The optimum rock bolt support system selection by using AHP method

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Abstract
Engineers may frequently encounter with the situation that need to select the optimum option among the alternatives related with mining and civil operations. Experience and intuition have traditionally been central to decision-making in mining because of the frequent lack of quantitative data. Qualitative analysis is based primarily on the judgment, knowledge and experience of one or more experts. However, decision-making methods can offer to the engineers to support their optimum selection for a particular application in the scientific way. This paper presents an application of the AHP method to the selection of the optimum rock bolt support system design. For this purpose nine types of rock bolt which are most practical for supporting excavations were selected and by comprehensive study of these rock bolts, twenty six parameters which are effective for choosing the best kind of rock bolt were presented. By using the Expert Choice software the appropriate kind of rock bolt is presented and sensitive analysis for the results was carried out. The result of this study shows that AHP application can assist the engineers to effectively evaluate the rock bolt support system alternatives for excavations.

Keywords: AHP, MADM, Rock bolt, Support System, Expert Choice

1- Introduction
Mining engineering was often regarded in the past as ‘an art rather than a science’. Experience and intuition have been central to decision making because of the frequent lack of quantitative data. Uncertainty in data has significantly impeded reliable decision making, particularly over resource allocation and timing of activities. Mining processes relate to multifunctional, interrelated activities. Reliable qualitative or quantitative data analysis to evaluate risk as well as its impact in the

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mining life cycle is both challenging as well as significant. The increasingly holistic nature of decision making in mining engineering, makes the need to integrate qualitative input more attractive [1].
Over nearly the past three decades, the analytic hierarchy process (AHP) has been advanced as a formal means to deal with implicit imprecision in a wide range of problems, e.g. in industrial control, military operations, economics, engineering, medicine, reliability, and pattern recognition and classification. The AHP is applied in this study, mainly because of its inherent ability to handle qualitative and quantitative criteria used in rock bolt selection problems. Furthermore, it can easily be understood and applied to all mining decisions by operating managers. Also, the AHP can help to improve the decision-making process. The hierarchical structure used in formulating the AHP model can enable all members of the evaluation team to visualise the problem systematically in terms of relevant criteria and subcriteria. Furthermore, using the AHP, the evaluation team can systematically compare and determine the priorities of the criteria and subcriteria [2].
A review of the literature reveals that the AHP techniques have been used for a variety of specific applications in decision-making in mining operations. Samanta et al. (2002) incorporated the AHP method to the selection of open cast mining equipment as this process of decision-making is not a well-defined process and because it involves interaction of several subjective factors or criteria [3]. Bitarafan and Ataei (2004) solved the underground mining method selection problem by using FADM with utilization of the AHP method and they also used Fuzzy Dominance Method in their analysis [4].Kazakidis et al. (2004) used the AHP and analyzed five different mining scenarios such as drilling technology investment analysis, ground support design, tunnelling systems design, shaft location selection and mine planning risk assessment.[2] Ataei (2005) used the AHP method to develop a location evaluation hierarchy for alumina cement plant in East-Azerbaijan province of Iran [5] Bottero and Peila (2005) compared two different excavation alternatives, microtunnelling and trench excavation for an urban sewer construction project by using AHP [6]. Yavuz (2008) presents an application of the AHP method to the selection of the optimum support design for the main transport road, which has been planned for deep coal seam panels of Western Lignite Corporation (WLC) Tuncbilek in Turkey [7].

2- Multiple Attribute Decision Making (MADM) method

2-1- Defining MADM

MADM methods are developed to handle concept selection problems. In this class of problems, the “best” solution is determined from a finite and usually small set of alternatives. The selection is performed based on the evaluation of the attributes and their preference information [8].

2-2- Analytic *Hierarchy Process*

This method has been developed by Saaty [9,10]. 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.

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. For a matrix of order n, $(n \times \frac{n-1}{2})$ comparisons are required. Use average over normalized columns to estimate the Eigen values of the matrix. The redundancy of the pair wise comparisons 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[10].

3- Applying MADM technique for optimum rock bolt selection

In this study, by comprehensive study on the effective parameters in rock bolt selection, twenty six attributes was adjusted and nine type of rock bolt their usage is common as support system, was selected as alternatives. Table 1 shows selected attributes and also, for simplicity in the text, indexes of each of them.

Table 1. Sub divided attributes and their index

Attributes				index
Load Transfer Capacity	*Engineering Geology*	*Blocky*		C_1
		Shearing Zone	*Dense Joints*	C_2
			Far Joints	C_3
		Bedding	*Hard Rock Roof*	C_4
			Soft Rock Roof	C_5
	Water in the Media	*Acidity Water*		C_6
		Non-Acidity Water		C_7
	Mechanism of Anchor	*Bolt Yield Strength*		C_8
		rock shearing strength		C_9
		Embedded Interface		C_{10}
		Annulus Thickness		C_{11}
		Roughness	*Smooth*	C_{12}
			Rough	C_{13}
Shank cost, Anchor cost, Man Work Cost, Machines				C_{14}
Ease of Installation	*Time of Installation*			C_{15}
	Man Work Skill			C_{16}
	Method of Installation	*Manual*		C_{17}
		Mechanized		C_{18}
Curing Time				C_{19}
Distance from Heading Face	*Excavation Method*	*Mechanized*		C_{20}
		Blasting		C_{21}
	Rock Strength	*Weak*		C_{22}
		Strong		C_{23}
Anchor Length	*Height of Dead Load*	*Strong Roof*		C_{24}
		Weak Roof		C_{25}
	Anchor Type			C_{26}

By using Expert Choice software which its methodology is based on AHP method, AHP model of this research was constructed. In the first step, by comparison between attributes global weight of each attribute was calculated. The result of this step is shown in figure 1. In the next step, by comparison between parameters based on each attribute decision matrix was calculated. Because of conference template, and pages limitation this matrix hasn't been shown in this article. Finally by expert choice the optimum rock bolt was calculated as can be seen in figurer 2.

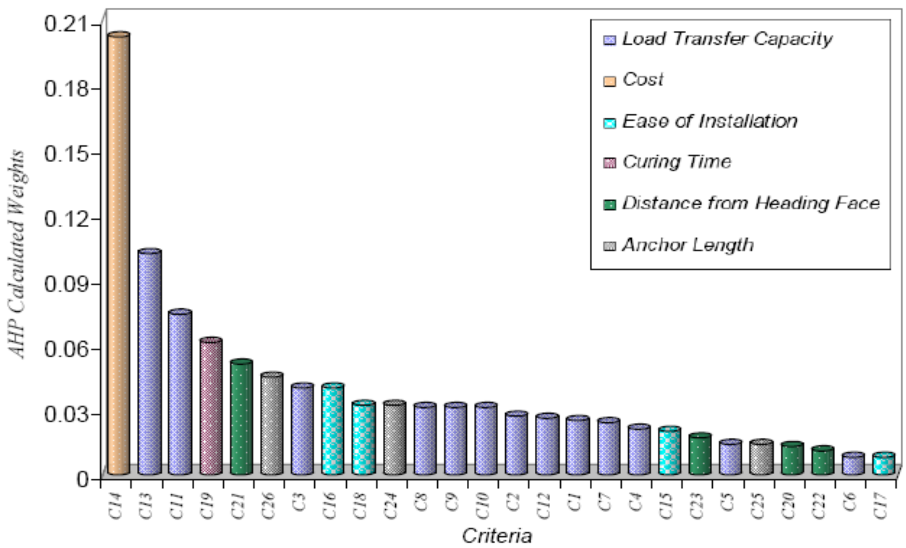

Figure 1. Global weights of the evaluation attributes calculated using AHP method

Maximum efficiency and minimum difference value is belong to the resin tensioned fully grouted bolts, which is due to the high load transfer capacity, long anchorage length, easy installation and applicability in various conditions. In addition to this, the bolt profile configurations and pretensioning increase significantly the bolt load capacity [11]. From the analyzed results it was revealed that untensioned resin grouted bolts are less effective than tensioned resin grouted bolts around 10%. Authors' laboratory and numerical simulations showed that Bolt pre-tension increases the level of shear resistance and shear stiffness. [11]

Based on the dynamic sensitivity analysis (figure 3), it can clearly be seen that in Resin Tension ,Cement Tension, Resin Untension, Swelex ELX (hybrid Swellex) and Cement Untension rock bolts the biggest priority of effects refer to load transfer capacity. Expansion shell and normal swelex are more sensitive to the load transfer capacity. However, cost and curing time for expansion shell and cost and distance from heading face are more eligible and have serious effect in sensitive analysis. Split set and slot&wedge are very sensitive to the cost and any changes in the cost of them can cause an important effect in the optimum selection of rock bolt type.

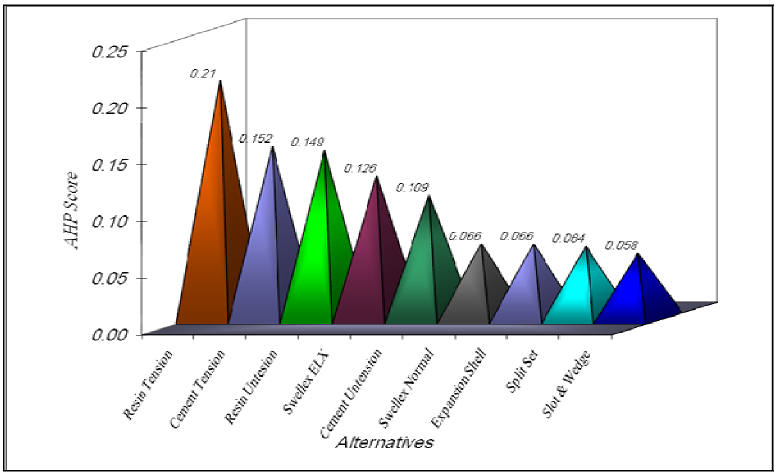

Figure 2. Ranking of the **preference** *order of the alternatives*

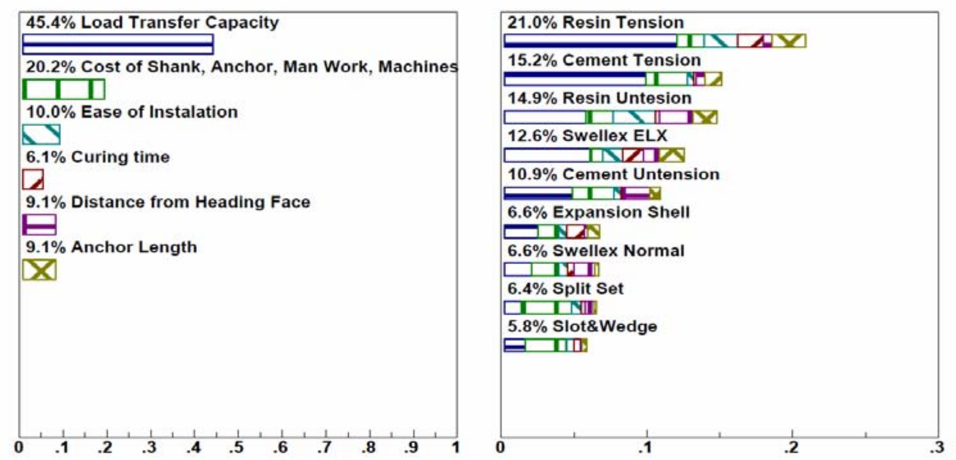

Figure 3. Dynamic sensitive analysis of main parameters with respect to goal

4- Conclusion

Many decisions that are made in the support system design tend to be multiple criteria decisions, such as the selection of the best rock bolt system which was discussed in this paper. There is a potential for increased use of the AHP in underground excavations to select the optimum rock bolt support system which was illustrated in this paper. From the results it was found that the untensioned resin grouted bolts are less effective than tensioned resin grouted bolts around 10%. According to the experimental and insitu results, it was inferred that bolts with weak embedded bond strengths and short anchorage length such as split set and slot and wedge respectively, carry low load transfer capacity which shows a very good agreement with current results presented by MCDM approach.

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