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# Ranking sawability of dimension stone using PROMETHEE method

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**Abstract**

Predicting the sawability of the dimension stone is one of the most important factors involved in production planning. Moreover, this factor can be used as an important criterion in the cost estimation and planning of the stone plants. The main purpose for carrying out this work was to rank the sawability of the dimension stone using the PROMETHEE method. In this research work, four important physical and mechanical properties of rocks including the uniaxial compressive strength, Schmiazek F-abrasivity, mohs hardness, and Young's modulus were evaluated as the criteria. During the research process, two groups of dimension stones were selected and analyzed. The rock samples were collected from a number of Iranian factories for the laboratory tests. The production rate of each sawn stone was selected to verify the proposed sawability ranking method. The results obtained showed that the new ranking method can be reliably used for evaluating the sawability of the dimension stone at any stone factory with different rocks only by the physical and mechanical properties testing.

**Keywords:** *Dimension Stone, Sawability Ranking, Production Rate, PROMETHEE Method.*

## 1. Introduction

In general, sawability of the dimension stone depends on some important parameters such as the textural characteristics, mechanical characteristics, structural characteristics, and the parameters related to the properties of the cutting tools and equipment. Under the same working conditions, the sawing process and the results obtained for it are strongly affected by the physical and mechanical properties of rocks. Up to the present time, many studies have been performed on the rock sawability. Some of these studies were reviewed in Table 1.

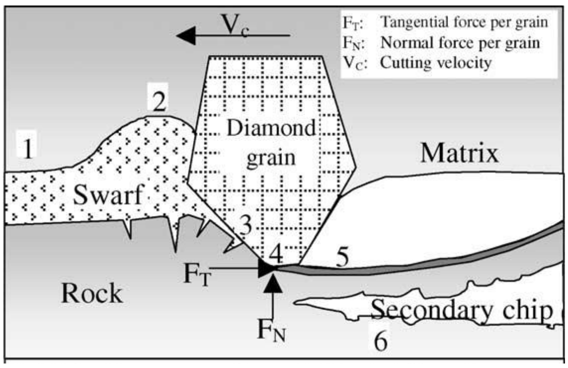
UCS, Uniaxial compressive strength; YM, Young’s modulus; BTS, Indirect Brazilian tensile strength; IS, Impact strength; SS, Shear strength; BS, Bending strength; H, Hardness; A, Abrasivity; D, Density; Gs, Grain size; Qc, Quartz content.

In the sawing process, the diamond particles on the segment surface remove the material through scratching and cracking the rock surface. During these processes, in front of the diamond grain, the stresses are affected by the tangential forces. In the sawing process, a swarf is formed by the tensile and compressive stresses. This mechanism involved is refered to as the primary chip formation. The swarf is forced out through the proves in front and beside the diamond grain. While the rock shows an elastic characteristic up to its ultimate stress, it is necessary for the sawing to reach a certain minimum grinding thickness. The rock is deformed by the compressive stress carried below the diamond. As the load is removed, an elastic revision leads to a critical tensile stress, which causes a brittle fracture. This process, affected by the tensile stresses, is described as the secondary chip formation; it is given in Figure 1. The swarf is removed by a coolant fluid [13].

The main aim for carrying out this work was to compare the different factors involved in the sawing process of the dimension stone. The comparison was made using a combination of the analytic hierarchy process (AHP) and the Fuzzy Delphi method, and also using the PROMETHEE method. The analysis is one of the multi-criteria techniques that provides a useful support in the choice among several alternatives with different objectives and criteria. The FDAHP method was used by the decision makers for determining the weights of the criteria, and then ranking the dimension stones was determined by the PROMETHEE method. This study was supported by the results obtained from a questionnaire carried out to know the opinions of the experts on this subject [31].

**Table 1. Main sawability studies with their parameters used in their studies.**

| Researchers | UCS | BTS | YM | IS | SS | BS | H | A | D | Gs | Qc |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Burgess (1978) [1] | | | | | | | | | | ● | ● |
| Wright and Cassapi (1985) [2] | ● | ● | | | | | ● | ● | | | ● |
| Birle and Ratterman (1986) [3] | | | | | | | ● | | | | |
| Jenning and Wright (1989) [4] | ● | ● | | | | | ● | | | | ● |
| Clausen et al. (1996) [5] | | | | | | | | | | ● | ● |
| Wei et al. (2003) [6] | ● | | | | | | ● | ● | | | ● |
| Eyuboglu et al. (2003) [7] | ● | ● | ● | | | | ● | | | | |
| Ersoy and Atici (2004) [8] | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| Kahraman et al. (2004) [9] | ● | ● | | ● | | | ● | ● | | | |
| Gunaydin et al. (2004) [10] | ● | ● | | ● | | | | | | | |
| Ozcelik et al. (2004) [11] | ● | ● | ● | | | | ● | | ● | | ● |
| Buyuksagis and Goktan (2005) [12] | ● | ● | | | | | ● | ● | | | ● |
| Ersoy et al. (2005) [13] | ● | ● | ● | ● | ● | ● | | ● | ● | | ● |
| Delgado et al. (2005) [14] | | | | | | | ● | | | | ● |
| Kahraman et al. (2005) [15] | | | | | ● | | | | | | ● |
| Fener et al. (2007) [16] | ● | ● | | ● | | | ● | ● | | | |
| Kahraman et al. (2007) [17] | ● | ● | | | | | | | ● | | ● |
| Ozcelik (2007) [18] | ● | ● | | | | | ● | | | | ● |
| Tutmez et al. (2007) [19] | ● | ● | | ● | | | ● | ● | | | |
| Buyuksagis (2007) [20] | ● | ● | | | | ● | ● | ● | ● | | ● |
| Mikaeil et al. (2008) [21] | ● | | | | | | | | | | ● |
| Mikaeil et al. (2011) [22] | ● | ● | ● | | | | ● | ● | | ● | ● |
| Mikaeil et al. (2011) [23] | ● | ● | | | | | ● | ● | | | |
| Ataei et al. (2011) [24] | ● | ● | | | | | ● | ● | | | |
| Mikaeil et al. (2011) [25] | ● | ● | | | | | | | | | |
| Mikaeil et al. (2011) [26] | ● | ● | ● | | | | ● | ● | | ● | ● |
| Mikaeil et al. (2011) [27] | ● | ● | ● | | | | ● | ● | | ● | ● |
| Mikaeil et al. (2011) [28] | ● | ● | | | | | | | | | |
| Ataei et al. (2012) [29] | ● | ● | | | | | ● | ● | | ● | ● |
| Ghaysari et al. (2012) [30] | | | | | | | | | | ● | |
| Mikaeil et al. (2013) [31] | ● | ● | ● | | | | ● | ● | | ● | ● |
| Sadegheslam (2013) [32] | ● | | ● | | | | | ● | | | ● |
| Mikaeil et al. (2014) [33] | ● | ● | | | | | | | | | |




1: Friction between swarf and matrix — 4: Plastic deformation
2: Matrix erosion by swarf and chip — 5: Elastic deformation
3: Friction between stone and grain — 6: Primary chipping zone

**Figure 1. Mechanical interaction between saw and stone during sawing process [21].**

## 2. PROMETHEE method

PROMETHEE is a multi-criterion decision-making method, which ranks the criteria using the pair comparison of the alternatives in each criterion separately. This method has been developed by Brans in 1982 [34], and further extended by Brans and Vincke [35] and Brans and Mareschal [36].

This method requires three factors to be implemented [34, 40]:

- Decision-making matrix (evaluation table)
- Criteria weights
- Information related to the preference function, which is determined by the decision maker, and implemented for comparing the alternatives in separate criteria.

The PROMETHEE method can be defined in five steps [34, 40]:

1- Determine the value for the preference function for all the pairs of objects in each criterion (Eq. 1).
2- Designate the individual preference degree for all the pairs of objects in each criterion (normalization of the value for the preference function).
3- Designate the multi-criteria preference degree for all pairs of objects (Eq. 2).
4- Determine the multi-criteria preference flow (outputs, inputs, and net) for each object (Eqs. 3, 4, and 5).
5- Determine the ranking objects based on the net flow.

PROMETHEE I represents the partial ranking based on the positive (see Formula 3) and negative (see Formula 4) flows. In this respect, if the positive flow is higher than the negative one, the alternative A is preferred to alternative B. In PROMETHEE I, the ranking of the alternatives may be incomplete, as it allows ignoring the negligible alternative differences. PROMETHEE II solves the problem, providing the complete ranking of the alternatives obtained based on the net preference flow (see Formula 5).

There exists an evaluation function for each alternative that is calculated separately for each criterion, and represented by *f*($\alpha$). The results obtained for the pair comparison of the alternatives using the *f(a)* evaluation function are shown by the $\mathrm{P_j}$ preference function in the criterion *j* (Formula 1 [34, 40]).

$$\begin{aligned} &P_j(a,b) = G_j[\mathrm{d_j(a,b)}] \qquad j = 1,2,\ldots,n \\ &d_j(a,b) = [\mathrm{f_j(a) - f_j(b)}] \\ &\mathrm{P_j}(a,b) = \begin{cases} 0 & if \quad d_j(a,b) \le 0 \\ 1 & if \quad d_j(a,b) > 0 \end{cases} \end{aligned} \tag{1}$$

Six possible shapes have been proposed for the preference functions by the developers of the PROMETHEE method to facilitate the selection of the specific preference function. The overall preference index $\pi\,(a,b)$, which takes all the criteria into account, can be computed using the $P_j$ preference functions. The value for the so-called index ranges between zero and one. The closer the value gets to one, the higher becomes the attractiveness of the alternative “a” among the other ones [37].

This preference index is based upon the positive and negative preference flows for each alternative. The positive $\varphi^{+}(a)$ preference flow (Formula 3) indicates the superiority of alternative A over the other alternatives, and the negative $\varphi^{-}(a)$ preference flow (Formula 4) shows its weakness. The difference between these preference flows represents the net preference flow $\varphi\,(a)$ (Formula 5) that has a direct relationship with the attractiveness of alternative A. $w_j$ represents criterion j in Formula 2 [34, 40].

$$\Pi(\mathrm{a,b}) = \sum_{j=1}^{k} w_j P_j(\mathrm{a,b}) \tag{2}$$

$$\varphi^{+}(\mathrm{a}) = \frac{1}{n-1}\sum_b \Pi(\mathrm{a,b}) \tag{3}$$

$$\varphi^{-}(\mathrm{a}) = \frac{1}{n-1}\sum_b \Pi(b,a) \tag{4}$$

$$\varphi(a) = \varphi^{+}(\mathrm{a}) - \varphi^{-}(\mathrm{a}) \tag{5}$$

Since the birth of the PROMETHEE method, it spread variously in many academic and application areas. Vukotic and Kecojevic [38] have presented a method for evaluating the rope shovel operators in surface coal mining, with the overall goal of minimizing the energy consumption and maximizing the production rate. They used multi-attribute decision making methods, i.e. PROMETHEE II, to conduct their evaluation. Hamadouche et al. [39] have developed a GIS-based multi-criteria decision-making approach for the biodiversity preservation of the Ahaggar National Park in Algeria. They suggested conceptual solutions to integrate the ELECTRE and PROMETHEE methods in the GIS software to enhance its performance in the spatial decision support in the land management problems. Behzadian et al. [40], in a comprehensive study, reviewed the scholarly research carried out since 1985. They reviewed 217 papers from 100 scholarly journals appeared on the subject of PROMETHEE. After a detailed study, they categorized the applications of the method into nine areas: environment management, hydrology and water management, buisiness and financial management, chemistry, logistics and transportation, manufacturing and assembly, energy management, social, and other topics (medicine, agriculture, education, design, government, and sports). The application of PROMETHEE has sustained different engineering areas in the recent years.

## 3. Application of PROMETHEE method to multi-criteria comparison of sawability

The main purpose for carrying out this work was to rank the sawability of the ornamental stone based on some effective factors. The sawability ranking was performed in two distinct groups, the granite and carbonate rocks. This difference is due to the equipment and sawing conditions. In this work, after determining the weights of the criteria by the FAHP method and laboratory studies (Figures 2 and 3), ranking the sawability of rocks was performed by the PROMETHEE method (PROMETHEE I and II). Firstly, the amount of each criterion was filled in the decision matrix for each criterion. The decision matrix was obtained with respect to the important rock properties. The values for the decision matrix and weights of the criteria are given in Tables 2 and 3.

The matrix of preference function for all pairs of alternatives in each criteria, calculated by Formula 1, are given in Tables 4 and 5.

The positive, negative, and net preference flows (calculated by Formulas 3, 4, and 5), and the final ranking (obtained on the net flow) are shown in Tables 6 and 7. The graphical preferences of the first and second groups or rocks are illustrated in Figures 4 and 5.

**Table 2. Decision matrix and criteria weights for first group of rocks.**

| | **UCS** | **SFA** | **YM** | **MH** |
|---|---|---|---|---|
| | **Mpa** | **N/mm** | **Gpa** | **n** |
| Harsin (Marble) | 71.5 | 0.135 | 32.5 | **3.5** |
| Anarak (Marble) | 74.5 | 0.109 | 33.6 | **3.2** |
| Ghermez (Travertine) | 53 | 0.122 | 20.7 | **2.9** |
| Hajiabad (Travertine) | 61.5 | 0.124 | 21 | **2.9** |
| Darebokhari (Travertine) | 63 | 0.127 | 23.5 | **2.95** |
| Salsali (Marble) | 68 | 0.105 | 31.6 | **3.1** |
| Haftoman (Marble) | 74.5 | 0.173 | 35.5 | **3.6** |
| Weight | 0.3716 | 0.3664 | 0.0855 | **0.1765** |

**Table 3. Decision matrix and criteria weights for second group of rocks.**

| | **UCS** | **SFA** | **YM** | **MH** |
|---|---|---|---|---|
| | **Mpa** | **N/mm** | **Gpa** | **n** |
| Chayan (Granite) | 173 | 7.58 | 48.6 | **6.6** |
| Ghermez Yazd (Granite) | 142 | 14.24 | 43.6 | **6.1** |
| Sefid Nehbandan (Granite) | 145 | 24.25 | 35.5 | **5.75** |
| Khoramdare (Granite) | 133 | 10.42 | 28.9 | **5.65** |
| Morvarid Mashhad (Granite) | 125 | 8.52 | 31.2 | **5.6** |
| Weight | 0.3716 | 0.3664 | 0.0855 | **0.1765** |

**Table 4. Matrix of preference function for first group of rocks.**

| | **Harsin** | **Anarak** | **Ghermez** | **Hajiabad** | **Darebokhari** | **Salsali** | **Haftoman** |
|---|---|---|---|---|---|---|---|
| **Harsin** | - | 0 | 1 | 1 | 1 | 1 | 0 |
| **Anarak** | 1 | - | 1 | 1 | 1 | 1 | 1 |
| **Ghermez** | 0 | 0 | - | 0 | 0 | 0 | 0 |
| **Hajiabad** | 0 | 0 | 1 | - | 0 | 0 | 0 |
| **Darebokhari** | 0 | 0 | 1 | 1 | - | 0 | 0 |
| **Salsali** | 0 | 0 | 1 | 1 | 1 | - | 0 |
| **Haftoman** | 1 | 1 | 1 | 1 | 1 | 1 | - |

**Table 5. Matrix of preference function for second group of rocks.**

| | Chayan | Ghermez Yazd | Sefid Nehbandan | Khoramdare | Morvarid Mashhad |
|---|---|---|---|---|---|
| **Chayan** | - | 1 | 1 | 1 | 1 |
| **Ghermez Yazd** | 0 | - | 0 | 1 | 1 |
| **Sefid Nehbandan** | 0 | 1 | - | 1 | 1 |
| **Khoramdare** | 0 | 0 | 0 | - | 1 |
| **Morvarid Mashhad** | 0 | 0 | 0 | 0 | - |

**Table 6. PROMETHEE I/II scores and final ranking for first group of rocks.**

| Rank | Alternatives | $\varphi$ | $\varphi^+$ | $\varphi^-$ |
|---|---|---|---|---|
| 1 | Haftoman | 0.9381 | 0.9381 | 0.0000 |
| 2 | Harsin | 0.5143 | 0.7571 | 0.2429 |
| 3 | Anarak | 0.1812 | 0.5596 | 0.3784 |
| 4 | Darebokhari | -0.0891 | 0.4555 | 0.5445 |
| 5 | Salsali | -0.3664 | 0.3168 | 0.6832 |
| 6 | Hajiabad | -0.4518 | 0.2594 | 0.7112 |
| 7 | Ghermez | -0.7263 | 0.1221 | 0.8485 |

**Table 7. PROMETHEE I/II scores and final ranking for second group of rocks.**

| Rank | Alternatives | $\varphi$ | $\varphi^+$ | $\varphi^-$ |
|---|---|---|---|---|
| 1 | Sefid Nehbandan | 0.5522 | 0.7761 | 0.2239 |
| 2 | Ghermez Yazd | 0.3142 | 0.6571 | 0.3429 |
| 3 | Chayan | 0.2672 | 0.6336 | 0.3664 |
| 4 | Khoramdare | -0.3595 | 0.3202 | 0.6798 |
| 5 | Morvarid Mshhad | -0.7741 | 0.1130 | 0.8870 |

Tables 6 and 7, and Figures 4 and 5 illustrate the preferences of the alternatives. For example, Haftoman and Harsin dominated over the other alternatives in Figure 2. It can be inferred from the results obtained (Table 6 and Figure 3) that in the group of carbonate rocks, according to the important defined criteria, the Haftoman, Harsin, Anarak, Darebokhari, Salsali, Hajiabad, and Ghermez rocks have the best sawability characteristics, respectively, and in the group of non-carbonate rocks, Sefid, Ghermez Yazd, Chyan, Khoramdare, and Morvarid have the best sawability characteristics, respectively (Table 7, Figure 4).

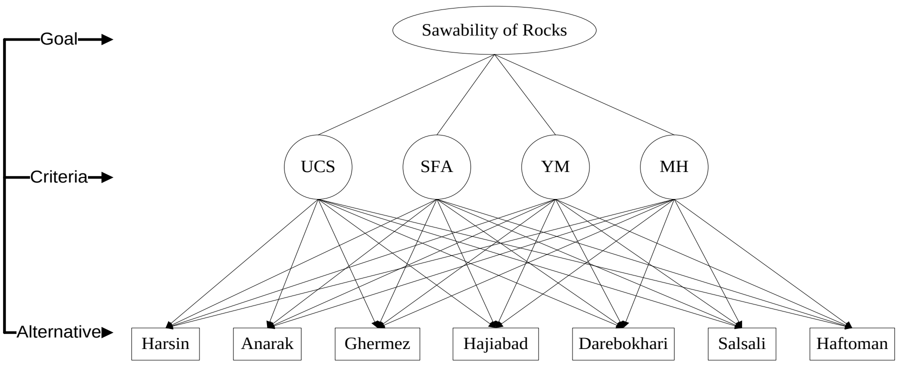



**Figure 2. Phase of decision making for first group of rocks.**

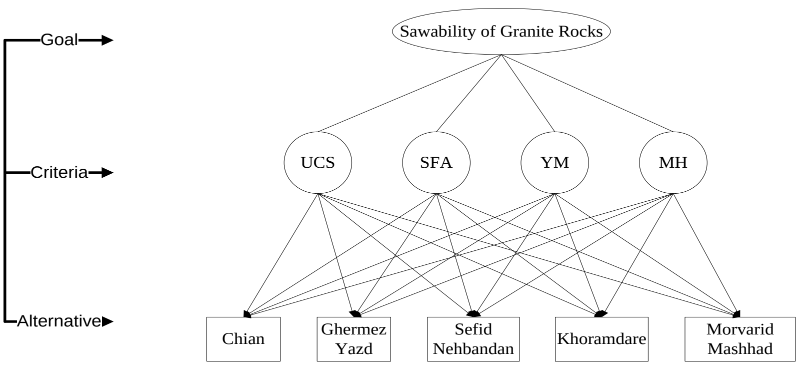



**Figure 3. Phase of decision making for second group of rocks.**

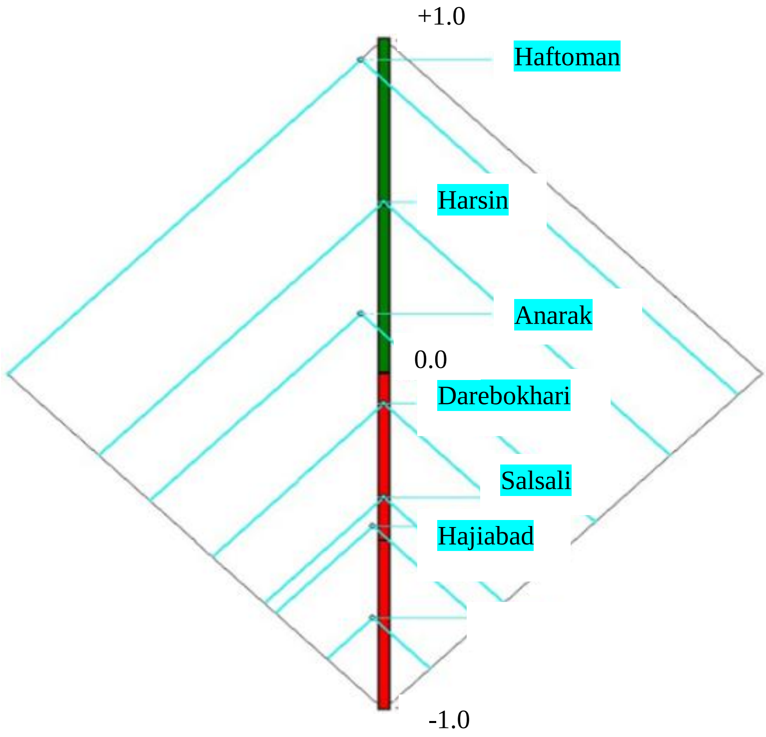



**Figure 4. Graphical preferences of first group of rocks.**

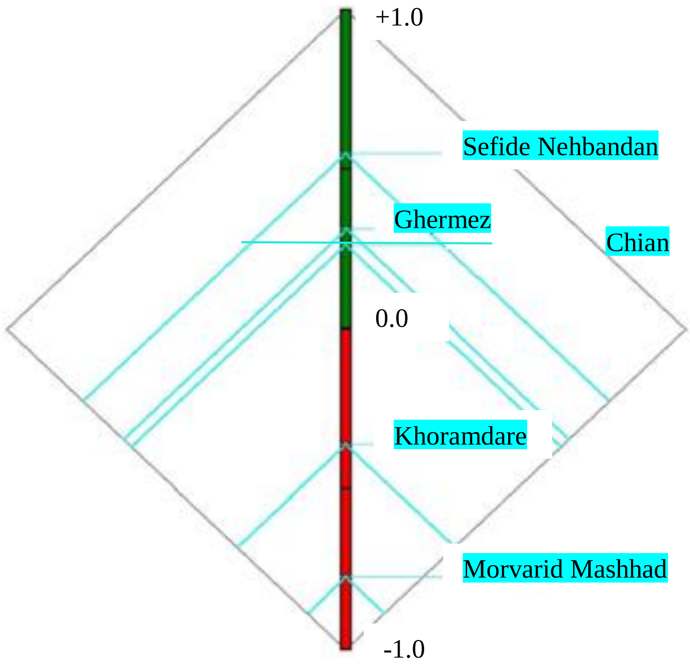



**Figure 5. Graphical preferences of second group of rocks.**

## 4. Discussion

For validation of the applied ranking method, field studies were carried out. The production rate of the sawing machine was used as a major criterion for evaluating the rock sawability of the studied rocks. For this purpose, some stone factories in Shamsabad were selected, and the performance of the diamond circular saw was measured on 12 different granite and carbonate rocks in term of the hourly production rates ($P_h$). The production rate of the studied rocks is shown in Table 8. The relationship between the production rate and $Q^+$ for the two groups of the studied rocks are shown in Figure 6.

**Table 8. Sawability ranking results of studied rocks.**

| Rank | Carbonate rock | Q | $Q^+$ | $Q^-$ | $P_c$ |
|---|---|---|---|---|---|
| 1 | Haftoman | 0.9381 | 0.9381 | 0 | 8 |
| 2 | Harsin | 0.5143 | 0.7571 | 0.2429 | 8.5 |
| 3 | Anarak | 0.1812 | 0.5596 | 0.3784 | 9 |
| 4 | Darebokhari | -0.0891 | 0.4555 | 0.5445 | 10 |
| 5 | Salsali | -0.3664 | 0.3168 | 0.6832 | 9 |
| 6 | Hajiabad | -0.4518 | 0.2594 | 0.7112 | 10 |
| 7 | Ghermez | -0.7263 | 0.1221 | 0.8485 | 11 |
| **Rank** | **Granite rock** | **Q** | $Q^+$ | $Q^-$ | $P_G$ |
| 1 | Sefid Nehbandan | 0.5522 | 0.7761 | 0.2239 | 5 |
| 2 | Ghermez Yazd | 0.3142 | 0.6571 | 0.3429 | 5.5 |
| 3 | Chayan | 0.2672 | 0.6336 | 0.3664 | 5 |
| 4 | Khoramdare | -0.3595 | 0.3202 | 0.6798 | 6 |
| 5 | Morvarid Mashhad | -0.7741 | 0.113 | 0.887 | 6.5 |

According to Table 8 and Figure 6, the first rock in the carbonate and granite rankings are Haftoman marble and Sefide Nehbandan, respectively. This means that sawability of the mentioned rocks is very poor; it is acceptable by the value of the production rate. On the opposite side, Ghermez travertine and Morvaride Mashhad granite have a maximum value of production rate and maximum value of Q in the new ranking method. As a result, it can be concluded that the applied ranking method is very useful to determine the best and worst sawability ranking of the rocks. The relationship between the production rate and the $Q^+$ value for the studied rocks was also investigated graphically for fitting a function to the set of data. Based on this analysis, among the many functions tested (linear, power, logarithmic, and exponential), the logarithmic and exponential curve relations were fitted to the two groups of data with higher correlations than all the other relationships. These relationships are presented in Figure 6. According to this figure, there is a statistically significant relationship between the production rate and $Q^+$ value. Also meaningful correlations were obtained between the power consumption and $CC_j$ value, with the prediction equations given in Equations 6 and 7.

$$P_c = -1.334\ln(Q^+) + 8.1544 \tag{6}$$

$$P_G = 6.7922e^{-0.397Q^+} \tag{7}$$

where $P_C$ and $P_G$ are the production rates of the carbonate and granite rocks, respectively, and $Q^+$ is the ranking value. Finally, it can be concluded that the applied sawability ranking method of the rocks is reasonable and acceptable for evaluating the production rates of the carbonate and granite rocks.

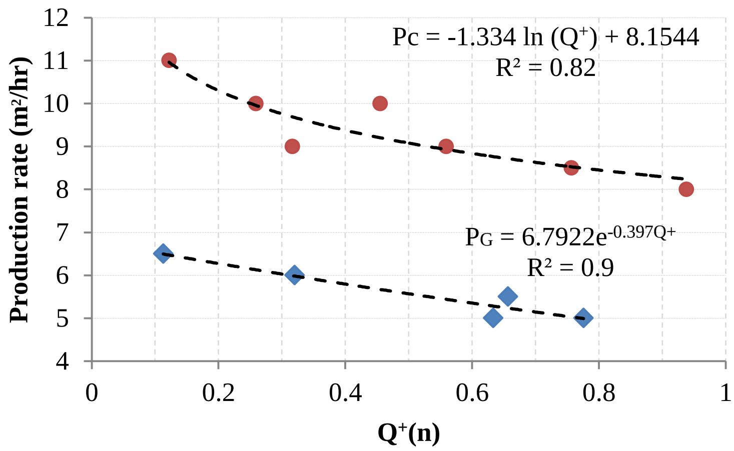



**Figure 6. Graph of production rate against Q+.**

## 5. Conclusions

In this work, a decision support system was developed for ranking the sawability of the dimension stone. This system was 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 sawability of the dimension stone. In this study, the FDAHP and PROMETHEE methods were used to evaluate the sawability of the dimension stone. FDAHP was used to determine the weights of the criteria, and the PROMETHEE method was used for ranking the sawability of the dimension stone. During this research work, 12 types of dimension stones belonging to the granite and carbonate rocks were tested in some factories located in Iran. The production rate of each sawn rock was determined to verify the results obtained for the applied approach for ranking them by the sawability criteria. The experimental results obtained confirmed the new ranking results precisely. This new ranking method can be used to evaluate the production rate of the dimension stone at any stone factory with different rocks. Some parameters such as the uniaxial compressive strength, Schmiazek F-abrasivity, mohs hardness, and Young's modulus must be obtained for the best sawability ranking.

## References


[1]. Burgess, R. B. (1978). Circular sawing granite with diamond saw blades. In: Proceedings of the Fifth Industrial Diamond Seminar., pp. 3-10.

[2]. Wright, D.N. and Cassapi, V.B. (1985). Factors influencing stone sawability, Industrial Diamond Review. 2: 84-87.

[3]. Birle J.D. and Ratterman, E. (1986). An approximate ranking of the sawability of hard building stones based on laboratory tests, Dimensional Stone Magazine, pp. 3-29.

[4]. Jennings, M. and Wright, D.N. (1989). Guidelines for sawing stone, Industrial Diamond Review, 49: 70–75.

[5]. Clausen, R., Wang, C.Y. and Meding, M. (1996). Characteristics of acoustic emission during single diamond scratching of granite. Industrial Diamond Review. 3: 96-9.

[6]. Wei, X., Wang, C.Y. and Zhou, Z.H. (2003). Study on the fuzzy ranking of granite sawability. J. Mater. Process. Technol. 139: 277-80.

[7]. Eyuboglu, A.S., Ozcelik, Y., Kulaksiz, S. and Engin, I.C. (2003). Statistical and microscopic investigation of disc segment wear related to sawing Ankara andesites, Int. J. Rock Mech. Min. Sci. 40: 405-414.

[8]. Ersoy, A. and Atici, U. (2004). Performance characteristics of circular diamond saws in cutting different types of rocks. Diamond and Related Materials. 13: 22-37.

[9]. Kahraman, S., Fener, M. and Gunaydin, O. (2004). Predicting the sawability of carbonate rocks using multiple curvilinear regression analysis. International Journal of Rock Mechanics & Mining Sciences. 41: 1123-1131.

[10]. Gunaydin, O., Kahraman, S. and Fener, M. (2004). Sawability prediction of carbonate rocks from brittleness indexes. J. South Afr. Inst. Min. Metall. 104: 239-244.

[11]. Ozcelik, Y., Polat, E., Bayram, F. and Ay, A.M. (2004). Investigation of the effects of textural properties on marble cutting with diamond wire. Int. J. Rock Mech. Min. Sci. 41(3): 228-234.

[12]. Buyuksagis, I.S. and Goktan, R.M. (2005). Investigation of marble machining performance using an instrumented block-cutter. Journal of Materials Processing Technology. 169: 258-262.

[13]. Ersoy, A., Buyuksagis, S. and Atici, U. (2005). Wear characteristics of circular diamond saws in the cutting of different hard and abrasive rocks, Wear. 258: 1422-1436.

[14]. Delgado, N.S., Rodriguez, R., Rio, A., Sarria, I.D, Calleja, L. and Argandona, V.G.R. (2005). The influence of microhardness on the sawability of Pink Porrino granite (Spain). Int. J. Rock Mech. Min. Sci. 42: 161-166.

[15]. Kahraman, S., Altun, H., Tezekici, B.S. and 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): 157-164.

[16]. Fener, M., Kahraman, S. and Ozder, M.O. (2007). Performance Prediction of Circular Diamond Saws from Mechanical Rock Properties in Cutting Carbonate Rocks, Rock Mech. Rock Engng. 40 (5): 505-517.

[17]. Kahraman, S., Ulker, U. and 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 Southern African Institute of Mining and Metallurgy. 107: 427-430.

[18]. Özçelik, Y. (2007). The effect of marble textural characteristics on the sawing efficiency of diamond segmented frame saws. Industrial Diamond Review. 2: 65-70.

[19]. Tutmez, B., Kahraman, S. and Gunaydin, O. (2007). Multifactorial fuzzy approach to the sawability

classification of building stones. Construction and Building Materials. 21: 1672-1679.

[20]. Buyuksagis, I.S. (2007). Effect of cutting mode on the sawability of granites using segmented circular diamond sawblade. Journal of Materials Processing Technology. 183: 399-406.

[21]. Mikaeil, R., Ataei, M. and Hoseinie, S.H. (2008). Predicting the production rate of diamond wire saws in carbonate rocks cutting, Industrial Diamond Review. 3: 28-34.

[22]. Mikaiel, R., Ataei, M. and Yousefi, R. (2011). Application of a fuzzy analytical hierarchy process to the prediction of vibration during rock sawing, Mining Science and Technology (China). 21: 611-619.

[23]. Mikaeil, R., Yousefi, R., Ataei, M. and Abbasian, R. (2011). Development of a New Classification System for Assessing of Carbonate Rock Sawability. Arch. Min. Sci. 56 (1): 57-68.

[24]. Ataei, M., Mikaiel, R., Sereshki, F. and Ghaysari, N. (2011). Predicting the production rate of diamond wire saw using statistical analysis. Arabian Journal of Geosciences. 5: 1289-1295.

[25]. Mikaiel, R., Ataei, M. and Yousefi, R. (2011). Correlation of production rate of dimension stone with rock brittleness indexes. Arabian Journal of Geosciences. 6: 115-121.

[26]. Mikaeil, R., Yousefi, R. and Ataei, M., (2011). Sawability Ranking of Carbonate Rock Using Fuzzy Analytical Hierarchy Process and TOPSIS Approaches. Scientia Iranica, Transactions B: Mechanical Engineering. 18: 1106-1115.

[27]. Mikaeil, R., Ataei, M. and Yousefi, R., (2011). Evaluating the Power Consumption in Carbonate Rock Sawing Process by Using FDAHP and TOPSIS Techniques, Efficient Decision Support Systems: Practice and Challenges-From Current to Future / Book 2", ISBN 978-953-307-441-2., 413-436.

[28]. Mikaeil, R., Ozcelik, Y., Ataei, M. and Yousefi, R. (2011). Correlation of Specific Ampere Draw with Rock Brittleness Indexes in Rock Sawing Process. Arch. Min. Sci. 56 (4): 741-752.

[29]. Ataei, M., Mikaeil, R., Hoseinie, S.H. and Hosseini, S.M. (2012). Fuzzy analytical hierarchy process approach for ranking the sawability of carbonate rock. International Journal of Rock Mechanics & Mining Sciences. 50: 83-93.

[30]. Ghaysari, N., Ataei, M., Sereshki, F. and Mikaiel, R. (2012). Prediction of Performance of diamond wire saw with respect to texture characterestic of rock, Arch. Min. Sci. 57 (4): 887-900.

[31]. Mikaeil, R., Ozcelik, Y., Ataei, M. and Yousefi, R. (2013). Ranking the sawability of dimension stone using Fuzzy Delphi and multi-criteria decision-making techniques. International Journal of Rock Mechanics & Mining Sciences. 58: 118-126.

[32]. Sadegheslam, G., Mikaeil, R., Rooki, R., Ghadernejad, S. and Ataei, M. (2013). Predicting the production rate of diamond wire saw using multiple nonlinear regression analysis, Geosystem engineering. 16(4): 275-285.

[33]. Mikaeil, R., Ataei, M., Ghadernejad, S. and Sadegheslam, G. (2014). Predicting the Relationship between System Vibration with Rock Brittleness Indexes in Rock Sawing Process. Archives of Mining Sciences, 59 (1): 121-135.

[34]. Brans, J.P. (1982). Lingenierie de la decision. Elaboration dinstruments daide a la decision. Methode PROMETHEE. In: Nadeau, R., Landry, M. (Eds.), Laide a la Decision: Nature, Instrument set Perspectives Davenir. Presses de Universite Laval, Quebec, Canada, pp. 183-214.

[35]. Brans, J.P. and Vincke, Ph. (1985). A preference ranking organization method: the PROMETHEE method. Management Science. 31: 647-656.

[36]. Brans, J.P. and Mareschal, B. (1994). The PROMCALC & GAIA decision support system for multicriteria decision aid, Decision Support Systems. 12 (4-5): 297-310.

[37]. Brans, J.P. and Mareschal, B. (2005). Multiple Criteria Decision Analysis: State of the Art Surveys. Springer Science + Business Media, In: Figueira, J., Greco, S., Ehrgott, M. (Eds.), 163-196.

[38]. Vukotic, I. and Kecojevic, V. (2014). Evaluation of rope shovel operators in surface coal mining using a Multi-Attribute Decision-Making model. International Journal of Mining Science and Technology. 24(2): 259-268.

[39]. Hamadouche, M.A., Mederbal, K., Kouri, L., Regagba, Z., Fekir, Y. and Anteur, D. (2014). GIS-based multicriteria analysis: an approach to select priority areas for preservation in the Ahaggar National Park, Algeria. Arab J Geosci. 7: 419-434.

[40]. Behzadian, M., Kazemzadeh, R.B., Albadvi, A. and Aghdasi, M. (2010). PROMETHEE: A comprehensive literature review on methodologies and applications. European Journal of Operational Research. 200: 198-215.

# رده‌بندی قابلیت برش سنگ‌های ساختمانی با استفاده از روش PROMETHEE

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**چکیده:**

تخمین قابلیت برش سنگ‌های ساختمانی یکی از فاکتورهای مهم در طراحی تولید است که علاوه بر آن نیز می‌تواند به‌عنوان یک معیار مهم در تخمین هزینه‌ها و طراحی کارخانه‌های سنگ‌بری مورد استفاده قرار بگیرد. هدف اصلی از انجام این کار تحقیقاتی رده‌بندی قابلیت برش سنگ‌های ساختمانی با استفاده از روش PROMETHEE است. در این کار تحقیقاتی ۴ مشخصه مهم فیزیکی و مکانیکی از سنگ‌ها مشتمل بر مقاومت فشاری تک‌محوری، شاخص سایندگی شیمازک، سختی موهس و مدول یانگ به‌عنوان معیارهای رده‌بندی مورد ارزیابی قرار گرفتند. در طول انجام این تحقیق، دو گروه از سنگ‌های ساختمانی برای ارزیابی انتخاب شدند. نمونه‌های سنگی برای انجام مطالعات آزمایشگاهی از کارخانه‌های سنگ‌بری در کشور ایران جمع‌آوری شدند. به‌منظور بررسی و ارزیابی رده‌بندی، میزان نرخ تولید هر یک از نمونه‌ها مورد استفاده قرار گرفت. نتایج حاصل از این تحقیق نشان داد که روش رده‌بندی جدید می‌تواند با قابلیت اعتماد بالایی برای ارزیابی قابلیت برش انواع مختلف سنگ‌های ساختمانی تنها با آزمایش‌های فیزیکی و مکانیکی مورد استفاده قرار بگیرد.

**کلمات کلیدی:** سنگ ساختمانی، رده‌بندی قابلیت برش، نرخ تولید، روش PROMETHEE.