propose systematic approaches for the selection of alternatives and justification of problem by using fuzzy set theory and hierarchical structure analysis. DMs usually find it more convenient to express interval judgments than fixed value judgments due to the fuzzy nature of the comparison process (Bozdog et al., 2003). This study concentrates on a fuzzy AHP approach introduced by Chang (1992), in which triangular fuzzy numbers are preferred for pair-wise comparison scale. Extent analysis method is selected for the synthetic extent values of the pair-wise comparisons. Some papers published used the fuzzy AHP procedure based on extent analysis method and showed how it can be applied to selection problems (Kahraman et al., 2003, 2004). The outlines of the fuzzy sets and extent analysis method for fuzzy AHP are as follows.

A fuzzy number is a special fuzzy set F = {(x, μ_F (x), x ∈R}, where x takes its values on the real line, R: $-\infty \leq x \leq \infty$ and μ_F (x) is a continuous mapping from R to the closed interval $[0,1]$. A triangular fuzzy number (TFN) expresses the relative strength of each pair of elements in the same hierarchy and can be denoted as M = (l, m, u), where l ≤ m ≤ u. The parameters l, m and u indicate the smallest possible value, the most promising value and the largest possible value, respectively in a fuzzy event. Triangular type membership function of M fuzzy number can be described as shown in Equation 1.

$$\mu_M(x) = \begin{cases} 0 & x < l \\ (x - l)/(m - l) & l \leq x \leq m \\ (u - x)/(u - m) & m \leq x \leq u \\ 0 & x > u \end{cases} \quad (1)$$

A linguistic variable is a variable whose values are expressed in linguistic terms. The concept of a linguistic variable is very useful in dealing with situations, which are too complex or not well defined to be reasonably described in conventional quantitative expressions (Zadeh, 1965; Zimmermann, 1991; Kaufman and Gupta, 1991).

In this study, the linguistic variables utilized in the model can be expressed in positive TFNs for each criterion as shown in Figure 1. The linguistic variables matching TFNs and the corresponding membership functions are provided as shown in Table 1. Proposed methodology employs a Likert Scale of fuzzy numbers starting from

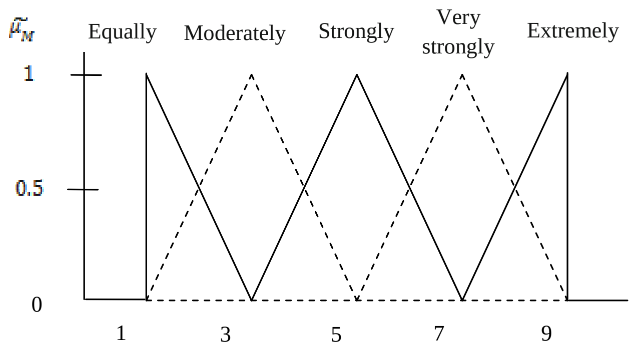

Figure 1. Linguistic variables for the importance weight of each criterion.

Table 1. Linguistic variables describing weights of the criteria and values of ratings.

Linguistic scale for importance	Fuzzy numbers for fuzzy AHP	Membership function	Domain	Triangular fuzzy scale (l, m, u)
Just equal	-	-	-	(1.0, 1.0, 1.0)
Equal importance	$\tilde{1}$	$\mu_M(x) = (3 - x)/(3 - 1)$	$1 \le x \le 3$	(1.0, 1.0, 3.0)
Weak importance of one over another	$\tilde{3}$	$\mu_M(x) = (x - 1)/(3 - 1)$	$1 \le x \le 3$	(1.0, 3.0, 5.0)
Essential or strong importance	$\tilde{5}$	$\mu_M(x) = (5 - x)/(5 - 3)$ $\mu_M(x) = (x - 3)/(5 - 3)$	$3 \le x \le 5$ $3 \le x \le 5$	(3.0, 5.0, 7.0)
Very strong importance	$\tilde{7}$	$\mu_M(x) = (7 - x)/(7 - 5)$ $\mu_M(x) = (x - 5)/(7 - 5)$	$5 \le x \le 7$ $5 \le x \le 7$	(5.0, 7.0, 9.0)
Extremely preferred	$\tilde{9}$	$\mu_M(x) = (9 - x)/(9 - 7)$ $\mu_M(x) = (x - 7)/(9 - 7)$	$7 \le x \le 9$ $7 \le x \le 9$	(7.0, 9.0, 9.0)
If factor i has one of the above numbers assigned to it when compared to factor j, then j has the reciprocal value when compared with i			Reciprocals of the above $M_1^{-1} \approx (1/u_1, 1/m_1, 1/l_1)$	

$\tilde{1}$ to $\tilde{9}$ symbolized with tilde (~) for the fuzzy AHP approach. Table 1 depicts AHP and fuzzy AHP comparison scale, considering the linguistic variables that describe the importance of criteria and alternatives to improve the scaling scheme for the judgment matrices.

By using TFNs via pair-wise comparison, the fuzzy judgment matrix $\tilde{A}$ (a_{ij}) can be expressed mathematically as shown in Equation 2:

$$\tilde{A} = \left\{ \begin{matrix} 1 & \tilde{a}_{12} & \tilde{a}_{13} & \cdots & \tilde{a}_{1(n-1)} & \tilde{a}_{1n} \\ \tilde{a}_{21} & 1 & \tilde{a}_{23} & \cdots & \tilde{a}_{2(n-1)} & \tilde{a}_{2n} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ \tilde{a}_{(n-1)1} & \tilde{a}_{(n-1)2} & \tilde{a}_{(n-1)3} & \cdots & 1 & \tilde{a}_{(n-1)n} \\ \tilde{a}_{n1} & \tilde{a}_{n2} & \tilde{a}_{n3} & \cdots & \tilde{a}_{n(n-1)} & 1 \end{matrix} \right. \quad (2)$$

The judgment matrix $\tilde{A}$ is an n $\times$ n fuzzy matrix containing fuzzy numbers $\tilde{a}_{ij}$.

$$\tilde{a}_{ij} = \begin{cases} 1, & i = j \\ \tilde{1}, \tilde{3}, \tilde{5}, \tilde{7}, \tilde{9} \text{ or } \ldots \tilde{1}^{-1}, \tilde{3}^{-1}, \tilde{5}^{-1}, \tilde{7}^{-1}, \tilde{9}^{-1}, & i \neq j \end{cases} \quad (3)$$

Let X = $\{x_1, x_2, \ldots, x_n\}$ be an object set, whereas $U = \{u_1, u_2, \ldots, u_m\}$ is a goal set. According to fuzzy extent analysis, the method can be performed with respect to each object for each corresponding goal, g_i, resulting in m extent analysis values for each object, given as $M_{gi}^1, M_{gi}^2, \ldots, M_{gi}^m$, i =1, 2, . . ., n, where all the M_{gi}^{j} $(j = 1,2,\ldots,m)$ are TFNs representing the performance of the object x_i with regard to each goal u_j. The steps of Chang (1992) extent analysis can be detailed as follows (Kahraman et al., 2003, 2004; Bozbura et al., 2007):

Step 1: The fuzzy synthetic extent value with respect to the ith object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^{j} \otimes \left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} \quad (4)$$

To obtain $\sum_{j=1}^{m} M_{gi}^{j}$, perform the fuzzy addition operation m extent analysis values for a particular matrix such that operation m extent analysis values for a particular matrix would be,

$$\sum_{j=1}^{m} M_{gi}^{j} = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j\right) \quad (5)$$

$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1}$, perform the fuzzy addition operation of

M_{gi}^{j} (j = |1,2, . . . ,m) values such that:

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

and then compute the inverse of the vector in Equation 6 such that:

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i}\right) \quad (7)$$

Step 2: The degree of possibility of $M_2 \geq M_1$ is defined as:

$$V(M_2 \geq M_1) = \sup_{y \geq x}\left[\min(\mu_{M_1}(x), \mu_{M_2}(y))\right] \quad (8)$$

and can be equivalently expressed as follows:

$$V(M_2 \geq M_1) = hgt(M_1 \cap M_2) = \mu_{M2}(d) = \begin{cases} 1, & if\ m_2 \geq m_1, \\ 0, & if\ l_1 \geq u_2, \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)}, & otherwise \end{cases} \quad (9)$$

where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2}. To compare M_1 and M_2, both values of V ($M_2 \geq M_1$) and V ($M_2 \geq M_1$) are required (Figure 2).

Step 3: The degree of possibility of a convex fuzzy number to be greater than k convex fuzzy numbers M_i $(i = 1,2,\ldots,k)$ can be defined by Equation 10.

V(M ≥ M_1, M_2, . . ., M_k) = V [(M ≥ M_1) and V [(M ≥ M_2) and . . . and
(M ≥ M_k)] = min V (M ≥ M_i), $i = 1,2,3,\ldots,k.$ (10)

Assume that:

$$d'(A_i) = \min V(S_i \geq S_k) \quad (11)$$

For $k = 1,2,\ldots,n;\ k \neq i$. Then, the weight vector is given in Equation 12:

$$W' = \left(d'(A_1), d'(A_2), \ldots, d'(A_n)\right)^T \quad (12)$$

where $A_i (i = 1,2,\ldots,n)$ has n elements.

Step 4: The normalized weight vectors are defined as:

$$W = \left(d(A_1), d(A_2), \ldots, d(A_n)\right)^T \quad (13)$$

where W is a non fuzzy number.

Fuzzy TOPSIS

In the following subsection, some basic important definitions of fuzzy sets from Zimmermann (1991), Buckley (1985), Zadeh (1965), Kaufmann and Gupta (1991), Yang and Hung (2007) and Chen et al. (2006) are reviewed and summarized. It is often difficult for a DM to assign a precise performance rating to an alternative for the criteria under consideration. The merit of using a fuzzy approach is to assign the relative importance of criteria using fuzzy numbers instead of precise numbers. Here, extends TOPSIS to the fuzzy environment.

Definition 1

Let ã = (l_1, m_1, u_1) and b̃ = (l_2, m_2, u_2) be two TFNs, then the vertex method is defined to calculate the distance between them, as Equation 14:

$$d(\tilde{a}, \tilde{b}) = \sqrt{\frac{1}{3}\left[(l_1 - l_2)^2 + (m_1 - m_2)^2 + (u_1 - u_2)^2\right]} \quad (14)$$

The problem can be described by following sets:

(1) A set of J possible candidates called $A = \{A_1, A_2, \ldots, A_j\}$

(2) A set of n criteria, $C = \{C_1, C_2, \ldots, C_i\}$

(3) A set of performance ratings of A_j $(j = 1,2,3,\ldots,J)$ with

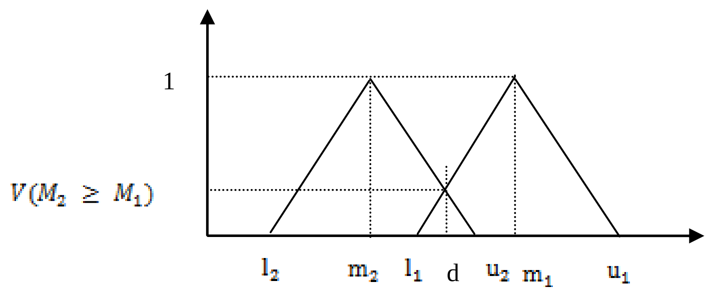

Figure 2. Intersection point "d" between two fuzzy numbers M_1 and M_2.

respect to criteria $C_i \ (i = 1, 2, 3 \ldots, n)$ called $\tilde{X} = \{\tilde{x}_{ij} \quad i = 1, 2, 3, \ldots, n, \ j = 1, 2, 3, \ldots, J\}$ (4) A set of importance weights of each criterion $w_i \ (i = 1, 2, 3, \ldots, n)$

As stated in the sets, problem matrix format can be expressed as follows:

$$\tilde{X} = \begin{bmatrix} \tilde{x}_{11} & \tilde{x}_{12} & \cdots & \tilde{x}_{1n} \\ \tilde{x}_{21} & \tilde{x}_{22} & \cdots & \tilde{x}_{2n} \\ \vdots & \vdots & \cdots & \vdots \\ \tilde{x}_{J1} & \tilde{x}_{J2} & \cdots & \tilde{x}_{Jn} \end{bmatrix}$$

Definition 2

Considering the different importance values of each criterion, the weighted normalized fuzzy-decision matrix is constructed as:

$\tilde{V} = [\tilde{v}_{ij}]_{n \times j} \quad i = 1, 2, \ldots, n, \ j = 1, 2, \ldots, J$ where

$$\tilde{v}_{ij} = \tilde{x}_{ij} \ (.) w_i \tag{15}$$

According to the briefly summarized fuzzy theory, fuzzy TOPSIS steps can be outlined as follows:

Step 1: Choose the linguistic ratings $(\tilde{x}_{ij} \quad i = 1, 2, 3 \ldots, n, j = 1, 2, 3 \ldots, J)$ for alternatives with respect to criteria. The fuzzy linguistic rating $(\tilde{x}_{ij})$ preserves the property that the ranges of normalized TFNs belong to [0.1]; thus, there is no need for normalization. Let $\tilde{x}_{ij} = (a_{ij}, b_{ij}, c_{ij}), \ \tilde{x}_j^- = (a_j^-, a_j^-, a_j^-)$ and $\tilde{x}_j^* = (c_j^*, c_j^*, c_j^*)$. We have:

$$\tilde{r}_{ij} = \begin{cases} \tilde{x}_{ij}(\div)\tilde{x}_j^* = \left(\dfrac{a_{ij}}{c_j^*}, \dfrac{b_{ij}}{c_j^*}, \dfrac{c_{ij}}{c_j^*}\right) \ if \ C_i \ is \ benefit \ criterion \quad c_j^* = \max_i c_{ij} \\ \tilde{x}_j^-(\div)\tilde{x}_{ij} = \left(\dfrac{a_j^-}{c_{ij}}, \dfrac{a_j^-}{b_{ij}}, \dfrac{a_j^-}{a_{ij}}\right) \ if \ C_i \ is \ cost \ criterion \quad a_j^- = \min_i a_{ij} \end{cases} \tag{16}$$

Step 2: Calculate the weighted normalized fuzzy decision matrix. The weighted normalized $\tilde{v}_{ij}$ value calculated by Equation 15.

Step 3: Identify positive ideal (A^*) and negative ideal (A^-) solutions. The fuzzy positive ideal solution (FPIS, A^*) and the fuzzy negative ideal solution (FNIS, A^-) are as shown in Equations 17 and 18.

$$A^* = \{\tilde{v}_1^*, \tilde{v}_2^*, \ldots, \tilde{v}_i^*\} = \left\{\left(\max_j v_{ij} \,|\, i \in I'\right), \left(\min_j v_{ij} \,|\, i \in I''\right)\right\} \ i = 1, 2, \ldots, n, j = 1, 2, \ldots, J \tag{17}$$

$$A^- = \{\tilde{v}_1^-, \tilde{v}_2^-, \ldots, \tilde{v}_i^-\} = \left\{\left(\min_j v_{ij} \,|\, i \in I'\right), \left(\max_j v_{ij} \,|\, i \in I''\right)\right\} \ i = 1, 2, \ldots, n, j = 1, 2, \ldots, J \tag{18}$$

where I′ is associated with benefit criteria and I″ is associated with cost criteria.

Step 4: Calculate the distance of each alternative from A^* and A^- using Equations 19 and 20.

$$D_j^* = \sum_{j=1}^{n} d(\tilde{v}_{ij}, v_i^*) \ j = 1, 2, \ldots, J \tag{19}$$

$$D_j^- = \sum_{j=1}^{n} d(\tilde{v}_{ij}, v_i^-) \ j = 1, 2, \ldots, J \tag{20}$$

Step 5: Calculate the similarities to ideal solution:

$$CC_j = \frac{D_j^-}{D_j^* + D_j^-} \quad j = 1, 2, \ldots, J \tag{21}$$

Step 6: Rank preference order. Choose an alternative with maximum CC_j^* or rank alternatives according to CC_j^* in descending orders.

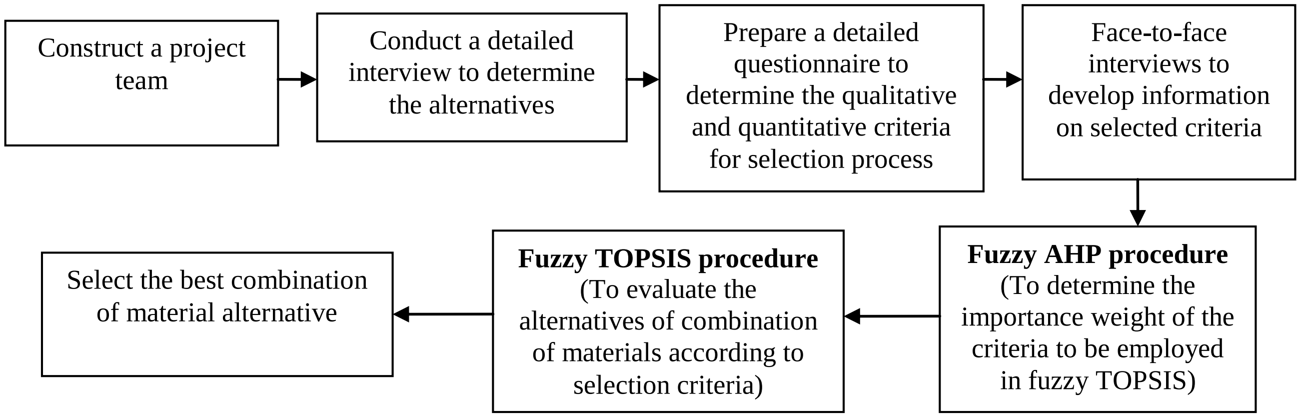

Figure 3. The evaluation procedure.

CASE STUDY

A real world case problem is selected to illustrate the application of the proposed approach. The selected company is a medium sized manufacturing enterprise, which employs about 400 people and is located in Amol, Iran. It manufactures a high variety of containers for food companies. Materials that the company uses are a combination of colors and polystyrene. In recent years, there has been a steady growth in demand for its products. This is an important motivation for the new combination of materials. Selection of the appropriate combination of materials is very important for this company, because it is in a competitive environment and the cost of raw materials is high. Besides, an appropriate choice of materials helps to reach optimum production rate and efficiency. Therefore, a hybrid fuzzy MCDM approach was designed to tackle the problems that could be seen in the selection process (Figure 3).

First, a project team including four engineers and two managers working for the company was constructed. Then, a detailed interview was conducted in order to determine the most suitable type of combination for the company's competitiveness. At this point, new combination of materials for company' immediate needs were produced. The company considered six different alternative models of the combinations, which are denoted as A_1, A_2, A_3, A_4, A_5 and A_6, respectively. Furthermore, a detailed questionnaire related to the data regarding the qualitative and quantitative criteria for the combination of material selection model was prepared. Then, a lot of face-to-face interviews were held to develop solid information on the selected criteria and alternatives. After a set of interviews, five criteria were determined to perform the analysis. The five criteria are: productivity, wastage, cost, style and compatibility with machines which are denoted as C_1, C_2, C_3, C_4 and C_5, respectively.

Typical productivity is for process time and tool life, that means, less time and less pressure on tools produce more products. Wastage means much of the sheet of the combination material transform into the product and has little waste. Style is used for plasticity, chemical uniformity and chemical quality. Some combinations of materials, despite a low waste, high productivity, high quality and good price, compiled extra pressure on the machines. For these reasons, compatibility with machines is considered an important criterion.

After determining all selection criteria and alternatives, the paired comparisons in the questionnaire, were made by using TFNs to tackle the ambiguities involved in the process of linguistic assessment of the data. The project team filled this questionnaire form by reaching general agreement on questions related to the importance of the criteria and alternatives via Delphi technique as a group decision making tool.

RESULTS AND DISCUSSION

The aim of using fuzzy AHP is to determine the importance of weight of the criteria that will be employed in fuzzy TOPSIS method. Table 2 depicts the pair-wise comparison matrix set by TFNs that matches linguistic statements of data. The fuzzy values of paired comparison were converted to crisp values via the Chang (1992) extent analysis as mentioned earlier. First, the fuzzy synthetic extent values were calculated by using Equation 4 with the help of Equations 5 to 7. Equations 8 and 9 were applied to express the degree of synthetic extent values. To have a weight vector given as in Equation 12, Equations 10 and 11 were applied by comparing the fuzzy numbers. After normalizing weight vector defined in Equation 13, the obtained priority weight vector of the criteria is figured out in the last column of Table 2. After fuzzy AHP procedure, fuzzy TOPSIS procedure starts establishing fuzzy evaluations of the alternative combination of materials (A_1, A_2, A_3, A_4, A_5, A_6) with respect to the individual criteria by using TFNs again. This is a decision matrix for ranking alternatives and it indicates the performance ratings of the alternatives according to the criteria.

We use the linguistic scales and their corresponding fuzzy numbers: (1,1,1)-very poor, (2,3,4)-poor, (4,5,6)-fair, (6,7,8)-good and (8,9,10)-very good. Table 3 shows the comparison of alternatives according to the criteria. After constructing decision matrix, normalized decision matrix is calculated.

The normalized decision matrix is obtained using Equation 16. In our calculation, two criteria'C_2 and C_3 are cost criterion; the others are defined as benefit criteria.

The weighted normalized fuzzy decision matrix can be obtained multiplying the normalized decision matrix by the weights of the criteria matrix (Table 2) which was found using fuzzy AHP. Table 4 shows weighted normalized decision matrix. The positive ideal solution

Table 2. Pair-wise comparisons of selection criteria via TFN.

	C_1	C_2	C_3	C_4	C_5	Priority weight
C_1	1,1,1	1,3,5	3,5,7	1/5,1/3,1	1,5,7	0.281
C_2	1/5,1/3,1	1,1,1	5,7,9	1/9,1/7,1/5	1/5,1/3,1	0.204
C_3	1/7,1/5,1/3	1/9,1/7,1/5	1,1,1	1/5,1/3,1	1/5,1/3,1	0.011
C_4	1,3,5	5,7,9	1,3,5	1,1,1	1,3,5	0.304
C_5	1/7,1/5,1	1,3,5	1,3,5	1/5,1/3,1	1,1,1	0.200

$V(S_{C1} \geq S_{C2}, S_{C3}, S_{C4}, S_{C5}) = 0.925$; $V(S_{C2} \geq S_{C1}, S_{C3}, S_{C4}, S_{C5}) = 0.671$;
$V(S_{C3} \geq S_{C1}, S_{C2}, S_{C4}, S_{C5}) = 0.038$; $V(S_{C5} \geq S_{C1}, S_{C2}, S_{C3}, S_{C4}) = 0.020$;
$V(S_{C4} \geq S_{C1}, S_{C2}, S_{C3}, S_{C5}) = 1.000$

Table 3. The comparison of alternatives according to the criteria.

	A_1	A_2	A_3	A_4	A_5	A_6
C_1	(4,5,6)	(2,3,4)	(8,9,10)	(2,3,4)	(6,7,8)	(6,7,8)
C_2	(2,3,4)	(1,1,1)	(6,7,8)	(4,5,6)	(2,3,4)	(6,7,8)
C_3	(4,5,6)	(4,5,6)	(2,3,4)	(6,7,8)	(4,5,6)	(8,9,10)
C_4	(6,7,8)	(2,3,4)	(8,9,10)	(4,5,6)	(4,5,6)	(6,7,8)
C_5	(2,3,4)	(2,3,4)	(8,9,10)	(4,5,6)	(2,3,4)	(6,7,8)

Table 4. Weighted normalized decision matrix.

	A_1	A_2	A_3	A_4	A_5	A_6
C_1	0.112,0.141,0.169	0.056,0.084,0.112	0.225,0.253,0.281	0.056,0.084,0.112	0.169,0.197,0.225	0.169,0.197,0.225
C_2	0.051,0.068,0.102	0.204,0.204,0.204	0.025,0.029,0.034	0.034,0.041,0.051	0.051,0.068,0.102	0.025,0.029,0.034
C_3	0.004,0.005,0.006	0.004,0.005,0.006	0.006,0.008,0.011	0.003,0.003,0.004	0.004,0.005,0.006	0.002,0.003,0.003
C_4	0.182,0.213,0.243	0.061,0.091,0.400	0.243,0.273,0.304	0.121,0.152,0.182	0.121,0.152,0.182	0.182,0.213,0.243
C_5	0.040,0.060,0.080	0.040,0.060,0.080	0.160,0.180,0.200	0.080,0.100,0.120	0.040,0.060,0.080	0.120,0.140,0.160

Table 5. The results.

	D^*	D^-	CC^*
A_1	2.023	0.275	0.120
A_2	2.009	0.373	0.157
A_3	1.920	0.370	0.161
A_4	2.069	0.225	0.098
A_5	2.025	0.287	0.124
A_6	1.900	0.283	0.130

(A^*) and negative ideal solution (A^-) are determined by using the weighted normalized values. Equations 17 and 18 are used to determine the positive ideal solution and negative ideal solution. The positive TFNs are in the range [0, 1]. Hence, the fuzzy positive ideal reference point (FPIS,A^*) is (1, 1, 1) and fuzzy negative ideal reference point (FNIS,A^-) is (0, 0, 0). In the last step, the relative closeness to the ideal solution was calculated. The relative closeness to the ideal solution was defined on Equations19 and 20. Equation 14 was used to calculate distances to ideal solutions. In the last step, the relative closeness to the ideal solution was calculated. The relative closeness to the ideal solution was defined on Equations 19 and 20. Equation 14 was used to calculate distances to ideal solutions. Table 5 summarizes the results. The higher the closeness means the better the rank, so the relative closeness to the ideal solution of the alternatives can be substituted as follows: $A_3 > A_2 > A_6 > A_5 > A_1 > A_4$. A_3 was defined as the best alternative for this company.

Conclusion

In this paper, a hybrid fuzzy MCDM based on fuzzy AHP and TOPSIS for selecting the most suitable combination of materials was proposed. For dealing with uncertainty and improving lack of precision in evaluating criteria and/or combination of material alternatives, fuzzy methods were used. We apply triangular numbers into traditional AHP and TOPSIS methods. Fuzzy AHP was applied for the calculation of importance of criteria by DMs and fuzzy TOPSIS used these scores for ranking the alternatives. As a result of this study, we found out that the proposed method is practical for ranking combination of material alternatives with respect to multiple conflicting criteria. For further research, the other fuzzy decision-making approaches, such as, VIKOR, ANP and DEMATEL can be used and compared with the results of this paper.

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