Tunnelling and Underground Space Technology 24 (2009) 173–184

Contents lists available at ScienceDirect

Tunnelling and Underground Space Technology

journal homepage: www.elsevier.com/locate/tust

Underground mining method selection by decision making tools

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ARTICLE INFO

Article history:
Received 28 January 2008
Received in revised form 3 July 2008
Accepted 29 July 2008
Available online 17 September 2008

Keywords:
Analytic hierarchy process
Multiple attribute decision making
Yager's method
Underground mining method selection

ABSTRACT

Underground mining method selection is one of the most important decisions that mining engineers have to make. Choosing a suitable underground mining method to extract a mineral deposit is very important in terms of economics, safety and productivity of mining operations. In real life, underground mining method selection is one of the multiple attribute decision making (MADM) problems and decision makers have always some difficulties in making the right decision in the multiple criteria environment. Analytic hierarchy process (AHP) and Yager's methods are the MADM tools and can be used for selection of the best underground mining method by considering the problem criteria. In this study, a computer program (UMMS) based on the AHP and the Yager's method was developed to analyze the underground mining method selection problems and produce the best underground mining method swiftly for different deposit shapes and ore bodies.

1. Introduction

Mineral exploitation in which all extractions are carried out beneath the earth's surface is termed as underground mining. Underground methods are employed when the depth of the deposit, the stripping ratio of overburden to ore (or coal or stone), or both become excessive for surface exploitation (Hartman and Mutmansky, 2002).

Underground mining method should be primarily selected to make use of underground resources optimally. Besides, the ground control on the mining areas, planning the ventilation system, decreasing the maintenance costs of gallery, developing new mining panels and preparing the underground production schedule are also directly related to underground mining method selection, such like geology of deposit. So, underground mining method selection process is extremely important in mine designs.

To make the right decision on underground mining method selection, all known criteria related to the problem should be taken into consideration. Increasing the number of criteria in decision making process makes the problem more complex, but the rightness of the decision also increases. Because of arising complexity in the decision process, many conventional methods consider only limited number of criteria. So, there is a need for alternative methods, which can consider all known criteria related to underground mining method selection in the decision making process.

Once selected a mining method, as it is nearly impossible to change it owing to the rising costs and mining losses, it is very important to re-analyze the decision made before carrying it out. The method that the decision makers generally use for this aim is the sensitivity analysis on the final decision.

2. Literature review

2.1. Studies on mining method selection

The problem of underground mining method selection has been studied in the literature. Boshkov and Wright (1973) proposed a classification system which was one of the first qualitative classification schemes. Morrison (1976) suggested a selection chart for mining method selection. Laubscher (1981) proposed a selection methodology of an appropriate mass underground mining method based on rock mass classification system. Nicholas (1981) presented a classification system for selection of the optimum mining method via numerical ranking with quantitative analysis. Hartman (1987) developed a selection chart based on the geometry of the deposit and the ground conditions of the ore zone for selecting mining method. Miller-Tait et al. (1995) modified the Nicholas' system and developed the UBC mining method selection process.

2.2. Studies on decision making techniques in mining

A review of the literature reveals that decision making techniques have been used for a variety of specific mining applications. Bascetin and Kesimal (1999) used Yager's method for selection of an optimum coal transportation system from pit to the power plant. Karadogan et al. (2001) solved an underground mining

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doi:10.1016/j.tust.2008.07.003

method selection problem by using the Yager's method and they used Satty's analytic hierarchy process (AHP) method for pair-wise comparison of the criteria. 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 of overall project for various depths. Kesimal and Bascetin (2002) used the Yager's method for solving equipment selection problem in open pit mine. Samanta et al. (2002) used the AHP method for selection of open cast mining equipment. Bitarafan and Ataei (2004) solved the similar problem by using the Yager's method with Satty's AHP method and they also used fuzzy dominance method in their analysis. Elevli and Demirci (2004) selected most suitable underground ore transport system for a chromate mine by using the one of the multiple attribute decision making (MADM) method namely Preference Ranking Organization MeTHod for Enrichment Evaluation (PROMETHEE). Kazakidis et al. (2004) used the AHP method 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. Ataei (2005) used the AHP method for the problem of selection of a new alumina cement plant location in East-Azerbaijan province of Iran. Acaroglu et al. (2006a, 2006b) used the Yager's and the AHP method for selection of roadheaders in tunneling applications. Bascetin et al. (2006) developed a computer program using the Yager's method for equipment and mining method selection in mining. Yavuz et al. (2008) used the AHP method for selection of optimum support type in the main haulage road in Lignite colliery.

In this paper, a computer program (UMMS) based on the AHP and the Yager's method for underground mining method selection was developed. The UMMS provides two different AHP models so that the decision makers can analyze the selection problem based on either only main criteria or main criteria with their sub-criteria. The UMMS also provides a Yager's method which is one of the fuzzy multiple attribute decision making (FMADM) methods as an alternative way to analyze the problem. Another important function provided by the UMMS is the sensitivity analysis. The decision makers can carry out the sensitivity analysis whenever he/she needs to observe the sensitivity of final solution against the variations in the main criteria considered.

3. Theory review

3.1. AHP model

The AHP method developed by Saaty (1980) gives an opportunity to represent the interaction of multiple factors in complex unstructured situations. The method is based on the pair-wise comparison of components with respect to attributes and alternatives. A pair-wise comparison matrix $n \times n$ is constructed, where n is the number of elements to be compared. The method is applied for the hierarchy problem structuring (Saaty, 2000).

After the hierarchy structuring the pair-wise comparison matrix is constructed for each level, where a nominal discrete scale from 1 to 9 (Table 1) is used for the evaluation (Saaty, 1980).

The next step is to find the relative priorities of criteria or alternatives implied by this comparison. The relative priorities are worked out using the theory of eigenvector. For example, if the pair comparison matrix is A, then,

$$(A - \lambda_{\max} \times I) \times w = 0 \quad (1)$$

To calculate the eigenvalue "$\lambda_{\max}$" and eigenvector $w = (w_1, w_2, \ldots, w_n)$, weights can be estimated as relative priorities of criteria or alternatives (Saaty, 2000).

Table 1
Scale for pair-wise comparisons (Saaty, 1980)

Relative intensity	Definition	Explanation
1	Of equal value	Two requirements are of equal value
3	Slightly more value	Experience slightly favors one requirement over another
5	Essential or strong value	Experience strongly favors one requirement over another
7	Very strong value	A requirement is strongly favored and its dominance is demonstrated in practice
9	Extreme value	The evidence favoring one over another is of the highest possible order of affirmation
2, 4, 6, 8	Intermediate values between two adjacent judgments	When compromise is needed

Since the comparison is based on the subjective evaluation, a consistency ratio is required to ensure the selection accuracy. The consistency index (CI) of the comparison matrix is computed as follows:

$$\mathrm{CI} = (\lambda_{\max} - n)/(n - 1) \quad (2)$$

where $\lambda_{\max}$ is maximal or principal eigenvalue and n is the matrix size. The consistency ratio (CR) is calculated as

$$\mathrm{CR} = \mathrm{CI}/\mathrm{RI} \quad (3)$$

where "RI" denotes random consistency index. Random consistency indices are given in Table 2 (Saaty, 2000).

As a general rule, a consistency ratio of 0.10 or less is considered acceptable. In practice, however, consistency ratios exceeding 0.10 occur frequently.

3.2. FMADM model

FMADM methods have been developed due to the lack of precision in assessing the relative importance of attributes and the performance ratings of alternatives with respect to an attribute. The problem of FMADM is to select/prioritize/rank a finite number of alternatives by evaluating a group of predetermined criteria. Thus, to solve this problem, an evaluation method to rate and rank, in order of preference, the set of alternatives must be constructed (Chen and Klein, 1997).

Although a large number of FMADM methods have been addressed in the literature, the focus of this paper is on Yager's (1978) method. This method is general enough to deal with both multiple objectives and multiple attribute problems and follows the max–min method of Bellman and Zadeh (1970), with the improvement of Saaty's method, which considers the use of a reciprocal matrix to express the pair-wise comparison of the criteria and the resulting eigenvector as subjective weights. The weighting procedure uses exponentials based on the definition of linguistic hedges, proposed by Zadeh (1973).

On describing multiple attribute decision making problems, only a single objective is considered, namely the selection of the best alternative from a set of alternatives. The decision method assumes the max–min principle approach. Formally, let $A = \{A_1, A_2, \ldots, A_m\}$ be the set of alternatives, $C = \{C_1, C_2, \ldots, C_n\}$ be the set of criteria, which can be given as fuzzy sets in the space of alternatives. Hence, the fuzzy set decision is the intersection of all criteria: $\mu_D(A) = \min[\mu_{C_1}(A), \mu_{C_2}(A), \ldots, \mu_{C_n}(A)]$. For all $(A_i) \in A$, and the optimal decision is yielded by, $\mu_D(A^*) = \max_A \mu_D(A)$, where A^* is the optimal decision. Main difference in this approach is that the importance of criteria is represented as exponential scalars. The rationale behind using weights (or importance levels) as exponents is that the higher the importance of criteria, the larger should