APPLICATION OF AHP-TOPSIS METHOD FOR LOADING-HAULAGE EQUIPMENT SELECTION IN OPEN PIT MINES

Aghajani[1], M. Osanloo[2]
[1]Faculty of Mining Engineering, Islamic Azad University, Savadkooh Branch, Iran.
a_aghajani@aut.ac.ir
[2]Professor, Department of Mining and Metallurgy Engineering,
Amirkabir University of technology, Tehran, Iran.
morteza.osanloo@gmail.com

ABSTRACT

Equipment selection is one of the most important stages in open pit design. Equipment selection is a complex multi person, multi-criteria decision problem. TOPSIS is a multi- attribute decision making (MADM) technique which is a practical and useful technique for ranking and selection of a number of externally determined alternatives through distance measure. In this paper, AHP and TOPSIS method were used to select optimal loading-haulage equipment in Sungun large copper mine of Iran. The result of this study show significant reduction of time consumption of calculation and good accuracy compared to existence methods.

RESUMEN

La selección del equipo es una de las etapas más importantes en el diseño del tajo a cielo abierto. La selección del equipo es un complejo problema de decisión multipersonal y de multicriterio. TOPSIS es una técnica para la toma de decisión de los multiatributos (MADM) que es una técnica práctica y útil para la clasificación y selección de un número de alternativas determinadas exteriormente con medida de la distancia. En este trabajo, el método AHP y TOPSIS fueron utilizados para la selección óptima del equipo de carga-transporte en la gran mina de cobre Sungun de Irán. El resultado de este estudio ofrece una importante reducción en el cálculo del consumo del tiempo y una buena exactitud comparados con métodos existentes.

INTRODUCTION

Equipment selection for open-pit mines is definitely a major decision which will impact greatly the economic viability of an operation (Bascetin, 2004). Equipment selection is one of the most important factor that affect open-pit design (pit slopes, bench high, block sizes and geometries, ramp layout as well as excavation sequences and open-pit layout) and production planning (bascetin,2003). Multiple attribute decision making (MADM) deals with the problem of choosing an alternative from a set of alternatives which are characterized in terms of their attributes. Nearly the past three decades, the AHP (analytic hierarchy process) and TOPSIS (technique for order performance by similarity to ideal solution) have been advanced as a formal means to deal with implicit imprecision in a wide range of problems, e.g. in mining engineering, military operations, economics, engineering, medicine, reliability, and pattern recognition and classification. There are many references to relevant applications in these and other field. (Herzog, 1996 -Osanloo, 2006 - DengYong, 2006 - Bandopadhay 1987).

There are many factors that affect the mining equipment selection. These factors are both qualitative and quantitative. Decision-makers need a decision support system that evaluates the factors in a complex structure for optimal decision making. Analytical hierarchy process (AHP) is an appropriate method that can support decision-making, when examining various equipment selection scenarios. First step in AHP trend is to demonstrate the hierarchy structuring of real complex problem which the general objective is positioned at the highest level (Saaty, 1990).

The AHP-TOPSIS is applied in large deposit of copper mine of Iran, mainly because of its inherent ability to handle qualitative and quantitative criteria used in equipment selection problem; also, the AHP-TOPSIS can help to improve the decision-making process.

ANALYTIC HIERARCHY PROCESS MODEL

This method has been developed by Saaty (saaty, 1990, 1994). The AHP structures the decision problem in levels which correspond to one understands of the situation: goals, criterion, sub-criterion, and alternatives. By breaking the problem into levels, the decision-maker can focus on smaller sets of decisions. In AHP technique the elements of each level compared to its related element in upper level inform by pair-wise comparison method. The results of these comparisons are shown in matrix form as below:

$$A=\begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ . & . & . & . \\ . & . & . & . \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} \quad \text{or} \quad A=\left[a_{ij}\right] \quad i,j=1,2,\ldots,n$$

Where: a_{ij} is the priority of element i compared to element j. It must be noted that, in pair comparison of criterion if the priority of element i compared to element j is equal to w_{ij} then the priority of element j compared to element i is equal to $1/w_{ij}$. The priority of element compared to it is equal to one.

AHP method is applied in this research for criteria weighting. So, at first, set up n criteria in the rows and columns of n × n matrix. Then, Perform pair wise comparisons of all the criteria according to the goal. The fundamental scale used for this purpose is shown in Table 1. For each pair of criteria (starting with Cr_1 and Cr_2) insert their determined relative intensity of value in the position (Cr_1, Cr_2) where the row of Cr_1 meets the column of Cr_2. In position (Cr_2, Cr_1) insert the reciprocal value, and in all positions in the main diagonal insert a '1'. For a matrix of order n, ((n) ´(n-1)/2) comparisons are required. Use average over normalized columns to estimate the eigenvalues of the matrix and for this reason calculate the sum of the n columns in the comparisons matrix then divide each element in the matrix by the sum of the column the element is a member of, and calculate the sums of each row.

Then normalize the sum of the rows (divide each row sum with the number of requirements). The result of this computation is referred to as the priority matrix and is an estimation of the eigenvalues of the matrix. If one can determine precisely the relative value of all criteria; the eigen values would be perfectly consistent. For instance, if it is determined that Cr_1 is much more valuable than Cr_2, Cr_2 is somewhat more valuable than Cr_3, and Cr_3 is slightly more valuable than Cr_1, an inconsistency has occurred and the result's accuracy is decreased.

The redundancy of the pair wise comparisons (table 1) makes the AHP much less sensitive to judgment errors; it also lets one measure judgment errors by calculating the consistency index of the comparison matrix, and then calculating the consistency ratio. As a general rule, a consistency ratio of 0·10 or less is considered acceptable.

Numerical assessment	*Linguistic meaning*
1	Equal important
3	Moderately more important
5	Strongly more important
7	Very strongly important
9	Extremely more important
2,4,6,8	Intermediate values of importance

Table 1 - Scale for pair wise comparisons

TOPSIS METHOD

TOPSIS is a useful technique in dealing with multi attribute or multi-criteria decision making (MADM/MCDM) problems in the real world (Hwang, 1981). It helps decision maker(s) (DMs) organize the problems to be solved, and carry out analysis, comparisons and rankings of the alternatives. Accordingly, the selection of a suitable alternative(s) will be made.

A MADM problem can be concisely expressed in a matrix format, in which columns indicate attributes considered in a given problem and list the competing alternatives in rows. Specifically, a MADM problem with m alternatives (A_1, A_2… A_m) that are evaluated by n attributes (C_1, C_2 … C_n) can be viewed as a geometric system with m points in n-dimensional space. An element x_{ij} of the matrix indicates the performance rating of the I^{th} alternative, A_i, with respect to the j^{th} attribute, C_j.

Hwang and Yoon (Hwang, 1981) developed TOPSIS based on the concept that the chosen alternative should have the shortest distance from the positive ideal solution and the longest distance from the negative ideal solution. More detailed information can be found in Yoon and Hwang [Yoon, 1995]. The terms used in the present study are briefly defined as follows:

- **Attributes:** *Attributes (C_j, j=1, 2 . . . n) should provide a means of evaluating the levels of an objective. There are twenty two attributes for each alternative in the present study.*
- **Alternatives:** *These are synonymous with 'options' or 'candidates'. Alternatives (A_i, i=1 . . . m) are mutually exclusive of each other.*
- **Attribute weights:** *Weight values (w_j) represent the relative importance of each attribute to the others. W={w_j| j = 1, 2 ... n}. It is the results of AHP analysis.*
- **Normalization:** *Normalization seeks to obtain comparable scales, which allows attribute comparison. The vector normalization is a commonly seen approach as defined in Eq. (2).*

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

The vector normalization method as shown in Eq. (2) can properly transform the performance rating to a value ranging from 0 to 1. For a given attribute, the sum of the normalized values across alternatives is not necessary to be 1 (Yoon, 1995).

Given the above terms, the formal TOPSIS procedure is defined as follows:

Step 1: Calculate normalized rating for each element in the decision matrix.

Step 2: Calculate weighted normalized ratings. The weighted normalized value v_{ij} is calculated by Eq. (3).

$$v_{ij} = w_j \times r_{ij} \qquad i = 1,2,\ldots,m\,;\ j = 1,2,\ldots,n$$

Step 3: Identify positive ideal (A*) and negative ideal (A-) solutions. The A* and A- are defined in terms of the weighted normalized values, as shown in Eqs. (4) and (5), respectively

$$A^* = \left\{v_1^*, v_2^*, \ldots, v_j^*, \ldots, v_n^*\right\} = \left\{(\max_i v_{ij} \,|\, j \in J) \,|\, i = 1,2,\ldots,m\right\}$$

$$A^- = \left\{v_1^-, v_2^-, \ldots, v_j^-, \ldots, v_n^-\right\} = \left\{(\min_i v_{ij} \,|\, j \in J) \,|\, i = 1,2,\ldots,m\right\}$$

Where J is the set of attributes.

Step 4: Calculate separation measures. The separation (distance) between alternatives can be measured by the n dimensional euclidean distance. The separation of each alternative from the positive ideal solution, A*, is given by Eq. (6).

$$S_i^* = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^*)^2}, \qquad i = 1,2,..,m$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, \qquad i = 1,2,..,m$$

SUNGUN COPPER MINE

Sungun mine is one of the largest copper deposits of Iran which is located in the north-west of the country close to Azerbaijan, Armenia and Turkey borders (figure1). Technical and economical studies were shown that the most appropriate of mining method for this deposit is open pit mining method. By this method 384 million tons of ore with 0.665 percentage of copper grade can be mined. Total mine's life estimated to be 31 years with annual production of 7 million tons in first 5 years and 14 million tons for remaining years. During this period 680 million tons of waste must be removed. So, the waste to ore ratio in this mine is 1.8:1 (Hoseinie, 2006).

Three potential transportation system alternatives have been evaluated. These are loader- truck (A_1), shovel-truck (A_2) and shovel-truck-belt conveyor (A_3) systems.

Figure 1 - Geographical location of Sungun coppers mine.

AHP MODEL FOR LOADING-HAULAGE SYSTEM SELECTION IN SUNGUN COPPER MINE

The structure of the problem according to Saaty's hierarchy is given in Figure 1. The goal is to select the loading–hauling system that can meet optimal production requirements. This goal is placed on the first level of the hierarchy. Two strategic factors, namely cost and operational/technical factors, are identified to achieve this goal, which form the second level of the hierarchy. The third level of the hierarchy covers the criteria defining the two strategic factors of cost and operational/technical factors of the second level. There are two criteria related to cost, namely capital and operating cost. The criteria associated with operational/technical factors are operating conditions and equipment technical parameters. Some criteria are divided into some sub criteria (figure 2). The normalized local priority weights of strategic factors, criteria and sub criteria are combined together with respect to all successive hierarchical levels to obtain the global composite priority weights of all sub criteria used in the fourth level of the AHP model.

Expert Choice software is used to determine the global priority weights. After calculating the global weights, they are rearranged in descending order of priority (figure 3).

In this study, twenty two attributes and three alternatives were considered. AHP model was used to attribute weighting because Weight of attribute should be given to decision makers for application TOPSIS method. For the first step of this methodology, the decision matrix, representing the performance values of each alternative with respect to each criterion, is

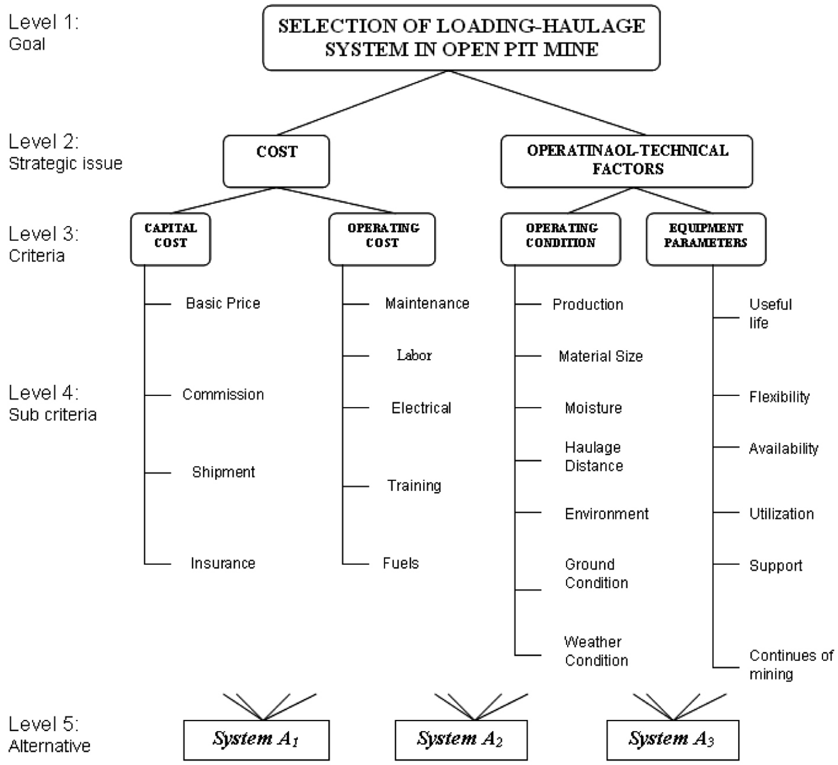

Figure 2- AHP model for loading–hauling system selection

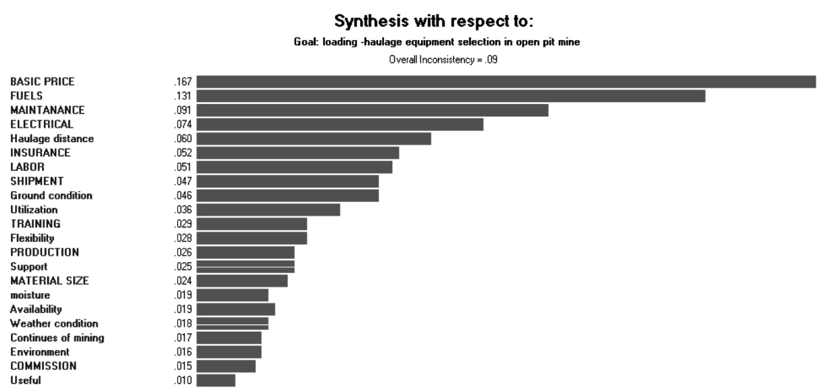

Figure 3- global priority weights with Expert Choice software

computed. Next, these performance values are multiplied with the criteria weights calculated with AHP. The step of defining the ideal solution consists of taking the best values of alternatives and with the similar principle, the negative-ideal solution is obtained by taking the worst values of alternatives. Table 2 is showing thirteen attributes are cost criteria and nine attributes are benefit criteria.

DISCUSSIONS

The hierarchical structure of the decision model of the paper with the alternatives and the identified criteria is portrayed in Figure 2. The decision problem consists of three levels: at the highest level the objective of the problem is situated while in the second level, the criteria are listed. The last level belongs to the alternatives. These alternatives are: loader- truck (A_1), shovel-truck (A_2) and shovel-truck-belt conveyor (A_3) systems. The normalized global priority weights among the four main criteria and twenty two sub-criteria and their ranking have been depicted in figure 2.

From the figure2, we can conclude that the cost criteria play a predominant role with an overall weight of 75 %, since during the loading-haulage equipment selection procedure; cost criteria are in most significant place. The weighted normalized decision matrix of the alternatives calculated by multiplying the normalized decision matrix and the weights are represented in table 2. Furthermore, the computed distances of each alternative to ideal solution (S^*) and non-ideal solution (S^-) have been shown in table 3.

The last step of the TOPSIS methodology consists of ranking the alternatives according to their relative closeness to the ideal solution (figure 4). Ultimately, Shovel-Truck has become the most desirable system among three alternatives with the final performance value of 0.585; while loader-Truck and Shovel-Truck-Conveyor belt have positioned at the second and third ranks with 0.503 and 0.447 as the final performance values, respectively.

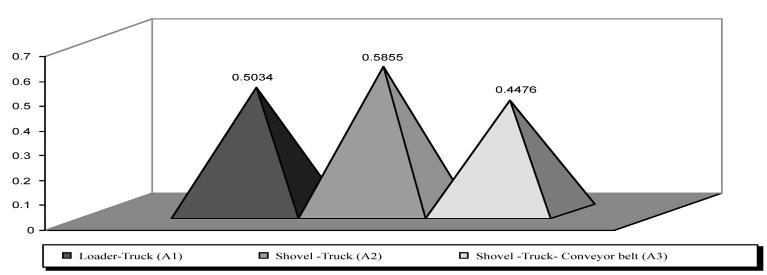

Figure 4- Ranking of the preference order of the alternatives

Alternative / attributes	System A1	System A2	System A3	Attributes weighting	$v_{ij} = w_j \times r_{ij}$			A*	A-
Basic price	0.235	0.281	0.292	0.167	0.0391	0.0468	0.0486	0.0391	0.0486
Commission	0.141	0.161	0.146	0.015	0.0021	0.0024	0.0022	0.0021	0.0024
Shipment	0.235	0.281	0.292	0.052	0.0123	0.0147	0.0153	0.0123	0.0153
Insurance	0.141	0.161	0.146	0.047	0.0067	0.0076	0.0069	0.0067	0.0076
Maintenance	0.188	0.201	0.175	0.091	0.0170	0.0182	0.0159	0.0159	0.0182
labor	0.188	0.161	0.146	0.051	0.0095	0.0081	0.0074	0.0074	0.0095
Electrical	0.047	0.201	0.263	0.074	0.0035	0.0148	0.0194	0.0035	0.0194
Training	0.094	0.120	0.088	0.029	0.0027	0.0034	0.0025	0.0025	0.0034
Fuels	0.282	0.120	0.146	0.131	0.0368	0.0157	0.0191	0.0157	0.0368
Production	0.188	0.321	0.292	0.026	0.0048	0.0083	0.0075	0.0075	0.0048
Material size	0.235	0.080	0.233	0.024	0.0056	0.0019	0.0056	0.0019	0.0056
Moisture	0.141	0.161	0.204	0.019	0.0027	0.0031	0.0039	0.0027	0.0039
Haulage distance	0.188	0.120	0.117	0.060	0.0112	0.0072	0.0070	0.0112	0.0070
Environment	0.235	0.161	0.117	0.016	0.0037	0.0026	0.0019	0.0019	0.0037
Ground condition	0.329	0.201	0.117	0.046	0.0151	0.0092	0.0054	0.0151	0.0054
Weather condition	0.329	0.201	0.175	0.018	0.0059	0.0036	0.0031	0.0059	0.0031
Useful life	0.235	0.361	0.379	0.010	0.0024	0.0038	0.0039	0.0039	0.0024
Flexibility	0.282	0.161	0.058	0.028	0.0078	0.0045	0.0016	0.0078	0.0016
Availability	0.235	0.241	0.204	0.019	0.0045	0.0047	0.0040	0.0047	0.0040
Utilization	0.188	0.321	0.263	0.036	0.0068	0.0116	0.0095	0.0116	0.0068
Support	0.141	0.201	0.233	0.025	0.0036	0.0051	0.0059	0.0036	0.0059
Continues of mining	0.141	0.201	0.292	0.017	0.0024	0.0035	0.0051	0.0051	0.0024

Table 2 - positive ideal (A^*) and negative ideal (A^-) solutions

	Loader-Truck	Shovel-truck	Shovel-truck-Conveyor belt
S^*	0.022521	0.016584	0.023212
S^-	0.022832	0.023428	0.018811

Table 3 - The distances of each alternative to ideal solution and non-ideal solution

CONCLUSION

Equipment selection is one of the most important factors that affect open-pit design and production planning. In this study combination of AHP-TOPSIS technique is introduced to select the suitable loading-haulage equipment in large open pit mines. So, the proposed method is used in large Sungun copper mine of Iran. The result of this studies shows that the procedure of selecting loading-haulage equipment by decision making is less consuming time and more reliable compared to traditional methods.

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