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Applications of The TOPSIS Method to Solve Some Decision Making Problems in Mining Operations

Madencilik Faaliyetlerinde Bazı Karar Verme Problemlerinin Çözümünde TOPSIS Yönteminin Uygulanması

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Abstract

Decision-Making (DM) is the first and one of the most important stages in the design or project procedure of mining engineering operations like other engineering professions. Every mining engineer might make precise decisions in all mining operations such as the selection of mining method, equipment, facility location, support type, mine planning and design, etc. There are a number of techniques available for solving different type of decision problems in the literature. In this paper, the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), which is the one of the Multiple Attribute Decision Making (MADM) techniques, was used to solve two independent mining based decision problems related to selection of equipment and facility location. As the decisions in the both facility location and equipment selection have radically influenced the economic life of any mining scenario, they are considered as complex MADM problem. After introducing the Multiple Criteria Decision Making (MCDM) together with its subgroups MADM and Multiple Objective Decision Making (MODM) methods, the TOPSIS method and its algorithm were explained in this paper shortly. The TOPSIS has not been extensively used to model decisions pertaining to the mining applications although most often it has been used for DM on corporate level. So, it was aimed to apply this method for two different mining operations. The TOPSIS method was used for a loader selection by considering the data obtained from Turkish Coal Enterprises (TKI) and a facility location selection for Marble Factory according to the data obtained from ELMAS Company in Turkey.

Keywords: Equipment selection, facility location, multi attribute decision making, TOPSIS.

Özet

Karar Verme (KV) diğer mühendislik dallarında olduğu gibi maden mühendisliği işlemlerinde tasarım ve proje süreçlerinin en önemli aşamalarından bir tanesi ve ilkidir. Her maden mühendisi madencilik yöntemi, ekipman, tesis yeri, tahkimat tipi, ocak planı ve tasarımı gibi bütün madencilik işlemlerinde önemli kararlar verir. Literatürde karar problemlerinin farklı tiplerinin çözümü için çok fazla teknik bulunmaktadır. Bu çalışmada, Çok Nitelikli Karar Verme (ÇNKV) tekniklerinden bir tanesi olan TOPSIS (the Technique for Order Preference by Similarity to Ideal Solution) yöntemi ekipman ve tesis yeri seçimi gibi birbirinden bağımsız iki madencilik tabanlı karar probleminin çözümünde kullanılmıştır. TOPSIS yöntemi, Türkiye Kömür İşletmelerinden (TKİ) elde edilen veriler yardımıyla yükleyici seçimi, ELMAS firmasından elde edilen verilere göre ise Mermer Fabrikası için kuruluş yeri seçiminde kullanılmıştır.

Anahtar kelimeler: Ekipman seçimi, kuruluş yeri, çok nitelikli karar verme, TOPSIS.

1. Introduction

Decision-Making (DM) can be defined as a selection process of the best one among the alternatives sets in order to obtain goal, and mostly has an uncertain situation (Karadogan et al., 2001). Every mining engineer is subjected to a number of mining DM problems in daily mining operations. In reality, all stages of mining have its own DM problems. Most of time, engineers do not use scientific methods for DM problems. These problems can mostly be solved by the engineers according to their past experiences and practical studies. Mining engineers often use their intuition in DM process. Experience and intuition have been central to DM because of the frequent lack of quantitative data including geology, grade distribution and ground condition as well as environmental, social and economic factors (Kazakidis, et al., 2004). In decision process, as it mentioned before, linguistic variables become in question and decision makers may not know how these variables are computed (Kesimal and Bascetin, 2002). So, the DM process may be qualitative, quantitative or combination of the two. The problem structuring and analysis process is conceptualized in Figure 1(Kazakidis, et al., 2004). The qualitative analysis is based primarily on the judgment, knowledge and experience of an expert (or team of experts). In a quantitative analysis, the focus is on facts and the data associated with a problem and a mathematical formulation that encompasses the objectives, variables and constraints of the particular problem. The quantitative analysis has traditionally been the subject of operation research and management science (Kazakidis, et al., 2004).

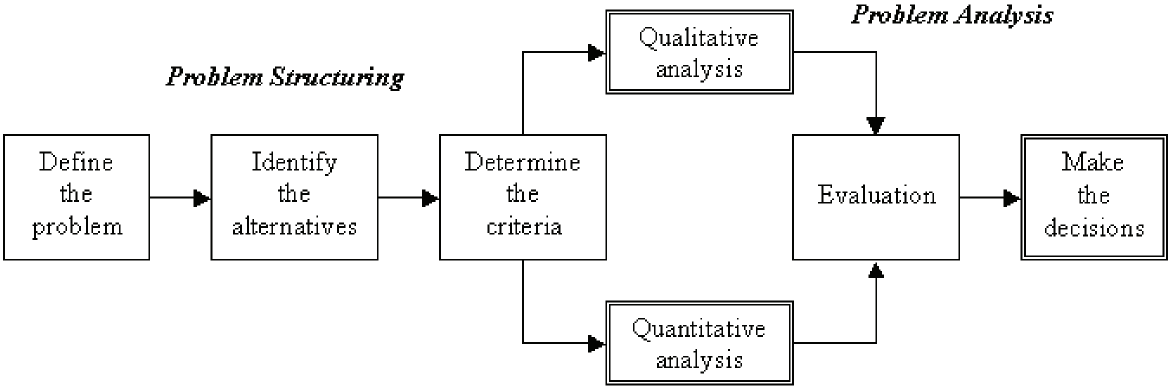

Figure 1. The problem structuring and analysis process in DM (Kazakidis et al., 2004).

A review of the literature reveals that DM techniques have been used for a variety of specific applications in DM in mining operations. Karadogan et al. (2001) solved an underground mining method selection problem by using Fuzzy Attribute Decision Making (FADM) and they used Satty's Analytic Hierarchy Process (AHP) method for criterion pair-wise comparison. Bitarafan and Ataei (2004) solved the similar problem by using FADM with Satty's AHP method and they also used Fuzzy Dominance Method (FDM) in their analysis. Kesimal and Bascetin (2002) used FADM method for solving equipment selection problem in open pit mine. Elevli et al. (2002) selected a new vertical shaft or ramp system by comparing the weighted alternative criteria for a small-scale underground mine on the basis of total investment cost, ore transport unit cost and Net Present Value (NPV) of overall project for various depths. Elevli and Demirci (2004) selected most suitable underground ore transport system for a Chromate mine by using the one of the MADM method namely Preference Ranking Organisation MeTHod for Enrichment Evaluation (PROMETHEE). Kazakidis et al. (2004) used AHP and analyzed five different mining scenarios such as drilling technology investment analysis, ground support design, tunneling systems design, shaft location selection and mine planning risk assessment. The selection of a loading-hauling system was evaluated using an AHP-based model for coal production in an open pit coal mine by Bascetin (2004). Ataei (2005) used AHP method for the problem of selection of a new alumina cement plant location in East-Azerbaijan province of Iran.

This paper focuses on the TOPSIS which is one of the MADM methods, as mentioned before. The TOPSIS approach enables the qualitative analysis using a combination of subjective and objective information or data. The TOPSIS has not been extensively used to model decisions pertaining to the mining applications although most often it has been used for DM on corporate level. Only, the TOPSIS method was used to solve underground mining method selection problem and hydraulic excavator selection problems by Yavuz and Alpay (2008) and Yavuz (2008) in the literature, respectively. This paper explains the TOPSIS approach and gives two different applications on a loader selection for mining operations in TKI Soma district and a factory location selection for Marble Industries.

2. Multiple Criteria Decision Making (MCDM)

MCDM is one of the most well-known branches of DM (Triantaphyllou, 2000). MCDM refers to making decisions in the presence of multiple, usually conflicting, criteria. The problems for MCDM are common occurrences in everyday life and broadly classified into two categories in this respect: MADM and MODM (Hwang and Yoon, 1981). However, very often the terms MADM and MCDM are used to mean the same class of models (Triantaphyllou, 2000). In actual practice, this classification is well fitted to the two facets of problem solving. Usually, MADM is used for selection (evaluation) and MODM is used for design (Hwang and Yoon, 1981). MODM solves the decision problems in which the decision space is continuous. This is a widely accepted classification and shown in Table I (Hwang and Yoon, 1981). The contrast of the features between these two classes is also shown in this table.

	MADM	**MODM**
Criteria	Attributes	Objectives
Objective	Implicit	Explicit
Attribute	Explicit	Implicit
Constraint	Inactive	Active
Alternative	Finite number, discrete	Infinite number, continuous
Interaction with DM	Not much	Mostly
Usage	Selection / Evaluation	Design

Table I. MADM versus MODM (Hwang and Yoon, 1981).

MODM is not associated with the problem where the alternatives are predetermined. The thrust of these models is to design the “best” alternative by considering the various interactions within the design constraints which best satisfy the DM by the way of attaining some acceptable levels of some quantifiable objectives.

The distinguishing feature of the MADM is that there are usually a limited (and countable small) number of predetermined alternatives. The alternatives have associated with them a level of the attributes based on which final decision is to be made. The final selection of the alternative is made with the help of inter and intra-attribute comparisons. The comparisons may involve explicit or implicit tradeoff.

In MADM methods, if the alternatives have an information and cardinal effect on DM process, the decision makers can use the TOPSIS method.

3. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

The TOPSIS was first developed by Hwang and Yoon (1981), based on the concept that the chosen alternative should have the shortest distance from the Positive Ideal Solution (PIS) and the farthest from the Negative-Ideal Solution (NIS) for solving a multiple criteria DM problem. Thus, the best alternative should not only have the shortest distance from the positive ideal solution, but also should have the largest distance from the negative ideal solution. In short, the ideal solution is composed of all best values attainable of criteria, whereas the negative ideal solution is made up of all worst values attainable of criteria (Chen and Tzeng, 2004).

Assume that each attribute takes the monotonically increasing (or decreasing) utility; then it is easy to locate the "ideal" solution which is composed of all best attribute values attainable, and the "negative-ideal" solution composed of all worst attribute values attainable. One approach is to take an alternative, which has the (weighted) minimum Euclidean distance to the ideal solution in geometrical sense (Srinivasan and Shocker, 1973; Zeleny, 1974). It is argued that this alternative should be farthest from the negative-ideal solution at the same time. Sometimes chosen alternative, which has the minimum Euclidean distance form the ideal solution, has the shorter distance (to the negative-ideal) than the other alternative(s). For example, in Figure 2 (Hwang and Yoon, 1981) an alternative A1 has shorter distances (both to ideal solution A* and to the negative ideal solution) than alternative A2. In Figure 2, the horizontal axes shows attribute X1 (increasing preference) and the perpendicular axes shows attribute X2 (increasing preference). The TOPSIS consider the distances to both the ideal and the negative-ideal solutions simultaneously by taking the relative closeness to the ideal solution (Hwang and Yoon, 1981).

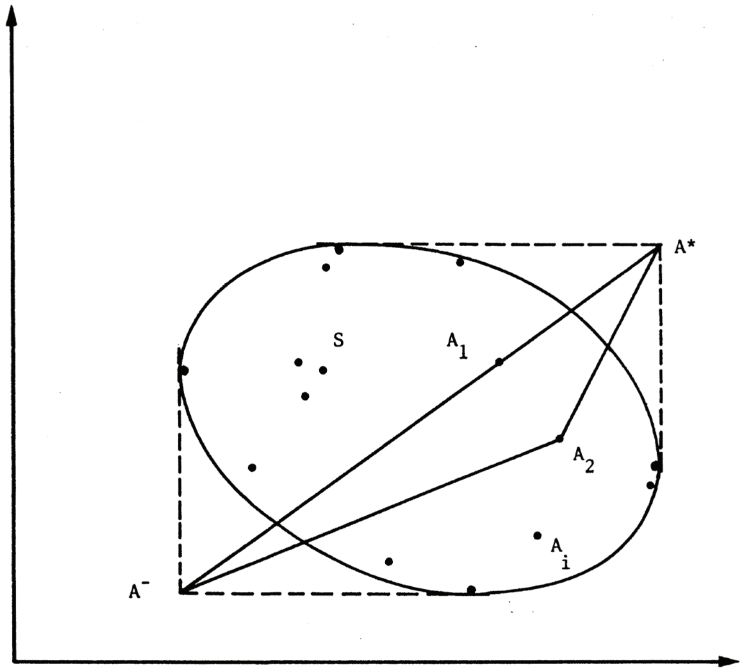

Figure 2. Euclidean distance to the ideal and negative-ideal solutions in two dimensional space (Hwang and Yoon, 1981).

3.1. The Algorithm of the TOPSIS

The TOPSIS method evaluates the following decision matrix, which contains m alternatives associated with n attributes or criteria (Hwang and Yoon, 1981);

$$D = \begin{array}{c} \\ A_1 \\ A_2 \\ . \\ . \\ . \\ A_i \\ . \\ . \\ . \\ A_m \end{array} \begin{array}{c} \begin{array}{ccccccccc} X_1 & X_2 & . & . & . & X_j & . & . & . & X_n \end{array} \\ \begin{bmatrix} x_{11} & x_{12} & . & . & . & x_{1j} & . & . & . & x_{1n} \\ x_{21} & x_{22} & . & . & . & x_{2j} & . & . & . & x_{2n} \\ . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . \\ x_{i1} & x_{i2} & . & . & . & x_{ij} & . & . & . & x_{in} \\ . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . & . \\ x_{m1} & x_{m2} & . & . & . & x_{mj} & . & . & . & x_{mn} \end{bmatrix} \end{array} \quad [1]$$

where, A_i is the i^{th} alternative considered and x_{ij} is the numerical outcome of the i^{th} alternati ve with respect to the j^{th} criterion.

The TOPSIS assumes that each attribute in the decision matrix takes either monotonically increasing or monotonically decreasing utility. Further, any outcome that is expressed in a non-numerical way should be quantified through the appropriate scaling technique (Hwang and Yoon, 1981).

Since all criteria cannot be assumed to be of equal importance, the method receives a set of weight from the decision maker. The calculation processes of this method are as follows and contain a series of successive steps (Hwang and Yoon, 1981).

3.1.1. Step 1: Construction of the Normalized Decision Matrix

This process tries to transform the various attribute dimensions into non-dimensional attributes, which allows comparison across the attributes. One way is to take the outcome of each criterion divided by the norm of the total outcome vector of the criterion at hand. An element rij of the normalized decision matrix R can be calculated as (Hwang and Yoon, 1981);

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{m} x_{ij}^2}} \quad [2]$$

Therefore, the normalized decision matrix R is;

$$R = \begin{bmatrix} r_{11} & r_{12} & . & . & . & r_{1n} \\ r_{21} & r_{22} & . & . & . & r_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ r_{m1} & r_{m2} & . & . & . & r_{mn} \end{bmatrix} \quad [3]$$

R is the normalized decision matrix where m is the number of alternatives, n is the number of criteria and rij is the normalized preference measure of the ith alternative in terms of the jth criterion. In this form, all attributes have the same unit length of vector (Hwang and Yoon, 1981).

3.1.2. Step 2: Construction of the Weighted Normalized Decision Matrix

A set of weights $w=(w_1,\ w_2,\ w_3,\ ...,\ w_j,\ ...,\ w_n),\ \sum_{j=1}^{n} w_j = 1,$ from the decision maker is accommodated to the decision matrix in this stage. This matrix can be calculated by multiplying each column of the matrix R with its associated weight wj. Therefore, the weighted normalized decision matrix V is equal to (Hwang and Yoon, 1981);

$$V = \begin{bmatrix} v_{11} & v_{12} & . & . & . & v_{1n} \\ v_{21} & v_{22} & . & . & . & v_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ v_{m1} & v_{m2} & . & . & . & v_{mn} \end{bmatrix} = RW = \begin{bmatrix} w_1.r_{11} & w_2.r_{12} & . & . & . & w_n.r_{1n} \\ w_1.r_{21} & w_2.r_{22} & . & . & . & w_n.r_{2n} \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ . & . & . & . & . & . \\ w_1.r_{m1} & w_2.r_{m2} & . & . & . & w_n.r_{mn} \end{bmatrix} \qquad [4]$$

where W is;

$$W = \begin{bmatrix} w_1 & 0 & 0 & . & . & . & 0 \\ 0 & w_2 & 0 & . & . & . & 0 \\ 0 & 0 & w_3 & . & . & . & 0 \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ . & . & . & . & . & . & . \\ 0 & 0 & 0 & . & . & . & w_n \end{bmatrix}, \text{ and } \sum_{j=1}^{n} w_j = 1. \qquad [5]$$

3.1.3. Step 3: Determination of Ideal and Negative Ideal Solutions

The ideal solution A* and the negative-ideal solution, denotes as are (Hwang and Yoon, 1981);

$$A^* = \left\{\left(\max_i v_{ij} \middle| j \in J\right), \left(\min_i v_{ij} \middle| j \in J'\right), i = 1,2,3,....,m\right\} = \left\{v_1^*, v_2^*, ..., v_n^*\right\} \qquad [6]$$

$$A^- = \left\{\left(\min_i v_{ij} \middle| j \in J\right), \left(\max_i v_{ij} \middle| j \in J'\right), i = 1,2,3,....,m\right\} = \left\{v_1^-, v_2^-, ..., v_n^-\right\} \qquad [7]$$

Where $J = \{j = 1, 2, 3, . . . , n$ and j is associated with benefit criteria$\}$,

$J' = \{j = 1, 2, 3, . . . , n$ and j is associated with cost criteria$\}$.

Therefore it is obvious that the previously created alternatives A* and represent the most preferable alternative, i.e. the ideal solution, and the least preferable alternative or negative-ideal solution, respectively (Hwang and Yoon, 1981).

3.1.4. Step 4: Calculation of the Separation Measure

The separation distances of each alternative from the ideal solution and the negative-ideal solution are reached by the n-dimensional Euclidean distance method. That means Si* is the distance (in an Euclidean sense) of each alternative from the ideal solution and is defined as (Hwang and Yoon, 1981):

$$S_i^* = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^*\right)^2} \text{ , for } i = 1, 2, 3, \ldots, m \tag{8}$$

and the distance from the negative-ideal solution defines as follows (Hwang and Yoon, 1981):

$$S_i^- = \sqrt{\sum_{j=1}^{n} \left(v_{ij} - v_j^-\right)^2} \text{ , for } i = 1, 2, 3, \ldots, m \tag{9}$$

3.1.5. Step 5: Calculation of the Relative Closeness to the Ideal Solution

The relative closeness of an alternative Ai with respect to the ideal solution A* is represented by (Hwang and Yoon, 1981);

$$C_i^* = \frac{S_i^-}{S_i^* + S_i^-} \tag{10}$$

where $0 < C_i^* < 1$ and $i = 1, 2, 3, \ldots, m$.

Apparently an alternative Ai is closer to the ideal solution as *Ci** approaches to 1. Thus, *Ci** equals to 1 if $A_i = A^*$, and Ci^- equals to *0* if $A_i = A^-$.

3.1.6. Step 6: Ranking of the Preference Order

A preference order can be ranked according to the order of *Ci**. Therefore, the best alternative is the one with the shortest distance to the ideal solution and with the (Euclidean distance method is guaranteed that this alternative has also the) longest distance to the negative-ideal solution (Hwang and Yoon, 1981).

4. CASE STUDIES

4.1. The Application of the TOPSIS for a Loader Selection

The TOPSIS technique was used for a wheel loader selection in order to be able to make a decision by considering the proposals according to the attributes which was put forward by Turkish Coal Enterprise (TKI). As it is known, some criteria which affect the DM process should be considered in the TOPSIS technique. The criteria used in this work to select the best alternative for a wheel loader are the expected technical features as follows:

- Operating weight should be between 80 and 90 tones,
- Diesel engine having the net power of minimum 650 HP and suitable for heavy working conditions,
- Rated bucket capacity of 12 yd^3 or greater,
- 45° discharge height of minimum 4 m or higher,
- Breakout force of minimum 60000 kg or greater,
- Lifting capacity of 17500 kg or greater,
- Static tipping load of 45000 kg or greater,
- Articulating angle of 30^o or greater,

- Tire protection chain should be available,
- Rops type operator cabin and suitable for all kind of climate conditions,
- L-5 class tubeless type tires and resistant to wearing,
- Machine should be equipped with torque converter, full power shift and 4×4 wheel drive.

Besides supplying the mentioned technical features, the wheel loader can be operated in local conditions such as 1000 m of altitude, -25 to +40 ^{o}C of air temperature and 1.1 to 1.8 ton/m^3 of soil density.

The loader specifications offered from 5 different sellers according to 10 criteria put forward by TKI are given in Table II.

Attributes	**Alternatives**				
	Model 1	Model 2	Model 3	Model 4	Model 5
Operating weight (tone)	89.8	88.2	89.5	90.3	85.6
Net gross (HP)	825	690	725	650	780
Rated bucket capacity (yd3)	13.5	14	12	12	14
45° Discharge height (m)	4.6	4.8	4.5	4.6	4.2
Breakout force (kg)	60800	76200	65500	60500	63000
Lifting capacity (kg)	21750	20500	19300	19800	20100
Static tipping load (kg)	61550	51250	45500	48600	47200
Articulating angle (º)	40º	35º	40º	38º	42º
Machine price ($)	801710	788670	810250	825350	792300
Tire protection chain price ($)	50580	130200	85300	115700	72400
Rops type operator cabin	Available	Available	Available	Available	Available
L-5 class tubeless type tires and resistant to wearing	Available	Available	Available	Available	Available
Torque converter, full power shift and 4×4 wheel drive	Available	Available	Available	Available	Available

Along the offers of sellers, decision matrix has been formed as the way given in Equation 1. In this decision matrix, each row denotes alternatives and each column denotes criteria. The last three attributes has not been included in the decision matrix because these attributes are of the same value.

$$D = \begin{bmatrix} 89.8 & 825 & 13.5 & 4.6 & 60800 & 21750 & 61550 & 40 & 801710 & 50580 \\ 88.2 & 690 & 14 & 4.8 & 76200 & 20500 & 51250 & 35 & 788670 & 130200 \\ 89.5 & 725 & 12 & 4.5 & 65500 & 19300 & 45500 & 40 & 810250 & 85300 \\ 90.3 & 650 & 12 & 4.6 & 60500 & 19800 & 48600 & 38 & 825350 & 115700 \\ 85.6 & 780 & 14 & 4.2 & 63000 & 20100 & 47200 & 42 & 792300 & 72400 \end{bmatrix}$$

In this matrix, 10 different criteria for 5 alternatives have been evaluated. An illustrative example of the TOPSIS technique for a wheel loader selection is explained by following the steps mentioned in the previous section.

Step 1: By using Equation 2, the first element of the normalized decision matrix (r11) is calculated as $0.4528\ (r_{11} = 89.8 \big/ \sqrt{(89.8^2 + 88.2^2 + 89.5^2 + 90.3^2 + 85.6^2)})$. Calculating the other elements of matrix in the same way, the normalized decision matrix R is constructed as;

$$R = \begin{bmatrix} 0.4528 & 0.5009 & 0.4597 & 0.4527 & 0.4154 & 0.4790 & 0.5383 & 0.4578 & 0.4461 & 0.2373 \\ 0.4447 & 0.4189 & 0.4768 & 0.4724 & 0.5206 & 0.4515 & 0.4482 & 0.4006 & 0.4388 & 0.6110 \\ 0.4513 & 0.4401 & 0.4087 & 0.4429 & 0.4475 & 0.4250 & 0.3979 & 0.4578 & 0.4508 & 0.4003 \\ 0.4553 & 0.3946 & 0.4087 & 0.4527 & 0.4134 & 0.4361 & 0.4250 & 0.4349 & 0.4592 & 0.5429 \\ 0.4316 & 0.4735 & 0.4768 & 0.4133 & 0.4304 & 0.4427 & 0.4128 & 0.4807 & 0.4408 & 0.3397 \end{bmatrix}$$

Step 2: The weights for each criteria assessed by an expert team consisting of two mining engineer and two mechanical engineer, who have 10 years of experience in TKI, were determined as;

$$w = (0.1,\ 0.15,\ 0.1,\ 0.05,\ 0.075,\ 0.075,\ 0.1,\ 0.05,\ 0.2,\ 0.1),\ \sum_{j=1}^{10} w_j = 1.$$

By using Equation 4, the first element of the weighted normalized decision matrix (v_{11}) is determined by multiplying the assigned weight to the first attribute and the first element of normalized matrix ($v_{11} = w_1 \cdot r_{11} = 0.1 \cdot 0.4528 = 0.0453$) . Calculating the other elements of matrix in the same way, the weighted normalized decision matrix *V* is constructed as below:

$$V = \begin{bmatrix} 0.0453 & 0.0751^* & 0.0460 & 0.0226 & 0.0312 & 0.0359^* & 0.0538^* & 0.0229 & 0.0892 & 0.0237^* \\ 0.0445 & 0.0628 & 0.0477^* & 0.0236^* & 0.0390^* & 0.0339 & 0.0448 & 0.0200^- & 0.0878^* & 0.0611^- \\ 0.0451 & 0.0660 & 0.0409 & 0.0221 & 0.0336 & 0.0319^- & 0.0398^- & 0.0229 & 0.0902 & 0.0400 \\ 0.0455^* & 0.0592^- & 0.0409^- & 0.0226 & 0.0310^- & 0.0327 & 0.0425 & 0.0217 & 0.0918^- & 0.0543 \\ 0.0432^- & 0.0710 & 0.0477^* & 0.0207^- & 0.0323 & 0.0332 & 0.0413 & 0.0240^* & 0.0882 & 0.0340 \end{bmatrix}$$

Step 3: In the each column of the weighted normalized decision matrix, the minimum and maximum values are marked according to Equation 6 and 7. The maximum values in the column 1 to 8 are the elements of ideal solution matrix because these attributes should be maximized. On the other hand, the minimum values of the last two columns are selected because the machine price and tire protection costs are minimized. In this situation, the ideal solution A* is determined as:

$$A^* = [0.0455\ \ 0.0751\ \ 0.0477\ \ 0.0236\ \ 0.0390\ \ 0.0359\ \ 0.0538\ \ 0.0240\ \ 0.0878\ \ 0.0237]$$

and the set of negative-ideal solution   is determined as:

$$A^- = [0.0432\ \ 0.0592\ \ 0.0409\ \ 0.0207\ \ 0.0310\ \ 0.0319\ \ 0.0398\ \ 0.0200\ \ 0.0918\ \ 0.0611]$$

Step 4: By using Equation 8, the first element of the distance from ideal solution matrix (S1*) is calculated as $0.0083\ ((0.0453-0.0455)^2 + (0.0751-0.0751)^2 + (0.0460-0.0477)^2 + (0.0226-0.0236)^2 + (0.0312-0.0390)^2 + (0.0359-0.0359)^2 + (0.0538-0.0538)^2 + (0.0229-0.0240)^2 + (0.0892-0.0878)^2 + (0.0237-0.0237)2)^{1/2}$. Following the same calculation procedure, the separation measure values are calculated as:

$$S_i^* = [0.0083\quad 0.0406\quad 0.0254\quad 0.0382\quad 0.0186]$$

Similarly; by using Equation 9, the first element of the distance from negative ideal solution matrix (S_1^-) is calculated as $0.0437\ ((0.0453-0.0432)^2 + (0.0751-0.0592)^2 + (0.0460-0.0409)^2 + (0.0226-0.0207)^2 + (0.0312-0.0310)^2 + (0.0359-0.0319)^2 + (0.0538-0.0398)^2 + (0.0229-0.0200)^2 + (0.0892-0.0918)^2 + (0.0237-0.0611)^2)^{1/2}$. Following the same calculation procedure, the separation measure values are calculated as:

$$S_i^- = [0.0437 \quad 0.0134 \quad 0.0227 \quad 0.0082 \quad 0.0309]$$

Step 5: By using Equation 10, the first element of the relative closeness to the ideal solution matrix (*Ci**) is calculated as 0.8404 ($0.0437/(0.0083+0.0437)$). In the same way, the relative closeness to the ideal solution is calculated as:

$$C_i^* = [0.8404 \quad 0.2481 \quad 0.4719 \quad 0.1767 \quad 0.6242]$$

Step 6: In this study, the preference order of five alternatives have been ranked according to the *Ci** values. So, the alternatives are ordered as: Alternative 1, Alternative 5, Alternative 3, Alternative 2 and Alternative 4. As a result of this evaluation, the best choice is Alternative 1 (Model 1) because it has the shortest distance to the ideal solution.

This example shows that the TOPSIS method can easily be used for the best convenient loader selection according to the desired technical features. Also, it can be realized that this method can be used for any equipment selection problem in mining industry. So, this method is very useful tool for either experienced or inexperienced engineers to decide on selecting the proper equipment.

4.2. The Application of the Topsis for a Factory Location Selection for Marble Industries

Besides equipment selection problem, another application of the TOPSIS method is illustrated in this section. This method was applied to determine the optimum facility location for a Marble Factory in Turkey. The determination of a facility location is well-known problem in operation research and DM area. Many researchers have studied on the selection of optimum location of mining facility (Ataei, 2005; Bhattacharya et al., 2001; Hajdasinski, 1995; Kumral, 2004; Magda, 1985; Zambo, 1968).

The natural stone production rate of Turkey was increased by 35% between 2000 and 2004. In 2004, 9% of the world's natural stone production comes from Turkey. Turkey's income from natural stone exports reached to a total of $626 million in 2004. It is constituted around 53% of the Turkey's total mining export income in that year (Ayhan, 2005). In 2011, natural stone exports increased to $1.675 billion and 43% of the country's total mining exports. In the future, it is expected that the Turkish marble industry's production rate will increase and new marble factories will be constructed in different region of Turkey. The most suitable facility location should be selected for marble factories to achieve planned production target considering the several criteria.

ELMAS Company is one of the milestone of Turkey's travertine and marble indurstries. It has their own travertine and marble quarries and two marble factories. The first ELMAS marble factory was founded in 1986 and they have been supplying the raw material their own travertine quarry in Denizli for 20 years, so far. In 1997, the company established the second factory in Eskisehir which is located in the western and northwestern part of Turkey. In Eskisehir factory, marble strips and rough draft slabs are sequentially subjected to calibrating, wax filling, dimensioning, polishing, chamfering, quality controlling and packing operations. The final products are transported to Izmir harbour for export. In 2006, the firm management decide to established a new factory. The four facility location alternatives are determined by the management as Eskisehir, Bozuyuk, Afyon-Iscehisar and Denizli district. In Figure 3 (Ozer, 2005); the location of travertine quarry, two present factories and four facility alternatives can be seen in the map.

Figure 3. The location of quarry, present factories and alternatives for a facility (Ozer, 2005).

The four facility location alternatives are compared according to 12 criteria (determined by the decision makers) as usual in the first stage of the application of the TOPSIS method. Both the qualitative and the quantitative values of all attributes for each alternative are given in Table III.

Attributes	**Alternatives**			
	(A) Eskisehir	(B) Bozuyuk	(C) Afyon	(D) Denizli
Land cost ($/m2)	10	5	7	8
Installation cost ($)	1000000	900000	750000	1200000
Transportation distance (km)	357	364	226	25
Tax reduction (%)	-	20	10	-
Raw material supply	Medium	Medium	Good	Very good
Manpower supply	Very good	Medium	Very bad	Bad
Climate	Bad	Bad	Bad	Good
Water supply	Very good	Very good	Good	Good
Market	Good	Good	Very good	Medium
Disposal of waste water	Very bad	Medium	Good	Very bad
Removal of waste marble	Very good	Bad	Bad	Very good
Local regulations	Bad	Good	Good	Medium

Table III. Alternatives and attributes for facility location selection.

Each linguistic variable is assigned a numerical value by using the scale explained in Table IV.

Utility based model	**Relative Intensity**	**Cost based model**
Very bad	1	Very good
Bad	3	Good
Medium	5	Medium
Good	7	Bad
Very good	9	Very bad

Table IV. Alternatives and attributes for facility location selection (Islier, 1997).

Decision matrix, whose each row denotes the alternatives and each column denotes the criteria, has been formed as the way given in Equation 1.

$$D = \begin{bmatrix} 10 & 1000000 & 357 & 0 & 5 & 9 & 5 & 9 & 7 & 1 & 9 & 3 \\ 5 & 900000 & 364 & 20 & 5 & 5 & 3 & 9 & 7 & 5 & 3 & 7 \\ 7 & 750000 & 226 & 10 & 7 & 1 & 3 & 7 & 9 & 7 & 3 & 7 \\ 8 & 1200000 & 25 & 0 & 9 & 3 & 7 & 7 & 5 & 7 & 9 & 5 \end{bmatrix}$$

In this matrix, 12 different criteria for 4 alternatives were evaluated. Following the mentioned procedure in the previous section, a factory location selection problem was solved by incorporating the TOPSIS technique. The weights for each criteria assessed by an expert team consisting of one geology engineer who is the manager of the firm and 20 years of experience in marble industry, two mining engineer who have 10 years of experience in marble industry and one firm owner, who have 40 years of experience were determined as;

$$w= (0.15,\ 0.05,\ 0.075,\ 0.075,\ 0.1,\ 0.125,\ 0.1,\ 0.025,\ 0.025,\ 0.075,\ 0.075,\ 0.0125),$$

$$\sum_{j=1}^{10} w_j = 1.$$

After following the same procedure (Step 2 to Step 6) explained before, the ideal solution is calculated as:

$$C_i^* = [0.4649 \quad 0.5382 \quad 0.4000 \quad 0.4336]$$

In this decision making problem, the preference orders of four alternatives have been ranked according to the values. So, the alternatives are ordered as: Alternative B, Alternative A, Alternative D, and Alternative C. As a result of this evaluation, Alternative B (Bozuyuk district) is the best choice because it has the shortest distance to the ideal solution. This application of the TOPSIS method reveals that the engineers (decision makers) can decide on the selection of the optimum facility location in more scientific way instead of relying on intuition or engineering judgment.

5. Conclusions

DM problems can always be encountered by mining engineer in deciding on the best alternative for the mining operations. However, the mining operations are often related with multifunctional and interrelated activities. The unexpected consequences can be encountered if the wrong decisions are made in mining industry without using the scientific methods by considering multifunctional and interrelated activities. DM based on the scientific methods will cause an increase in the productivity of mining sector and also will cause mining engineers to be more active in the process. Among the different MADM methods, the TOPSIS is easier method to be understood and applied than the others. When it is considered that human mind can cope with seven plus or minus two criteria considering the relationships under normal conditions (Saaty and Ozdemir, 2003), using a suitable MADM method especially in the solution of complex problems will provide mining engineers to achieve more accurate results.

The TOPSIS method was successfully applied to the real decision making problems in mining industry such as a loader selection for an open pit and a facility location selection for a travertine factory. In the process of decision making on a loader, the attributes of the machine and tire protection prices were minimized while the others were maximized in order to be able to select the convenient loader for the open pit of TKI. Similarly, in the process of selection of the facility location, the attributes of the land cost, installation cost and transportation distance were minimized while the others were maximized to determine the best location of travertine factory.

The TOPSIS will be very helpful to mining engineers in a wide range of decision making problem. It enabled the capture of the experience and opinions of specialists to the structure of a DM model and validates the results.

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