

Selection of an Appropriate Quarrying Technology for Dimension Stone Quarries Using Combined Multi-Criteria Decision-making Method, Case Study at Hoa Quang Bac Quarry

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Abstract: Nowadays, unselected quarrying technologies for dimension stone quarries, including manual and traditional technologies to modern technologies, have been applied in the whole nation. These technologies include blasting with detonation fuse, blasting with explosive, splitting wedge, diamond wire sawing, disc sawing, diamond wire sawing combined with splitting wedge and disc sawing combined with diamond wire sawing and splitting wedge. Due to characteristics of each technology, there exist different quarrying cost, consumed time, safety, environment and stone loss. Therefore, it is difficult for the quarries to select the most suitable one of the technologies. Basing on the comprehensive assessment of the criterion above to select the most proper technology for each dimension stone quarry, the paper used multi-criteria decision – making method combining between Analytic Hierarchy Process (AHP) for selecting criteria weigh and multi-criteria ranking method Promethee II for ranking the technologies. The study was applied to Hoa Quang Bac quarry and technology combining disc sawing and diamond wire sawing was chosen as the most appropriate technology for mine.

Keywords: Dimension stone; quarry; technology; Hoa Quang Bac; AHP; Promethee II

1. Introduction

Dimension stone is a type of natural stone including magmatic, sedimentary and metamorphic rock in intact status without discontinuities, quarried and processed to various sizes, shapes, polishes. They could be applied for making wall tiles, floor tiles and city pavement tiles. Furthermore, these stones also ensure lithological, crystal components, rock mechanics (Ashmole & Motloun, 2008).

In the world, the demand for dimensional stone in building and decorating has significantly increased. Particularly, there are about 35 percent of these stones for floor tiles, 25 percent of one for wall tiles and the others for different applications. The project of the world building association, the dimensions stone for cutting into slabs will account for 30 percent. There is going to increase about 2,5 times for the tiles in the next 15 years and it will continue developing due to high demand, modern technologies and suitable price compared with that of ceramics.

Nowadays, current extraction for dimension stone, technologies for extracting dimension stone are used separately or combined each other (Nguyễn Anh Tuấn, 2016). Selected equipment fleet in these mines is mostly based on cutting and hauling technologies but is not based on block sizes being suitable with the working parameters of cutting, transport machines for the goal of huge economical profit. At these mines, there are some extracting technologies like blasting with detonating fuse, blasting with explosive, splitting wedge, disc saw, diamond wire saw, disc saw - diamond wire saw, diamond wire saw - wedge, disc saw - diamond wire saw-wedge (Samarakoon et al., 2023). The application of these technologies also depends on random decision of each mine and there is not a clear foundation for selecting one of the technologies, so the usage of them has become diversity. Therefore, selecting the most suitable technology for each condition of mine needs to be considered more criteria: quarrying cost, block-stone quality, consumed time, mining safety, environment and stone loss. The quarrying cost is a necessary expenditure to recover a cubic meter of dimensional stone. The block stone quality represents smooth or rough surface, expanding discontinuities in stone, generating more expenditure at the processing stage. Consumed time is an interval of essential time to make a cubic meter of dimensional stone. Mining safety is a working condition reducing risk from using quarrying technologies. Working environment is working condition from quarrying technologies generating like dust, noise... Stone loss is a part of stone left due to rough surface of stone block and generating discontinuities from quarrying activities.

Due to these criteria causing more difficult to select the most suitable quarrying technology with each mine, multi-criteria decision-making method is applied, including Analytic Hierachy Process (AHP) and Multi – criteria ranking method Promethee II to select the most appropriate technology (Bogdanovic et al., 2012; R. A., 2013; Stojanovic et al., 2015; Wang & Tu, 2015). The AHP was used to define the criteria weights above while the Promethee II was deployed to rank the technologies when criteria weights were first known. From the method, the paper wrote a computer program to find the best technology and did an experiment at Hoa Quang Bac quarry to test the research result.

2. Methodology

2.1. Introduction on quarrying technologies for dimension stone

2.1.1. Blasting technology (Detonating fuse)

To extract block stone by detonating fuse, adjacent drilling holes are put parallelly and equally interval of from 15 cm to 40 cm for each type of rock, detonating fuse in a splitted plane. The diameters of holes are usually from 28 cm to 33 cm. In a hole, there could be charged from 1 to 2 detonating fuses following explosive density in the fuse.

2.1.2. Blasting technology (Explosive)

Similarity to blasting technology with detonating fuse, but the energy used to split stone is from explosive charged in the holes. Blasting technology with explosives needs to be interested in calculating spacings between co-plane holes, face powder unit and amount of explosive charged in each hole to ensure quality splitting blasting.

2.1.3. Wedge technology

Wedge technology for splitting dimensional stone includes two firmly relative stages each by drilling adjacent holes in vertical and horizontal direction in preexisting plane. When splitting stone into standard blocks by drilling holes of 20-42m diameter depends on size of flug and feather. In wedge technology, hole length is chosen from 8 cm to 10 cm. However, in fracture rock, the length could be calculated more deeply due to specific conditions of rock mass. Furthermore, a significant parameter in splitting stone with wedge technology is spacing between the holes. The spacings depend morely on power hitting the wedge. In the past time, the power hitting to the flug was fully carried out with manual force due to workers' labours hitting to hammer. From there, the spacing was chosen from 5 cm to 15 cm. However, the power for splitting from compressed air and hydraulic power make the spacings longer (Viet et al., 2020).

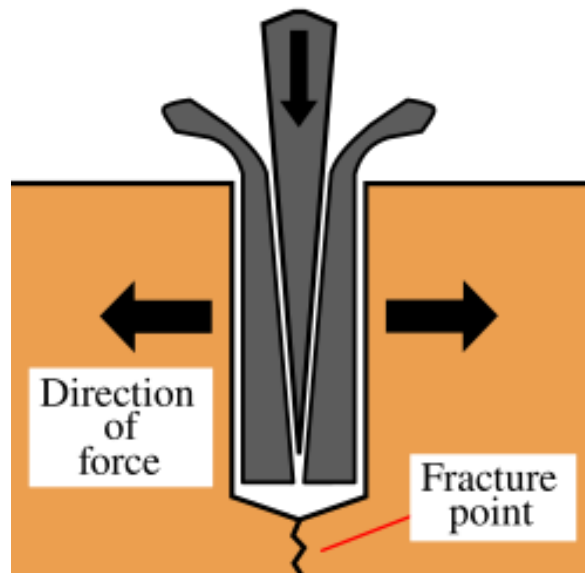


Fig. 1. Principle of wedge technology (Viet et al., 2020)



a. Power generated from compressed air



b. Power generated from hydraulic

Fig. 2. Compressing air and hydraulic power make hitting force for wedge technology (Viet et al., 2020)

2.1.4. Wire sawing technology.

Diamond wire sawing machine contains three basic components: diamond wire, sawing machine, orientation track. Diamond wire is put along the holes drilled in rock to make a circular ring connecting over the flywheel of sawing machine. The wire is pulled to make a movement along the wall of hole to cut rock. When cutting operation, the sawing machine runs inversely to make a tension force for diamond wire.

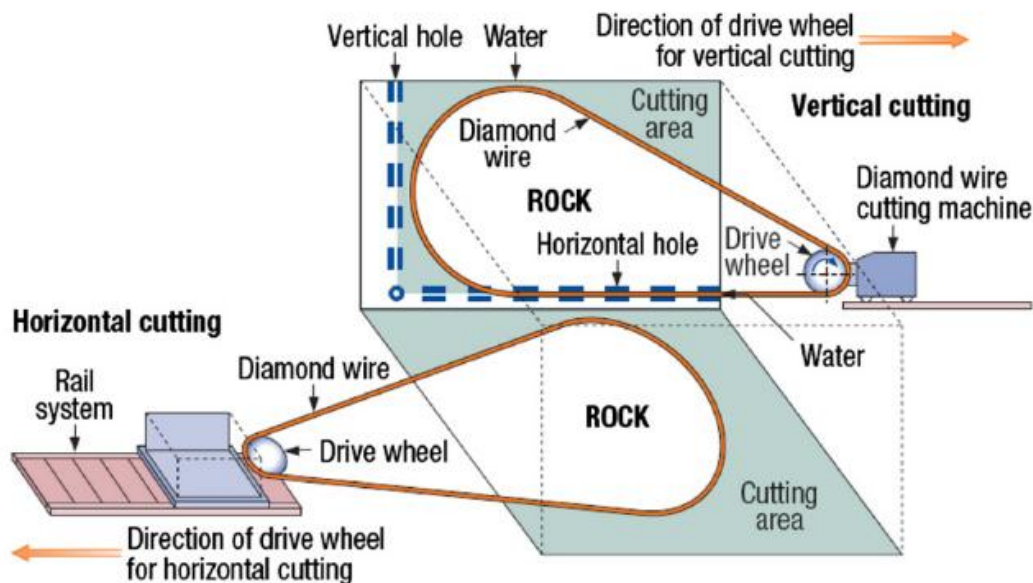


Fig. 3. Cutting stone blocks by diamond wire (Ozcelik & Yilmazkaya, 2011)

2.1.5. Combined technology between disc and diamond wire sawings

This technology is applied with the combination of a disc sawing machine and diamond wire sawing machine. Disc sawing is a main technique due to its high productivity, smooth cutting plane and block size suitable for the processing plants.

Cutting sequence: Disc sawing machine moves along a track and sawing blade cut deeply into rock from 15-20cm, depending on soft or hard rock, down to a specific depth. When disc cutting machine completes a track, the machine will be moved to next track. With this technology, the machine will run in both right angle directions. The other plane (bottom plane) will cut by diamond wire machine.



Fig. 4. Combination between disc sawing and diamond wire machines in a dimension stone quarry

2.1.6. Combined technology between diamond wire and wedge

Diamond wire technology is deployed to cut two planes including the bottom plane and the long-side plane of stone blocks, wedge technology is also used to split the other side of stone block.

2.1.7. Combined technology among disc sawing, diamond wire sawing and wedge

Disc sawing technology is used to cut along long-side planes of stone block in parallel directions with intervals equal to the width of stone block. The bottom plane of stone block is cut by diamond wire sawing machine. The other plane is splitted by wedge technique.



Fig. 5. Combined technology among disc sawing, diamond wire sawing and wedge is operated in a dimension stone quarry

2.2. Selection of stone quarrying technology

Nowadays, at dimension stone quarries there have existed more quarrying technologies, such as blasting with detonating fuse, blasting with explosives, wedge, disc sawing, diamond wire sawing, diamond wire sawing combining with wedge, disc sawing combining with diamond wire sawing and disc sawing combining with diamond wire sawing and wedge. Selecting a proper quarrying technology for each mining condition needs to be based on more criteria: mining cost, block quality, consumed time, production safety, impacted environment and stone loss.

Therefore, combined multi-criteria decision-making method, including Analytic Hierarchy Process (AHP) and multi-criteria ranking (Promethee II), is applied to select the most suitable quarrying technology. In which, the AHP is considered to determine criteria weights for alternatives, consisting of blasting with detonating fuse, blasting with explosives, wedge, disc sawing, diamond wire sawing, diamond wire sawing combined with wedge, disc sawing combined with diamond wire sawing and disc sawing combined with diamond wire sawing and wedge, and multi-criteria ranking (Promethee II) help to rank prior dimension stone quarrying technology from the criterias and their weights.

2.2.1. Determining criteria weights from analytic hierarchy process

The AHP was first suggested by Saaty in 1980, an Iraqi scientist. The method helps schedulers in choosing complex issues with joining more schedulers and standards existed at more different periods (Akcan & Güldeş, 2019). The AHP, one of multiple criteria decision-making methods, is being used easily and flexibly (Zoran, 2011). The AHP could solve complex problems due to more criteria, and these criteria also conflict with each other. The AHP uses experts' opinions, and it does not need more calculating data. The method consists of three main steps including analysis, assessment, and conclusion.

Particularly, criteria contain mining cost, block quality, consumed time, production safety, impacted environment and stone loss. Alternatives are quarrying technologies, such as blasting with detonating fuse, blasting with explosives, wedge, disc sawing, diamond wire sawing, diamond wire sawing combined with wedge, disc sawing combined with diamond wire sawing and disc sawing combined with diamond wire sawing and wedge like seen in Figure 6.

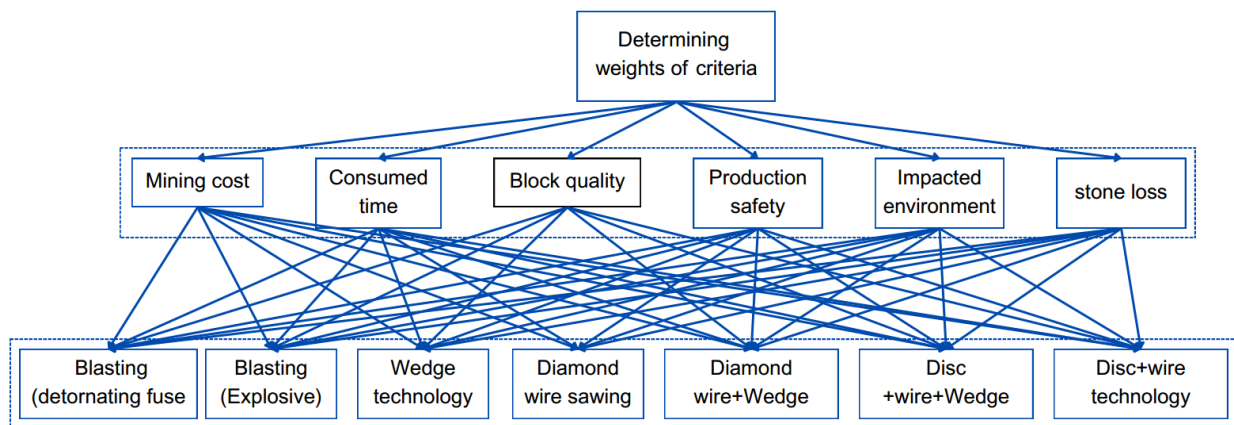


Fig. 6. Determining weights of the criteria from Analytic Hierarchy Process (AHP)

The AHP do project with the following steps (Ordoobadi, 2010; Saaty, 2008):

Step 1: Defining prior levels of criteria

Assessing criteria with different prior values is shown in Table 1. The author collected assessments from experts and mining managers of dimension stone quarries on the roles of assessing criteria in selecting quarrying technologies for dimension stone. With six criteria as seen in Figure 6 and experting assessment for scores with the criteria, square matrix of 6x6 was made.

Tab. 1. Pair -wise comparison scale for AHP preference

No	Verbal judgement	Number rating
1	Equally preferred	1
2	Moderately preferred	3
3	Strongly preferred	5
4	Very strongly preferred	7
5	Extremely preferred	9

Tab. 2. Data matrix for defining preferred value with each criterion in selecting dimension stone quarrying technology

	C ₁	C ₂	C ₃	C ₄	C ₅	C ₆
C ₁	1	3	5	7	9	3
C ₂	1/3	1	3	5	7	3
C ₃	1/5	1/5	1	1/3	2	1/3
C ₄	1/7	1/3	3	1	3	1/2
C ₅	1/9	1/7	1/2	1/3	1	1/5
C ₆	1/3	1/3	3	2	5	1

Note: C₁ – quarrying cost criterion; C₂- block quality criterion; C₃- quarrying safety criterion; C₄ – consumed time criterion; C₅ – Environment criterion; C₆ – stone loss criterion.

Table 2 shows a group including six criteria and these results from comparing in pairs made a square matrix of 6x6, called symmetric matrix of factors $a_{ij} = 1/a_{ji}$ ($i, j = 1, n$); $a_{ij} = 1$ if $i=j$). The factor in cells in Table

2 is average value of the score of evaluation experts. It is seen that the matrix above is inverse symmetric matrix in diagonal line from the left to the right.

Step 2: Calculating criteria weights

After calculating the matrix above, the criteria weights were given by the sum of column cell in the matrix. After that, taking each value in the matrix was divided by the sum of the columns in Equation (1). The values collected were replaced in respective cells in the matrix. The weight for each respective criterion $C_1, C_2, C_3, C_4, \dots, C_6$ was equal to the average sum of the cells in rows. The result was a matrix of 6×1 .

From the matrix of average value of the score of evaluation experts, the cells in the matrix were calculated in Equation (1).

$$w_{ij} = \frac{a_{ij}}{\sum_{i=1}^n a_{ij}} \quad (i = 1, n; j = 1, n) \quad (1)$$

In which: a_{ij} – value of cells of the matrix in Table 2; i – row index; j – column index.

From Equation (1), values in Table 3 were calculated to give weight for each criterion.

Tab. 3. Weight matrix for criterion

	C_1	C_2	C_3	C_4	C_5	C_6	Weights
C_1	0.47156	0.63897	0.34483	0.44211	0.33333	0.37344	0.43404
C_2	0.15719	0.21299	0.20690	0.31579	0.25926	0.37344	0.25426
C_3	0.09431	0.00402	0.06897	0.03158	0.07407	0.04149	0.05241
C_4	0.06737	0.04260	0.13793	0.06316	0.11111	0.06224	0.08073
C_5	0.05240	0.03043	0.03448	0.02105	0.03704	0.02490	0.03338
C_6	0.15719	0.07100	0.20690	0.12632	0.18519	0.12448	0.14518

From the matrix in Table 3, weight for each criterion is calculated in Equation (2) below:

$$w_j = \frac{\sum_{i=1}^n w_{ij}}{n} \quad (j=1, n) \quad (2)$$

In which: w_j – weight of j^{th} criterion.

After having criteria weights, correlation assessment of experts is given, the correlation rate (CR) is considered in Equation (3) below:

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

In which: CI – correlate index.

CI is corelate index shown in Equation (4) below:

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (4)$$

In which: $\lambda_{\max}$ eigenvalue of comparison matrix shown in Equation (5).

$$\lambda_{\max} = \sum_{i=1}^n (w_i * \sum_{j=1}^n a_{ij}) \quad (5)$$

n – number of element in square matrix; RI – randon index taken in Table 4.

Tab. 4. Randon index coresponding to the number of criteria n

n	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0,0	0,00	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49	1,51	1,54	1,56	1,57	1,59

In all cases, the CR is not bigger than 10%. With matrix of 3×3 , the CR is not bigger than 5% and the one with matrix of 4×4 is not bigger than 9%. The CR is not bigger than 10% with matrix 6×6 . The CR is not bigger than the values claimed to be corelatetive. From Equation (2), (3), (4), the CR was equal to 0,035 (3,5%), not bigger than 10%, so the calculation ensures corelation in assessment activities.

2.2.2. Ranking dimension stone quarrying technologies

To rank priority on dimension stone quarrying technologies based on the criteria, it is clear which technology has the most important to select. With six criteria, including mining cost, block quality, consuming time, production safety, impacted environment and stone loss, and seven alternatives, including blasting with detonating fuse, blasting with explosives, wedge, disc sawing, diamond wire sawing, diamond wire sawing combined with wedge, disc sawing combined with diamond wire sawing and disc sawing combined with diamond wire sawing and wedge. From computed values such as mining cost, consumed time according to the sizes and technologies of dimension stone and the data taken from the opinions of

experts and mining managers following assessment rate in Table 5, matrix of 7×6 was established corresponding to the rows of alternatives and the columns of criteria in Table 6 and Table 7.

Tab. 5. Assessment rate of criteria for comparison alternatives

Verbal judgement	Number rating	
	Positive criteria (+)	Negative criteria (-)
Very low	1	9
Low	3	7
Average	5	5
High	7	3
Very high	9	1

Tab. 6. Assessment table for technologies corresponding to the criterion and each size of recovery dimension stone

No	Alternatives	Mining cost (-)	Stone Block quality (+)	Working safety (+)	Consumed time (-)	Impacted Environment (-)	Stone loss (-)
1	Blasting (detonating fuse)	635742	Very low	Very low	2.83	Very high	Very high
2	Blasting (explosive)	678301	Low	Very low	2.83	Very high	Very high
3	Diamond wire sawing	638504	High	Average	1.03	Low	Low
4	Wedge	496928	Average	Low	11.02	Average	Cao
5	Disc+Diamond wire sawing	407476	Very high	Very high	2.6	Very low	Very low
6	Diamond wire sawing+wedge	735271	High	High	3.44	Low	Average
7	Dics+diamond wire sawing+wedge	488188	High	High	4.94	Very high	Very low

Tab. 7. Assessment table for the technologies corresponding to the criteria and each size of recovery dimension stone with quantitative value.

No	Alternatives	C1	C2	C3	C4	C5	C6
1	M1	635742	1	1	2.83	9	9
2	M2	678301	3	1	2.83	9	9
3	M3	638504	7	5	1.03	3	3
4	M4	496928	5	3	11.02	5	7
5	M5	407476	9	9	2.60	1	1
6	M6	735271	7	7	3.44	3	5
7	M7	488188	7	7	4.94	1	1

Note: C₁ – quarrying cost criterion; C₂- block quality criterion; C₃- quarrying safety criterion; C₄ – consuming time criterion; C₅ – Environment criterion; C₆ – stone loss criterion; M₁- Blasting (detonating fuse); M₂ - Blasting (explosive); M₃ - Diamond wire sawing; M₄ – wedge; M₅ - Disc+Diamond wire sawing; M₆ - Diamond wire sawing+Wedge; M₇ - Dics+diamond wire sawing+wedge.

From change in mining cost and consumed time for each technology and recovery size. Multi-criteria ranking method Promethee II was developed by Brands and was first used in 1982 at a Canada conference (Saaty, 2008). The method has been applied in some sectors as bank, resource, invesment, health, chemistry, tourism. The method was developed to handle optimal problems. Preferred structure of the Promethee II is pairwise comparison. In this case, the preference deviation between the value of two alternatives with the same criteria. When the deviation is small, decision maker will get small preference to the better alternative. Moreover, preference is nearly balance if the deviation is minimal. The preference is a float number changing from 0 to 1. This means that each standard of preference function as shown in Equation (6) below.

$$P_j(a,b) = F_j[d_j(a,b)] \quad \forall a,b \in A \quad (6)$$

In which: $P_j(a,b)$ - preference function between two different alternatives “a” và “b”; $d_j(a,b)$ – deviation margin between two alternatives with the same j^{th} criteria; A – a group of comparison alternatives.

$$d_j(a,b) = g_j(a) - g_j(b), \quad 0 \leq P_j(a,b) \leq 1. \quad (7)$$

The promethee II is always based on pairwise comparison, the indexes of pairwise preference is formed with Equation (8) follow:

$$\begin{cases} \pi(a, b) = \sum_{j=1}^n P_j(a, b) w_j \\ \pi(b, a) = \sum_{j=1}^n P_j(b, a) w_j \end{cases} \quad (8)$$

In which: $\pi(a, b)$ – a has more preferred degree than b in the criteria; $\pi(b, a)$ – b has more preferred degree than a; w_j – criteria weights are set for comparison.

The value $\pi(a, b)$ và $\pi(b, a)$ always is positive and shown in Equation 9:

$$\begin{cases} \pi(a, a) = 0 \\ 0 \leq \pi(a, b) \leq 1 \\ 0 \leq \pi(b, a) \leq 1 \\ 0 \leq \pi(a, b) + \pi(b, a) \leq 1 \end{cases} \quad (9)$$

Equation (9) shows that $\pi(a, b) \approx 0$ mean that negative outranking flow of alternative a to alternative b and $\pi(a, b) \approx 1$ is that positive outranking flow of alternative a to alternative b. When the $\pi(a, b)$, $\pi(b, a)$ are computed in pairwise comparison matrix, net outranking flow will be calculated. In this method, each alternative a is compared with (m-1) the other alternative in the matrix. The positive outranking flow and the negative outranking flow are shown in Equation (10) and Equation (11).

$$\varphi^+(a) = \frac{1}{m-1} \sum_{x \in A} \pi(a, x) \quad (10)$$

$$\varphi^-(a) = \frac{1}{m-1} \sum_{x \in A} \pi(x, a) \quad (11)$$

In which: m – number of alternatives in the matrix.

The promethee II give a net outranking flow of the alternatives. The net outranking flow provides a comprehensive ranking. Steps operate the Promethee II below (Brans & Vincke, 1985; Doumpos & Zopounidis, 2004):

- Step 1: Determining decision comparison in Equation (12):

$$R_{ij} = \frac{[x_{ij} - \min x_{ij}]}{[\max x_{ij} - \min x_{ij}]} \quad (i=1,2,\dots,m; j=1,2,\dots,n) \quad (12)$$

For negative criateria, Equation (12) could be rewritten in Equation (13):

$$R_{ij} = \frac{[\max x_{ij} - x_{ij}]}{[\max x_{ij} - \min x_{ij}]} \quad (i=1,2,\dots,m; j=1,2,\dots,n) \quad (13)$$

In which: x_{ij} – a assessment value of i^{th} alternative with j^{th} criteria; R_{ij} – comparison value of x_{ij} value; n – number of assessment criterion; $\min x_{ij}$ $\max x_{ij}$ – max and min of x_{ij} value.

After step 1, all of the matrix values is from 0 to 1.

- Step 2: Calculating the difference between j^{th} alternative and the other alternatives at the criterion.

- Step 3: Calculating preference functions $P_j(a, b)$ (Brans et al., 1984). The preference functions are simplified in Equation (14) and Equation (15).

$$P_{ij}(a, b) = 0 \text{ if } R_{aj} \leq R_{bj} \quad (14)$$

$$P_{ij}(a, b) = (R_{aj} - R_{bj}) \text{ if } R_{aj} > R_{bj} \quad (15)$$

- Step 4: Calculating full preference function by adding into criteria weight in Equation (16).

$$\pi(a, b) = [\sum_{j=1}^n w_j P_j(a, b)] / \sum_{j=1}^n w_j \quad (16)$$

- Step 5: Defining positive outranking flow and negative outranking flow in Equation (17) and Equation (18):

$$\varphi^+ = \frac{1}{m-1} \sum_{b=1}^m \pi(a, b) \quad (a \neq b) \quad (17)$$

$$\varphi^- = \frac{1}{m-1} \sum_{b=1}^m \pi(b, a) \quad (b \neq a) \quad (18)$$

- Step 6: Defining net outranking flow for each alternative in Equation (19):

$$\varphi(a) = \varphi^+(a) - \varphi^-(a) \quad (19)$$

In which: $\varphi^+(a)$ – positive outranking flow for alternative a; $\varphi^-(a)$ – negative outranking flow for alternative a; $\varphi(a)$ – net outranking flow for alternative a.

- Step 7: Defining ranking for alternatives is depend on the $\varphi(a)$ value. The $\varphi(a)$ is higher, alternative a has better ranking than different compared one. Therefore, alternative obtaining the highest ranking has the highest $\varphi(a)$ value.

With analysis above, a dimension stone quarrying technology optimization program was coded according to the algorithm shown in Figure 7. The program was written in Matlab program in Figure 8. From calculating on the program, the best technology is chosen to ensure the effectiveness for quarries.

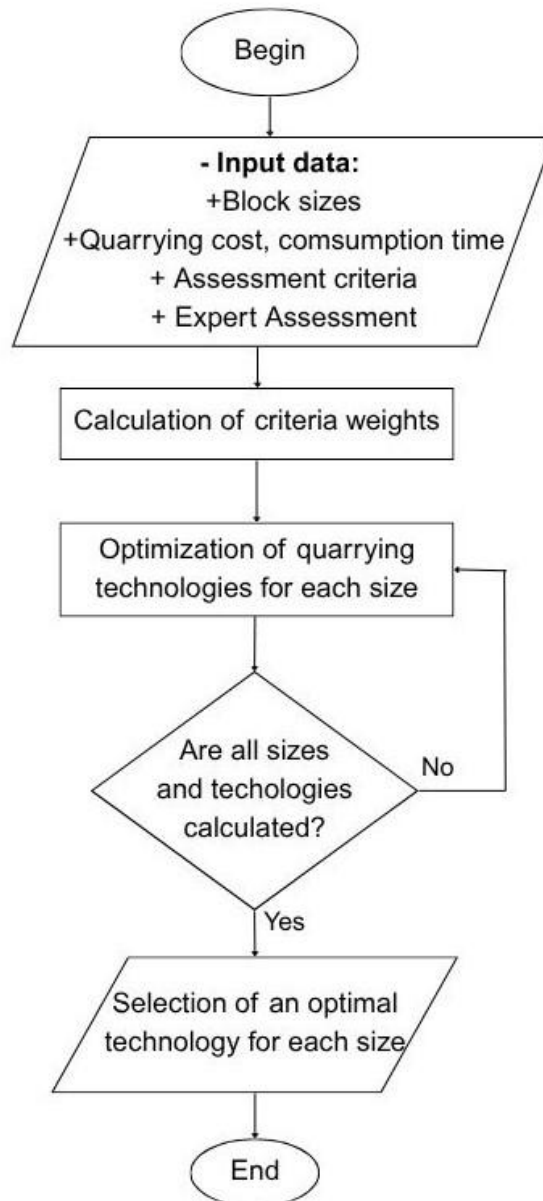


Fig. 7. Algorithm flowchart for optimizing dimension stone quarrying technology



Fig. 8. Program for optimizing dimension stone quarrying technology

3. Case study

3.1. Introduction

Hoa Quang Bac quarry is in Dak Lak Province. The quarry is 16 km from Northwestern of Tuy Hoa ward.

3.2. Block size of dimension stone at Hoa Quang Bac Quarry

Based on joint sets, quarrying equipment fleet, hauling and processing activities at the quarry, the block sizes of dimension stone of Hoa Quang Bac quarry was shown in Table 8.

Tab. 8. The block sizes of dimension stone of Hoa Quang Bac quarry

No	Name of block size	Length, m	Width, m	Height, m	Volume, m ³
I	Cutting with direction paralleling the trike of joint set 1				
1	Size 1 1	1.6	1.3	0.6	1.248
2	Size 1 2	1.4	1.1	0.6	0.924
3	Size 1 3	1.1	0.9	0.6	0.594
4	Size 1 4	1.8	1.4	1.35	3.402
5	Size 1 5	1.5	1.2	1.35	2.43
6	Size 1 6	1.3	1	1.35	1.755
7	Size 1 7	1	0.8	1.35	1.08
8	Size 1 8	0.8	0.6	1.35	0.648
II	Cutting with direction paralleling the trike of joint set 2				
1	Size 2 1	2	1.4	0.6	1.68
2	Size 2 2	1.7	1.2	0.6	1.224
3	Size 2 3	1.4	1	0.6	0.84
4	Size 2 4	1.1	0.8	0.6	0.528
5	Size 2 5	2	1.4	1.35	3.78
6	Size 2 6	1.7	1.2	1.35	2.754
7	Size 2 7	1.4	1	1.35	1.89
8	Size 2 8	1.1	0.8	1.35	1.188
9	Size 2 9	0.9	0.6	1.35	0.729
III	Cutting with direction paralleling the trike of joint set 3				
1	Size 3 1	1.6	1.3	0.6	1.248
2	Size 3 2	1.4	1.1	0.6	0.924
3	Size 3 3	1.1	0.9	0.6	0.594
4	Size 3 4	2	1.4	1.35	3.78
5	Size 3 5	1.7	1.2	1.35	2.754
6	Size 3 6	1.4	1	1.35	1.89
7	Size 3 7	1.1	0.8	1.35	1.188
8	Size 3 8	0.9	0.6	1.35	0.729

3.3. Optimizaion of dimension stone quarrying technology

3.3.1. Defining quarrying cost, consumed time coresponding with the block sizes and the technologies.

Based on the block sizes and the technologies such as blasting with detonating fuse, blasting with explosives, wedge, disc sawing, diamond wire sawing, diamond wire sawing combined with wedge, disc sawing combined with diamond wire sawing and disc sawing combined with diamond wire sawing and wedge, input data was entered a program for calculating quarrying costs and consumed time of the technologies as shown in Fig 9. When changing in the technologies and the block sizes by pressing button “calculation”, the costs and the time were computed as shown in Figure 9.

Fig. 9. Program for calculating quarrying cost and consumed time of the technologies

3.3.2. Optimization of quarrying technology

In the optimization, the technologies were assessed with the criteria, such as mining cost, block quality, consuming time, production safety, impacted environment and stone loss. In which, the higher value, negative criteria (mining cost, consuming time, impacted environment) is worse. The higher value, positive criteria (block quality, production safety) is better.

Therefore, to assess criteria weight, the AHP was employed, and to rank the technologies, the Promethee II was chosen. Defining the criteria weights and ranking the technologies based on the program for optimizing the technology is shown in Fig 10. Calculating the weights by pressing the button “weights” will get the weights corresponding to the criteria and the result will be checked through the CR computed equal to 0,033242 (3,32%), less than 10% to meet the demand. Preference ranking for each technology by selecting the name of block size and pressing the button “Optimization” will be computed. Moreover, to optimize the technology for all block size by pressing the button “data export”, the data for preferred technology with block sizes is represented in Table 9.

Fig. 10. Program for optimizing dimension stone quarrying technology

Tab. 9. Data for preferred technology with block sizes

No	Name of block size	Blasting	Detonating fuse	Diamond wire	Wedge	Disc-diamond wire	Diamond wire – wedge	Disc-diamond wire-wedge
1	Size 1_1	6	7	2	5	1	4	3
2	Size 1_2	7	6	2	5	1	4	3
3	Size 1_3	6	7	2	5	1	4	3
4	Size 1_4	6	7	2	5	1	4	3

5	Size 1 5	6	7	2	5	1	4	3
6	Size 1 6	6	7	2	5	1	4	3
7	Size 1 7	7	6	2	5	1	4	3
8	Size 1 8	6	7	2	5	1	4	3
9	Size 2 1	6	7	2	5	1	4	3
10	Size 2 2	6	7	2	5	1	4	3
11	Size 2 3	7	6	2	5	1	4	3
12	Size 2 4	6	7	2	5	1	4	3
13	Size 2 5	6	7	2	5	1	4	3
14	Size 2 6	6	7	2	5	1	4	3
15	Size 2 7	6	7	2	5	1	4	3
16	Size 2 8	7	6	2	5	1	4	3
17	Size 2 9	6	7	2	5	1	4	3
18	Size 3 1	6	7	2	5	1	4	3
19	Size 3 2	7	6	2	5	1	4	3
20	Size 3 3	6	7	2	5	1	4	3
21	Size 3 4	6	7	2	5	1	4	3
22	Size 3 5	6	7	2	5	1	4	3
23	Size 3 6	6	7	2	5	1	4	3
24	Size 3 7	7	6	2	5	1	4	3
25	Size 3 8	6	7	2	5	1	4	3

From the result through the program and the result data, it is seen that the most outranking technology is disc sawing coordinating with diamond wire sawing for Hoa Quang Bac dimension stone quarry. The change in the size of stone block has a little effective to selecting the technologies for the quarry. The result will help the mine to select the technology, contributing to be a foundation for calculating economic benefit and defining the optimizing recovery rate for dimension stone quarry.

4. Conclusion

Selecting the technologies for dimension stone quarries is significantly important in the currently mining conditions due to diversity technology application. The selection of the technologies depends more on criteria including mining cost, block quality, consuming time, production safety, impacted environment and stone loss. Combined multiple attributes decision-making method is Analytic Hierarchy Process (AHP) and multi-criteria ranking method (Promethee II) is claimed to be an effective approach for optimizing selection for the technology. The AHP is used to assess the criteria weights after that the Promethee II is deployed to ranking the technologies based on the criteria and their weights. The combined method was applied for Hoa Quang Bac quarry. From the application, disc sawing coordinated with diamond wire sawing was chosen as the optimization technology for the quarry. As a result, the combined method is suitable for selecting the best technology for dimension stone quarries.

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