Equipment Selection by using Fuzzy TOPSIS Method

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Abstract. In this study, Fuzzy TOPSIS method was performed for the selection of open pit truck and the optimal solution of the problem was investigated. Data from Turkish Coal Enterprises was used in the application of the method. This paper explains the Fuzzy TOPSIS approaches with group decision-making application in an open pit coal mine in Turkey. An algorithm of the multi-person multi-criteria decision making with fuzzy set approach was applied an equipment selection problem. It was found that Fuzzy TOPSIS with a group decision making is a method that may help decision-makers in solving different decision-making problems in mining.

1. Introduction

Multiple Criteria Decision Making (MCDM) is one of the most considerable branches of Decision Making (DM). MCDM refers to making decisions in the presence of multiple, usually conflicting, criteria. The problems in MCDM are classified into two categories: Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). However, very often the terms MADM and MCDM are used to mean the same class of models and mostly confused in practice. Usually, MADM is used when the model cannot be stated in mathematical equations and otherwise MODM is used.

One of the challenging DM problems in mining operations is to choose the best equipment among the alternatives. Equipment selection is an important task for mine management due to its operational cost, and also an integral part of mine planning and design. Equipment selection is not a well-defined process because it involves the interaction of several subjective factors or criteria. Besides, decisions are often complicated and may even embody contradictions. Therefore; equipment selection is considered as MCDM process, and suitable decision-making methods should be employed in this process.

A review of literature reveals that different DM techniques have been used for a variety of equipment selection problems in mining [1-7]. However, Bazzazi et al. [8] and Lashgari et al. [9] used the Fuzzy TOPSIS method for equipment selection problem. This paper explains the Fuzzy TOPSIS approaches with group decision-making application and gives an application on a truck selection for mining operations in an open pit coal mine in Turkey.

2. Fuzzy TOPSIS Method

Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is currently one of the most popular MCDM methods and worked satisfactorily in various application areas. This method was first developed by Hwang and Yoon [10] for solving MCDM problems with the basic principle to choose the alternative which has the shortest distance from the positive ideal solution (best) and the farthest distance from negative-ideal solution (worst).
Later, Chen [11] extended the TOPSIS method to a fuzzy environment using triangular fuzzy numbers to replace the numeric linguistic scales for rating and weighting. After that, a number of methods proposed extensions of the Fuzzy TOPSIS method after Chen. In this paper, Chen’s [11] Fuzzy TOPSIS method was applied in the DM process. This method is very suitable for solving the group DM problem under fuzzy environment. In this method, the importance weights of various criteria and the ratings of qualitative criteria are considered as linguistic variables. These linguistic variables can be expressed in positive triangular fuzzy numbers as Tables 1 and 2.

| Table 1. Linguistic variables for the importance weight of each criterion |
|-----------------------------------------------|
| Description | Value |
|------------|-------|
| Very low (VL) | (0; 0; 0:1) |
| Low (L) | (0; 0:1; 0:3) |
| Medium low (ML) | (0:1; 0:3; 0:5) |
| Medium (M) | (0:3; 0:5; 0:7) |
| Medium high (MH) | (0:5; 0:7; 0:9) |
| High (H) | (0:7; 0:9; 1:0) |
| Very high (VH) | (0:9; 1:0; 1:0) |

| Table 2. Linguistic variables for the ratings |
|-----------------------------------------------|
| Description | Value |
|------------|-------|
| Very poor (VP) | (0; 0; 1) |
| Poor (P) | (0; 1; 3) |
| Medium poor (MP) | (1; 3; 5) |
| Fair (F) | (3; 5; 7) |
| Medium good (MG) | (5; 7; 9) |
| Good (G) | (7; 9; 10) |
| Very good (VG) | (9; 10; 10) |

The importance weight of each criterion can be obtained by either directly assign or indirectly using pairwise comparisons. In here, it is suggested that the decision makers use the linguistic variables (shown in Tables 1 and 2) to evaluate the importance of the criteria and the ratings of alternatives with respect to various criteria. Assume that a decision group has \( K \) persons, then the importance of the criteria and the rating of alternatives with respect to each criterion can be calculated as:

\[
x_{ij} = \frac{1}{K} \left( x_{ij}^1 + x_{ij}^2 + \ldots + x_{ij}^K \right)
\]

(1)

\[
w_{ij} = \frac{1}{K} \left( w_{ij}^1 + w_{ij}^2 + \ldots + w_{ij}^K \right)
\]

(2)

where \( x_{ij} \) and \( w_{ij} \) are the rating and the importance weight of the \( K \)th decision maker. As stated above, a fuzzy multi-criteria group decision-making problem which can be concisely expressed in matrix format as:

\[
D = \left[ x_{ij} \right]_{m \times n}
\]

(3)

\[
W = \left[ w_{ij} \right]_{n}
\]

(4)

where \( x_{ij} \); \( \forall i; j \) and \( w_{ij} \); \( j = 1, 2, \ldots, n \) are linguistic variables. These linguistic variables can be described by triangular fuzzy numbers, \( x_{ij} = (a_{ij}, b_{ij}, c_{ij}) \) and \( w_{ij} = (w_{ij1}, w_{ij2}, w_{ij3}) \).
To avoid the complicated normalization formula used in classical TOPSIS, the linear scale transformation is used here to transform the various criteria scales into a comparable scale. Therefore, we can obtain the normalized fuzzy decision matrix denoted by $R$.

$$R = \left[ r_{ij} \right]_{m \times n} \quad (5)$$

where $B$ and $C$ are the set of benefit criteria and cost criteria, respectively, and

$$r_{ij} = \left( \frac{a_{ij}}{c_{ij}}, \frac{b_{ij}}{c_{ij}}, \frac{c_{ij}}{c_{ij}} \right), \ j \in B; \quad (6)$$

$$c_j = \max c_{ij} \text{ if } j \in B; \quad (7)$$

The normalization method mentioned above is to preserve the property that the ranges of normalized triangular fuzzy numbers belong to $[0, 1]$. Considering the different importance of each criterion, we can construct the weighted normalized fuzzy decision matrix as

$$V = \left[ v_{ij} \right]_{m \times n}, i=1,2,..., m, j=1,2,...,n \quad (8)$$

where $v_{ij} = r_{ij} \Theta w_{ij}$. \quad (9)

According to the weighted normalized fuzzy decision matrix, we know that the elements $v_{ij}, \forall i, j$ are normalized positive triangular fuzzy numbers and their ranges belong to the closed interval $[0, 1]$. Then, we can define the fuzzy positive-ideal solution (FPIS, $A^*$) and fuzzy negative-ideal solution (FNIS, $A^-$) as

$$d_i^* = \sum_{j=1}^{n} d(v_{ij}, v_{ij}^*), \ i=1,2,..., m \quad (10)$$

$$d_i^- = \sum_{j=1}^{n} d(v_{ij}, v_{ij}^-), \ i=1,2,..., m. \quad (11)$$

where $d(\,\cdot\,\,\cdot)$ is the distance measurement between two fuzzy numbers.

A closeness coefficient is defined to determine the ranking order of all alternatives once the $d_i^*$ and $d_i^-$ of each alternative $A_i \ (i=1, 2, ..., m)$ has been calculated. The closeness coefficient of each alternative is calculated as

$$CC_i = \frac{d_i^-}{d_i^*}, \ i=1,2,..., m. \quad (12)$$

Obviously, an alternative $A_i$ is closer to the FPIS ($A^*$) and farther from FNIS ($A^-$) as $CC_i$ approaches to 1. Therefore, according to the closeness coefficient, we can determine the ranking order of all alternatives and select the best one from among a set of feasible alternatives.

3. Results and discussions

The Fuzzy TOPSIS technique was used for an open pit mine truck selection in order to be able to make a decision by considering the proposals according to the attributes which were put forward by Turkish Coal Enterprise (TKI). After preliminary screening from the decision makers, two truck model $A_1$ and $A_2$ remain for further evaluation. A committee of five decision-makers, $D_1, D_2, D_3, D_4$ and $D_5$ has been formed to conduct the interview and to select the most suitable candidate. Seven benefit criteria are considered: Carrying Capacity ($C_1$), Manufacturer of Engine ($C_2$), Truck Box Features ($C_3$), Truck Suspension System ($C_4$), Hill Climbing Ability ($C_5$), Truck Unloading Time ($C_6$), Delivery Time ($C_7$).

The Chen [11] method is applied to solve this problem and the computational procedure is summarized. The decision-makers were used the linguistic weighting variables in Step 1 (shown in Table 1) to assess the importance of the criteria and present it in Table 3. The decision-makers were used the
linguistic rating variables in Step 2 (shown in Table 2) to evaluate the rating of alternatives with respect to each criterion and present it in Table 4. Converting the linguistic evaluation was applied in Step 3 (shown in Tables 3 and 4) into triangular fuzzy numbers to construct the fuzzy decision matrix and determine the fuzzy weight of each criterion.

Table 3. The importance weight of the criteria.

| Criteria | $D_1$ | $D_2$ | $D_3$ | $D_4$ | $D_5$ |
|----------|-------|-------|-------|-------|-------|
| C1       | VH    | VH    | H     | MH    | VH    |
| C2       | VL    | VL    | VL    | MH    | L     |
| C3       | H     | VH    | VH    | ML    | H     |
| C4       | H     | H     | H     | M     | H     |
| C5       | H     | VL    | H     | M     | H     |
| C6       | H     | L     | M     | M     | H     |
| C7       | M     | H     | M     | M     | H     |

Table 4. The ratings of the three candidates by decision makers under all criteria.

| Criteria | Alternatives | Decision-makers | $D_1$ | $D_2$ | $D_3$ | $D_4$ | $D_5$ |
|----------|--------------|-----------------|-------|-------|-------|-------|-------|
| C1       | $A_1$        | P               | G     | G     | VG    | MP    |
|          | $A_2$        | G               | P     | P     | VP    | VG    |
| C2       | $A_1$        | VG              | P     | VP    | VG    | F     |
|          | $A_2$        | G               | G     | VG    | VP    | G     |
| C3       | $A_1$        | G               | G     | VG    | VG    | VG    |
|          | $A_2$        | VP              | P     | VG    | VG    | VG    |
| C4       | $A_1$        | G               | G     | G     | VG    | VG    |
|          | $A_2$        | MP              | P     | MP    | F     | F     |
| C5       | $A_1$        | VG              | VG    | VG    | VG    | VG    |
|          | $A_2$        | VP              | VP    | VP    | F     | P     |
| C6       | $A_1$        | VG              | VG    | G     | VG    | VG    |
|          | $A_2$        | P               | VP    | MG    | F     | P     |
| C7       | $A_1$        | P               | G     | G     | VG    | VG    |
|          | $A_2$        | G               | VP    | VP    | F     | P     |

The normalized fuzzy decision matrix was constructed in Step 4. Then, the weighted normalized fuzzy decision matrix was constructed in Step 5. In the Step 6, FPIS and FNIS were determined as

$A^+ = [(0.321, 0.511), (0.877, 0.833), (0.298, 0.518), (0.328, 0.724), (0.412, 0.902), (0.488, 0.819), (0.457, 0.759), (0.775, 0.533), (0.146, 0.197), (0.758, 0.503), (0.755, 0.339), (0.626, 0.124), (0.567, 0.221), (0.619, 0.283)]$.

$A^- = [(0.321, 0.511), (0.877, 0.833), (0.298, 0.518), (0.328, 0.724), (0.412, 0.902), (0.488, 0.819), (0.457, 0.759), (0.775, 0.533), (0.146, 0.197), (0.758, 0.503), (0.755, 0.339), (0.626, 0.124), (0.567, 0.221), (0.619, 0.283)]$.

The distance of each alternative from FPIS and FNIS were calculated in Step 7. In Step 8, the closeness coefficient of each alternative was calculated as:

$CC_1 = 0.572$ and $CC_2 = 0.303$.

According to the closeness coefficient, the ranking order of the three candidates is $A_1$ and $A_2$ in Step 9. Obviously, the best selection is $A_1$ according to DM process.
4. Conclusions
The mining engineers can frequently encounter with the selection of the optimum option among the alternatives related to the mining operation. Every mining engineer might make precise decisions in all mining operations and the DM must use a suitable DM technique to make right decisions. There are a number of techniques available for solving different type of decision problems in the literature. In this study, the Fuzzy TOPSIS, which is one of the MADM techniques, is used to solve an equipment selection problem.

Unlike the traditional approach to the open pit mine truck selection, the Fuzzy TOPSIS is more scientific method providing the integrity and objectivity of estimation process. The model is transparent and easy to comprehend and apply by the decision maker. For truck selection, the proposed model is unique in its identification of multiple attributes, minimal data requirement and minimal time consumption.

The Fuzzy TOPSIS based DM applications can be applied for different parts of the mining industry. The result of this study shows that such a Fuzzy TOPSIS application can assist the engineers to effectively evaluate the alternatives in mining engineering.

Acknowledgment(s)
The author wishes to thank Mining Engineer Dr. Soner OGRETMEN and Turkish Coal Enterprises (TKI) management for their assistance.

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