We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,300

Open access books available

172,000

International authors and editors

190M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Numbers displayed above are based on latest data collected.
For more information visit www.intechopen.com

Evaluating the Power Consumption in Carbonate Rock Sawing Process by Using FDAHP and TOPSIS Techniques

Reza Mikaeil¹, Mohammad Ataei¹ and Reza Yousefi²

¹*Faculty of Mining, Petroleum & Geophysics, Shahrood University of Technology, Shahrood*

²*School of mechanical engineering, Sharif University of Technology, Tehran
Iran*

1. Introduction

The prediction of rock sawability is important in the cost estimation and the planning of the stone plants. An accurate estimation of rock sawability helps to make the planning of the rock sawing projects more efficient. Rock sawability depends on non-controlled parameters related to rock characteristics and controlled parameters related to properties of cutting tools and equipment. In the same working conditions, the sawing process and its results are strongly affected by mineralogical and mechanical properties of rock.

Up to now, many studies have been done on the relations between sawability and rock characteristics in stone processing. Norling (1971) correlated sawability with petrographic properties and concluded that grain size was more relevant to sawability than the quartz content. Burgess (1978) proposed a regression model for sawability, which was based on mineralogical composition, hardness, grain size and abrasion resistance. Vaya and Vikram (1983) found a fairly good correlation between the Brinell hardness test and diamond sawing rates. However, the variables involved were so many that they believed no mathematical solution would be possible. They also considered the Specific Energy (SE) concept, in conjunction with mineralogy, to give a better understanding of the sawing responses of various rock types. Ertingshausen (1985) investigated the power requirements during cutting of Colombo Red granite in up-cutting and down-cutting modes. He found out that the required power was less for the up-cutting mode when the cutting depth was below 20–25 mm. For deeper cuts, however, the power consumption was less for the down-cutting mode. Wright and Cassapi (1985) tried to correlate the petrographic analysis and physical properties with sawing results. The research indicated cutting forces to have the closest correlation. Birle et al. (1986) presented similar work in 1986, but again considered only blade life as the criterion on which a ranking system should be based. Hausberger (1989) concluded that an actual sawing test was the most reliable method for determining the machinability of a rock type. He observed that the higher proportion of minerals with well defined cleavage planes helps the cutting to be easier. Jennings and Wright (1989) gave an overall assessment of the major factors which affect saw blade performance. They found out that hard materials usually require a smaller size diamond than do softer stones because the load per particle is not sufficiently high and greater clearance is required for swarf.

Conversely, if large diamond grits are used on hard materials, the penetration of the diamond is limited, and normally either excessive grit pull-out will occur or large wear flats will appear on the diamond particles. Unver (1996) developed empirical equations for the estimation of specific wear and cutting force in the sawing of granites. He used mean quartz grain size, NCB cone indenter hardness number, and mean plagioclase grain size in his equations. Clausen et al. (1996) carried out a study on the acoustic emission during single diamond scratching of granite and suggested that acoustic emission could be used in sawability classification of natural stones. They also concluded that the cutting process is affected by the properties and frequency of minerals, grain size and degree of interlocking. Tonshoff and Asche (1997) discussed the macroscopic and microscopic methods of investigating saw blade segment wear. Luo (1997) investigated the worn surfaces of diamond segments in circular saws for the sawing of hard and relatively soft granites. He found out that for the sawing of hard granite, the worn particles were mainly of the macro-fractured crystal and/or pull-out hole type. Ceylanoglu and Gorgulu (1997) correlated specific cutting energy and slab production with rock properties and found good correlations between them. Webb and Jackson (1998) showed that a good correlation could be obtained between saw blade wear performance and the ratio of normal to tangential cutting forces during the cutting of granite. Xu (1999) investigated the friction characteristics of the sawing process of granites with diamond segmented saw blade. The results of the experimental studies indicated that most of the sawing energy is expended by friction of sliding between diamonds and granites. Xipeng et al. (2001) found that about 30 percent of the sawing energy might be due to the interaction of the swarf with the applied fluid and bond matrix. Most of the energy for sawing and grinding is attributed to ductile ploughing. Brook (2002) developed a new index test, called Brook hardness, which has been specifically developed for sliding diamond indenters. The consumed energy is predictable from this new index test. Konstanty (2002) presented a theoretical model of natural stone sawing by means of diamond-impregnated tools. In the model, the chip formation and removal process are quantified with the intention of assisting both the toolmaker and the stonemason in optimising the tool composition and sawing process parameters, respectively.

Li et al. (2002) proposed a new machining method applicable to granite materials to achieve improved cost effectiveness. They emphasized the importance of the tribological interactions that occur at the interface between the diamond tool surface and the workpiece. Accordingly, they proposed that the energy expended by friction and mechanical load on the diamond crystal should be balanced to optimize the saw blade performance. Xu et al. (2003) conducted an experimental study on the sawing of two kinds of granites with a diamond segmented saw blade. The results of their study indicated that the wear of diamond grits could also be related to the high temperatures generated at individual cutting points, and the pop-out of diamonds from the matrix could be attributed to the heat conducted to saw blade segments. Ilio and Togna (2003) proposed a theoretical model for the interpretation of saw blade wear process. The model is based on the experimentally determined matrix characteristics and grain characteristics. The model indicates that a suitable matrix material must not only provide the necessary grain support in the segment, but it should also wear at an appropriate rate in order to maintain constant efficiency in cutting. Eyuboglu et al. (2003) investigated the relationship between blade wear and the sawability of andesitic rocks. In their study, a multiple linear regression analysis was carried out to derive a prediction equation of the blade wear rate. They showed that the wear rate of

andesite could be predicted from the statistical model by using a number of stone properties. The model indicated the Shore scleroscope hardness as the most important rock property affecting wear rate. Xu et al. (2003) carried out an experimental study to investigate the characteristics of the force ratio in the sawing of granites with a diamond segmented blade. In the experiments, in order to determine the tangential and the normal force components, horizontal and vertical force components and the consumed power were measured. It was found out that the force components and their ratios did not differ much for different granites, in spite of the big differences in sawing difficulty. Gunaydin et al. (2004) investigated the correlations between sawability and different brittleness using regression analysis. They concluded that sawability of carbonate rocks can be predicted from the rock brittleness, which is half the product of compressive strength and tensile strength. Ersoy et al. (2004, 2005) experimentally studied the performance and wear characteristics of circular diamond saws in cutting different types of rocks. They derived a statistical predictive model for the saw blade wear where specific cutting energy, silica content, bending strength, and Schmidt rebound hardness were the input parameters of the model. An experimental study was carried out by Xipeng and Yiging (2005) to evaluate the sawing performance of Ti-Cr coated diamonds. The sawing performances of the specimens were evaluated in terms of their wear performances during the sawing of granite. It was concluded that the wear performance of the specimens with coated diamonds were improved, as compared with uncoated diamonds. Delgado et al. (2005) experimentally studied the relationship between the sawability of granite and its micro-hardness. In their study, sawing rate was chosen as the sawability criterion, and the micro-hardness of granite was calculated from mineral Vickers micro-hardness. Experimental results indicated that the use of Vickers hardness microindenter could provide more precise information in sawability studies. Mikaeil et al. (2008a and 2008b) developed a new statistical model to predicting the production rate of carbonate rocks based on uniaxial compressive strength and equal quartz content. Additionally, they investigated the sawability of some important Iranian stone. Yousefi et al. (2010) studied the factors affecting on the sawability of the ornamental stone. Especially, among the previous studies some researchers have developed a number of classification systems for ranking the sawability of rocks. Wei et al. (2003) evaluated and classified the sawability of granites by means of the fuzzy ranking system. In their study, wear performance of the blade and the cutting force were used as the sawability criteria. They concluded that with the fuzzy ranking system, by using only the tested petrographic and mechanical properties, a convenient selection of a suitable saw blade could be made for a new granite type. Similarly, Tutmez et al. (2007) developed a new fuzzy classification of carbonate rocks based on rock characteristics such as uniaxial compressive strength, tensile strength, Schmidt hammer value, point load strength, impact strength, Los Angeles abrasion loss and P-wave velocity. By this fuzzy approach, marbles used by factories were ranked three linguistic qualitative categories: excellent, good and poor. Kahraman et al. (2007) developed a quality classification of building stones from P-wave velocity and its application to stone cutting with gang saws. They concluded that the quality classification and estimation of slab production efficiency of the building stones can be made by ultrasonic measurements.

The performance of any stone factory is affected by the complex interaction of numerous factors. These factors that affect the production cost can be classified as energy, labour, water, diamond saw and polishing pads, filling material and packing. Among the above

factors, energy is one of the most important factors. In this chapter, it was aimed to develop a new hierarchy model for evaluating and ranking the power consumption of carbonate rock in sawing process. By this model, carbonate rocks were ranked with the respect to its power consumption. This model can be used for cost analysis and project planning as a decision making index. To make a right decision on power consumption of carbonate rock, all known criteria related to the problem should be analyzed. Although an increasing in the number of related criteria makes the problem more complicated and more difficult to reach a solution, this may also increase the correctness of the decision made because of those criteria. Due to the arising complexity in the decision process, many conventional methods are able to consider limited criteria and may be generally deficient. Therefore, it is clearly seen that assessing all of the known criteria connected to the power consumption by combining the decision making process is extremely significant.

The major aim of this chapter is to compare the many different factors in the power consumption of the carbonate rock. The comparison has been performed with the combination of the Analytic Hierarchy Process (AHP) and Fuzzy Delphi method and also the use of TOPSIS method. The analysis is one of the multi-criteria techniques that provide useful support in the choice among several alternatives with different objectives and criteria. FDAHP method has been used in determining the weights of the criteria by decision makers and then ranking the power consumption of the rocks has been determined by TOPSIS method. The study was supported by results that were obtained from a questionnaire carried out to know the opinions of the experts in this subject.

This chapter is organized as follows; in the second section, a brief review is done on concept of the fuzzy sets and fuzzy numbers. In the third section FDAHP method is illustrated. This section is included the methodology of FDAHP method. Fourth section also surveys TOPSIS method. In the fifth section, after explanation of effective parameters on power consumption, the FDAHP method is applied for determination of the weights of the criteria given by experts. Then the ranking the power consumption of carbonate rocks is carried out by TOPSIS method. Eventually, in sixth and seventh sections, results of the application are reviewed. These sections discuss and concludes the paper. According to the authors' knowledge, ranking the power consumption using the FDAHP-TOPSIS is a unique research.

2. Fuzzy sets and fuzzy numbers

To deal with vagueness of human thought, Zadeh (1965) first introduced the fuzzy set theory, which was oriented to the rationality of uncertainty due to imprecision or vagueness. A major contribution of fuzzy set theory is its capability of representing vague data. The theory also allows mathematical operators and programming to apply to the fuzzy domain. A fuzzy set is a class of objects with a continuum of grades of membership. Such a set is characterized by a membership (characteristic) function, which assigns to each object a grade of membership ranging between zero and one. With different daily decision making problems of diverse intensity, the results can be misleading if the fuzziness of human decision making is not taken into account (Tsaur et al., 2002) Fuzzy sets theory providing a more widely frame than classic sets theory, has been contributing to capability of reflecting real world (Ertugrul & Tus, 2007).

Fuzzy sets and fuzzy logic are powerful mathematical tools for modeling; uncertain systems in industry, nature and humanity; and facilitators for common-sense reasoning in decision making in the absence of complete and precise information. Their role is significant when

applied to complex phenomena not easily described by traditional mathematical methods, especially when the goal is to find a good approximate solution (Bojadziev & Bojadziev, 1998). Fuzzy set theory is a better means for modeling imprecision arising from mental phenomena which are neither random nor stochastic. Human beings are heavily involved in the process of decision analysis. A rational approach toward decision making should take into account human subjectivity, rather than employing only objective probability measures. This attitude, towards imprecision of human behavior led to study of a new decision analysis filed fuzzy decision making (Lai & Hwang, 1996). A tilde ' $\sim$ ' will be placed above a symbol if the symbol represents a fuzzy set. A triangular fuzzy number (TFN), $\tilde{M}$ is shown in Fig. 1. A TFN is denoted simply as $(l|m,m|u)$ or (l,m,u) . The parameters l , m and u , respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event.

Fig. 1. A triangular fuzzy number, $\tilde{M}$

Each TFN has linear representations on its left and right side such that its membership function can be defined as

$$\mu(x|\tilde{M}) = \begin{cases} 0, & x < l, \\ (x-l)/(m-l), & l \leq x \leq m, \\ (u-x)/(u-m), & m \leq x \leq u, \\ 0, & x > u. \end{cases} \quad (1)$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

$$\tilde{M} = (M^{l(y)}, M^{r(y)}) = (l + (m-l)y, u + (m-u)y), \quad y \in [0,1], \quad (2)$$

Where $l(y)$ and $r(y)$ denote the left side representation and the right side representation of a fuzzy number, respectively. Many ranking methods for fuzzy numbers have been developed in the literature. These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation. The algebraic operations with fuzzy numbers have been explained by Kahraman (2001) and Kahraman et al. (2002).

3. Fuzzy Delphi Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) is an approach that is suitable for dealing with complex systems related to making a choice from among several alternatives and which provides a comparison of the considered options, firstly proposed by Saaty (1980). The AHP is based on the subdivision of the problem in a hierarchical form. In fact, the AHP helps organize the rational analysis of the problem by dividing it into its single parts; the analysis then supplies an aid to the decision makers who, making several pair-wise comparisons, can appreciate the influence of the considered elements in the hierarchical structure; the AHP can also give a preference list of the considered alternative solutions (Bentivegna et al., 1994; Roscelli, 1990; Saaty, 1980; Saaty & Vargas, 1990).

The AHP is a tool that can be used for analyzing different kinds of social, political, economic and technological problems, and it uses both qualitative and quantitative variables. The fundamental principle of the analysis is the possibility of connecting information, based on knowledge, to make decisions or previsions; the knowledge can be taken from experience or derived from the application of other tools. Among the different contexts in which the AHP can be applied, mention can be made of the creation of a list of priorities, the choice of the best policy, the optimal allocation of resources, the prevision of results and temporal dependencies, the assessment of risks and planning (Saaty & Vargas, 1990). Although the AHP is to capture the expert's knowledge, the traditional AHP still cannot really reflect the human thinking style (Kahraman et al., 2003).

The traditional AHP method is problematic in that it uses an exact value to express the decision maker's opinion in a comparison of alternatives (Wang & Chen, 2007). And AHP method is often criticized due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process (Deng, 1999). To overcome all these shortcomings, FDAHP was developed for solving the hierarchical problems. Decision makers usually find that it is more confident to give interval judgments than fixed value judgments. This is because usually he/she is unable to explicit his/her preference to explicit about the fuzzy nature of the comparison process.

Delphi method is a technique for structuring an effective group communication process by providing feedback of contributions of information and assessment of group judgments to enable individuals to re-evaluate their judgments. Since its development in the 1960s at Rand Corporation, Delphi method has been widely used in various fields (Liu and Chen, 2007a, Liu and Chen, 2007b, Hoseinie et al. 2009, Cheng and Tang, 2009, Cheng et al. 2009). On the other hand, Delphi Method use crisp number and mean to become the evaluation criteria, these shortcomings might distort the experts' opinion. In order to deal with the fuzziness of human participants' judgments in traditional Delphi method, Ishikawa et al. (Ishikawa et al. 1993) posited fuzzy set theory proposed by Zadeh (Zadeh, 1965) into the Delphi method to improve time-consuming problems such as the convergence of experts' options presented by Hwang and Lin (Hwang and Lin, 1987). The FDM is a methodology in which subjective data of experts are transformed into quasi-objective data using the statistical analysis and fuzzy operations. The main advantages of FDM (Kaufmann and Gupta, 1988) are that it can reduce the numbers of surveys to save time and cost and it also includes the individual attributes of all experts. This paper proposes the use of FDAHP for determining the weights of the main criteria.

3.1 Methodology of FDAHP

Calculate the relative fuzzy weights of the decision elements using the following three steps based on the FDM and aggregate the relative fuzzy weights to obtain scores for the decision alternation.

(1) Compute the triangular fuzzy numbers (TFNs) $\tilde{a}_{ij}$ as defined in Eq. (3). In this work, the TFNs (shown as Fig. 2) that represent the pessimistic, moderate and optimistic estimate are used to represent the opinions of experts for each activity time.

Fig. 2. The membership function of the Fuzzy Delphi Method.

$$\tilde{a}_{ij} = (\alpha_{ij}, \delta_{ij}, \gamma_{ij}) \quad (3)$$

$$\alpha_{ij} = \text{Min}(\beta_{ijk}), k = 1, \dots, n \quad (4)$$

$$\delta_{ij} = \left(\prod_{k=1}^n \beta_{ijk} \right)^{1/n}, k = 1, \dots, n \quad (5)$$

$$\gamma_{ij} = \text{Max}(\beta_{ijk}), k = 1, \dots, n \quad (6)$$

Where, $\alpha_{ij} \leq \delta_{ij} \leq \gamma_{ij}$, $\alpha_{ij}, \delta_{ij}, \gamma_{ij} \in [1/9, 1] \cup [1, 9]$ and $\alpha_{ij}, \delta_{ij}, \gamma_{ij}$ are obtained from Eq. (4) to Eq. (6). α_{ij} indicates the lower bound and γ_{ij} indicates the upper bound. β_{ijk} indicates the relative intensity of importance of expert k between activities i and j . n is the number of experts in consisting of a group.

(2) Following outlined above, we obtained a fuzzy positive reciprocal matrix $\tilde{A}$

$$\tilde{A} = [\tilde{a}_{ij}], \tilde{a}_{ij} \times \tilde{a}_{ji} \approx 1, \forall i, j = 1, 2, \dots, n$$

Or

$$\tilde{A} = \begin{bmatrix} (1,1,1) & (\alpha_{12}, \delta_{12}, \gamma_{12}) & (\alpha_{13}, \delta_{13}, \gamma_{13}) \\ (1/\gamma_{12}, 1/\delta_{12}, 1/\alpha_{12}) & (1,1,1) & (\alpha_{23}, \delta_{23}, \gamma_{23}) \\ (1/\gamma_{13}, 1/\delta_{13}, 1/\alpha_{13}) & (1/\gamma_{23}, 1/\delta_{23}, 1/\alpha_{23}) & (1,1,1) \end{bmatrix} \quad (7)$$

(3) Calculate the relative fuzzy weights of the evaluation factors.

$$\tilde{Z}_i = [\tilde{a}_{ij} \otimes \dots \otimes \tilde{a}_{im}]^{1/n}, \tilde{W}_i = \tilde{Z}_i \otimes (\tilde{Z}_i \oplus \dots \oplus \tilde{Z}_n)^{-1} \quad (8)$$

Where $\tilde{a}_1 \otimes \tilde{a}_2 \cong (\alpha_1 \times \alpha_2, \delta_1 \times \delta_2, \gamma_1 \times \gamma_2)$; the symbol $\otimes$ here denotes the multiplication of fuzzy numbers and the symbol $\oplus$ here denotes the addition of fuzzy numbers. $\tilde{W}_i$ is a row vector in consist of a fuzzy weight of the i th factor. $\tilde{W}_i = (\omega_1, \omega_2, \dots, \omega_n)$ $i=1, 2, \dots, n$, and W_i is a fuzzy weight of the i th factor.

4. TOPSIS method

TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) is one of the useful MADM techniques to manage real-world problems (Yoon & Hwang, 1985). TOPSIS method was firstly proposed by Hwang & Yoon (1981). According to this technique, the best alternative would be the one that is nearest to the positive ideal solution and farthest from the negative ideal solution (Benitez, et al., 2007). The positive ideal solution is a solution that maximizes the benefit criteria and minimizes the cost criteria, whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria (Wang & Elhag, 2006). In short, the positive ideal solution is composed of all best values attainable of criteria, whereas the negative ideal solution consists of all worst values attainable of criteria (Wang, 2008). In this paper TOPSIS method is used for determining the final ranking of the sawability of rocks. TOPSIS method is performed in the following steps:

Step 1. Decision matrix is normalized via Eq. (9):

$$r_{ij} = \frac{w_{ij}}{\sqrt{\sum_{i=1}^J w_{ij}^2}} \quad j = 1, 2, 3, \dots, J \quad i = 1, 2, 3, \dots, n \quad (9)$$

Step 2. Weighted normalized decision matrix is formed:

$$v_{ij} = w_i \times r_{ij}, \quad j = 1, 2, 3, \dots, J \quad i = 1, 2, 3, \dots, n \quad (10)$$

Step 3. Positive ideal solution (PIS) and negative ideal solution (NIS) are determined:

$$A^* = \{v_1^*, v_2^*, \dots, v_i^*, \dots, v_n^*\} \quad \text{Maximum Values} \quad (11)$$

$$A^- = \{v_1^-, v_2^-, \dots, v_i^-, \dots, v_n^-\} \quad \text{Minimum Values} \quad (12)$$

Step 4. The distance of each alternative from PIS and NIS are calculated:

$$d_j^* = \sqrt{\sum_{i=1}^n (v_{ij} - v_j^*)^2} \quad (13)$$

$$d_j^- = \sqrt{\sum_{i=1}^n (v_{ij} - v_j^-)^2} \quad (14)$$

Step 5. The closeness coefficient of each alternative is calculated:

$$CC_j = \frac{d_j^-}{d_j^* + d_j^-} \tag{15}$$

Step 6. By comparing CCj values, the ranking of alternatives are determined.

5. Application of FDAHP-TOPSIS method to multi-criteria comparison of sawability

The purpose of this paper was to ranking the power consumption of rock in sawing process, with the help of effective factors. Firstly, a comprehensive questionnaire including main criteria of effective factor is designed to understand and quantify the affecting factors in the process. Then, five decision makers from different areas evaluated the importance of these factors with the help of the mentioned questionnaire. FDAHP is utilized for determining the weights of main criteria and finally, TOPSIS approach is employed for ranking. By this way, the ranking of carbonate sawability according to their overall efficiency is obtained. Carbonate rock sawability depends on non-controlled parameters related to rock characteristics and controlled parameters related to properties of cutting tools and equipment. In the same working conditions, the sawing process and its results are strongly affected by mineralogical and mechanical properties of rock. The mineralogical and mechanical properties of rock which related to rock sawability are shown in Fig. 3.

Fig. 3. Important characteristics influencing the rock sawability

$$\alpha_{ij} = \text{Min}(\beta_{ijk}), k = 1, \dots, n$$

2. Fuzzy pair-wise comparison matrix $\tilde{A}$

By this way, decision makers' pair-wise comparison values are transformed into triangular fuzzy numbers as in Table 3.

	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
C ₁	(1, 1, 1)	(0.7, 1, 1.4)	(0.7, 1.2, 2.3)	(0.6, 0.7, 1)	(0.6, 0.7, 1)	(0.6, 0.8, 1)
C ₂	(0.7, 1, 1.4)	(1, 1, 1)	(0.7, 1.2, 1.7)	(0.7, 0.7, 0.8)	(0.6, 0.7, 1)	(0.7, 0.8, 1)
C ₃	(0.4, 0.8, 1.4)	(0.6, 0.8, 1.4)	(1, 1, 1)	(0.4, 0.6, 1)	(0.3, 0.6, 0.8)	(0.4, 0.6, 1)
C ₄	(1, 1.4, 1.8)	(1.3, 1.4, 1.4)	(1, 1.7, 2.3)	(1, 1, 1)	(0.8, 1, 1.3)	(1, 1.1, 1.3)
C ₅	(1, 1.4, 1.8)	(1, 1.4, 1.8)	(1.3, 1.8, 3)	(0.8, 1.1, 1.3)	(1, 1, 1)	(0.8, 1.1, 1.3)
C ₆	(1, 1.3, 1.8)	(1, 1.3, 1.4)	(1, 1.6, 2.3)	(0.8, 1, 1)	(0.8, 0.9, 1.3)	(1, 1, 1)
C ₇	(0.4, 0.7, 1.4)	(0.6, 0.7, 1)	(0.4, 0.8, 1)	(0.4, 0.5, 0.8)	(0.3, 0.5, 0.8)	(0.4, 0.5, 1)
C ₈	(0.4, 0.7, 1)	(0.6, 0.7, 1)	(0.7, 0.9, 1)	(0.4, 0.5, 0.7)	(0.3, 0.5, 0.7)	(0.4, 0.6, 0.7)
C ₉	(0.4, 0.8, 1.4)	(0.4, 0.8, 1.4)	(0.6, 1, 1.7)	(0.3, 0.6, 0.8)	(0.3, 0.6, 0.8)	(0.3, 0.6, 1)
C ₁₀	(1.3, 1.5, 1.8)	(1, 1.5, 1.8)	(1, 1.8, 3)	(0.8, 1.1, 1.3)	(0.8, 1.1, 1.3)	(1, 1.2, 1.3)
C ₁₁	(1, 1.1, 1.4)	(0.7, 1.1, 1.4)	(0.7, 1.4, 2.3)	(0.6, 0.9, 1)	(0.6, 0.8, 1)	(0.7, 0.9, 1)
C ₁₂	(0.7, 1.1, 1.4)	(0.7, 1.1, 1.4)	(1, 1.3, 2.3)	(0.6, 0.8, 1)	(0.7, 0.8, 0.8)	(0.6, 0.8, 1)

C ₇	C ₈	C ₉	C ₁₀	C ₁₁	C ₁₂
(0.7, 1.5, 2.3)	(1, 1.4, 2.3)	(0.7, 1.2, 2.3)	(0.6, 0.7, 0.8)	(0.7, 0.9, 1)	(0.7, 0.9, 1.4)
(1, 1.5, 1.7)	(1, 1.4, 1.7)	(0.7, 1.2, 2.3)	(0.6, 0.7, 1)	(0.7, 0.9, 1.4)	(0.7, 0.9, 1.4)
(1, 1.2, 2.3)	(1, 1.1, 1.4)	(0.6, 1, 1.7)	(0.3, 0.5, 1)	(0.4, 0.7, 1.4)	(0.4, 0.8, 1)
(1.3, 2, 2.3)	(1.4, 1.9, 2.3)	(1, 1.7, 3)	(0.8, 0.9, 1.3)	(1, 1.2, 1.8)	(1, 1.3, 1.8)
(1.3, 2.1, 3)	(1.4, 2.1, 3)	(1.3, 1.7, 3)	(0.8, 1, 1.3)	(1, 1.2, 1.8)	(1.3, 1.3, 1.4)
(1, 1.9, 2.3)	(1.4, 1.8, 2.3)	(1, 1.6, 3)	(0.8, 0.9, 1)	(1, 1.1, 1.4)	(0.4, 0.6, 1)
(1, 1, 1)	(0.6, 1, 1.4)	(0.4, 0.8, 1.7)	(0.3, 0.5, 1)	(0.4, 0.6, 1.4)	(0.4, 0.6, 1)
(0.7, 1, 1.7)	(1, 1, 1)	(0.6, 0.9, 1.7)	(0.3, 0.5, 0.7)	(0.4, 0.6, 1)	(0.4, 0.7, 1)
(0.6, 1.2, 2.3)	(0.6, 1.1, 1.7)	(1, 1, 1)	(0.3, 0.5, 1)	(0.4, 0.7, 1.4)	(0.4, 0.8, 1)
(1, 2.2, 3)	(1.4, 2.1, 3)	(1, 1.8, 3)	(1, 1, 1)	(1.3, 1.3, 1.4)	(1, 1.4, 1.8)
(0.7, 1.7, 2.3)	(1, 1.6, 2.3)	(0.7, 1.4, 2.3)	(0.7, 0.8, 0.8)	(1, 1, 1)	(0.7, 1.1, 1.4)
(1, 1.6, 2.3)	(1, 1.5, 2.3)	(1, 1.3, 2.3)	(0.6, 0.7, 1)	(0.7, 0.9, 1.4)	(1, 1, 1)

Table 3. Fuzzy pair-wise comparison matrix

3. Calculate the relative fuzzy weights of the evaluation factors.

$$\begin{aligned}\tilde{Z}_1 &= [\tilde{a}_{11} \otimes \tilde{a}_{12} \otimes \dots \tilde{a}_{112}]^{1/12} = [0.6948, 0.968, 1.3738] \\ \tilde{Z}_2 &= [\tilde{a}_{21} \otimes \tilde{a}_{22} \otimes \dots \tilde{a}_{212}]^{1/12} = [0.7451, 0.968, 1.2989] \\ \tilde{Z}_3 &= [\tilde{a}_{31} \otimes \tilde{a}_{32} \otimes \dots \tilde{a}_{312}]^{1/12} = [0.5373, 0.7861, 1.2268]\end{aligned}$$

$$\tilde{Z}_4 = [\tilde{a}_{41} \otimes \tilde{a}_{42} \otimes \dots \tilde{a}_{412}]^{1/12} = [1.0284, 1.3098, 1.7181]$$

$$\tilde{Z}_5 = [\tilde{a}_{51} \otimes \tilde{a}_{52} \otimes \dots \tilde{a}_{512}]^{1/12} = [1.0502, 1.3773, 1.8295]$$

$$\tilde{Z}_6 = [\tilde{a}_{61} \otimes \tilde{a}_{62} \otimes \dots \tilde{a}_{612}]^{1/12} = [0.9, 1.1823, 1.5363]$$

$$\tilde{Z}_7 = [\tilde{a}_{71} \otimes \tilde{a}_{72} \otimes \dots \tilde{a}_{712}]^{1/12} = [0.4665, 0.6661, 1.0885]$$

$$\tilde{Z}_8 = [\tilde{a}_{81} \otimes \tilde{a}_{82} \otimes \dots \tilde{a}_{812}]^{1/12} = [0.508, 0.6897, 0.9733]$$

$$\tilde{Z}_9 = [\tilde{a}_{91} \otimes \tilde{a}_{92} \otimes \dots \tilde{a}_{912}]^{1/12} = [0.4601, 0.7858, 1.2189]$$

$$\tilde{Z}_{10} = [\tilde{a}_{101} \otimes \tilde{a}_{102} \otimes \dots \tilde{a}_{1012}]^{1/12} = [1.0284, 1.4483, 1.8295]$$

$$\tilde{Z}_{11} = [\tilde{a}_{111} \otimes \tilde{a}_{112} \otimes \dots \tilde{a}_{1112}]^{1/12} = [0.7451, 1.1074, 1.4128]$$

$$\tilde{Z}_{12} = [\tilde{a}_{121} \otimes \tilde{a}_{122} \otimes \dots \tilde{a}_{1212}]^{1/12} = [0.7717, 1.0353, 1.4128]$$

$$\sum \tilde{Z}_i = [8.9356, 12.327, 16.919]$$

$$\tilde{W}_1 = \tilde{Z}_1 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0411, 0.0785, 0.1537]$$

$$\tilde{W}_2 = \tilde{Z}_2 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.044, 0.0785, 0.1454]$$

$$\tilde{W}_3 = \tilde{Z}_3 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0318, 0.064, 0.1373]$$

$$\tilde{W}_4 = \tilde{Z}_4 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0608, 0.1063, 0.1923]$$

$$\tilde{W}_5 = \tilde{Z}_5 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0621, 0.1117, 0.2047]$$

$$\tilde{W}_6 = \tilde{Z}_6 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0532, 0.0959, 0.1719]$$

$$\tilde{W}_7 = \tilde{Z}_7 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0276, 0.054, 0.1218]$$

$$\tilde{W}_8 = \tilde{Z}_8 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.03, 0.056, 0.1089]$$

$$\tilde{W}_9 = \tilde{Z}_9 \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0272, 0.0637, 0.1364]$$

$$\tilde{W}_{10} = \tilde{Z}_{10} \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0608, 0.1175, 0.2047]$$

$$\tilde{W}_{11} = \tilde{Z}_{11} \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.044, 0.0898, 0.1581]$$
$$\tilde{W}_{12} = \tilde{Z}_{12} \otimes (\tilde{Z}_1 \oplus \tilde{Z}_2 \oplus \tilde{Z}_3)^{-1} = [0.0456, 0.084, 0.1581]$$

The final weights of each parameter are calculated as follow:

$W_1 = (\prod_{i=1}^3 \omega_j)^{1/3} = 0.07928$, $W_2=0.0796$, $W_3=0.0655$, $W_4=0.1076$, $W_5=0.1125$, $W_6=0.0958$, $W_7=0.05675$, $W_8=0.0569$, $W_9=0.0619$, $W_{10}=0.1136$, $W_{11}=0.0857$, $W_{12}=0.0847$. Mentioned priority weights have indicated for each criterion in table 4.

Criteria	Global weights
Uniaxial Compressive Strength	0.1136
Hardness	0.1125
Equal Quartz Content	0.1076
Abrasiveness	0.0958
Tensile Strength	0.0857
Young’s Modules	0.0847
Grain Size & Shape	0.0796
Texture	0.0793
Matrix Type & Cementation	0.0655
Schmidt Hammer Rebound	0.0619
Density	0.0569
Weathering	0.0568

Table 4. Priority weights for criteria

5.2 Ranking the sawability of carbonate rock

In attempting to present a ranking system for assessing rock sawability, using all mentioned parameters is difficult from a practical point of view. In this ranking system three following rules have been considered: (a) the number of parameters used should be small, (b) equivalent parameters should be avoided, and (c) parameters should be considered within certain groups. Considering these rules, the parameters which have been chosen for assessing the rock sawability are listed as follows:

a.

b.

c.

d.

Uniaxial Compressive Strength (UCS)

Schmiazek F-abrasivity factor (SF-a)

Mohs Hardness (MH)

Young’s Modulus (YM)

5.3 Uniaxial Compressive Strength (UCS)

Uniaxial compressive strength is one of the most important engineering properties of rocks. Rock material strength is used as an important parameter in many rock mass classification systems. Using this parameter in classification is necessary because strength of rock material constitutes the strength limit of rock mass (Bieniawski, 1989). Factors that influence the UCS

of rocks are the constitutive minerals and their spatial positions, weathering or alteration rate, micro-cracks and internal fractures, density and porosity (Hoseinie et al. 2009). Therefore, uniaxial compressive strength test can be considered as representative of rock strength, density, weathering, texture and matrix type. Thus, the summation of the weights of five parameters (texture, weathering, density, matrix type and UCS) is considered as weight of UCS. In total, the weight of UCS is about 0.372.

5.4 Schimazek F-abrasivity factor (SF-a)

Abrasiveness influences the tool wear and sawing rate seriously. Abrasiveness is mainly affected by various factors such as mineral composition, the hardness of mineral constituents and grain characteristics such as size, shape and angularity (Ersoy and Waller, 1995). Schimazek's F-abrasiveness factor is depend on mineralogical and mechanical properties and has good ability for evaluation of rock abrasivity. Therefore, this index has been selected for using in ranking system. F-abrasivity factor is defined as

$$F = \frac{EQC \times Gs \times BTS}{100} \quad (16)$$

Where F is the Schimazek's wear factor (N/mm), EQC is the equivalent quartz content percentage, Gs is the median grain size (mm), and BTS is the in direct Brazilian tensile strength. Regarding the rock parameters which are used in questionnaires, summation of the weights of abrasiveness, grain size, tensile strength and equivalent quartz content is considered as weight of Schimazek's F-abrasiveness factor. In total the weight of this factor is 0.3687.

5.5 Mohs Hardness (MH)

Hardness can be interpreted as the rock's resistance to penetration. The factors that affect rock hardness are the hardness of the constitutive minerals, cohesion forces, homogeneity, and the water content of rock (Hoseinie et al. 2009). Thus, hardness is a good index of all above given parameters of rock material. Considering the importance of hardness in rock sawing, hardness, after Schimazek F-abrasivity factor, is considered the most relevant property of rock material. Regarding the questionnaires, summation of the weights of Mohs hardness and Schmidt hammer rebound value was considered as total weight of mean Mohs hardness. In total the weight of this factor is 0.1745.

5.6 Young's Modulus (YM)

According to rock behaviour during the fracture process, especially in sawing, the way that rocks reach the failure point has a great influence on sawability. The best scale for rock elasticity is Young's modulus. Based on ISRM suggested methods (ISRM, 1981), the tangent Young's modulus at a stress level equal to 50% of the ultimate uniaxial compressive strength is used in this ranking system. Regarding the questionnaires, the weight of this factor is about 0.0847 in total. According to FDAHP results the final weights of major parameters are shown in fig. 4.

5.7 Laboratory tests

For laboratory tests, some rock blocks were collected from the studied factories. An attempt was made to collect rock samples that were big enough to obtain all of the test specimens of

each rock type from the same piece. Each block sample was inspected for macroscopic defects so that it would provide test specimens free from fractures, partings or alteration zones. Then, test samples were prepared from these block samples and standard tests have been completed to measure the above-mentioned parameters following the suggested procedures by the ISRM standards (ISRM, 1981). The results of laboratory studies are listed in table 5 and used in next stage.

Fig. 4. The final weights of major parameters in power consumption ranking system

Rock sample		UCS	BTS	EQC	Gs	SF-a	YM	MH
		MPa	MPa	%	mm	N/mm	GPa	n
1	MHAR(Marble)	71.5	6.8	3.6	0.55	0.135	32.5	3.5
2	MANA(Marble)	74.5	7.1	3.4	0.45	0.109	33.6	3.2
3	TGH(Travertine)	53	4.3	2.8	1.01	0.122	20.7	2.9
4	THAJ(Travertine)	61.5	5.6	2.6	0.85	0.124	21	2.9
5	TDAR(Travertine)	63	5.4	2.7	0.87	0.127	23.5	2.95
6	MSAL(Marble)	68	6.3	3.2	0.52	0.105	31.6	3.1
7	MHAF(Marble)	74.5	7.2	4	0.6	0.173	35.5	3.6

Table 5. The result of laboratory studies

After determining the weights of the criteria with FDAHP method and laboratory studies, ranking the sawability of carbonate rocks is performed by TOPSIS method. Firstly, the amount of each criterion is filled in decision matrix for each criterion. Decision matrix is obtained with respect to important rock properties (Table. 6). Decision matrix is normalized via Eq. (9) (Table. 7). Then, weighted normalized matrix is formed by multiplying each value with their weights (Table. 8). Positive and negative ideal solutions are determined by taking the maximum and minimum values for each criterion:

$$A^* = \{ 0.1547, 0.1863, 0.0393, 0.0748 \}$$

$$A^- = \{ 0.1101, 0.1130, 0.0229, 0.0602 \}$$

Then the distance of each method from PIS (positive ideal solution) and NIS (negative ideal solution) with respect to each criterion are calculated with the help of Eqs. (13) and (14). Then closeness coefficient of each rock is calculated by using Eq. (15) and the ranking of the rocks are determined according to these values.

	UCS	SF-a	YM	MH
	C1:	C2:	C3:	C4:
1	71.5	0.135	32.5	3.5
2	74.5	0.109	33.6	3.2
3	53	0.122	20.7	2.9
4	61.5	0.124	21	2.9
5	63	0.127	23.5	2.95
6	73	0.105	31.6	3.1
7	74.5	0.173	35.5	3.6

Table 6. Decision matrix

	UCS	SF-a	YM	MH
	C1:	C2:	C3:	C4:
1	0.3991	0.3937	0.4243	0.4166
2	0.4158	0.3176	0.4387	0.3809
3	0.2958	0.3556	0.2703	0.3452
4	0.3432	0.3619	0.2742	0.3452
5	0.3516	0.3709	0.3068	0.3511
6	0.4074	0.3065	0.4126	0.3690
7	0.4158	0.5052	0.4635	0.4285

Table 7. Normalized decision matrix

	UCS	SF-a	YM	MH
	C1:	C2:	C3:	C4:
1	0.1485	0.1452	0.0360	0.0727
2	0.1547	0.1171	0.0372	0.0665
3	0.1101	0.1311	0.0229	0.0602
4	0.1277	0.1334	0.0232	0.0602
5	0.1308	0.1368	0.0260	0.0613
6	0.1516	0.1130	0.0350	0.0644
7	0.1547	0.1863	0.0393	0.0748

Table 8. Weighted normalized matrix

The power consumption ranking of carbonate rocks are also shown in Table 9 in the descending order of priority.

Rank	Carbonate rock	dj*	dj-	CCj
1	MHAF(Marble)	0	0.0886	1
2	MHAR(Marble)	0.0418	0.0532	0.5602
3	MANA(Marble)	0.0697	0.0475	0.4050
4	MSAL(Marble)	0.0742	0.0434	0.3693
5	TDAR(Travertine)	0.0582	0.0317	0.3528
6	THAJ(Travertine)	0.0632	0.0270	0.2992
7	TGH(Travertine)	0.0743	0.0181	0.1958

Table 9. Rankings of the sawability of carbonate rocks according to CCj values

6. Discussion and validation of the new ranking

A new hierarchical model is developed here to evaluate and ranking the sawability (power consumption) of carbonate rock with using of effective criteria and considering of decision makers’ judgments. The proposed approach is based on the combination of Fuzzy Delphi and Analytic Hierarchy Process (FDAHP) methods. Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is also used in this study. FDAHP was used for determining the weights of the criteria according to decision makers then rankings of carbonate rocks were determined by TOPSIS. The proposed method was applied for Iranian ornamental stone to evaluation the power consumption in rock sawing process. The sawability ranking results of tested carbonate rocks are shown in section 5.

For validation of applied ranking system, experimental procedure was carried out. For this purpose, a fully-instrumented laboratory cutting rig was used. The rig was based on a commercially available machine and was capable of simulating realistic cutting conditions. It consists of three major sub-systems, a cutting unit, instrumentation and a personal computer. Sawing tests were performed on a small side-cutting machine, with a maximum spindle motor power of 7.5 kW. Cutting parameters such as feed rate, depth of cut, and peripheral speed control in the monitoring system. The variation of ampere was measured with a digital ampere-meter. The circular diamond saw blade used in the present tests had a diameter of 410 mm and a steel core of thickness 2.7 mm, 28 pieces of diamond impregnated segments (size 40×10×3 mm) were brazed to the periphery of circular steel core with a standard narrow radial slot. The grit sizes of the diamond were approximately 30/40 US mesh at 25 and 30 concentrations. This blade is applied for travertine, limestone and marble types of the stones, which are non-abrasive and medium hard. During the sawing trials, water was used as the flushing and cooling medium and the peripheral speed and depth of cut were maintained at constant 1770 rpm and 35 mm. Each rock was sawn at particular feed rate (200, 300 and 400 cm/min). During the sawing trials, the ampere and power consumption were monitored and calculated. The monitored ampere and calculated power consumption are listed in Table 10. According to Tables 9 and 10, the first rock in ranking (MHAF) has a maximum value of power consumption among other rock samples. It means that the new developed ranking is correct.

Rock sample		Test 1		Test 2		Test 3	
		Fr=200 (cm/min)		Fr=300 (cm/min)		Fr=400 (cm/min)	
		I(A)	P(W)	I(A)	P(W)	I(A)	P(W)
1	MHAF(Marble)	12	2280	17.5	4370	28.6	8588
2	MHAR(Marble)	11.5	2090	16.4	3952	22	6080
3	MSAL(Marble)	11.5	2090	15.7	3686	20.2	5396
4	MANA(Marble)	11.2	1976	16.5	3990	22.2	6156
5	THAJ(Travertine)	11.2	1976	15.4	3572	19	4940
6	TDAR(Travertine)	10.6	1748	15.6	3648	17.2	4256
7	TGH(Travertine)	9.5	1330	12	2280	18	4560

Table 10. Ampere and calculated power consumption in sawing trials

The calculated power consumption of each carbonate rock in Figure 5 shows that the new ranking method for carbonate rock is reasonable and acceptable for evaluating them.

Fig. 5. The power consumption of carbonate rocks in sawing trials

7. Conclusion

In this chapter, a decision support system was developed for ranking the power consumption of carbonate rocks. This system designed to eliminate the difficulties in taking into consideration many decision criteria simultaneously in the rock sawing process and to guide the decision makers for ranking the power consumption of carbonate rocks. In this study, FDAHP and TOPSIS methods was used to determine the power consumption degree of the carbonate rocks. FDAHP is utilized for determining the weights of the criteria and TOPSIS method is used for determining the ranking of the power consumption of carbonate rocks. During this research a fully-instrumented laboratory sawing rig at different feed rate for two groups of carbonate rocks were carried out. The power consumptions were used to verify the result of applied approach for ranking them by sawability criteria. The experimental results confirm the new ranking results precisely.

This new ranking method may be used for evaluating the power consumption of carbonate rocks at any stone factory with different carbonate rock. Some factors such as uniaxial compressive strength, Schmiasek F-abrasivity, mohs hardness and young's modulus must be obtained for the best power consumption ranking.

8. Acknowledgment

The authors would like to say thank to educational workshop centre of Sharif University of Technology and central laboratory of Shahrood University of Technology for providing the facilities in order to perform an original research.

9. References

- Ataei, M., (2005). Multi-criteria selection for alumina-cement plant location in East-Azerbaijan province of Iran. *The Journal of the South African Institute of Mining and Metallurgy*, 105(7), pp. 507–514.
- Atici U, Ersoy A., (2009). Correlation of specific energy of cutting saws and drilling bits with rock brittleness and destruction energy. *journal of materials processing technology*, 209, pp. 2602–2612.
- Ayag, Z., Ozdemir, R. G., (2006). A fuzzy AHP approach to evaluating machine tool alternatives. *Journal of Intelligent Manufacturing*, 17, pp. 179–190.
- Basligil, H., (2005). The fuzzy analytic hierarchy process for software selection problems. *Journal of Engineering and Natural Sciences*, 2, pp. 24–33.
- Bieniawski ZT (1989). Engineering rock mass classifications. New York: Wiley.
- Benitez, J. M., Martin, J. C., Roman, C., (2007). Using fuzzy number for measuring quality of service in the hotel industry. *Tourism Management*, 28(2), pp. 544–555.
- Bentivegna, V., Mondini, G., Nati Poltri, F., Pii, R., (1994). Complex evaluation methods. An operative synthesis on Multicriteria techniques. In: *Proceedings of the IV International Conference on Engineering Management*, Melbourne.
- Birle J. D., Ratterman E., (1986). An approximate ranking of the sawability of hard building stones based on laboratory tests, *Dimensional Stone Magazine*, July-August, pp. 3-29.
- Bojadziev, G., Bojadziev, M., (1998). Fuzzy sets fuzzy logic applications. Singapore: *World Scientific Publishing*.
- Bozdag, C. E., Kahraman, C., Ruan, D., (2003). Fuzzy group decision making for selection among computer integrated manufacturing systems. *Computer in Industry*, 51, pp. 13–29.
- Brook, B. (2002). Principles of diamond tool technology for sawing rock. *Int. J. Rock Mech. Min. Sci.* 39, pp 41-58.
- Buckley, J. J., (1985). Fuzzy hierarchical analysis. *Fuzzy Sets and Systems*, 17, pp. 233–247.
- Burgess R. B., (1978). Circular sawing granite with diamond saw blades. In: *Proceedings of the Fifth Industrial Diamond Seminar*, pp. 3-10.
- Buyuksagis I.S, (2007). Effect of cutting mode on the sawability of granites using segmented circular diamond sawblade. *Journal of Materials Processing Technology*, 183, pp. 399–406.
- Ceylanoglu, A. Gorgulu, K. (1997). The performance measurement results of stone cutting machines and their relations with some material properties. In: V. Strakos, V. Kebo,

- L. Farana, L. Smutny, eds. *Proceedings of the Sixth International Symposium on Mine Planning and Equipment Selection*. Rotterdam: Balkema, pp. 393-8.
- Chang, D. Y., (1996). Applications of the extent analysis method on fuzzy AHP. *European Journal of Operational Research*, 95, pp. 649-655.
- Chang, Y. H., Cheng, C. H., Wang, T. C., (2003). Performance evaluation of international airports in the region of east Asia. In *Proceedings of Eastern Asia Society for transportation studies*, Vol. 4, pp. 213-230.
- Chan, F. T. S., Kumar, N., (2007). Global supplier development considering risk factors using fuzzy extended AHP-based approach. *Omega International Journal of Management Science*, 35, pp. 417-431.
- Chen, C. T., Lin, C. T., Huang, S. F., (2006). A fuzzy approach for supplier evaluation and selection in supply chain management. *International Journal of Production Economics*, 102, pp. 289-301.
- Chen Chao-Shi, Liu Ya-Ching, (2007). A methodology for evaluation and classification of rock mass quality on tunnel engineering. *Tunnelling and Underground Space Technology*. 22, pp. 377-387.
- Cheng Jao-Hong, Lee Chih-Ming, Tang Chih-Huei. (2009). An Application of Fuzzy Delphi and Fuzzy AHP for Multi-criteria Evaluation on Bicycle Industry Supply Chains. *WSEAS TRANSACTIONS on SYSTEMS and CONTROL*. Issue 1, Volume 4.
- Cheng Jao-Hong, Lee Chih-Ming, Tang Chih-Huei. (2009). An Application of Fuzzy Delphi and Fuzzy AHP on Evaluating Wafer Supplier in Semiconductor Industry. *WSEAS TRANSACTIONS on INFORMATION SCIENCE and APPLICATIONS*. Issue 5, Volume 6.
- Chou, T. Y., Liang, G. S., (2001). Application of a fuzzy multi-criteria decision making model for shipping company performance evaluation. *Maritime Policy & Management*, 28(4), pp. 375-392.
- Clausen R, Wang CY, Meding M. (1996). Characteristics of acoustic emission during single diamond scratching of granite. *Industrial Diamond Review*, 3, pp. 96-9.
- Delgado N.S, Rodriguez R, Rio A, Sarria I.D, Calleja L, Argandona V.G.R. (2005). The influence of microhardness on the sawability of Pink Porrino granite (Spain). *International Journal of Rock Mechanics & Mining Sciences*, 42, pp. 161-6.
- Deng, H., (1999). Multicriteria analysis with fuzzy pair-wise comparison. *International Journal of Approximate Reasoning*, 21, pp. 215-231.
- Enea, M., Piazza, T., (2004). Project selection by constrained fuzzy AHP. *Fuzzy Optimization and Decision Making*, (Vol. 3). New York: Kluwer Academic Publishers, pp. 39-62.
- Ersoy A, Waller MD (1995). Textural characterization of rocks. *J Eng Geol*; 39 (3- 4), pp. 123-36.
- Ersoy A, Atici U, (2004). Performance characteristics of circular diamond saws in cutting different types of rocks. *Diamond and Related Materials*, 13, pp. 22-37.
- Ersoy A., Buyuksagis S., Atici U., (2005). Wear characteristics of circular diamond saws in the cutting of different hard and abrasive rocks, *Wear* 258, pp. 1422-1436.
- Ertingshausen, W. (1985). Wear processes in sawing hard stone, *Industrial Diamond Review*. 5, pp.254-258.
- Ertugrul, I., Karakasoglu, N., (2006). The fuzzy analytic hierarchy process for supplier selection and an application in a textile company. In *Proceedings of 5th international symposium on intelligent manufacturing systems*, pp. 195-207.

- Ertugrul, I., Tus, A., (2007). Interactive fuzzy linear programming and an application sample at a textile firm. *Fuzzy Optimization and Decision Making*, 6, pp. 29-49.
- Ertugrul, I., Karakasoglu, N., (2009). Performance evaluation of Turkish cement firms with fuzzy analytic hierarchy process and TOPSIS methods, *Expert Systems with Applications*, 36 (1), pp. 702-715.
- Eyuboglu A.S, Ozcelik Y, Kulaksiz S, Engin I.C, (2003). Statistical and microscopic investigation of disc segment wear related to sawing Ankara andesites, *International Journal of Rock Mechanics & Mining Sciences*, 40, pp. 405-414.
- Fener M, Kahraman S, & Ozder M.O; (2007). Performance Prediction of Circular Diamond Saws from Mechanical Rock Properties in Cutting Carbonate Rocks, *International Journal of Rock Mechanics & Rock Engineering*, 40 (5), pp. 505-517.
- Gu, X., Zhu, Q., (2006). Fuzzy multi-attribute decision making method based on eigenvector of fuzzy attribute evaluation space. *Decision Support Systems*, 41, pp. 400-410.
- Gunaydin O., Kahraman S., Fener M., (2004). Sawability prediction of carbonate rocks from brittleness indexes. *The Journal of the South African Institute of Mining and Metallurgy*, 104, pp. 239-244.
- Haq, A. N., Kannan, G., (2006). Fuzzy analytical hierarchy process for evaluating and selecting a vendor in a supply chain model. *International Journal of Advanced Manufacturing*, 29, pp. 826-835.
- Hartman H. L., (1992). SME Mining Engineering Handbook. Society for Mining, Metallurgy, and Exploration, Inc. Littleton, Colorado, 2nd Edition, Vol. 1.
- Hartman, H. L., Mutmansky, J. M., (2002). Introductory Mining Engineering. John Wiley & Sons, New Jersey.
- Hoseinie S.H., Aghababaei H., Pourrahimian Y. (2008). Development of a new classification system for assessing of rock mass drillability index (RDi). *International Journal of Rock Mechanics & Mining Sciences*, 45, pp. 1 - 10.
- Hoseinie S.H., Ataei M., Osanloo M. (2009). A new classification system for evaluating rock penetrability. *International Journal of Rock Mechanics & Mining Sciences*. 46, pp. 1329-1340.
- Hsieh, T. Y., Lu, S. T., Tzeng, G. H., (2004). Fuzzy MCDM approach for planning and design tenders selection in public office buildings. *International Journal of Project Management*, 22, pp. 573-584.
- Hausberger P. (1989). Causes of the different behaviour of rocks when machined with diamond tools. *Industrial Diamond Review*, 3, pp. 1-25.
- Hwang, C. L., Yoon, K., (1981). Multiple attributes decision making methods and applications. Berlin: Springer.
- Hwang, C.L., Lin, M.L., (1987). Group Decision Making under Multiple Criteria, Springer-Verlag, Berlin Heidelberg, New York.
- Ilio, A.D. Togna, A. (2003). A theoretical wear model for diamond tools in stone cutting, *Int. J. Mach. Tools Manuf.* 43, pp. 1171-1177.
- International Society for Rock Mechanics, (1981). Rock characterisation, testing and monitoring: ISRM suggested methods. Oxford: Pergamon.
- Ishikawa, A., Amagasa, T., Tamizawa, G., Totsuta, R., Mieno, H., 1993. The Max-Min Delphi Method and Fuzzy Delphi Method via Fuzzy Integration, *Fuzzy Sets and Systems*, Vol. 55.

- Jennings M., Wright D., (1989). Guidelines for sawing stone, *Industrial Diamond Review*, 49, pp. 70–75.
- Kahraman, C., (2001). Capital budgeting techniques using discounted fuzzy cash flows. In: Ruan, D., Kacprzyk, J., Fedrizzi, M. (Eds.), *Soft Computing for Risk Evaluation and Management: Applications in Technology, Environment and Finance*, Physica-Verlag, Heidelberg, pp. 375–396.
- Kahraman, C., Ruan, D., Tolga, E., (2002). Capital budgeting techniques using discounted fuzzy versus probabilistic cash flows. *Information Sciences*, 42 (1–4), pp. 57–76.
- Kahraman, C., Ruan, D., & Dogan, I., (2003). Fuzzy group decision making for facility location selection. *Information Sciences*, 157, pp. 135–153.
- Kahraman, C., Cebeci, U., Ulukan, Z., (2003). Multi-criteria supplier selection using fuzzy AHP. *Logistics Information Management*, 16 (6), pp. 382–394.
- Kahraman, C., Cebeci, U., Ruan, D., (2004). Multi-attribute comparison of catering service companies using fuzzy AHP: The case of Turkey. *International Journal of Production Economics*, 87, pp. 171–184.
- Kahraman S, Fener M, Gunaydin O. (2004). Predicting the sawability of carbonate rocks using multiple curvilinear regression analysis. *International Journal of Rock Mechanics & Mining Sciences*, 41; pp. 1123–1131.
- Kahraman S, Altun H, Tezekici B.S., Fener M, (2005). Sawability prediction of carbonate rocks from shear strength parameters using artificial neural networks. *International Journal of Rock Mechanics & Mining Sciences*, 43(1), pp 157–164.
- Kahraman S., Ulker U., Delibalta S., (2007). A quality classification of building stones from P-wave velocity and its application to stone cutting with gang saws. *The Journal of the South African Institute of Mining and Metallurgy*, 107, pp 427–430.
- Kaufmann, A., Gupta, M.M., (1988). *Fuzzy Mathematical Models in Engineering and Management Science*. North-Holland, Amsterdam.
- Konstanty, J. (2002). Theoretical analysis of stone sawing with diamonds. *J. Mater. Process Technol.* 123, pp. 146–54.
- Lai, Y. J., Hwang, C. L., (1996). *Fuzzy multiple objective decision making*. Berlin: Springer.
- Leung, L., Cao, D., (2000). Theory and methodology in consistency and ranking of alternatives in fuzzy AHP. *European Journal of Operational Research*, 124, pp. 102–113.
- Li, Y. Huang, H. Shen, J.Y. Xu, X.P. Gao, Y.S. (2002). Cost-effective machining of granite by reducing tribological interactions, *J. Mater. Process. Technol.* 129, pp. 389–394.
- Liu YC, Chen CS (2007). A new approach for application of rock mass classification on rock slope stability assessment. *Engineering Geology*, 89, pp. 129–43.
- Luo, S.Y. (1997). Investigation of the worn surfaces of diamond sawblades in sawing granite, *J. Mater. Process. Technol.* 70, pp. 1–8.
- Mikhailov, L., Tsvetinov, P., (2004). Evaluation of services using a fuzzy analytic hierarchy process. *Applied Soft Computing*, 5, pp. 23–33.
- Mikaeil R, Ataei M, Hoseinie S.H. (2008). Predicting the production rate of diamond wire saws in carbonate rocks cutting, *Industrial Diamond Review*, (IDR). 3, pp. 28–34.
- Mikaeil, .R, Zare Naghadehi, .M, Sereshki, .F, (2009). Multifactorial Fuzzy Approach to the Penetrability Classification of TBM in Hard Rock Conditions. *Tunnelling and Underground Space Technology*, Vol. 24, pp. 500–505.
- Mikaeil, .R, Zare Naghadehi, .M, Ataei, .M, KhaloKakaie, R, (2009). A Decision Support System Using Fuzzy Analytical Hierarchy Process (FAHP) and TOPSIS Approaches

- for Selection of the Optimum Underground Mining Method. *Archives of Mining Sciences*, Vol. 54, No 2, pp. 341–368.
- Norling, R. G. (1971). Mechanical properties and the composition of some Swedish natural stone types and their effect on cutting results. In: Presentation at the Conference on *Diamond in the Construction and Stone Industry*, in German.
- Ozcelik Y, Polat E, Bayram F, Ay A.M. (2004). Investigation of The Effects of Textural Properties on Marble Cutting with Diamond Wire. *International Journal of Rock Mechanics & Mining Sciences*, Sci. Vol. 41, No. 3.
- Özcelik Y. (2007). The effect of marble textural characteristics on the sawing efficiency of diamond segmented frame saws. *Industrial Diamond Review*, 2, pp. 65-70.
- Roscelli, R. (1990). *Misurare nell'incertezza*. Celid, Torino.
- Saaty, T. L. (1980). *The analytic hierarchy process*. New York: McGraw- Hill.
- Saaty, T.L., Vargas, L.G. (1990). *The Analytic Hierarchy Process series*. University of Pittsburg.
- Tang, Y., & Beynon, M. J. (2005). Application and development of a fuzzy analytic hierarchy process within a capital investment study. *Journal of Economics and Management*, 1(2), pp. 207–230.
- Tang, L. L., Kuo, Y. C., Lee E. S. (2005). A multi-objective model for Taiwan notebook computer distribution problem. In Y.-C. Lan (Ed.), *Global integrated supply chain systems*, (pp. 171). Hershey, PA, USA: Idea Group Publishing.
- Tolga, E., Demircan, M., Kahraman, C. (2005). Operating system selection using fuzzy replacement analysis and analytic hierarchy process. *International Journal of Production Economics*, 97, pp. 89–117.
- Tonshoff, H.K., Asche, J. (1997). Wear of metal-bond diamond tools in the machining of stone, *Industrial Diamond Review*, 1, pp. 7–13.
- Tsaur, S. H., Chang, T. Y., Yen, C. H. (2002). The evaluation of airline service quality by fuzzy MCDM. *Tourism Management*, 23, pp. 107–115.
- Tutmez B., Kahraman S., Gunaydin O. (2007). Multifactorial fuzzy approach to the sawability classification of building stones. *Construction and Building Materials*, 21, pp. 1672–1679.
- Tuysuz, F., Kahraman, C. (2006). Project risk evaluation using a fuzzy analytic hierarchy process: an application to information technology projects. *International Journal of Intelligent Systems*, 21, pp. 229–284.
- Unver B. (1996). A statistical method for practical assessment of sawability of rocks. In: M. Barla, ed. *Eurock '96*. Rotterdam: Balkema, pp. 59-65.
- Van Laarhoven, P. J. M., Pedrcyz, W. (1983). A fuzzy extension of Saaty's priority theory. *Fuzzy Sets and Systems*, 11, pp. 229–241.
- Vaya and Vikram. (1983). Mineralogical parameters in granite sawing, technical paper, University of Jodhpur, pp. 7-79.
- Wang, M. Y., Elhag, T. M. S. (2006). Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment. *Expert Systems with Applications*, 31, pp. 309–319.
- Wang, T. C., Chen, Y. H. (2007). Applying consistent fuzzy preference relations to partnership selection. *Omega, the International Journal of Management Science*, 35, pp. 384–388.
- Wang, Y. J., (2008). Applying FMCDM to evaluate financial performance of domestic airlines in Taiwan. *Expert Systems with Applications*, 34, pp. 1837–1845.
- Webb, S.W. Jackson, W.E. (1998). Analysis of blade forces and wear in diamond stone cutting, *ASME J. Manuf. Sci. Eng.* 120, pp. 84–92.

- Wei X, Wang C.Y, Zhou Z.H. (2003). Study on the fuzzy ranking of granite sawability. *Journal of Materials Processing Technology*, 139, pp. 277–80.
- Wright and Cassapi. (1985). Factors influencing stone sawability, *Industrial Diamond Review*, 2, pp. 84–87.
- Xipeng, X. Yiging, Y. (2005). Sawing performance of diamond with alloy coatings, *Surf. Coat. Technol.* 198, pp. 459–463.
- Xu, X. (1999). Friction studies on the process in circular sawing of granites, *Tribol. Lett.* 7, pp. 221–227.
- Xu, X. Li, Y. Malkin, S. (2001). Forces and energy in circular sawing and grinding of granite, *J. Manuf. Sci. Eng.* 123, pp. 13–22.
- Xu, X.P. Li, Y. Zeng, W.Y. Li, L.B. (2002). Quantitative analysis of the loads acting on the abrasive grits in the diamond sawing of granites, *J. Mater. Process. Technol.* 129, pp. 50–55.
- Xu, X. Li, Y. Yu, Y. (2003). Force ratio in the circular sawing of granites with a diamond segmented blade, *J. Mater. Process. Technol.* 139, pp. 281–285.
- Yoon, K., Hwang, C. L. (1985). Manufacturing plant location analysis by multiple attribute decision making: Part II. Multi-plant strategy and plant relocation. *International Journal of Production Research*, 23(2), pp. 361–370.
- Zadeh, L. A., (1965). Fuzzy sets. *Information and Control*, 8, pp. 338–353.
- Zare Naghadehi, .M, Mikaeil .R, Ataei, M. (2009). The Application of Fuzzy Analytic Hierarchy Process (FAHP) Approach to Selection of Optimum Underground Mining Method for Jajarm Bauxite Mine, Iran. *Expert Systems with Applications*, 36, pp. 8218–8226.
- Zhu, K., Jing, Y., Chang, D. (1999). A discussion on extent analysis method and applications of fuzzy AHP. *European Journal of Operational Research*, 116, pp. 450–456.

IntechOpen

Efficient Decision Support Systems - Practice and Challenges in Multidisciplinary Domains

Edited by Prof. Chiang Jao

ISBN 978-953-307-441-2

Hard cover, 478 pages

Publisher InTech

Published online 06, September, 2011

Published in print edition September, 2011

This series is directed to diverse managerial professionals who are leading the transformation of individual domains by using expert information and domain knowledge to drive decision support systems (DSSs). The series offers a broad range of subjects addressed in specific areas such as health care, business management, banking, agriculture, environmental improvement, natural resource and spatial management, aviation administration, and hybrid applications of information technology aimed to interdisciplinary issues. This book series is composed of three volumes: Volume 1 consists of general concepts and methodology of DSSs; Volume 2 consists of applications of DSSs in the biomedical domain; Volume 3 consists of hybrid applications of DSSs in multidisciplinary domains. The book is shaped decision support strategies in the new infrastructure that assists the readers in full use of the creative technology to manipulate input data and to transform information into useful decisions for decision makers.

How to reference

In order to correctly reference this scholarly work, feel free to copy and paste the following:

Reza Mikaeil, Mohammad Ataei and Reza Yousefi (2011). Evaluating the Power Consumption in Carbonate Rock Sawing Process by Using FDAHP and TOPSIS Techniques, Efficient Decision Support Systems - Practice and Challenges in Multidisciplinary Domains, Prof. Chiang Jao (Ed.), ISBN: 978-953-307-441-2, InTech, Available from: <http://www.intechopen.com/books/efficient-decision-support-systems-practice-and-challenges-in-multidisciplinary-domains/evaluating-the-power-consumption-in-carbonate-rock-sawing-process-by-using-fdahp-and-topsis-technique>

INTECH
open science | open minds

InTech Europe

University Campus STeP Ri
Slavka Krautzeka 83/A
51000 Rijeka, Croatia
Phone: +385 (51) 770 447
Fax: +385 (51) 686 166
www.intechopen.com

InTech China

Unit 405, Office Block, Hotel Equatorial Shanghai
No.65, Yan An Road (West), Shanghai, 200040, China
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元
Phone: +86-21-62489820
Fax: +86-21-62489821

© 2011 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](https://creativecommons.org/licenses/by-nc-sa/3.0/), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen