CHOICE OF MARBLE BLOCK CUTTING MACHINE BY USING ANALYTIC HIERARCHY PROCESS (AHP) METHOD

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Abstract

In marble and natural stone factories, the most important factor that affects productivity and capacity of the plant, and amount of the investment is the block cutting machines. The marble block cutting machines are classified as circular saw (Stripper, Trimmer), blade (Gangsaw), and wire (Multiwire) block cutting machine according to the cutting pattern of the marble. Selection among the machines is based on a great number of economic and technical criteria. Therefore, scientific methods must be used when selecting the machines.

AHP, one of the multi-criteria decision-making methods, is a powerful and lucid method that allows the decision makers to combine qualitative and quantitative factors during the decision-making process; and it can express the process on a mathematical basis.

In this study, the AHP method is employed in selection of the block cutting machines used in the marble and natural stone factories. For this purpose, the marble block cutting machines are introduced at first, and then, the application of AHP method is explained. Finally, 3 types of block cutting machines which are the most preferred machines in the industry are examined by applying the AHP method according to 11 different criteria; and it is concluded that the suitable options for the plants are Gangsaw with a ratio of 41.74%, Multiwire with 32.84%, and Stripper with 25.42%, respectively.

Keywords: Decision-making, Analytic Hierarchy Process (AHP), Marble block cutting machine

1. INTRODUCTION

Turkey has maintained its rapid growth in terms of the marble and natural stone sector since 20 years, and proven itself to be an important manufacturer in the international markets. In the marble and natural stone market, it is important to manufacture quality products with a higher unit selling price as well as the high quantities of production and sales. Naturally, every step to be taken in order to increase both the production amount and quality will have a cost. Therefore, the manufacturers must increase productivity in order to make high profit. The manufacturing process in the marble and natural stone sector is as follows;

- To manufacture the blocks in quarry and then, transport the manufactured blocks to the factory;
- To strengthen the blocks as considered necessary;
- To split the blocks into slabs and plates;
- To strengthen the slabs and plates as considered necessary;
- To process the surfaces and edges of the slabs and plates (polishing, honing, aging, etc.);
- To size as slabs, plates, tiles, etc.; and
- To package and put the products on the market.

The manufacturing process includes many factors such as workmanship, electricity, water, cutting sockets, abrasives, polishing stones, etc. as well as the raw material.

When planning a marble and natural stone factory, selection of machinery and equipment involved in the manufacturing process will directly affect the capacity
of the plant, quality of the products, cost of manufacturing, and consequently, productivity of the plant. In other words, it is important how the machinery that constitutes the backbone of the facility will be established.

Splitting the blocks into slabs and plates is a stage in the marble and natural stone manufacturing process, which is the largest work item in terms of both the initial investment and electricity and cutting socket consumption. At this stage which is also defined as block cutting process, the circular saw block cutters (Stripper), blade block cutters (Gangsaw), or wire block cutters (Multiwire) are used.

When selecting the machinery, many criteria should be taken into account such as price, water requirements, abrasive consumption, energy consumption, labour need, etc. This brings the need to apply scientific methods when making a selection among the different machines. These methods, also named as multi-criteria decision-making methods, include AHP (Analytic Hierarchy Process), Fuzzy AHP, TOPSIS, ANP (Analytic Network Process), Electre, and Dematel, inter alia.


In this study, the block cutter machine selection criteria to be used at the establishment stage of the marble and natural stone plants are determined, and the optimal block cutter is selected by applying the AHP (Analytic Hierarchy Process) method. Differently from the other studies, this study addresses the selection criteria in a wide range, and considers multi-wire block cutting machines among the alternatives for the first time.

2. MATERIALS AND METHODOLOGY

This study consists of two phases: (i) identification of the block cutting machines which are commonly used in the market, and their technical characteristics, operating parameters, and performance; and (ii) selection of the optimum block cutting machine.

For this purpose, 1600-mm diameter circular saw stripper and 80-blade gangsaw which are the most preferred machines by the marble processing plants, and 68-line Multiwire block cutting machine which is newly known in Turkey were used as a base; and the technical characteristics of each machine were obtained from the relevant manufacturers. Also, information was received from the enterprises using any of the aforementioned machines about the operating parameters and performance of the machines. The AHP (Analytic Hierarchy Process) method was applied in the comparison of the machines, and the Microsoft Office Excel program was used in the calculations.

2.1. Marble Block Cutting Machines and Their Characteristics

The marble and natural stone block cutting machines can be examined in three main groups according to their relevant cutting principles: circular saw, blade, and wire block cutting machines.

A circular saw block cutting machine (Stripper) consists of up-down moving bridge fitted on columns, and vertical and horizontal saws reciprocating on the bridge (Figure 1). These machines are named as two- or four-column Stripper according to the number of columns bearing the unit. Operating principle of these machines is as follows: The vertical saw cuts the surface of marble block, and then, the horizontal saw separates the cut slab from the block. New slabs are cut as a result of displacement of the block or cutting unit as much as the cutting thickness. In certain models, it is possible to insert more than one vertical saw and cut more slabs in one cycle. Diameter of the vertical saw is a factor restricting the width of the slab to be manufactured, and typically, 60-cm wide slabs are produced using 1600-mm diameter saws.

A blade block cutting machine, also named as gangsaw, consists of a frame fitter on four columns, and diamond-socket blades stretched on the frame, and a flywheel (Figure 2). The frame on which the blades are fitted is eccentrically attached to the flywheel by an arm, and
reciprocates with rotation of the flywheel. Cutting takes place by lifting the block upside in some models, or by lowering the blades in other models. Number of blades can be 40 or 80 according to the size of the machine. Also, there are some gangsaw models in which the blades are vertically positioned and the block is horizontally fed while moving up-down, but they are not common.

Since they are not popular in Turkey, the wire block cutting machines referred to as Multiwire or wire gangsaw are used in Europe during the past ten years, especially in the marble and natural stone factories cutting hard stones, and increasingly become widespread every passing year. This machine consists of the flywheels reciprocally positioned on the columns at a certain low angle, and diamond beady wires (also used in the marble quarries) passed through those flywheels (Figure 3). Cutting takes place by rotation of the flywheels and up-down moving of the cutting unit. As a result of rotation, the diamond wires horizontally and endlessly move, and the diamond beads rotate around their own axis due to the contraction resulting from the angle between the flywheels. This compensates the abrasion rate on the beads. Number of flywheels and wires may vary according to the size of the machine.

The technical characteristics of the circular saw, blade, and wire block cutting machines referenced in the study are given in the Table 1.

2.2. AHP (Analytic Hierarchy Process) Method

The Analytic Hierarchy Process (AHP) was put forward for the first time by Myers and Alpert in 1968, and then, developed as a model and made useful to solve decision-making problems by Saaty in 1977 (Anon a, Baltalar 2008). The method is a quantitative technique that evaluates a finite number of options together with the qualitative ones, if any, in a decision problem according to multiple criteria, and prioritizes the options; and its purpose is to help the decision makers to decide more efficiently. This method stands out amongst others since it allows decision makers to combine qualitative and quantitative factors in the decision-making process, it is a powerful and lucid method, and it can express the process on a mathematical basis.

The AHP method can be easily applied in proper recruitment, selection of subcontractors capable of meeting the requirements of the plant, and on an individual basis, in selection of a mate or household goods. The Method consists of the following stages;

- Building a hierarchical structure,
- Determining the priorities,
- Paired comparison matrix and its solution,
- Formation of a priority vector,
- Calculation of the consistency ratio, and
- Finding the distribution of results at the decision points.

At the hierarchical structure building stage, the criteria and options for evaluation are determined. The structure consists of the main goal on the top, and then, the criteria that will affect the decision, and finally, the alternatives to the decision (Figure 4).
Table 1 Characteristics of Stripper, Gangsaw, and Multiwire

<table>
<thead>
<tr>
<th></th>
<th>Stripper (Ф1600 mm)</th>
<th>Gangsaw (80 blades)</th>
<th>Multiwire (68 lines)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum High</td>
<td>5160 mm</td>
<td>5230 mm</td>
<td>6800 mm</td>
</tr>
<tr>
<td>Maximum Width</td>
<td>5610 mm</td>
<td>4500 mm</td>
<td>4400 mm</td>
</tr>
<tr>
<td>Maximum Length</td>
<td>8160 mm</td>
<td>13150 mm</td>
<td>1150 mm</td>
</tr>
<tr>
<td>Cutting Unit</td>
<td>Ф1600 mm vertical, Ф40 mm horizontal saw, 80 nr blade (4550 mm)</td>
<td>68 lines diamond wire</td>
<td></td>
</tr>
<tr>
<td>Cutting High</td>
<td>610 mm</td>
<td>2050 mm</td>
<td>2200 mm</td>
</tr>
<tr>
<td>Cutting Width</td>
<td>2300 mm</td>
<td>2000 mm</td>
<td>1975 mm</td>
</tr>
<tr>
<td>Cutting Length</td>
<td>3500 mm</td>
<td>3300 mm</td>
<td>3500 mm</td>
</tr>
<tr>
<td>Main Engine Power</td>
<td>132 kw</td>
<td>132 kw</td>
<td>315 kw</td>
</tr>
<tr>
<td>Total Engine Power</td>
<td>162 kw</td>
<td>143 kw</td>
<td>335 kw</td>
</tr>
<tr>
<td>Average Socket Speed</td>
<td>470-520 r/min</td>
<td>75 cm.1/min</td>
<td>20-35 m/sec</td>
</tr>
<tr>
<td>Cutting Feed Rate</td>
<td>0,4 m/min</td>
<td>300 mm/h</td>
<td>800 mm/h</td>
</tr>
<tr>
<td>Socket Thickness</td>
<td>12 mm</td>
<td>8 mm</td>
<td>11 mm</td>
</tr>
<tr>
<td>Water Consumption</td>
<td>200 l/min</td>
<td>800 l/min</td>
<td>1000 l/min</td>
</tr>
<tr>
<td>Abrasive Consumption</td>
<td>5000-8000 m²/saw</td>
<td>16000-20000 m²/80 blade</td>
<td>35-45 m²/m wire</td>
</tr>
<tr>
<td>Abrasive Cost</td>
<td>1500 $/group saw</td>
<td>13000 $/80 blade</td>
<td>75 $/m wire</td>
</tr>
<tr>
<td>Machine Price</td>
<td>70000-100000 $</td>
<td>200000-350000 $</td>
<td>650000-800000 $</td>
</tr>
<tr>
<td>Montage Cost</td>
<td>10000-15000 $</td>
<td>40000-50000 $</td>
<td>20000-30000 $</td>
</tr>
<tr>
<td>Vibration</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
</tr>
<tr>
<td>Noise</td>
<td>83,9-88,6 dB</td>
<td>77,2-82,5 dB</td>
<td>73,1-76,8 dB</td>
</tr>
</tbody>
</table>

Figure 4 Hierarchical structure

At the stage of determination of the priorities, the criteria are compared, and their advantages over the others are determined. Paired comparisons were designed to establish the priority distributions of the decision criteria and alternatives, and the scale “1-9” suggested by Saaty in 1994 is used in order to simplify the procedure (Table 2).
Table 2 Comparison scale [16]

<table>
<thead>
<tr>
<th>Importance</th>
<th>Description</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Both factors have the equal importance.</td>
<td>Both activities make equal contribution to the goal.</td>
</tr>
<tr>
<td>3</td>
<td>The factor 1 is more important than the factor 2.</td>
<td>An activity is slightly more preferable to the other by experience and judgment.</td>
</tr>
<tr>
<td>5</td>
<td>The factor 1 is much more important than the factor.</td>
<td>An activity is highly more preferable to the other by experience and judgment.</td>
</tr>
<tr>
<td>7</td>
<td>The factor 1 is significantly important compared to the factor 2.</td>
<td>An activity is strongly preferred, and its dominance is easily observed in practice.</td>
</tr>
<tr>
<td>9</td>
<td>The factor 1 has absolutely prevailing importance compared to the factor 2.</td>
<td>The evidence for preferring an activity to the other is highly reliable.</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values</td>
<td>The values, between two consecutive judgments, to be used when conciliation is required.</td>
</tr>
</tbody>
</table>

The paired comparison matrices are prepared individually for each criterion in order to determine the advantages of alternatives over the others. The matrices are square matrices, and the priorities are determined using the comparison scale. Accordingly, the diagonal of the matrix will take the value 1 since it will reflect the comparison of an alternative or criterion with itself (Equation 1).

\[
A = \begin{bmatrix}
1 & \cdots & a_n \\
\vdots & \ddots & \vdots \\
a_n & \cdots & 1 \\
\end{bmatrix}
\]

A priority vector is formed by adding the columns, and dividing each value by this total sum of columns, and then, calculating the average of the rows. Thus, a single-column vector is obtained, and it is named as the priority vector (Equation 2). When the operation is repeated for each criterion, a number of B column vectors is formed. The matrix C is created by combining those vectors. The normalizing operation is also performed for the matrix C by adding the columns, and dividing each value by the total sum of columns; and then, the priority vector W is found by calculating the average of the rows (Equation 3).

\[
b_{ij} = \frac{a_{ij}}{\sum a_{ij}} \rightarrow B_i = \begin{bmatrix} b_{i1} \\ \vdots \\ b_{in} \end{bmatrix}
\]

\[
C = \frac{c_{11} \cdots c_{1n}}{c_{n1} \cdots c_{nn}} \rightarrow w_i = \frac{\sum_{i=1}^{n} c_{ij}}{n} \rightarrow W = \begin{bmatrix} w_{1} \\ \vdots \\ w_{n} \end{bmatrix}
\]

The result to be obtained by an AHP study may vary according to the consistency of the one-to-one comparisons made by the decision maker between the factors. Therefore, the consistency ratio CR should be calculated in order to test the consistence of the calculated priority vector. CR is a comparison of the number of factors with the \( \lambda \) coefficient which is called the basic value.

In order to calculate the value of \( \lambda \), the column vector D is calculated from the matrix multiplication of the comparison matrix A by the priority vector B (Equation 4). Then, the basic value E for each evaluation factor is calculated from the reciprocal members of the column vectors D and W, and the basic value \( \lambda \) and consistency indicator CI are calculated from the arithmetic mean of those values (Equation 5).

\[
D = \begin{bmatrix}
1 & \cdots & a_n \\
\vdots & \ddots & \vdots \\
a_n & \cdots & 1 \\
\end{bmatrix}
\begin{bmatrix}
w_{1} \\
\vdots \\
w_{n} \\
\end{bmatrix}
\rightarrow D = \begin{bmatrix} d_{1} \\ \vdots \\ d_{n} \end{bmatrix}
\]

\[
E_i = \frac{d_i}{w_i} \rightarrow \lambda = \frac{\sum_{i=1}^{n} E_i}{n} \rightarrow CI = \frac{\lambda - 1}{n-1}
\]

In order to calculate the consistency ratio CR, CI is divided by the random consistency index number (RI) (Equation 6). A consistency ratio CR smaller than 10% means that the matrices are consistent. Otherwise, the one-to-one comparisons made by the decision maker between the factors should be reviewed. The random consistency index number is selected from the Table 3 according to the size of the matrix.

\[
CR = \frac{CI}{RI} \rightarrow \{CR < %10, \text{Consistent}\}
\]
The last stage of the AHP method is to find the result distribution at the decision points. To do this, a decision matrix \( K \) is created from the column vectors \( S \) which are formed after completion of comparisons and which indicate the percentage distributions of the factor according to the decision points (Equation 7). The column vector \( L \) is obtained when the decision matrix is multiplied by the column vector \( W \) (Equation 8). This vector is the percentage distribution of the decision points, and its total sum is 1. The decision maker determines his/her selection according to the value in the column vector \( L \).

\[
S = \begin{bmatrix} s_{1} \\ \vdots \\ s_{m1} \end{bmatrix} \quad \rightarrow \quad K = \begin{bmatrix} s_{11} & \cdots & s_{1n} \\ \vdots & \ddots & \vdots \\ s_{m1} & \cdots & s_{mn} \end{bmatrix} \quad \rightarrow \quad L = \begin{bmatrix} L_{11} \\ \vdots \\ L_{m1} \end{bmatrix} \quad \rightarrow \quad \left\{ \sum L_{i} = 1, L_{\text{max}} = \text{The best alternative} \right\}
\]

### Table 3 Random consistency index numbers

<table>
<thead>
<tr>
<th>N</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
</tr>
</thead>
<tbody>
<tr>
<td>RI</td>
<td>0.00</td>
<td>0.00</td>
<td>0.58</td>
<td>0.90</td>
<td>1.12</td>
<td>1.24</td>
<td>1.41</td>
<td>1.45</td>
<td>1.49</td>
<td>1.51</td>
<td>1.48</td>
<td>1.56</td>
<td>1.57</td>
<td>1.59</td>
</tr>
</tbody>
</table>

3 APPLICATION OF AHP IN SELECTION OF MARBLE BLOCK CUTTING MACHINES

For the AHP application, a decision-making team, which consists of three mining engineers, an electrical and electronics engineer and a marble factory owner, was established. The two of mining engineers are academicians also the authors and the other is a general manager of a private marble company and 26 years experienced in marble sector too. The electrical and electronic engineer is working as a consultant for any companies particularly the marble sector. The last member of the team, marble factory owner, has been managing own factory for 19 years. The team agreed on the judgments by discussing the decisions according to their experience and the specifications of block cutting machines.

In application, a hierarchical structure was formed as the first stage by the decision-making team. The aim was to determine the optimum block cutting machine, and options were the circular saw, blade, and wire block cutting machines. It was assumed that the best option would be the machine both with the lowest investment rate, operating costs, and rate of waste (loss) and with the highest capacity (production rate). Accordingly, totally 11 criteria were determined for selection: the cutting principle, maximum cutting depth, water consumption, production rate, investment, energy consumption, abrasive (sockets and beads) consumption, labour (work force requirements), losses, noise level, and vibration level generated by the machine during operation. The hierarchical structure is schematically shown in the Figure 5.

At the stage of determination of the priorities, the comparison matrices were formed individually for each criterion. When forming the matrices, the comparison scale given in the Table 2 was used. The paired comparison matrices are listed below.
Cutting principle (C1): Although the number of cutting saws can be increased for the circular saw block cutting machine (A1), this can be done in a limited number. On the contrary, the cutting unit consists of 80 blades in the blade block cutter (A2) and 68 lines of diamond wires in the wire block cutter (A3). Therefore, it was considered that A2 is more important than A3 (3 points); A2 is absolutely superior to A1 (9 points); and A3 is more dominant compared to A1 (7 points). Accordingly, the paired comparison matrix (A), normalized matrix (C), and priority vector (W) were calculated, and the consistency analysis were performed (CR), and then, it was seen that the matrix is consistent. The calculations are given below.

\[
A[C1] = \begin{bmatrix}
1.0000 & 0.1111 & 0.1429 \\
9.0000 & 1.0000 & 3.0000 \\
7.0000 & 0.3333 & 1.0000 \\
\end{bmatrix} \rightarrow \ C[C1] = \begin{bmatrix}
0.0588 & 0.0769 & 0.0345 \\
0.5294 & 0.6923 & 0.7241 \\
0.4118 & 0.2308 & 0.2414 \\
\end{bmatrix} \rightarrow \ W[C1] = \begin{bmatrix}
0.0567 \\
0.6486 \\
0.2946 \\
\end{bmatrix}
\]
Maximum cutting depth (C2): The maximum cutting depth for A1 is limited to the radius of the saw, and the both other options allow for cutting along the height of the block. When considering that the dimensions of slabs and plates directly affect the price in marble production, it can be said that the options A2 and A3 are absolutely superior (9) to A1 for this criterion. When comparing the options A2 and A3, it is seen that the option A3 is slightly superior (2) with a difference of 15 cm. The paired comparison matrix A[C2] and calculations are given below.

\[
\begin{array}{ccc}
1.0000 & 0.1111 & 0.1111 \\
0.9000 & 1.0000 & 0.5000 \\
0.3333 & 0.2000 & 1.0000 \\
\end{array}
\times
\begin{array}{c}
0.0526 \\
0.4737 \\
0.5791 \\
\end{array}
= 
\begin{array}{c}
0.0524 \\
0.4737 \\
0.6207 \\
\end{array}
\rightarrow 
\begin{array}{c}
E[C2]= 3.0665 \\
C[C2]= 0.3685 \\
CR[C2]= 0.0465 \\
\end{array}
\]

Water consumption (C3): The water consumption of A1 is lower compared to the others; and it was considered suitable that A1 is given 5 to 6 points since the options A2 and A3 are very close to each other. The comparison between the other two alternatives indicated that the option A2 is slightly superior (2). The paired comparison matrix A[C3] and calculations are given below.

\[
\begin{array}{ccc}
1.0000 & 5.0000 & 6.0000 \\
0.2000 & 1.0000 & 2.0000 \\
0.1667 & 0.5000 & 1.0000 \\
\end{array}
\times
\begin{array}{c}
0.7225 \\
0.5253 \\
0.3108 \\
\end{array}
= 
\begin{array}{c}
2.2132 \\
1.5253 \\
0.7621 \\
\end{array}
\rightarrow 
\begin{array}{c}
E[C3]= 3.0166 \\
C[C3]= 0.1741 \\
CR[C3]= 0.0252 \\
\end{array}
\]

Production rate (C4): Since the cutter penetration rate and cutting depth of the option A1 are 0.4 m/min and 610 mm, respectively; its theoretical production rate is calculated as follows:

\[Q_{A1} = 0.4 \times \frac{610}{1000} \times 60 \rightarrow Q_{A1} = 14.6 \ m^2/h\]

With respect to the option A2, since its drop rate, cutting length, and number of blades are 300 mm/h, 3300 mm, and 80, respectively; its theoretical production rate is calculated as follows:

\[Q_{A2} = \frac{3300}{1000} \times \frac{300}{1000} \times (80 - 1) \rightarrow Q_{A2} = 78.1 \ m^2/h\]

With respect to the option A3, the drop rate of wires, cutting length and number of wire lines are 800 mm/h, 3500 mm, and 68, respectively. Accordingly, its theoretical production rate is calculated as follows:

\[Q_{A3} = \frac{3500}{1000} \times \frac{800}{1000} \times (68 - 1) \rightarrow Q_{A3} = 187.6 \ m^2/h\]

In the circumstances, when A1 and A2 are compared to each other, it is seen that the option A2 is very superior (4). When A1 and A3 are compared, it is seen that A3 is absolutely superior (9); and when A2 and A3 are compared, it is seen that A3 is very superior (5). The paired comparison matrix A[C4] and calculations are given below.

\[
\begin{array}{ccc}
1.0000 & 0.2500 & 0.1111 \\
0.4000 & 1.0000 & 0.2000 \\
0.9000 & 5.0000 & 1.0000 \\
\end{array}
\times
\begin{array}{c}
0.0714 \\
0.2857 \\
0.6429 \\
\end{array}
= 
\begin{array}{c}
0.0714 \\
0.1600 \\
0.7627 \\
\end{array}
\rightarrow 
\begin{array}{c}
W[C4]= 0.1994 \\
C[C4]= 0.0654 \\
CR[C4]= 0.7352 \\
\end{array}
\]
Investment (C5): When evaluating the options, it is seen that the cheapest option is A1, and the most expensive one is A3; so A1 is very superior to A2 (6), and absolutely superior to A3 (9). When comparing the options A2 and A3, it is seen that A2 is very superior to A3 (4). The paired comparison matrix A[C5] and calculations are given below.

Energy consumption (C6): When examining the options, it is seen that the motor powers of A1, A2, and A3 are 162, 143, and 335 kW, respectively. For the energy needs of machines are proportional to the motor power, it is seen that A2 is more important than A1 (3) and significantly more important than A3 (6). In addition, it can be said A1 is highly superior to A3 (7). The paired comparison matrix A[C6] and calculations are given below.

Abrasive consumption (C7): Since the cutting principles and units of the machines are different, their abrasive consumption values are in different units. In order to make comparisons, the costs of the cutters used in the options A1, A2, and A3 were taken as a basis. Accordingly, the average abrasive costs per m² (t) are calculated as follows:

\[ t_{A1} = \frac{1500}{(5000+8000) / 2} \rightarrow t_{A1} = 0.23 \text{ $/ m}^2 \]

\[ t_{A2} = \frac{13000}{(16000+20000) / 2} \rightarrow t_{A2} = 0.72 \text{ $/ m}^2 \]

\[ t_{A3} = \frac{75}{65+55 / 2} \rightarrow t_{A3} = 1.87 \text{ $/ m}^2 \]

So, it can be said that the option A1 is absolutely superior to the other options (6-9), and A2 is very superior to A3 (4). The paired comparison matrix A[C7] and calculations are given below.
Labour (C8): For the option A1, at least one worker should be employed to take and pile the cut slabs after the block is placed in the carriage and cutting process is commenced. Therefore, the daily work force requirement of the option A1 is identified as 8 man-hours. With respect to the options A2 and A3, the work force is required only for routine controls after the block is fed to the machine and the machine is started until the completion of cutting process, and the person in charge may be used for other works. So, the daily work force requirement is considered as 2 man-hours. Since the tension of wires is adjusted automatically, and no stretching is performed in the option A3 in contrast with A2, it is thought that A3 is slightly more advantageous. The paired comparison matrix A[C8] and calculations are given below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000 0.1250 0.1111</td>
<td>0.0556 0.0400 0.0690</td>
<td>0.0548</td>
</tr>
<tr>
<td>8.0000 1.0000 0.5000</td>
<td>0.4444 0.3200 0.3103</td>
<td>0.3583</td>
</tr>
<tr>
<td>9.0000 2.0000 1.0000</td>
<td>0.5000 0.6400 0.6207</td>
<td>0.5869</td>
</tr>
</tbody>
</table>

Wastes (C9): Apart from the block defects, the biggest loss encountered in cutting of marbles and natural stones results from the thickness of the cutting member. The diamond sockets and beads thin due to abrasion and losses decrease as from the commencement of use of saws, blades or wires. At the beginning stage of the process, the thickness values of cutters used in the option A1, A2, and A3 are 12 mm, 8 mm, and 11 mm, respectively. It can be said that the most loss would take place in A1, then A3, and finally A2. Although the difference varies between 1 and 3 mm, it would be better understood that it is very important considering the price of the product, and the fact that even a difference of 1 mm would bring 1 slab or plate after every 20 surface cutting operations. Accordingly, it is concluded that the option A2 is very superior to the others (7-9); and A3 is superior to A1 (3). The paired comparison matrix A[C9] and calculations are given below.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.0000 0.1111 0.3333</td>
<td>0.0769 0.0886 0.0400</td>
<td>0.0685</td>
</tr>
<tr>
<td>9.0000 1.0000 7.0000</td>
<td>0.6923 0.7975 0.8400</td>
<td>0.7766</td>
</tr>
<tr>
<td>3.0000 0.1429 1.0000</td>
<td>0.2308 0.1139 0.1200</td>
<td>0.1549</td>
</tr>
</tbody>
</table>

Vibration (C10): Since cutting process is due to reciprocating motion of the blades in the option A2, vibration occurs in the working environment at a certain frequency. Since this is not the case for the options A1 and A3, it can be said that A1 and A3 are superior (7-9). The paired comparison matrix A[C10] and calculations are given below.

<table>
<thead>
<tr>
<th></th>
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</tr>
</thead>
<tbody>
<tr>
<td>1.0000 0.1111 0.1429</td>
<td>0.6207 0.5294 0.6364</td>
<td>0.5955</td>
</tr>
<tr>
<td>0.5000 7.0000 1.0000</td>
<td>0.0690 0.0588 0.0455</td>
<td>0.0577</td>
</tr>
<tr>
<td>0.0821</td>
<td>0.0911</td>
<td>0.0708 Consistent</td>
</tr>
</tbody>
</table>

Noise (C11): In respect of the noise measurements performed during the block cutting by the machines, the readings taken were 85 dB for the option A1, and about 80 and 75 dB for the options A2 and A3. Accordingly, it can be said that the option A1 is very loud; and the options A2 and A3 are superior (8-9). The paired
The paired comparison matrix \(A[C11]\) and calculations are given below.

\[
A[C11]= \begin{bmatrix}
1.0000 & 0.1250 & 0.1111 \\
8.0000 & 1.0000 & 0.5000 \\
9.0000 & 2.0000 & 1.0000 \\
\end{bmatrix}
\]

\[
C[C11]= \begin{bmatrix}
0.0556 & 0.0400 & 0.0690 \\
0.4444 & 0.3200 & 0.3103 \\
0.5000 & 0.6400 & 0.6207 \\
\end{bmatrix}
\]

\[
W[C11]= \begin{bmatrix}
0.0548 \\
0.3583 \\
0.5869 \\
\end{bmatrix}
\]

\[
D[C11]= \begin{bmatrix}
1.0000 & 0.1250 & 0.1111 \\
8.0000 & 1.0000 & 0.5000 \\
9.0000 & 2.0000 & 1.0000 \\
\end{bmatrix}
\]

\[
E[C11]= \begin{bmatrix}
0.0548 \\
0.1648 \\
0.5869 \\
\end{bmatrix}
\]

\[
\lambda[C11]= \begin{bmatrix}
3.0057 \\
3.0437 \\
3.0618 \\
\end{bmatrix}
\]

\[
\frac{\lambda[C11]}{\max(\lambda[C11])} = \begin{bmatrix}
3.0371 \\
0.0185 \\
0.0320 \\
\end{bmatrix}
\]

At the next stage of the AHP application, the advantages of criteria from C1 to C11 over the others were determined. The paired comparison matrix \(A[C]\) and calculations prepared according to the importance of each criterion are as follows.

\[
A[C]= \begin{bmatrix}
1.0000 & 0.1667 & 2.0000 & 0.1111 & 0.1667 & 0.1429 & 0.1429 & 0.1250 & 0.1111 & 1.0000 & 1.0000 \\
6.0000 & 1.0000 & 7.0000 & 0.2500 & 0.2000 & 0.3333 & 0.2500 & 3.0000 & 0.1667 & 2.0000 & 2.0000 \\
0.5000 & 0.1429 & 1.0000 & 0.1250 & 0.1250 & 0.1111 & 0.1111 & 0.1111 & 0.5000 & 0.3333 \\
9.0000 & 4.0000 & 8.0000 & 1.0000 & 3.0000 & 2.0000 & 2.0000 & 3.0000 & 2.0000 & 4.0000 & 5.0000 \\
6.0000 & 5.0000 & 8.0000 & 0.3333 & 1.0000 & 1.0000 & 0.5000 & 0.3333 & 0.1667 & 6.0000 & 6.0000 \\
7.0000 & 3.0000 & 9.0000 & 0.5000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 5.0000 & 5.0000 \\
7.0000 & 4.0000 & 9.0000 & 0.5000 & 2.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 5.0000 & 5.0000 \\
8.0000 & 0.3333 & 9.0000 & 0.3333 & 3.0000 & 1.0000 & 1.0000 & 1.0000 & 1.0000 & 3.0000 & 3.0000 \\
9.0000 & 6.0000 & 9.0000 & 0.5000 & 6.0000 & 5.0000 & 6.0000 & 2.0000 & 1.0000 & 7.0000 & 7.0000 \\
1.0000 & 0.5000 & 2.0000 & 0.2500 & 0.1667 & 0.2000 & 0.2000 & 0.3333 & 0.1429 & 1.0000 & 1.0000 \\
1.0000 & 0.5000 & 3.0000 & 0.2000 & 0.1667 & 0.2000 & 0.2000 & 0.3333 & 0.1429 & 1.0000 & 1.0000 \\
\end{bmatrix}
\]

\[
C[C]= \begin{bmatrix}
0.0180 & 0.0068 & 0.0299 & 0.0271 & 0.0099 & 0.0119 & 0.0115 & 0.0102 & 0.0236 & 0.0282 & 0.0275 \\
0.1081 & 0.0406 & 0.1045 & 0.0609 & 0.0119 & 0.0278 & 0.0202 & 0.2452 & 0.0354 & 0.0563 & 0.0550 \\
0.0090 & 0.0058 & 0.0149 & 0.0305 & 0.0074 & 0.0093 & 0.0090 & 0.0091 & 0.0236 & 0.0414 & 0.0092 \\
0.1622 & 0.1623 & 0.1194 & 0.2437 & 0.1783 & 0.1668 & 0.1612 & 0.2452 & 0.4248 & 0.1127 & 0.1376 \\
0.1081 & 0.2029 & 0.1194 & 0.0812 & 0.0594 & 0.0834 & 0.0403 & 0.0272 & 0.0354 & 0.1690 & 0.1651 \\
0.1261 & 0.1217 & 0.1343 & 0.1219 & 0.0594 & 0.0834 & 0.0806 & 0.0817 & 0.0425 & 0.1408 & 0.1376 \\
0.1261 & 0.1623 & 0.1343 & 0.1219 & 0.1189 & 0.0834 & 0.0806 & 0.0817 & 0.0354 & 0.1408 & 0.1376 \\
0.1441 & 0.0135 & 0.1343 & 0.0812 & 0.1783 & 0.0834 & 0.0806 & 0.0817 & 0.1062 & 0.0845 & 0.0826 \\
0.1622 & 0.2435 & 0.1343 & 0.1219 & 0.3566 & 0.4171 & 0.4837 & 0.1635 & 0.2124 & 0.1972 & 0.1927 \\
0.0180 & 0.0203 & 0.0299 & 0.0609 & 0.0999 & 0.0167 & 0.0161 & 0.0272 & 0.0303 & 0.0282 & 0.0275 \\
0.0180 & 0.0203 & 0.0448 & 0.0487 & 0.0099 & 0.0167 & 0.0161 & 0.0272 & 0.0303 & 0.0282 & 0.0275 \\
\end{bmatrix}
\]

\[
W[C]= \begin{bmatrix}
0.0186 \\
0.0696 \\
0.0129 \\
0.1922 \\
0.0992 \\
0.1112 \\
0.0973 \\
0.2441 \\
0.0525 \\
0.0262 \\
\end{bmatrix}
\]
At the final stage, the decision matrix \( L \) was created from the column vectors \( W[CI] \) formed as a result of the comparison procedures, and then, the percentage distribution of each decision points was obtained by multiplying it by the column vector \( W[C] \) which is expression of the weights of criteria, and adding the rows.

The weight distributions according to the column vector \( L \) were found 25% for the option A1, and 41.74% for A2, and 32.84% for A3. Accordingly, it can be said that the optimum block cutting machine for cutting the marble blocks is the option A2 (Gangsaw with 80 blades).

### 4 CONCLUSION

The AHP method, one of the multi-criteria decision-making methods, stands out with its lucidity and practicability. The method provides opportunity to think simpler and act easier since it allows for evaluation of a specified number of criteria together in selection of any option.

Establishment of machinery is an important activity in the feasibility studies of the marble and natural stone cutting plants. The block cutting machines are the most important item in terms of both the amount of investment and the capacity of plant.
However, when the criteria are evaluated together, it is seen that the optimum machine is the blade block cutter. It is understood that the parameter which has mostly affected the result is the advantages of criteria over others. So, the decision maker must take the priorities of the plant into consideration when creating the paired comparison matrices of the criteria. For example, in a country with cheaper workforce and lower energy prices, such criteria will diminish in importance, and the final result may change.

In conclusion, it can be said that the AHP method is applicable for marble and natural stone plants and it can be used to solve other problems with many affecting criteria such as selection of plant location, personnel selection, supplier selection, etc. as well as the selection of other machinery and equipment involved in the manufacturing process.

REFERENCES
