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Evaluating the Sawability of Rocks by Chain-Saw Machines using the PROMETHEE Technique

Reza Mikaeil[1]; Akbar Esmaeilzadeh[1]; Sara Aghaei[1]; Sina Shaffiee Haghshenas[2]; Amir Jafarpour[3]; Javad Mohammadi[4]; Mohammad Ataei[4];

[1] Department of Mining and Engineering, Faculty of Environment, Urmia University of Technology, Urmia, Iran

[2] Department of Civil Engineering, University of Calabria, Via Bucci, 87036 Rende, Italy, http://orcid.org/0000-0003-2859-3920

[3] Department of Mining and Metallurgical Engineering, Yazd University

[4] School of Mining, Petroleum & Geophysics Engineering, Shahrood University of Technology, Shahrood, Iran

Abstract

One of the most significant factors in the estimation of dimension stone quarry cost is the production rate of rock cutting machines. Evaluating the production rate of chain-saw machines is a very significant and practical issue. In this research, it has been attempted to evaluate and select the suitable working-face for a quarry by examining the maximum production rate in the Dehbid and Shayan marble quarries. For this purpose, field studies were carried out which included measuring operational characteristics of the chain-saw cutting machine, the production rate and sampling for laboratory tests from seven active case studies. Subsequently, the physical and mechanical properties of rocks including: Uniaxial Compressive Strength (UCS), Brazilian Tensile Strength (BTS), Los Angeles abrasion, quartz content, water absorption percentage, porosity, Schmidt hardness and grain size for all sample measurements were studied after transferring the samples to a rock-mechanics laboratory. Finally, the sawability of the quarried working-faces was evaluated using the PROMETHEE multi-criteria decision-making (MCDM) model according to the physical and mechanical properties. The results of the study indicated that the number 1 and 5 working-faces from the Dehbid and Shayan quarries are the most suitable working-faces in terms of production rate with the maximum recorded production values (4.95 and 3.1 m²/h), and with net flow rates (2.67 and -0.36) respectively.

1. Introduction

The production rate of stone cutting machines plays a key role in dimension stone quarries when considering the final costs of extracting a stone block. Numerous methods are used to extract dimension stones in quarries. Currently, the diamond cutting-wire method is used in most quarries for extraction **(Korman et al. 2016; Mikaeil et al., 2018a)**. Using diamond cutting wire has disadvantages such as high risk of hazards and reduced safety compared to other methods. The chainsaw machine cutting method is a suitable solution for extracting dimension stones that has advantages such as: increased safety, the quality of the extracted stone block and ease of work. Given the advantages of a chainsaw cutting machine, it is predicted that the use of this machine will completely replace the use of other methods for cutting dimension stones in the next few years. The production rate in the chainsaw machine extraction method depends on various factors including the physical and mechanical characteristics of the stone, structural characteristics of

the machine and operational parameters of the machine. Therefore, to assess the production rate, access to sufficient information about the type of the mineral, physical and mechanical characteristics of the intended stone and controllable parameters, including the characteristics of the chainsaw machine and operational parameters are key factors. As of yet, many studies have been conducted on the effect of stone properties on the performance of cutting machines, an important part of which is presented in **Table 1**.

It is certain that in the coming years, the use of chainsaws will be a complete alternative to the diamond wire cutting method. Also, it should be noted that many studies on the use of chainsaws have been conducted by researchers in recent years, which shows the efficiency of the chainsaw cutting method.

It is evident that many studies performed on stone cutting have suggested diamond cutting wire and cutting discs, and in this regard, a lot of research (unlike the necessary research on chainsaw cutting machines) has been carried out. Today, however, stone cutting methods with the use of chainsaw machines is on the rise. Some of the important studies done in this field could be de-

Corresponding author: Sina Shaffiee Haghshenas
s.shaffiee@yahoo.com

Table 1: Studies on the performance of stone cutting machines

Researchers	Year	Saw type		Physical and mechanical properties											
		W	C	UCS	BTS	YM	IS	SS	BS	H	A	D	Gs	Qc	Ws
Burgess and Birle	1978		●										●	●	
Wright and Cassapi	1985		●	●		●				●	●			●	
Birle and Ratterman	1986		●							●					
Jennings and Wright	1989		●	●		●				●				●	
Clausen et al.	1996		●										●	●	
Ciccu et al.	**1999**	●					●			●					●
Agus et al.	**2003**	●								●			●	●	
Wei et al.	2003		●	●						●	●			●	
Eyuboglu et al.	2003		●	●	●	●				●					
Ersoy and Atici	2004		●	●	●	●	●	●	●	●	●	●	●	●	
Kahraman et al.	2004		●	●	●	●	●			●	●				
Gunaydin et al.	2004		●	●	●	●	●								
Ozcelik et al.	**2004**	●		●	●	●				●		●		●	
Buyuksagis and Goktan	2005		●	●	●					●	●			●	
Ersoy et al.	2005		●	●	●	●	●	●	●		●	●		●	
Delgado et al.	2005		●							●				●	
Kahraman et al.	2005		●					●						●	
Cai et al.	**2007**	●		●			●	●		●			●		
Fener et al.	2007		●	●	●		●			●	●				
Kahraman et al.	2007		●	●	●							●		●	
Ozcelik	**2007**	●		●	●					●				●	
Tutmez et al.	2007		●	●	●		●			●	●				
Buyuksagis	2007		●	●	●				●	●	●	●		●	
Mikaeil et al.	**2008**	●		●										●	
Kahraman and Gunaydin	2008		●							●		●			
Mikaeil et al.	2011		●	●	●										
Ataei et al.	2012		●	●	●					●	●				
Ataei et al.	**2012**	●		●	●					●	●		●	●	
Yurdakul and Akdas	2012		●	●	●				●	●	●	●			
Ghaysari et al.	**2012**	●										●			
Mikaeil et al.	2013		●	●	●	●				●	●		●	●	
Sadegheslam et al.	**2013**	●		●		●					●			●	
Careddu and Cai	**2014**	●	●												
Careddu and Lanceni	**2015**	●	●												
Tumac	2015		●							●	●				
Mikaeil et al.	2016		●	●	●	●				●	●		●	●	
Aryafar and Mikaeil	2016		●	●	●	●				●	●		●	●	
Tumac	2016		●	●	●						●	●			
Almasi et al.	**2017a**	●		●	●	●				●	●		●	●	
Almasi et al.	**2017b**	●		●	●	●				●	●		●	●	
Almasi et al.	**2017c**	●		●	●	●				●	●		●	●	
Kamran et al.	**2017**	●		●	●	●				●	●		●	●	
Akhyani et al.	2017		●	●	●	●				●	●		●	●	
Mikaeil et al.	**2017**	●		●	●	●				●	●		●	●	
Yilmazkaya et al.	**2018**	●		●			●	●	●	●			●	●	
Tumac and Shaterpour	2018		●				●	●	●				●	●	
Aryafar et al.	2018a		●	●	●	●				●	●		●	●	
Aryafar et al.	2018b		●	●	●	●				●	●		●	●	
Akhyani et al.	2018		●	●	●	●									
Mikaeil et al.	2018b		●	●	●	●				●	●		●	●	
Mikaeil et al.	2018c		●	●	●	●				●	●		●	●	
Careddu et al.	**2018**	●		●					●		●	●			
Careddu et al.	**2019**	●		●					●		●	●			
Akhyani et al.	2019		●	●	●	●				●	●		●	●	
Mohammadi et al.	2019		●	●	●	●				●	●		●	●	
Dormishi et al.	2019a		●	●	●	●				●	●		●	●	
Dormishi et al.	2019b		●	●	●	●				●	●		●	●	
Mikaeil et al.	2019a		●	●	●	●				●	●		●	●	
Haghshenas et al.	2019		●	●	●	●				●	●		●	●	
Hosseini et al.	2019		●	●	●	●				●	●		●	●	
Hosseini et al.	2020a		●	●	●	●				●	●		●	●	
Hosseini et al.	2020b		●	●	●	●				●	●		●	●	

W, Diamond wire saw; C, Circular saw, Frame saw and Chain saw; 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; Ws, Wave speed.

scribed as follows. Sariisik and Sariisik (2010) analyzed the productivity of chainsaw cutting machines in the production of stone blocks in the Kalkik and Kokabas travertine quarries located in Turkey. In this study, the researchers described the steps of both methods used for extraction. They concluded that the effective parameters in the chainsaw machine extraction method, in the production of stone blocks and ultimately the productivity of the mine, included the geological and geotechnical conditions of the mine, the characteristics of the chainsaw machine used and the operational parameters **(Sariisik and Sariisik 2010)**.

Copur et al. (2006) studied the cutting performance of chainsaw machines in a travertine quarry in Basaranella, Turkey and on laboratory samples. In this research, the performance of the chainsaw machine depended on the geological characteristics of the mine (joint, dip and persistence of the stone layer), characteristics of the undisturbed stone sample (uniaxial compressive strength, Brazilian tensile strength and elasticity characteristics), mechanical parameters (torque capacities, power, throwing, blade length and cutting tool characteristics) as well as operating parameters (blade angle, chain rotation speed and cart speed). The researchers concluded that for travertine extraction, a combination of two methods of chainsaw machine and diamond wire cutting machine increased and improved the extraction performance by up to 20% **(Copur et al. 2006)**. In another study, **Copur (2010)** investigated and estimated the performance of a chainsaw cutting machine via linear cuts and conduct of experiments on stone blocks. The findings of experimental studies and field research suggested that the cutting operation of this machine can be simulated by linear cutting experiments, and the stated model can be selected as a useful and reliable tool for selecting, designing, predicting performance and optimizing the chainsaw cutting machine **(Copur et al. 2010)**. In addition, **Copur et al. (2011)** conducted field and laboratory studies (linear cutting test) on dimension stones (two kinds of travertine and three kinds of marble) to predict the performance of chainsaw cutting machines. In this investigation, two field and laboratory models were employed as the baseline and the findings suggested that the type of chainsaw cutting machine should match with the rock characteristics in the mine; in the meantime, prior to choosing the machine model, mechanical and physical characteristics of the rock such as uniaxial compressive strength, Brazilian tensile strength, specific gravity, static and dynamic elasticity module, Poisson's ratio and porosity should be considered. The findings of this study showed that among the physical and mechanical characteristics, the two parameters of uniaxial compressive strength and Brazilian tensile strength are the most significant and effective parameters. This study was the first field model on the basis of chainsaw penetration index while the uniaxial compressive strength of the stone, chainsaw machine weight and arm cutting depth were chosen as the main predicting parameters. Another model according to the results of linear cutting experiments and specific energy was chosen as the predicting parameter **(Copur et al. 2011)**. **Tumac et al. (2013)** predicted the performance of chainsaw cutting machines using hardness parameters and other mechanical properties of the rock. In this study, six samples of dimension stones from six quarries in Turkey were investigated. The mechanical specifications of this study were: uniaxial compressive strength, Brazilian tensile strength, surcharge absorption index, Schmidt's hammer hardness index and scleroscope hardness index. The relationship between surface cutting rate and each of the stone mechanical parameters was then analyzed. The obtained results showed that by increasing uniaxial compressive strength, the surface shear rate decreased **(Tumac et al. 2013)**. In yet another study, **Tumac (2013)** studied the performance estimate of a chainsaw machine using a hardness scale and the mechanical and physical properties of the stone. In this research, the scleroscope hardness index was used to determine the performance of chainsaw machines. The measured hardness values were achieved to be correlated with the physical and mechanical characteristics of rock and cutting parameters (normal force, cutting force and specific energy) resulting from linear cutting tests, without cutting and net cutting speed of the machine. **Hekimoglu (2014)** conducted his study on the effects of increasing the performance of chainsaw cutting machines on extracting dimension stones. In this study, in order to increase the performance of chainsaw cutting machines, the focus is on cutting rate sections and reducing the friction of cutting tools, which is achieved by reducing the original cutting tools and improving them, thus improving the performance of the chainsaw machine **(Hekimoglu et al. 2014)**. **Korman et al. (2015)** simulated the process of chainsaw machine cutting by a linear cutting machine. Laboratory studies were performed on a fixed stone sample with cutting depths of 0.2 to 0.6 mm. In this laboratory simulation, the main parameter was cutting energy. The results of this experiment indicated that the cutting energy was directly related to the cutting depth and inversely related to the sawing speed **(Korman et al. 2015)**. **Mohammadi et al. (2018)** also performed their study on modeling and predicting the production rate of chainsaw cutting machines by way of intelligent neural networks. To this end, first the laboratory test parameters on calcium carbonate stone were investigated and the operating parameters of the machine, arm angle, saw speed and machine speed were taken into account. Some properties of the stone were studied such as uniaxial compressive strength, Los Angeles abrasion test and Schmidt hammer as input data. Given that in this research, the production rate by the chainsaw cutting machine was the output of the experiment, the findings of the performance indicators of the model showed that a very good prediction had been
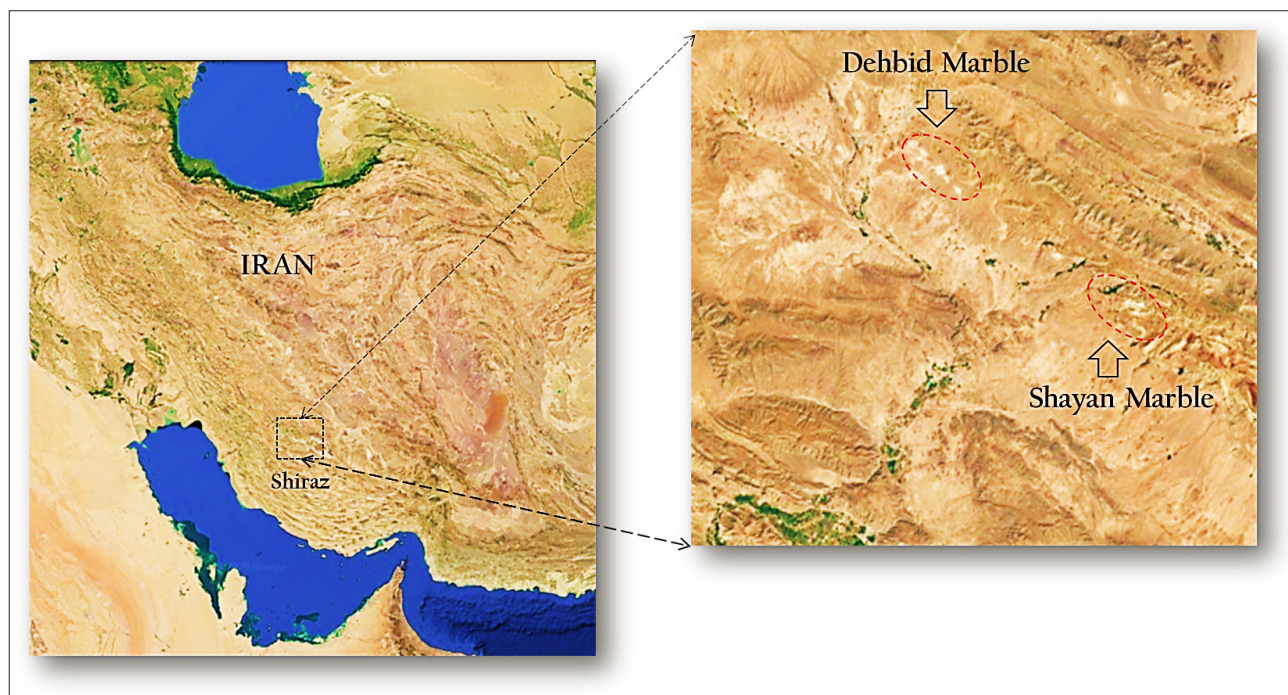
Figure 1: Geographical location of the Dehbid and Shayan quarries

made for measuring the production of the chainsaw machine using intelligent neural networks **(Mohammadi et al. 2018)**.

Mohammadi et al. (2019) conducted another study with the aim of developing and predicting the production rate of a chainsaw cutting machine using RBF and GMDH intelligent neural networks. Finally, first some laboratory studies were carried out on 7 carbonate stone samples and the production rate of each experiment was measured. Operational characteristics of machines (arm angle, saw speed and machine speed) as well as three important physical and mechanical characteristics (uniaxial compressive strength, Los Angeles abrasion test and Schmidt hammer hardness) were taken into account as input data and the production rate was considered as output data. The obtained results suggested that the developed model can provide better results for forecasting the production rate of a chainsaw cutting machine **(Mohammadi et al., 2019)**. Given the importance of the stone cutting method with the chainsaw cutting machine and in accordance with the fact that scant research has been done in this regard, in this research, it was attempted to rank the faces extracted by chainsaw machines in accordance with the production rate via the PROMETHEE multi-criterion decision-making method.

Since the ranking of the faces exacted in quarries can contribute to reduced costs and also the extraction time, two marble quarries in Dehbid and Shayan were chosen in this study for ranking. In the first step, stone samples were taken from faces extracted in the mentioned quarries. Then, field and laboratory studies were performed on the studied faces and samples to determine the production rate and physical and mechanical characteristics. In the next stage, the PROMETHEE decision method od was employed to rank the faces. Seven faces were chosen as decision options with the physical and mechanical properties of the stone being selected as decision criteria and the criteria were scored by the simple weighting method. In the end, according to the input and output currents and the obtained net current, the faces were ranked by cutting-ability with a chainsaw cutting machine.

2. Case studies

To assess the performance of the chainsaw cutting machine on marble dimension stone quarries, field and laboratory studies respecting active faces in two marble quarries of Dehbid and Shayan in the Fars province were done by focusing on the subject of cutting capability (production rate evaluation). The Dehbid and Shayan marble quarries are located in the Fars province, northeast of Shiraz city, with an altitude of 2450 meters and 3200 meters above sea level, respectively, have a certain marble reserve of 19 million tons and 4 million tons, respectively, as they have employed 550 and 240 people and produce an annual rate of 300 thousand tons and 100 thousand tons. **Figure 1** shows the geographical location of the quarries in question and the distance between the two quarries. The Dehbid and Shayan quarries are located 127 km and 124 km northeast of Shiraz, respectively, and these quarries are located at a distance of 34 km from each other **(Ataei, 2008)**.

The quarries started working about 30 years ago and now the Dehbid mine has 28 extraction steps and the Shayan mine has 18 extraction benches. **Figure 2** shows

Figure 2: Dehbid Marble Mine (A) and Shayan Marble Mine (B).

Table 2: Results of samples analysis for the case studies quarries

Case studies	Working face No.	C_1 Gs (mm)	C_2 H (n)	C_3 P (%)	C_4 Wa (%)	C_5 Qc (%)	C_6 A (%)	C_7 BTS (MPa)	C_8 UCS (MPa)
Dehbid	S_1	1.5	68	1	0.5	0.9	3.4	8.6	92
	S_2	1.3	70	0.8	0.4	0.9	2.8	9	99
	S_3	1	71	0.5	0.5	0.8	3.5	9.1	100
	S_4	0.5	72	1.5	0.8	0.9	3.1	8	90
Shayan	S_5	1.5	76	0.8	0.8	2.3	2.4	8.4	109
	S_6	0.5	73	0.8	0.3	2.1	2	8.2	105
	S_7	0.3	77	0.3	0.3	2.2	2.3	8.9	111

a close view of the two quarries. Seven laboratory marble samples of standard dimensions, including 4 samples from the Dehbid marble mine and 3 samples from the Shayan marble mine were collected. Each sample was placed under experiment to determine physical, chemical and mechanical properties under standard conditions. Seven active mining faces extracted in the mentioned quarries (4 faces in Dehbid mine and 3 in Shayan mine) were studied in this research. It should be noted that the extraction operation in the mentioned faces was done by a model of a chainsaw cutting machine. A sample with dimensions of 30 × 30 × 30 cm was taken from each face to be sent to the laboratory for physical and mechanical experiments, and field measurements were simultaneously done along with the collection operation.

2.1. Physical and mechanical characteristics

Among the significant parameters on the performance of the chainsaw cutting machine are the physical and mechanical properties. Important physical parameters include grain size (Gs), equal quartz content (Qc), porosity (P) and water absorption percentage (Wa). Important mechanical parameters are the uniaxial compressive strength (UCS), Brazilian tensile strength (BTS), Los

Angeles abrasion (A) and Schmidt hammer hardness (H). The results of the mechanical and physical tests for samples No. 1 to No. 4 of the Dehbid marble mine and No. 5 to No. 7 of the Shayan marble mine are given in **Table 2**.

3. Sawability study using PROMETHEE Multi Criteria Model

In order to select the best option using the PROMETHEE method, the following steps were performed to evaluate the cutting capability of the studied faces in the Dehbid and Shayan quarries:

3.1. Decision matrix

In the first step, the decision matrix including criteria (C1: C8) and problem options (S1: S7) was established based on the results of field and laboratory studies. **Table 3** shows the research related decision matrix.

In addition, each option was evaluated against each of the criteria. Then, in order for all the data to have the same dimension, dimensioning operations were performed on them. **Table 4** indicates the dimensionless data.

3.2. Determining the weight of the criteria

Based on **Equation 1,** the weight of each criterion should be determined according to their degree of sig-

Table 3: Decision Matrix schema.

	C1	C2	C3	C4	C5	C6	C7	C8
S1	1.5	68	1	0.5	0.9	3.4	8.6	92
S2	1.3	70	0.8	0.4	0.9	2.8	9	99
S3	1	71	0.5	0.5	0.8	3.5	9.1	100
S4	0.5	72	1.5	0.8	0.9	3.1	8	90
S5	1.5	76	0.8	0.8	2.3	2.4	8.4	109
S6	0.5	73	0.8	0.3	2.1	2	8.2	105
S7	0.3	77	0.3	0.3	2.2	2.3	8.9	111

Table 4: Dimensioning the decision matrix.

	C1	C2	C3	C4	C5	C6	C7	C8
S1	0.537	0.354	0.426	0.343	0.214	0.453	0.377	0.343
S2	0.466	0.364	0.340	0.274	0.214	0.373	0.395	0.371
S3	0.385	0.370	0.213	0.343	0.190	0.466	0.399	0.373
S4	0.179	0.375	0.639	0.549	0.214	0.413	0.351	0.336
S5	0.537	0.396	0.340	0.549	0.548	0.319	0.368	0.407
S6	0.179	0.380	0.340	0.206	0.501	0.266	0.361	0.392
S7	0.107	0.401	0.127	0.206	0.524	0.306	0.391	0.414

Table 5: Weights set for criteria.

Criteria	C1	C2	C3	C4	C5	C6	C7	C8
weight	0.2	0.15	0.1	0.05	0.1	0.12	0.13	0.15

nificance and the extent of cutting capability by a chainsaw saw. The weight of the criteria is determined in such a way that the total weight of the criteria equals one (see **Table 5**; **Ataei 2010; Rad et al., 2012)**. In this study the weight of the criteria was determined based on the experience and knowledge of the authors using simple weighting methods.

$$\sum_{j=1}^{k} W_j = 1 \qquad (1)$$

Where Wj is the degree of importance of each of the criteria and k is the number of criteria.

3.3. Pair comparison of options

In the PROMETHEE method, the options are compared in a two-by-two way in terms of each of the criteria. In this method, the discrepancy between the two-by-two evaluation of options is taken into account in terms of the intended criterion. The preference function for each criterion converts the numerical difference between the evaluation of the two options into a number between 0 and 1 (**Ataei 2010**). **Table 6** shows the paired comparison matrix of options in terms of each of the criteria.

3.4. Determining cumulative preferential indicators

Preferential-cumulative indices are determined based on **Equations 2** and **3** (**Ataei 2010**):

Table 6: Paired comparison matrix of options.

	C1	C2	C3	C4	C5	C6	C7	C8		C1	C2	C3	C4	C5	C6	C7	C8
(S2) → (S1)	1	1	1	1	0	0	1	1	(S2) → (S7)	0	0	0	0	0	1	1	0
(S1) →(S2)	0	0	0	0	0	1	1	1	(s4) → (S3)	1	1	0	0	1	0	0	0
(S3) →(S1)	1	1	1	0	0	1	1	1	(S3) → (S4)	0	0	1	1	0	1	1	1
(S1) →(S3)	0	0	0	0	1	0	0	0	(S5) → (S3)	0	1	0	0	1	0	0	1
(S4) → (S1)	1	1	0	0	0	0	0	0	(S3) → (S5)	1	0	1	1	0	1	1	0
(S1) → (S4)	0	0	1	1	0	1	1	1	(S6) → (S3)	1	1	0	1	1	0	0	1
(S5) → (S1)	0	1	1	0	1	0	0	1	(S3) → (S6)	0	0	1	0	0	1	1	0
(S1) → (S5)	0	0	0	1	0	1	1	0	(S7) → (S3)	1	1	1	1	1	0	0	1
(S6) → (S1)	1	1	1	1	1	0	0	1	(S3) → (S7)	0	0	0	0	0	1	1	1
(S1) → (S6)	0	0	0	0	0	1	1	0	(S5) → (S4)	0	1	1	0	1	0	1	1
(S7) → (S1)	1	1	1	1	1	0	1	1	(S4) → (S5)	1	0	0	0	0	1	0	0
(S1) → (S7)	0	0	0	0	0	1	0	0	(S6) → (S4)	0	1	1	1	1	0	1	1
(S3) → (S2)	1	1	1	0	0	1	1	1	(S4) → (S6)	0	0	0	0	0	1	0	0
(S2) → (S3)	0	0	0	1	1	0	0	0	(S7) → (S4)	1	1	1	1	1	0	1	1
(S4) → (S2)	1	1	0	0	0	1	0	0	(S4) → (S7)	0	0	0	0	0	1	0	0
(S2) → (S4)	0	0	1	1	0	0	1	1	(s6) → (S5)	1	0	0	1	0	0	0	0
(S5) → (S2)	0	1	0	0	1	0	0	1	(S5) → (S6)	0	1	0	0	1	1	1	1
(S2) → (S5)	1	0	0	1	0	1	1	0	(S7) → (S5)	1	1	1	1	0	0	1	1
(S6) → (S2)	1	1	0	1	1	0	0	1	(S5) → (S7)	0	0	0	0	1	1	0	0
(S2) → (S6)	0	0	0	0	0	1	1	0	(S7) → (S6)	1	1	1	0	1	1	1	1
(S7) → (S2)	1	1	1	1	1	0	0	1	(S6) → (S7)	0	0	0	0	0	0	0	0

Table 7: Determining the cumulative preference index.

	C1	C2	C3	C4	C5	C6	C7	C8	π		C1	C2	C3	C4	C5	C6	C7	C8	π
(S2) → (S1)	0.2	0.15	0.1	0.05	0	0	0.13	0.15	0.78	(S2) → (S7)	0	0	0	0	0	0.12	0.13	0	0.25
(S1) → (S2)	0	0	0	0	0	0.12	0	0	0.12	(s4) → (S3)	0.2	0.15	0	0	0.1	0	0	0.15	0.45
(S3) → (S1)	0.2	0.15	0.1	0	0	0.12	0.13	0.15	0.85	(S3) → (S4)	0	0	0.1	0.05	0	0.12	0.13	0	0.55
(S1) → (S3)	0	0	0	0	0.1	0	0	0	0.1	(S5) → (S3)	0	0.15	0	0	0.1	0	0	0.15	0.4
(S4) → (S1)	0.2	0.15	0	0	0	0	0	0	0.35	(S3) → (S5)	0.2	0	0.1	0.05	0	0.12	0.13	0	0.6
(S1) → (S4)	0	0	0.1	0.05	0	0.12	0.13	0.15	0.55	(S6) → (S3)	0.2	0.15	0	0.05	0.1	0	0	0.15	0.65
(S5) → (S1)	0	0.15	0.1	0	0.1	0	0	0.15	0.5	(S3) → (S6)	0	0	0.1	0	0	0.12	0.13	0	0.35
(S1) → (S5)	0	0	0	0.05	0	0.12	0.13	0	0.3	(S7) → (S3)	0.2	0.15	0.1	0.05	0.1	0	0	0.15	0.75
(S6) → (S1)	0.2	0.15	0.1	0.05	0.1	0	0	0.15	0.75	(S3) → (S7)	0	0	0	0	0	0.12	0.13	0	0.25
(S1) → (S6)	0	0	0	0	0	0.12	0.13	0	0.25	(S5) → (S4)	0	0.15	0.1	0	0.1	0	0.13	0.15	0.95
(S7) → (S1)	0.2	0.15	0.1	0.05	0.1	0	0.13	0.15	0.88	(S4) → (S5)	0.2	0	0	0	0	0.12	0	0	0.32
(S1) → (S7)	0	0	0	0	0	0.12	0	0	0.12	(S6) → (S4)	0.2	0.15	0.1	0.05	0.1	0	0.13	0.15	0.88
(S3) → (S2)	0.2	0.15	0.1	0	0	0.12	0.13	0.15	0.85	(S4) → (S6)	0	0	0	0	0	0.12	0	0	0.12
(S2) → (S3)	0	0	0	0.05	0.1	0	0	0	0.15	(S7) → (S4)	0.2	0.15	0.1	0.05	0.1	0	0.13	0.15	0.88
(S4) → (S2)	0.2	0.15	0	0	0	0.12	0	0	0.47	(S4) → (S7)	0	0	0	0	0	0.12	0	0	0.12
(S2) → (S4)	0	0	0.1	0.05	0	0	0.13	0.15	0.43	(s6) → (S5)	0.2	0	0	0.05	0	0	0	0	0.25
(S5) → (S2)	0	0.15	0	0	0.1	0	0	0.15	0.4	(S5) → (S6)	0	0.15	0	0	0.1	0.12	0.13	0.15	0.65
(S2) → (S5)	0.2	0	0	0.05	0	0.12	0.13	0	0.5	(S7) → (S5)	0.2	0.15	0.1	0.05	0	0	0.13	0.15	0.78
(S6) → (S2)	0.2	0.15	0	0.05	0.1	0	0	0.15	0.65	(S5) → (S7)	0	0	0	0	0.1	0.12	0	0	0.22
(S2) → (S6)	0	0	0	0	0	0.12	0.13	0	0.25	(S7) → (S6)	0.2	0.15	0.1	0	0.1	0.12	0.13	0.15	0.95
(S7) → (S2)	0.2	0.15	0.1	0.05	0.1	0	0	0.15	0.75	(S6) → (S7)	0	0	0	0	0	0	0	0	0

Table 8: Calculation of input and output currents.

	S_1	S_2	S_3	S_4	S_5	S_6	S_7	Output currents
S_1	0	0.78	0.85	0.35	0.5	0.75	0.88	4.11
S_2	0.12	0	0.85	0.47	0.4	0.65	0.75	3.24
S_3	0.1	0.15	0	0.45	0.4	0.65	0.75	2.5
S_4	0.55	0.43	0.55	0	0.95	0.88	0.88	4.24
S_5	0.3	0.5	0.6	0.32	0	0.25	0.78	2.75
S_6	0.25	0.25	0.35	0.12	0.65	0	0.95	2.75
S_7	0.12	0.25	0.25	0.12	0.22	0	0	0.96
Input Currents	1.44	2.36	3.45	1.83	3.12	3.18	4.99	

$$\forall a,b \in A, \begin{cases} \pi(a,b) = \sum_{j=1}^{k} P_j(a,b) w_j \\ \\ \pi(b,a) = \sum_{j=1}^{k} P_j(b,a) w_j \end{cases} \quad (2)$$

Where p is a inception of exacting preference, $\pi(a,b)$ is which degree a is preferred to b over all the criteria and $\pi(b,a)$ how b is preferred to a, that a and b belong to the set of A.

$$\forall a,b \in A, \begin{cases} \pi(a,a) = 0 \\ 0 \le \pi(a,b) \le 1 \\ 0 \le \pi(b,a) \le 1 \\ 0 \le \pi(a,b) + \pi(b,a) \le 1 \end{cases} \quad (3)$$

It is clear that:

$\pi(a,b) \to 0$ Option "a" has a weak overall advantage over option b.

$\pi(a,b) \to 1$ Option "a" has a strong overall advantage over option b.

According to **Equations 2** and **3**, the cumulative preference index for options was obtained as **Table 7**.

3.5. Partial and complete ranking of options

At this stage, in order to rank the options, the preference of each option over the other options, as well as the preference of all options over the intended option should be specified. The preference of each option over the other options is called positive ranking current or output current and the preference of other options over the intended option is named negative ranking current or input current. A positive ranking current or output current suggests how much the option has priority over the other options. This current is, in fact, the power of the intended option in the ranking, and the higher the value for the option, the better the intended option. Hence, the option

with the largest output current is the superior option. Negative ranking current or input current also shows the degree to which other options have priority over the intended option. This current is in fact the weakness of the intended option in the ranking, and the lower its degree on the intended option, the better the intended option will be. Therefore, the option with the smallest input current is the best option **(Ataei 2010)**. **Table 8** shows how to estimate the input and output currents.

Finally, according to the obtained values for the input and output currents, the net current and the final ranking of the options were obtained. Table 9 shows the net stream values and the ranking of options.

According to **Table 9**, the number one face of the Dehbid mine with its values of net current has output

Table 9: Ranking of studied stopes in the Dehbid and Shayan quarries.

Mine	Options	Net current	Output current	Input current	Ranking
Dehbid	S1	2.67	4.11	1.44	1
	S2	0.88	3.24	2.36	3
	S3	-0.95	2.5	3.45	6
	S4	2.41	4.24	1.83	2
Shayan	S5	-0.37	2.75	3.12	4
	S6	-0.61	2.57	3.18	5
	S7	-4.03	0.96	4.99	7

and input currents of 2.67, 4.11 and 1.44, respectively, and the number five face of the Shayan mine with values of -0.37, 2.75 and 3.18, respectively. The net steams are introduced as the best faces in the studied quarries in terms of production rate capability.

4. Model validation

In order to validate the results of the proposed decision model, field studies were performed on the studied faces to measure the production rate of the chainsaw machine performance. In the Dehbid mine, 9 chainsaw cutting machines were produced by the Fantini company of different models and in the Shayan mine, 3 chainsaw cutting machines were produced by the Fantini company and 2 chainsaw cutting machines produced by the Benetti company were used to extract dimension stones. The types of production models of chainsaw machines by different companies have different properties selected depending on the geological conditions, mineral characteristics, excavation plan, climatic conditions, etc. The proportion between the extraction operation parameters and dimension characteristics of a chainsaw cutting machine reduces energy consumption and cutting time, improves work technically and economically (reduced cost of each stone block), increases productivity in terms of production rate, etc. The key operating parameters controlled by the operator are the cart speed, the speed of the

Table 10: Characteristics of the machines used in this study

Model	BL	ECD	UCL	EP	MW	CS	ChS	CW	AR	HTV
	(m)	(m)	(m)	(KW)	(kg)	(cm/min)	(m/s)	(mm)	°	(L)
Fantini-70RA/P	7.2	5	6.3	50	10500	0-13	0-0.7	38	360	300
BL: Blade length, UCL: Useful cutting length, EP: Electrical power, MW: Machine weight with rail, CS: Cart speed, ChS: Chain speed, CW: Cutting width, AR: Arm rotation, HTV: Hydraulic tank volume										

Table 11: Results of field surveys of the studied benches

No.	Operation condition			Production Rate (m^2/hr)						
				Dehbid Mine				Shayan Mine		
	AR	ChS	CS	S1	S2	S3	S4	S5	S6	S7
1	65	0.125	8	3.8	3.5	3.7	3.2	2.6	2.8	1.8
2	70	0.125	8	4.5	4	4.3	3.5	2.8	3	1.8
3	75	0.125	8	4.85	4.1	4.3	3.6	2.9	3	2.4
4	80	0.125	8	4.01	3.8	4.3	3.8	2.6	2.9	2
5	85	0.125	8	4	3.5	3.3	2.9	2.4	2.4	2
6	75	0.1	8	3.4	3	2.8	2.8	2.4	2	1.6
7	75	0.117	8	4.1	3.5	2.9	3.4	2.7	2.4	2
8	75	0.125	8	4.85	4.2	3.5	4	3	2.9	2.3
9	75	0.133	8	4.85	4.2	3.5	4.2	3.1	2.9	2.4
10	75	0.142	8	4.85	4.2	3.5	4.2	3.1	2.9	2.4
11	75	0.125	6.5	3	3	3	2.9	2.2	2.1	1.4
12	75	0.125	7	4	3.5	3.4	2.3	2.5	2.5	1.8
13	75	0.125	7.5	4.73	3.9	4	3.4	2.9	2.6	2.2
14	75	0.125	8	4.95	4.1	4.3	4	2.9	2.8	2.5

chain and the angle of the blade. The desired values of the operating parameters are based on the suggestions made by the manufacturing company and the experience of the chainsaw operator. Operator skills is one of the effective parameters in the stone cutting process. In order for the field study conditions to remain constant, the chainsaw machine used in both quarries, which includes 7 working faces, was selected from a model with the same properties. **Figure 3** shows the chainsaw cutting machine used in these quarries. The characteristics of the chain saw machine used in this study are given in **Table 10**. The results of field studies on 7 studied working faces are given in **Table 11**.

According to **Table 11**, it can be seen that under constant operating conditions in the Dehbid and Shayan quarries, from among 15 different conditions of chainsaw cutting machine, the No. 1 face of Dehbid mine had the highest production rate in more than 80% compared to other faces in this mine and face No. 5 from the Shay-

Figure 3: Chainsaw cutting machine was used in the case study quarries.

an mine had the highest such production rate in more than 65% of operating conditions compared to the other two faces from this mine.

5. Conclusions

In this research, attempts were done to assess the cutting capability of dimension stones extracted by a chain saw cutting machine in the Dehbid and Shayan quarries. Finally, the cutting capability of the seven faces included in this study were graded according to physical and mechanical characteristics including: uniaxial compressive strength of the stone, Brazilian tensile strength, Los Angeles abrasion, quartz percentage, water absorption percentage, porosity, Schmidt hardness and granule size by using a PROMETHEE decision model. The study results showed that face No. 1 of the Dehbid mine with some net currents, output and input currents of 2.67, 4.11 and 1.44, respectively, and face No. 5 of the Shayan mine with values of -0.37, 2.75 and 3.18 were introduced as the most suitable face machine with high cutting capability in the studied quarries. Then, in order to validate the results of the recommended decision model, field studies were conducted under different operating conditions of the chainsaw cutting machine in the studied quarries. The results of the model validation (comparison of the ranking obtained from the decision model with those of the production rate registered in the mine) showed that in more than 80 and 65% of the cases intended for the face chainsaw cutting machine, selected works in the Dehbid and Shayan quarries accounted for the highest production rates, respectively. Finally, this study shows that the cutting-capability of the studied faces can be evaluated based on physical and mechanical properties using decision-making models.

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6. References

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SAŽETAK

Ocjena rezivosti stijena s lančanom sjekačicom primjenom tehnike PROMATHEE

Jedan od najvažnijih čimbenika u procjeni cijene vađenja građevinskoga kamena jest njegov iznos pridobivanja tijekom strojnoga rezanja. Procjena iznosa proizvodnje takvih strojeva ima vrlo veliku i praktičnu ulogu. Ovdje je načinjena procjena i odabir prikladnoga radilišta unutar kamenoloma radi postizanja najvećega iznosa proizvodnje. Za analizu su odabrani kamenolomi mramora Dehbid i Shayan. Načinjena su terenska ispitivanja, tj. mjerenje operativnih svojstava sjekačice, iznosa pridobivanja te uzorkovanje za laboratorij na sedam smjestišta. Zatim su u laboratoriju za mehaniku stijena izmjerena fizička i mehanička svojstva stijena poput jednoosne kompresijske čvrstoće, brazilske vlačne čvrstoće, abrazije metodom Los Angeles, udjela kvarca, postotka apsorpcije vlage, šupljikavosti, Schmidtove čvrstoće i veličine zrna. Na kraju je ocijenjena rezivost materijala na radilištu kamenoloma uporabom tehnike PROMETHEE, koja predstavlja alat za donošenje odluka na temelju više kriterija koji obuhvaćaju fizička i mehanička svojstva. Rezultati su pokazali kako radilišta označena brojevima 1 i 5, na kamenolomima Dehbid i Shayan, imaju najbolja svojstva postizanja većega brutoiznosa (4,95 i 3,2 m²/sat) i netoiznosa (2,67 i -0,36 m²/sat) proizvodnje.

Ključne riječi:
kamenolom građevinskoga kamena, lančana sjekačica, iznos proizvodnje, PROMETHEE

Author's contribution

Reza Mikaeil (Associate Professor) performed the design, implementation of the research. **Akbar Esmaeilzade** (Assistant professor) did analysis of the data collected from the questionnaires. **Sara Aghaei** (Master degree), **Sina Shaffiee Haghshenas** (Master degree), **Amir Jafarpour** (Master degree) completed literature review and participated in all work. **Javad Mohammadi** (Phd) performed the field work and executed experimental tests. **Mohammad Ataei** (Full Professor) managed the whole process and supervised it from the beginning to the end.