Selection of plant location in the natural stone industry using the fuzzy multiple attribute decision making method

by M. Yavuz*

Introduction

For all branches of engineering, selection of plant location is a common concern and crucial to all companies' eventual success. Selecting a plant location is very important for all companies in minimizing cost and maximizing the use of resources. The new plant location should be evaluated carefully for the company's competitiveness. To achieve this goal, some potential criteria must be considered in selecting a particular plant location, such as investment cost, human resources, availability of the material, climate, etc. All the criteria affecting the optimum plant location selection can be classified into two categories as subjective and objective.

Subjective criteria are qualitatively defined as climate, manpower, etc. while objective criteria are quantitatively defined as land and installation cost.

Multiple criteria decision making (MCDM) is one of the most considerable branches of decision-making. MCDM is used to solve the plant location problem in the FMADM model. To determine the optimum plant location for a new natural stone factory, which is planned to be established by a mining firm located in the Eskisehir region of Turkey, an analysis was carried out by incorporating the method and the analytic hierarchy process (AHP) method. The analysis shows that the Yager's method can easily be applied to the selection of plant location in the natural stone and mining industry when the difficulties encountered in the application process of the AHP method is taken into account.

Keywords: Natural stone, plant location, decision making, Yager's method, analytic hierarchy process (AHP).

Synopsis

Determining the most convenient plant location is one of the most commonly encountered problems in engineering applications. This paper presents a fuzzy multiple attribute decision making (FMADM) model which is developed for the selection of the optimum plant location for natural stone factories in the mining industry. The criteria affecting the decision making process in natural stone industry were determined to solve the plant location problem in the FMADM model. To determine the optimum plant location for a new natural stone factory, which is planned to be established by a mining firm located in the Eskisehir region of Turkey, an analysis was carried out by incorporating the method and the analytic hierarchy process (AHP) method. The analysis shows that the Yager's method can easily be applied to the selection of plant location in the natural stone and mining industry when the difficulties encountered in the application process of the AHP method is taken into account.

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Abstract

Determining the most convenient plant location is one of the most commonly encountered problems in engineering applications. This paper presents a fuzzy multiple attribute decision making (FMADM) model which is developed for the selection of the optimum plant location for natural stone factories in the mining industry. The criteria affecting the decision making process in natural stone industry were determined to solve the plant location problem in the FMADM model. To determine the optimum plant location for a new natural stone factory, which is planned to be established by a mining firm located in the Eskisehir region of Turkey, an analysis was carried out by incorporating the method and the analytic hierarchy process (AHP) method. The analysis shows that the Yager's method can easily be applied to the selection of plant location in the natural stone and mining industry when the difficulties encountered in the application process of the AHP method is taken into account.

Keywords: Natural stone, plant location, decision making, Yager's method, analytic hierarchy process (AHP).
Stone factories will be constructed in different regions of Turkey. The most suitable location must be selected to achieve the planned production target in natural stone industry. To solve this problem, fuzzy multiple attribute decision making (FMADM), that is the MADM technique, was used in this study and an FMADM model was developed to help the decision maker working in natural stone processing. In the developed model, an expert team determined all the criteria affecting the plant location of the natural stone industry and weighted the pairwise comparison matrices at the first stage of the problem solving process. The FMADM, since its invention, has been a tool in the hands of decision makers and researchers; and it is one of the most commonly used MADM tools. The FMADM method has been increasingly incorporated in mining applications such as: roadheader selection, selection of post-mining usage of land, open pit mine equipment selection, underground mining method selection and the selection of loading-hauling system in an open pit mine. In this paper, an analysis was carried out by employing the FMADM method in order to determine the optimum plant location for a new natural stone factory, which is planned to be established by a mining firm in Turkey. Also, an analytic hierarchy process (AHP) method was applied to solve the same problem for comparison of the solutions.

Fuzzy multiple attribute decision making method

Fuzzy multiple attribute decision making (FMADM) methods have been developed due to the lack of precision in assessing the relative importance of attributes and the performance ratings of alternatives for an attribute. The imprecision may come from a variety of sources such as: unquantifiable information, incomplete information, nonobtainable information and partial ignorance. The classic MADM methods cannot effectively handle the problems with such imprecise information.

The problem of fuzzy MADM is to select/prioritize/rank a finite number of courses of action (or alternatives) by evaluating a group of predetermined criteria. Thus, to solve this problem, an evaluation procedure to rate and rank, in order of preference, the set of alternatives must be constructed. The fuzzy MADM problem is described below: 

- A set of $m$ possible courses of action (referred to as alternatives), $A = \{A_1, A_2, \ldots, A_i, \ldots, A_m\}$
- A set of $n$ attributes (or criteria), $C = \{C_1, C_2, \ldots, C_j, \ldots, C_n\}$ with which alternative performances are measured
- A performance rating of alternative $A_i$ with respect to attribute (or criterion) $C_j$, which is given by the $m \times n$ fuzzy decision matrix $R = [r^i_j]$, where $r^i_j$ is a fuzzy set (or fuzzy number)
- A set of $n$ fuzzy weights $W = \{w^i\}$, where $w^i$ is also a fuzzy set (or fuzzy number) and denotes the importance of criterion $C_i$ in the evaluation of the alternatives

A large number of articles in the literature on decision-making analysis have addressed to the FMADM methods. The focus of this paper is on the Yager’s method, which is generally enough to deal with multiple attribute problems. Yager’s method follows the max-min method of Bellman and Zadeh, with the improvement of Saaty’s method, which considers the use of a reciprocal matrix to express the pairwise comparison criteria and the resulting eigenvector as subjective weights (priorities). The weighting procedure uses exponentials based on the definition of linguistic hedges, proposed by Zadeh.

On describing multiple attribute decision-making problems, only a single objective is considered, namely the selection of the best alternative from a set of alternatives. The decision method assumes the max-min principle approach. The fuzzy set decision is the intersection of all criteria:

$$\mu_{\alpha}(A) = \min \left[ \mu_{C_1}(A), \mu_{C_2}(A), \ldots, \mu_{C_n}(A) \right]$$

for all $A_i \in A$, and the optimal decision is yielded by:

$$\mu_{\alpha}(A) = \max _{A_i} \mu_{\alpha}(A_i)$$

where $\alpha$ is the optimal decision and $\mu$ is membership degrees of alternatives for each criterion.

A main difference in this approach is that the importance of criteria is represented as exponential scalars. This is based on the idea of linguistic hedges. The rationale behind using weights (or importance levels) as exponents is that the higher the importance of criteria, the larger should be the exponent, giving the minimum rule. Conversely, the less important a criterion, is the smaller its weight. This seems intuitive.

Formally:

$$\mu_{\alpha}(A) = \min \left[ \left[ \mu_{C_1}(A) \right]^x, \left[ \mu_{C_2}(A) \right]^x, \ldots, \left[ \mu_{C_n}(A) \right]^x \right]$$

where $\alpha$ is weight of the criteria (for $\alpha > 0$), Yager suggests the use of Saaty’s method for pairwise comparison of the criteria (attributes). A pair-wise comparison of criteria (attributes) could improve and facilitate the assessment of criteria importance. Yager suggests that, for a decision problem, the use of the resulting eigenvector expresses a decision maker’s empirical estimation of the level of importance of alternatives for a given criterion.

General information about the analyzed company

ELMAS natural stone factories are one of the most important groups of Turkey’s travertine industries. They have their own travertine quarries and two factories. The first ELMAS natural stone factory was founded in 1986, and they have been supplying the raw material from their own travertine quarry in Denizli for 21 years, so far. In 1997, the second natural stone factory was established in Eskisehir, which is located in the northwestern part of Turkey (Figure 1). After a travertine block produced from the travertine quarry in Denizli, the block is transported to the natural stone processing factory either in Denizli or Eskisehir. The travertine blocks can either go to a gang saw machine or to a block cutting machine. In the Denizli factory, travertine blocks are cut only as a strip and rough draft slabs (Figure 2). The strips and rough draft slabs are transported to the factory in Eskisehir to be processed as polished travertine slabs. In the Eskisehir factory, travertine strips and rough draft slabs are processed in a sequence of calibrating, wax...
filling, dimensioning, polishing, chamfering, quality controlling and packing operations (Figure 2). Finally the terminal products are transported to Izmir port to be exported. The firm management has decided to establish a new natural stone factory in 2008. The four alternative plant locations are determined by the management as follows: Eskisehir-Muttalip, Bozuyuk, Afyon-Iscehisar and Denizli district. The four facility alternatives, the location of travertine quarry and two present factories can be seen in the map (Figure 1).

Application of FMADM to determine the location of new ELMAS natural stone factory

The criteria and sub-criteria assessed by an expert team consisting of one geology engineer, who is the manager of the firm and has 20 years of experience in the natural stone industry, two mining engineers, who have 10 years of experience in the natural stone industry, and one firm owner, who has 40 years of experience in the natural stone industry. All decisions have a common hierarchical structure whereby options are evaluated against the various criteria that promote the ultimate decision objective. The most convenient problem of the new natural stone factory plant location selection was structured in a hierarchy of different levels, as shown in Figure 3. The number of criteria and alternatives should be considered by the pairwise comparison matrix applications because of the consistency and validity of the decision-making process as stated by some researchers. The number of alternatives should be 7±2, otherwise the grouping method should be applied.

After structuring a hierarchy, the pairwise comparison matrix was constructed for each level. During the pairwise consideration, a nominal scale, given in Table I, was used for the evaluation. Each main criterion affecting plant location selection was compared with the others and the pairwise comparison matrix of main criteria was constructed and is given in Table II. In constructing pairwise comparison matrices, every expert team member constructed his own matrices. And, the final form of each pairwise comparison matrices was obtained, by averaging and rounding the values, assigned by each member.
Selection of plant location in the natural stone industry

After performing the comparison, the maximum eigen value ($\lambda_{max}$), consistency index ($CI$) and consistency ratio ($CR$) were found to perform pairwise comparison’s consistency.

$$\lambda_{max} = \frac{1}{n} \sum_{i=1}^{n} \sum_{j=1}^{n} a_{ij} \times w_j$$

where $\lambda_{max}$ is the maximal or principal eigen value, and $n$ is the matrix size, $a_{ij}$ is an element of pairwise comparison matrix, $w_j$ and $w_i$ is the $j$th and $i$th element of eigen values, respectively.

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

$$CR = \frac{CI}{RI}$$

where $RI$ is the random indices.

To find out whether the resulting consistency index is acceptable, the consistency ratio should be calculated. The consistency indices of randomly generated reciprocal matrices from the scale 1 to 9 are called the random indices, $RI$. The ratio of consistency index to $RI$ for the same-order matrix is called the consistency ratio, $CR$. Random indices are given in Table III.

As a general rule, a consistency ratio of 0.10 or less is considered acceptable. This means that the result here is less than ideal. In practice, however, consistency ratios exceeding 0.10 occur frequently.

As shown in Table II, the economy criterion is the most important factor (eigen value or priority 0.581) and it is followed by the production criterion. The mean $\lambda_{max}$ value is 4.081 which is near the matrix size and the $CR$ value is 0.030 which is less than 0.1. The pairwise comparison is acceptable and there is no need to make new comparisons again.

After constructing the pairwise comparison matrix of main criteria, all the subgroups of each main criterion should be compared with the others as shown in Table IV, V, VI and VII.

The respective weights of sub-criteria were finally obtained from the eigenvector of the matrix as shown in Table VIII. The total eigen values for each sub-criterion were

Table I

<table>
<thead>
<tr>
<th>Relative intensity definition</th>
<th>Of equal value</th>
<th>Slightly more value</th>
<th>Essential or strong value</th>
<th>Very strong value</th>
<th>Extreme value</th>
<th>Intermediate values</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
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<tr>
<td>5</td>
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<td>7</td>
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<tr>
<td>9</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>2,4,6,8</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

$\lambda_{max} = 4.081, CR = 0.030 \leq 0.1; OK$

After performing the comparison, the maximum eigen value ($\lambda_{max}$), consistency index ($CI$) and consistency ratio ($CR$) were found to perform pairwise comparison’s consistency.

Table II

<table>
<thead>
<tr>
<th>Main criteria</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
<th>Eigen values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy ($C_1$)</td>
<td>1</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>0.581</td>
</tr>
<tr>
<td>Production ($C_2$)</td>
<td>1/3</td>
<td>1</td>
<td>4</td>
<td>3</td>
<td>0.257</td>
</tr>
<tr>
<td>Marketing ($C_3$)</td>
<td>1/7</td>
<td>1/4</td>
<td>1</td>
<td>2</td>
<td>0.094</td>
</tr>
<tr>
<td>Environmental ($C_4$)</td>
<td>1/5</td>
<td>1/3</td>
<td>1/2</td>
<td>1</td>
<td>0.066</td>
</tr>
</tbody>
</table>

$\lambda_{max} = 4.081, CR = 0.030 \leq 0.1; OK$

Table III

<table>
<thead>
<tr>
<th>Order of the matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
</tr>
<tr>
<td>RI</td>
</tr>
</tbody>
</table>

* For validation, consistency and redundancy, the best number of criteria should be 7±2
Selection of plant location in the natural stone industry

calculated by multiplying the eigen value of its sub-criterion
given in Table IV (0.112 for Land sub-criterion) with the
eigen value of the main criteria given in Table II (0.581).
The eigenvector corresponds to the weights to be
associated with the memberships of each criterion. The
exponential weighting was consequently defined for each
criterion as: α1=0.065, α2=0.044, α3=0.33, α4=0.141,

\[ \lambda_{\text{max}} = 4.121, \text{CR} = 0.045 \leq 0.1; \text{OK} \]

<table>
<thead>
<tr>
<th>Table IV</th>
<th>Pairwise comparison matrix for the economy criterion and its sub-criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy criterion (C1)</td>
<td>C11</td>
</tr>
<tr>
<td>Land (C11)</td>
<td>1</td>
</tr>
<tr>
<td>Installation (C12)</td>
<td>1/2</td>
</tr>
<tr>
<td>Transportation (C13)</td>
<td>5</td>
</tr>
<tr>
<td>Tax reduction (C14)</td>
<td>3</td>
</tr>
</tbody>
</table>

\[ \lambda_{\text{max}} = 5.068, \text{CR} = 0.015 \leq 0.1; \text{OK} \]

<table>
<thead>
<tr>
<th>Table V</th>
<th>Pairwise comparison matrix for production criterion and its subcriteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production criterion (C2)</td>
<td>C21</td>
</tr>
<tr>
<td>Raw material (C21)</td>
<td>1</td>
</tr>
<tr>
<td>Manpower (C22)</td>
<td>1/2</td>
</tr>
<tr>
<td>Technology (C23)</td>
<td>1/3</td>
</tr>
<tr>
<td>Climate (C24)</td>
<td>1/4</td>
</tr>
<tr>
<td>Water supply (C25)</td>
<td>1/5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table VI</th>
<th>Pairwise comparison matrix for marketing criterion and its subcriteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketing criterion (C3)</td>
<td>C31</td>
</tr>
<tr>
<td>Close to market (C31)</td>
<td>1</td>
</tr>
<tr>
<td>New markets (C32)</td>
<td>1/2</td>
</tr>
</tbody>
</table>

\[ \lambda_{\text{max}} = 2, \text{CR} = 0 \leq 0.1; \text{OK} \]

<table>
<thead>
<tr>
<th>Table VII</th>
<th>Pairwise comparison matrix for environmental criterion and its subcriterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmental criterion (C4)</td>
<td>C41</td>
</tr>
<tr>
<td>Waste water (C41)</td>
<td>1</td>
</tr>
<tr>
<td>Waste stone (C42)</td>
<td>3</td>
</tr>
<tr>
<td>Visual pollution (C43)</td>
<td>7</td>
</tr>
<tr>
<td>Local regulations (C44)</td>
<td>2</td>
</tr>
</tbody>
</table>

\[ \lambda_{\text{max}} = 4.099, \text{CR} = 0.037 \leq 0.1; \text{OK} \]
Selection of plant location in the natural stone industry

Table IX shows the membership levels (ML) assigned by the expert team for each criterion (VH: Very High, H: High, MLL: More or Less High, M: Medium, MLL: More or Less Low, L: Low, VL: Very Low). The membership decision function (MDF) according to Yager\textsuperscript{10} was determined for each alternative and they are also given in Table IX.

Using membership degrees of alternatives for each criterion and weights of the criteria, the following results were obtained for each alternative according to Equation [3]:

\[ \mu_D(A_1) = \min(0.20, 0.901, 0.95, 0.934, 0.35, 0.934) \]

\[ \mu_D(A_2) = \min(0.35, 0.955, 0.80, 0.990, 0.50, 0.970, 0.05, 0.877) \]

\[ \mu_D(A_3) = \min(0.20, 0.897, 0.95, 0.997, 0.50, 0.954, 0.05, 0.817) \]

\[ \mu_D(A_4) = \min(0.20, 0.936, 0.95, 0.998, 0.50, 0.972, 0.05, 0.884) \]

Using the max-min Bellman and Zadeh principle, the final set was determined as below yielding the result:

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In conclusion, the Denizli (A_4) alternative resulted as the most suitable natural stone plant location with the membership degree of 0.862 when the membership degrees of the other alternatives were compared.
Selection of plant location in the natural stone industry

Sensitivity analysis

In order to improve the quality of the results, a sensitivity analysis was performed on the final outcome. Sensitivity analysis is concerned with ‘what kind of question should be asked to see if the final answer is stable to changes with different inputs from the aspect of judgements or priorities’. If the eigenvector of a criterion increases, the eigenvectors of the remaining criteria must decrease proportionately, and the global eigenvectors of the alternatives must be recalculated. Sensitivity analysis can also be used to determine the most important or critical criterion by computing the absolute or percentage amount by which the weight of any criterion must be changed in order to cause a switch in the ranking of either the top alternative or in any pair of alternatives.

Increasing or decreasing values of the eigenvector of the main criterion in a pairwise comparison matrix simulated for several scenarios. There was no change in the judgement evaluations in the final priority ranking when the eigenvector value of each criterion increased/decreased up to 6%. That is, the alternative ‘A4’ can always be selected as the most convenient option for the plant location, and alternative ‘A3’, ‘A2’ and ‘A1’ sequentially followed this alternative considering the final priorities.

The final decision found by the proposed FMADM model was compared with the simulated scenarios in Figure 5.

When the priority of the economy criterion is increased by 8%, alternative ‘A4’ should be selected (Figure 5). It can be concluded from the sensitivity analysis that the final result of the proposed FMADM model is mainly sensible to the increase of economy criterion.

Application of the AHP method to solve the same problem

The AHP method is one of the most widely used MADM tools and can be successfully applied to various mining applications. This is an eigen value approach to the pairwise comparison of components’ attributes and alternatives. Some key and basic steps involved in this methodology are:

1. State the problem
2. Broaden the objectives of the problem or consider all actors, objectives and its outcome
3. Identify the criteria that influence the behavior
4. Structure the problem in a hierarchy of different levels
5. Compare each element in the corresponding level and calibrate them on the numerical scale. This requires \( n \times (n - 1)/2 \) comparisons, where \( n \) is the number of elements with the considerations that diagonal elements are equal or 1 and the other elements will simply be the reciprocals of the earlier comparisons
6. Perform calculations to find the \( CI \), \( CR \), and normalized values for each criteria or alternative
7. If the \( \lambda_{max}, CI \) and \( CR \) are satisfactory then the decision is taken based on the normalized values; or else the procedure is repeated till these values lie in a desired range.

The AHP method was performed for the selection of the best plant location. The hierarchy structure is given in Figure 3 and the eigen values in the Table II; IV–VII were used in the analysis. After constructing a pairwise comparisons matrix of main criteria as shown in Table II and sub-criteria of each main criterion as shown in Table IV-VII, the pairwise comparison of the alternatives based on the each sub-criterion should be performed. Thus, fifteen pairwise comparison matrices between the alternatives and each sub-group were obtained, and four matrices were constructed in order to calculate each alternative’s final eigen values according to the main criteria. As there were four alternatives, the pairwise comparison matrix order was \( 4 \times 4 \) for each sub-group. An example of pairwise comparison matrices for the land cost sub-criterion of the economy main criterion is presented in Table X.

After the construction of a pairwise comparison matrix of alternatives for the other sub-criteria of the economy main criterion (installation, transportation and tax reduction), another matrix was constructed to calculate the final eigen values of the economy main criterion. Table XI shows overall priorities calculated from the sub-criteria of the economy main criterion. It is readily observed from Table XI that the most suitable alternative is Denizli (A4), which has the highest eigen value, when judged by the economy main criterion.

The final eigen values of the economy main criterion for each alternative is calculated by summing the product of the relative eigen values of each criterion and the relative eigen
Selection of plant location in the natural stone industry

Table X

<table>
<thead>
<tr>
<th>Land Cost (C1)</th>
<th>Eskeşehir (A1)</th>
<th>Bozuyuk (A2)</th>
<th>Aşyon (A3)</th>
<th>Denizli (A4)</th>
<th>Eigen Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eskisehir (A1)</td>
<td>1</td>
<td>1/5</td>
<td>1/2</td>
<td>1/2</td>
<td>0.097</td>
</tr>
<tr>
<td>Bozuyuk (A2)</td>
<td>5</td>
<td>3</td>
<td>3</td>
<td>5.33</td>
<td></td>
</tr>
<tr>
<td>Aşyon (A3)</td>
<td>2</td>
<td>1/3</td>
<td>1</td>
<td>0.186</td>
<td></td>
</tr>
<tr>
<td>Denizli (A4)</td>
<td>2</td>
<td>1/3</td>
<td>1</td>
<td>0.186</td>
<td></td>
</tr>
</tbody>
</table>

\[ \lambda_{max} = 4.004, CR = 0.002 = 0.1 \times OK \]

Table XI

<table>
<thead>
<tr>
<th>Overall priorities of the economy main criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Economy (C1)</td>
</tr>
<tr>
<td>---------------</td>
</tr>
<tr>
<td>A1</td>
</tr>
<tr>
<td>A2</td>
</tr>
<tr>
<td>A3</td>
</tr>
<tr>
<td>A4</td>
</tr>
</tbody>
</table>

Conclusion

Travertine processing is one of the most important parts of the natural stone industry. Today, the investment cost of an average sized natural stone processing plant is about $5 million. Because of the size of the investment, it is very important to determine the optimum natural stone plant location. The developed FMADM model from this study can be used for all natural stone types, and can generate an analysis for the worldwide natural stone industry.

DM applications can be applied for different branches of the mining industry. The number of criteria and alternatives should be considered by the decision maker in the DM, especially constructing pairwise comparison matrix applications because of the consistency and validity of the DM process. The number of alternatives should be 7±2, otherwise the grouping method should be applied in the same way presented in this study.

The selection of the most convenient plant location involves the interaction of several subjective and objective factors or criteria. Decisions are often complicated and many even embody contradiction. In this study, both FMADM and AHP models were developed considering the four main criteria and fifteen sub-criteria. Among four alternatives under consideration, variant Denizli (A4) is the most acceptable one with allowance for all main and sub-criteria in these analyses. However, a decision maker has to cope with several pairwise comparison matrices in the AHP method. This main disadvantage of the application of the AHP method can be overcome by employing the FMADM method in which fewer matrices are evaluated.

Unlike the traditional approach to plant location selection, FMADM is a more scientific method providing the integrity and objectivity of the estimation process. The model is transparent, and easy to comprehend and apply by the decision maker. The proposed method can be programmed to run effectively on relatively low-cost computing systems, thus providing the potential for wide-spread exploitation of the technique within the natural stone industry worldwide.

References

2. www.die.gov.tr (in Turkish).
Selection of plant location in the natural stone industry


