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Selection of the best strategy for Iran's quarries: SWOT-FAHP method

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Abstract
Iran has high potential and unique stone reserves in terms of variety of color, texture, quality, and economic value; nevertheless, in spite of growing mine production during the past decade, in many instances this potential has been overlooked. Therefore it is necessary to investigate strategic factors of these mines. The purpose of this study is to evaluate and determine the best strategies for Iran's quarries. To this end, the mines were analyzed using the Strengths, Weaknesses, Opportunities and Threats (SWOT) approach in combination with Fuzzy Analytic Hierarchy Process (FAHP). Firstly, an environmental analysis was performed and then the SWOT factors were identified. In this way, the sub-factors which have very significant effects on the mines were determined. Using the SWOT matrix, alternative strategies were developed. Subsequently, the strategies were prioritized and the best strategies for these mines were determined. The results show that conservative strategies are the best strategy group for Iran's quarries.

Keywords: *SWOT; fuzzy AHP; Decision factors; Strategy; Quarry.*

1. Introduction

Dimension stone is any type of natural rock material that is quarried in order to make blocks or slabs of rock that is cut to specific sizes and shapes. Dimensional stone is a collective term for various natural stones used for structural or decorative purposes in construction and monumental applications [1]. Stone production involves the separation of the block from the massif in a regular shape and desired dimensions free of any fracture and flaw as far as possible [2] important rocks used as dimensional stone are granite, limestone, marble, sandstone, and slate [3]. The major application of dimensional stone is within the construction sector, which accounts for over 80% of consumption, with the funerary monumental industry accounting for 15%, and various special applications for around 3% [4]. Considering the importance of building stones, strategic analysis of stone mines seems essential. In this paper, a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis was applied using the fuzzy approaches of a multi-attribute evaluation method, called the analytic hierarchy process (AHP) to the dimensional stone mines of Iran. Strategy selection with SWOT analysis is a complex problem in which many qualitative aspects must be considered. These kinds of aspects make the evaluation process hard and vague. The judgments from experts are always vague and linguistic rather than exact values. Thus, it is suitable and flexible to express the judgments of experts in fuzzy quantities. Additionally, the hierarchical structure is a good approach to describe these kinds of complicated evaluation problems. Fuzzy AHP has the capability of taking these situations into account with a hierarchical structure.

In this study, firstly the factors in the SWOT groups and alternative strategies were determined. Then the relative weights of these factors and the scores of the strategies were computed [4]. The aim of this study is to determine the priorities of strategies for Iran's quarries.

2. Iran's quarries

Iran's potential is good in the quarry and it is one of the major producers of dimensional stones. In terms of variety of color, texture, quality, and economic value, some of these reserves are unique and can be extracted and exported, creating jobs and income for the country [5]. Table 1 shows the number of active quarries, the numbers of quarries are preparing, the number of inactive quarries and the amount of reserve of different dimensional stones of Iran. As can be seen in Table 1, Iran has good potential in terms of dimensional stones.

Table 1. Statistics of stone deposits and mines in Iran [6]

Stone Type	Number of active quarries	Number of quarries under development	Number of inactive quarries	Reserve (1000 tons)
Travertine	155	16	36	350,307
Porcelain	156	5	25	249,148
Marble	398	2	26	672,215
Granite	232	37	273	476,691
Total	**950**	**60**	**360**	**1,748,361**

3. Using FAHP in SWOT Analysis

In the following discussion, the fundamentals of SWOT analysis and fuzzy AHP are given. Later, these techniques are combined to prioritize the mines strategies.

3.1. SWOT analysis

SWOT analysis is the most common techniques that can be used to analyze strategic cases [7]. SWOT is a frequently used tool for analyzing internal and external environments to attain a systematic approach and support for a decision situation [8,9]. The internal and external factors are referred to as strategic factors, and they are summarized within the SWOT analysis. Strengths and weaknesses constitute factors within the system that enable and hinder the organization from achieving its goal, respectively. Opportunities and threats were considered as exogenous factors that facilitate and limit the organization in attaining its goals, respectively [10]. SWOT analysis suggests the appropriate strategies in four categories SO, ST, WO and WT. The strategies identified as SO, involve making good use of opportunities by using the existing strengths. The ST is the strategies associated with using the strengths to remove or reduce the effects of threats. Similarly, the WO strategies seek to gain benefit from the opportunities presented by the external environmental factors by taking into account the weaknesses. The fourth and last is WT, in which the organization tries to reduce the effects of its threats by taking its weaknesses into account [9,11]. Figure1 shows how SWOT analysis fits into an environment scan.

The final goal of a strategic planning process, of which SWOT is an early stage, is to develop and adopt a strategy resulting in a good fit between internal and external factors [12].

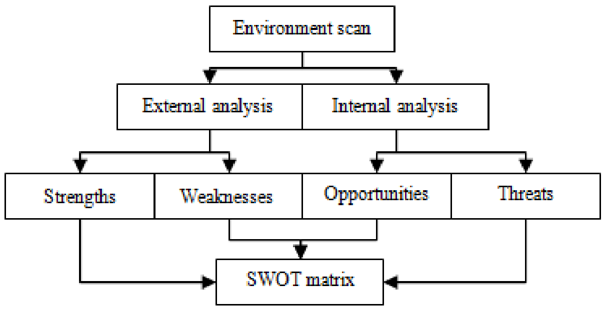

Figure1. SWOT analysis framework

3.2. Fuzzy Analytic Hierarchy Process (FAHP)

The concept of fuzzy sets was first presented by Zadeh [13], which was oriented to the rationality of uncertainty due to imprecision or vagueness. Fuzzy sets theory providing a more widely frame than classic sets theory, has been contributing to capability of reflecting real world [14]. Fuzzy set theory is a better means for modeling imprecision arising from mental phenomena which are neither random nor stochastic. Human beings are heavily involved in the process of decision analysis. [15].

AHP is a decision analysis technique aiming at assessing multi-attribute alternatives [16]. AHP was proposed by Saaty [17,18]. AHP has been applied extensively to cope with situations with multiple criteria where subjective judgment is inherent. Furthermore, the AHP approach encourages and assists the user to methodically and logically appraise the importance of each criterion in relation to the others in a hierarchical structure [19]. The traditional AHP still cannot really reflect the human thinking style [20]. The traditional AHP method is problematic in that it uses an exact value to express the decision maker's opinion in a comparison of alternatives [21]. AHP method is often criticized due to its use of unbalanced scale of judgments and its inability to adequately handle the inherent uncertainty and imprecision in the pair-wise comparison process [22]. To overcome the shortcomings, FAHP was developed for solving the hierarchical problems.

In the literature, fuzzy AHP has been widely used in solving many complicated decision making problems. Van Laarhoven and Pedrcyz [23] proposed the first studies that applied fuzzy logic principle to AHP. Chang [24] introduced a new approach for handling FAHP, with the use of triangular fuzzy numbers for pair-wise comparison scale of FAHP, and the use of the extent analysis method for the synthetic extent values of the pair-wise comparisons. Ataei [25] used multi-criteria decision making for the selection of the alumina-cement plant location in the East-Azerbaijan province of Iran. Lee and Lin [26] combined fuzzy AHP with SWOT to evaluate the environmental relationships of international distribution centers in the Pacific-Asia region. Kahraman et al. [27] used FAHP in SWOT analysis to evaluate and determine the alternative strategies for e-government applications in Turkey. Zare Naghadehi et al. [28] used FAHP approach to select optimum underground mining method for Jajarm Bauxite Mine, Iran. Finally, Nepal et al. [29] proposed a fuzzy-AHP approach to prioritize customer satisfaction attributes in target planning for automotive product development.

In this study the extent FAHP, which was originally introduced by Chang is utilized [24]. This method uses the triangular fuzzy numbers as a pair-wise comparison scale for deriving the priorities of factors and sub-factors. Also triangular fuzzy numbers are used for pair-wise comparison matrices. In addition, modeling using triangular fuzzy numbers has proven to be an effective way for formulating decision problems where the information available is subjective and imprecise [30,31,32]. In practical applications, the triangular form of the membership function is used most often for representing fuzzy numbers [33,34,35]. The definition of the triangular fuzzy numbers and the steps of Chang's extent analysis method are given in Appendix A and B respectively.

3.4. SWOT- FAHP analysis

Conventional SWOT does not provide the means to analytically determine the importance of the factors or to assess decision alternatives according to the factors [11]. Furthermore, SWOT analysis cannot appraise the strategic decision-making situation comprehensively [7]. The results of a SWOT analysis are often only a listing or an incomplete qualitative examination of internal and external factors [36,37,38]. FAHP is utilized in the SWOT approach to eliminate the weaknesses in the measurement and evaluation steps of the SWOT analysis. In this paper SWOT is used in combination with FAHP to provide a quantitative measure of the importance of each factor and to determine the priorities of the strategies. FAHP is applied in order to determine the overall priorities of the alternative strategies identified with SWOT analysis. To this end, these steps should be taken:

Step 1. *Identifying SWOT sub-factors and determining the alternative strategies*

As a first step, the factors in the SWOT groups and alternatives strategies should be identified. SWOT sub-factors should be recognized and the alternative strategies might be defined according to SWOT sub-factors. Using SWOT matrix, four alternative strategy categories including SO, ST, WO and WT are proposed.

Step 2. *Developing hierarchical structure based on the SWOT factors and sub-factors*

In this step, the problem to be solved is divided into a hierarchical structure with decision elements (Goal, Criteria, Sub-criteria and alternatives).

Step 3. *Pair-wise comparison*

Decision makers from different backgrounds may define different weight vectors. They usually cause not only the imprecise evaluation but also serious persecution during decision process. For this reason, group decision was used to improve pair-wise comparison. Firstly, each decision maker (Di) individually carries out pair-wise comparison by using Saaty's [39] 1–9 scale (Table 2).

Then, comprehensive pair-wise comparison matrixes are built by integrating decision makers' grades through Eq. (1) [40]. In this way, decision makers' pair-wise comparison values transform into triangular fuzzy numbers.

$$(\tilde{x}_{ij}) = (a_{ij}, b_{ij}, c_{ij})$$

$$l_{ij} = \min_{k}\{a_{ijk}\}, \qquad (1)$$

$$m_{ij} = \frac{1}{K}\sum_{k=1}^{K} b_{ijk}\ , \qquad u_{ij} = \max_{k}\{d_{ijk}\}$$

***Step 4.** Determining the relative weights of factors and sub-factors*

Weights of all criteria and sub-criteria are determined after forming fuzzy pair-wise comparison matrices. According to the FAHP method, synthesis values should first be calculated. Then fuzzy values are compared and priority weights are calculated according to appendix B.

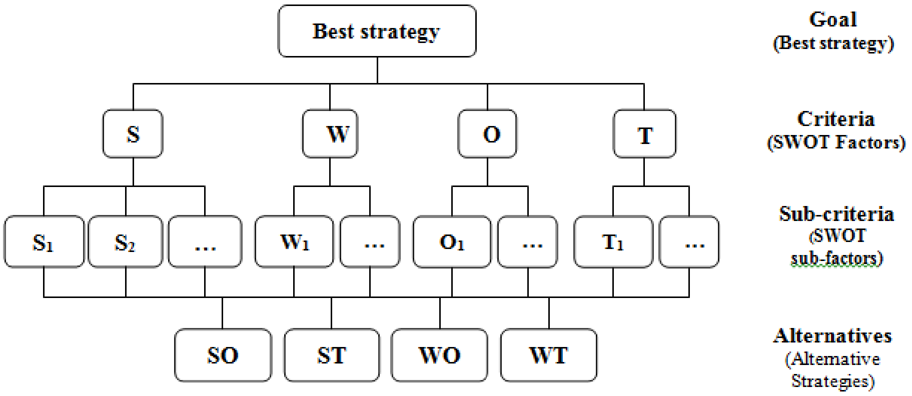

Figure2. The hierarchical structure representation of the SWOT model

Table 2. Pair-wise comparison scale [39]

Preferences expressed in numeric variables	Preferences expressed in linguistic variables
1	Equal importance
3	Moderate importance
5	Strong importance
7	Very strong importance
9	Extreme importance
2,4,6,8	Intermediate values between adjacent scale values

4. Implementing the SWOT- FAHP analysis for Iran's quarries

To implement the SWOT- FAHP analysis for Iran's quarries, first an external environment analysis is performed with the help of an expert team familiar with the Iran's dimensional stone mines. In this way, external SWOT sub-factors (opportunities, threats) are identified. In addition, an internal analysis is performed to determine the internal sub-factors (strengths, weaknesses). Based on these analyses, the strategically important sub-factors can be determined. Identified sub-factors are shown in Table 3.

Alternative strategies based on the SWOT factors and sub-factors are developed using the SWOT matrix (Table 4). Four alternative strategy groups exist in SWOT matrix. The aim of the current study is to determine priorities of these strategies and to find the best of them for Iran's quarries.

The problem is converted into a hierarchical structure (Figure 3) in order to transform the sub-factors and alternative strategies into a state in which they can be measured by the FAHP. The aim of "Determining the best strategy" is placed in the first level of the structure, the SWOT factors in the second level, the SWOT sub-factors in the third level and the alternative strategies in the last level of the model.

In the pair-wise comparison step, first the SWOT factors are compared with respect to the goal using the Saaty's scale. This study proposes a group decision based on FAHP. Firstly, each decision maker (Di) individually carries out pair-wise comparison by using Saaty's 1–9 scale. Then, a comprehensive pair-wise comparison matrix is built as in Table 5 by integrating five decision makers' grades through Eq. (1).

Table 3. SWOT factors and sub-factors for the strategy selection

	Factors	Sub-factors
Internal factors	**Strengths**	S_1: Existence of experienced manpower in mines S_2: High production according to the above facilities S_3: High investment in stone mines S_4: Feasibility to produce stone with various colors
	Weaknesses	W_1: Traditional management instead of scientific management W_2: Lack of management and support systems, including marketing and sales and etc W_3: Use of old machinery and equipment and not replace them in time W_4: Low production efficiency W_5: Lack of proper maintenance system for machineries and equipments
External factors	**Opportunities**	O_1: Existance of high stone reserves in the country O_2: High manpower potential in the country at various levels O_3: Domestic demand of processing factory for raw stones O_4: Take advantage of the government granted facilities for investment in stone mines
	Threats	T_1: Country sanctions and therefore lack of global effective interactions and tariffs T_2: Rising energy prices and transport costs if subsidies elimination T_3: High interest rates of banking facilities T_4: High prices of machinery and mine operating equipments T_5: Alternative products including ceramic and tile

Table 4. SWOT matrix

	Internal factors	
External factors	**Strengths (S)** S_1: Experienced manpower S_2: High production potency S_3: High investment in stone mines S_4: production of colored stones	**Weaknesses (W)** W_1: Traditional management W_2: Lack of support systems W_3: Using old machinery W_4: Low production efficiency W_5: Lack of proper maintenance
Opportunities (O) O_1: High stone reserves O_2: High manpower potential O_3: Domestic demand for raw stones O_4: Take advantage of facilities	**SO Strategies** 1- Developing productions according to high potential of Iran's stone mines 2- Developing exports considering the possibility of produce various products	**WO Strategies** 1- Using mechanized systems and automation to improve production efficiency 2- Developing the scientific management in the stone mines 3- Replacing worn out machineries
Threats (T) T_1: Country sanctions T_2: Rising energy prices T_3: High interest rates of facilities T_4: High prices of machinery T_5: Alternative products	**ST Strategies** 1- Increasing competitiveness with the development of various products 2- Cost reducing with mass production of good quality products	**WT Strategies** 1- Government sustaining of domestic manufactures of equipment and increase investment in this sector 2- Improving the interaction with various countries

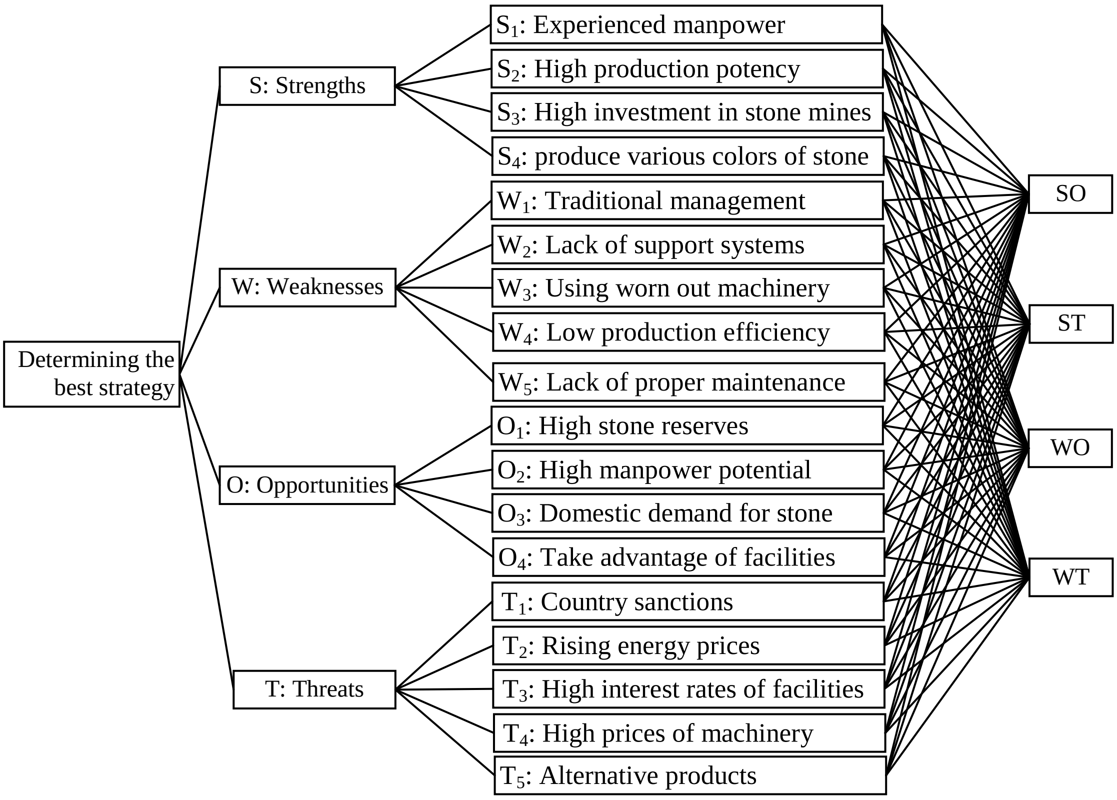

Figure 3. Hierarchical structure of SWOT model for Iran's quarries

Table 5. Fuzzy pair-wise comparison of SWOT factors

	S	W	O	T	$\sum_{j=1}^{m} M_{gi}^{j}$
S: Strengths	(1,1,1)	(0.33,0.61,1)	(0.5,0.83,1)	(0.33,0.61,1)	(2.17,3.06,4)
W: Weaknesses	(1,1.64,3)	(1,1,1)	(1,2,3)	(0.5,0.83,1)	(3.5,5.47,8)
O: Opportunities	(1,1.2,2)	(0.33,0.5,1)	(1,1,1)	(0.5,0.67,1)	(2.83,3.37,5)
T: Threats	(1,1.64,3)	(1,1.2,2)	(1,1.5,2)	(1,1,1)	(4,5.34,8)

Weights of all criteria are determined according to the Chang's extent analysis method that is given n Appendix B, Synthesis values must be calculated first. From Table 5, synthesis values with respect to main goal are calculated as follows:

$$\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j} = (12.5,17.23,25)$$

$$\left[\sum_{i=1}^{n}\sum_{j=1}^{m} M_{gi}^{j}\right]^{-1} = (0.040,0.058,0.080)$$

$S_S = (2.17,3.06,4) \otimes (0.040,0.058,0.080) = (0.087,0.177,0.320)$

$S_W = (3.5,5.47,8) \otimes (0.040,0.058,0.080) = (0.140,0.317,0.640)$

$S_O = (2.83,3.37,5) \otimes (0.040,0.058,0.080) = (0.113,0.195,0.400)$

$S_T = (4,5.34,8) \otimes (0.040,0.058,0.080) = (0.160,0.310,0.640)$

These fuzzy values are compared and these values are obtained:

$V(S_S \geq S_W) = 0.56$, $V(S_S \geq S_O) = 0.92$, $V(S_S \geq S_T) = 0.55$,

$V(S_W \geq S_S) = 1$, $V(S_W \geq S_O) = 1$, $V(S_W \geq S_T) = 1$,

$V(S_O \geq S_S) = 1$, $V(S_O \geq S_W) = 0.68$, $V(S_O \geq S_T) = 0.68$,

$V(S_T \geq S_S) = 1$, $V(S_T \geq S_W) = 0.98$, $V(S_T \geq S_O) = 1$,

Then priority weights are calculated as:

$$d'(S) = \min(0.56, 0.92, 0.55) = 0.55$$
$$d'(W) = \min(1,1,1) = 1$$
$$d'(O) = \min(1, 0.68, 0.68) = 0.68$$
$$d'(T) = \min(1, 0.98, 1) = 0.98$$

Thus, the weight vector from Table 5 is calculated as $W' = (0.55,1,0.68,0.98)^T$. The normalized weight vector is $W_{Factors} = (0.171,0.312,0.211,0.306)^T$.

The weights for the SWOT sub-factors and the alternative strategies are calculated in a similar way to the fuzzy evaluation matrices. Pair-wise comparison matrices for the SWOT sub-factors are given in Tables 6-9 together with the calculated local weights.

The local weights of the alternative strategies with respect to each SWOT sub-factors are calculated. The details of the pair-wise comparison matrices and the calculated local weights are provided in Table 10. Figure 4 illustrates the priority weights of the categorized sub-factors. In the last stage of the analysis, overall priority weights of the alternative strategies are calculated as shown in Table 11.

Table 6. Fuzzy pair-wise comparison of strengths

	S1	S2	S3	S4	Local weights
S1	(1,1,1)	(1,2.33,4)	(2,2.67,3)	(0.25,0.58,1)	0.304
S2	(0.25,0.429,1)	(1,1,1)	(1,2.67,5)	(0.17,0.31,0.5)	0.244
S3	(0.333,0.375,0.5)	(0.2,0.38,1)	(1,1,1)	(0.2,0.47,1)	0.106
S3	(1,1.714,4)	(2,3.27,6)	(1,2.14,5)	(1,1,1)	0.346

Table 7. Fuzzy pair-wise comparison of weaknesses

	W1	W2	W3	W4	W5	Local weights
W1	(1,1,1)	(0.25,0.417,0.5)	(1,2.333,3)	(0.167,0.306,0.5)	(1,1.67,2)	0.184
W2	(2,2.4,4)	(1,1,1)	(1,2.67,4)	(0.25,0.528,1)	(1,2,4)	0.258
W3	(0.333,0.43,1)	(0.25,0.375,1)	(1,1,1)	(0.25,0.528,1)	(0.5,0.67,1)	0.114
W4	(2,3.273,6)	(1,1.89,4)	(1,1.89,4)	(1,1,1)	(0.333,1.11,2)	0.266
W5	(0. 5,0.6,1)	(0.25,0.5,1)	(1,1.5,2)	(0.5,0.9,3)	(1,1,1)	0.178

Table 8. Fuzzy pair-wise comparison of opportunities

	O1	O2	O3	O4	Local weights
O1	(1,1,1)	(1,1.67,2)	(1,1.333,2)	(1,3,5)	0.319
O2	(0.5,0.6,1)	(1,1,1)	(0.33,0.61,1)	(0.5,1.5,3)	0.215
O3	(0.5,0.75,1)	(1,1.636,3)	(1,1,1)	(2,3.33,5)	0.312
O4	(0.2,0.333,1)	(0.33,0.67,2)	(0.2,0.3,0.5)	(1,1,1)	0.154

Table 9. Fuzzy pair-wise comparison of threats

	T1	T2	T3	T4	T5	Local weights
T1	(1,1,1)	(3,0.333,4)	(1,2,3)	(1,2,3)	(1,1.67,3)	0.296
T2	(0.25,0.3,0.333)	(1,1,1)	(0.25,0.583,1)	(0.2,0.511,1)	(1,1.333,2)	0.113
T3	(0.333,0.5,1)	(1,1.714,4)	(1,1,1)	(0.2,0.567,1)	(1,2.67,4)	0.231
T4	(0.333,0.5,1)	(1,1.957,5)	(1,1.765,5)	(1,1,1)	(2,3.67,5)	0.281
T5	(0.333,0.6,1)	(0.5,0.75,1)	(025,0.375,1)	(0.2,0.273,0.5)	(1,1,1)	0.080

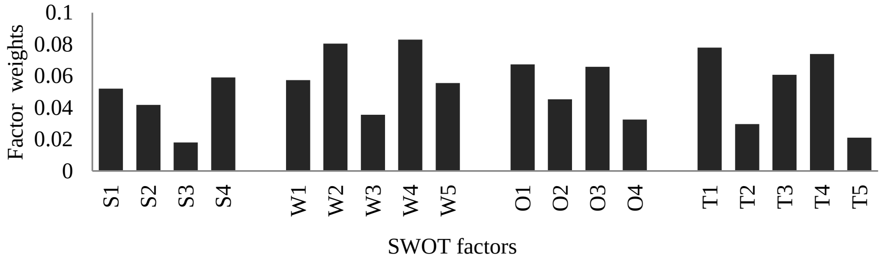

Figure 4. The priority weights of the SWOT sub-factors

Table 10. Pair-wise comparisons of the alternative strategies based on the SWOT sub-factors

		SO	ST	WO	WT	Local weights
S1	**SO**	(1,1,1)	(2,3,4)	(3,5,7)	(6,6.67,7)	0.581
	ST	(0.25,0.333,0.5)	(1,1,1)	(3,3.67,5)	(7,7.67,8)	0.419
	WO	(0.143,0.2,0.333)	(0.2,0.273,0.333)	(1,1,1)	(2,3.33,4)	0.000
	WT	(0.143,0.15,0.167)	(0.125,0.130,0.143)	(0.25,0.3,0.5)	(1,1,1)	0.000
S2	**SO**	(1,1,1)	(0.5,0.83,1)	(3,4.33,6)	(1,3,5)	0.398
	ST	(1,1.2,22)	(1,1,1)	(2,3,4)	(2,4,6)	0.399
	WO	(0.167,0.217,0.33)	(0.143,0.2,0.333)	(1,1,1)	(1,2,3)	0.146
	WT	(0.2,0.333,1)	(0.167,0.25,0.5)	(0.333,0.5,1)	(1,1,1)	0.057
S3	**SO**	(1,1,1)	(0.333,0.78,1)	(1,2.67,4)	(1,3,5)	0.336
	ST	(1,1.286,3)	(1,1,1)	(1,2.33,3)	(2,3.33,4)	0.348
	WO	(0.25,0.375,1)	(0.333,0.429,1)	(1,1,1)	(2,3,4)	0.249
	WT	(0.2,0.333,1)	(0.25,0.3,0.5)	(0.25,0.333,0.5)	(1,1,1)	0.067
S4	**SO**	(1,1,1)	(1,2,3)	(5,6,7)	(4,6,8)	0.529
	ST	(0.333,0.5,1)	(1,1,1)	(4,5.67,7)	(4,6,8)	0.471
	WO	(0.143,0.167,0.2)	(0.143,0.176,0.25)	(1,1,1)	(0.5,1.17,2)	0.000
	WT	(0.125,0.167,0.25)	(0.125,0.167,0.25)	(0.5,0.857,2)	(1,1,1)	0.000
W1	**SO**	(1,1,1)	(2,3.33,5)	(0.11,0.167,0.2)	(0.25,0.31,0.33)	0.000
	ST	(0.2,0.3,0.5)	(1,1,1)	(0.11,0.12,0.13)	(0.13,0.16,0.2)	0.000
	WO	(5,6.279,9)	(8,8.308,9)	(1,1,1)	(1,2.33,3)	0.701
	WT	(3,3.273,4)	(5,6.412,8)	(0.333,0.429,1)	(1,1,1)	0.299
W2	**SO**	(1,1,1)	(0.5,0.83,1)	(0.2,0.26,0.33)	(0.25,0.31,0.33)	0.000
	ST	(1,1.2,2)	(1,1,1)	(0.2,0.34,0.5)	(0.2,0.29,0.33)	0.000
	WO	(3,3.83,5)	(2,2.903,5)	(1,1,1)	(0.33,0.33,0.33)	0.401
	WT	(3,3.273,4)	(3,3.462,5)	(3,3,3)	(1,1,1)	0.599
W3	**SO**	(1,1,1)	(0.5,0.83,1)	(0.11,0.13,0.14)	(0.14,0.17,0.2)	0.000
	ST	(1,1.2,2)	(1,1,1)	(0.11,0.13,0.14)	(0.14,0.23,0.33)	0.000
	WO	(7,8.217,9)	(7,7.916,9)	(1,1,1)	(2,3.33,5)	0.733
	WT	(5,5.89,7)	(3,4.437,7)	(0.2,0.3,0.5)	(1,1,1)	0.267
W4	**SO**	(1,1,1)	(1,1,1)	(0.11,0.13,0.14)	(0.14,0.16,0.17)	0.000
	ST	(1,1,1)	(1,1,1)	(0.11,0.12,0.14)	(0.14,0.23,0.33)	0.000
	WO	(7,7.916,9)	(7,8.217,9)	(1,1,1)	(2,3,4)	0.767
	WT	(6,6.3,7)	(3,4.437,7)	(0.25,0.333,0.5)	(1,1,1)	0.233
W5	**SO**	(1,1,1)	(0.5,0.83,1)	(0.2,0.24,0.33)	(0.17,0.22,0.33)	0.000
	ST	(1,1.2,2)	(1,1,1)	(0.14,0.19,0.25)	(0.2,0.26,0.33)	0.000
	WO	(3,4.091,5)	(4,5.362,7)	(1,1,1)	(0.33,0.78,1)	0.511
	WT	(3,4.5,6)	(3,3.83,5)	(1,1.286,3)	(1,1,1)	0.489
O1	**SO**	(1,1,1)	(4,5.67,7)	(1,2,3)	(5,6.33,8)	0.601
	ST	(0.143,0.176,0.25)	(1,1,1)	(0.17,0.25,0.33)	(0.5,0.83,1)	0.000
	WO	(0.333,0.5,1)	(3,4,6)	(1,1,1)	(3,4.33,6)	0.399
	WT	(0.125,0.158,0.2)	(1,1.2,2)	(0.167,0.23,0.33)	(1,1,1)	0.000
O2	**SO**	(1,1,1)	(5,6.67,8)	(1,2.33,4)	(5,6.33,8)	0.615
	ST	(0.125,0.15,0.2)	(1,1,1)	(0.14,0.23,0.33)	(0.5,1.17,2)	0.000
	WO	(0.25,0.429,1)	(3,4.437,7)	(1,1,1)	(3,4.33,5)	0.385
	WT	(0.125,0.158,0.2)	(0.5,0.857,2)	(0.2,0.231,0.333)	(1,1,1)	0.000
O3	**SO**	(1,1,1)	(0.33,1.11,2)	(2,2.67,3)	(3,3.33,4)	0.358
	ST	(0.5,0.9,3)	(1,1,1)	(1,1.67,3)	(1,2,3)	0.276
	WO	(0.33,0.38,0.5)	(0.333,0.6,1)	(1,1,1)	(5,6.33,8)	0.366
	WT	(0.25,0.3,0.33)	(0.33,0.5,1)	(0.125,0.158,0.2)	(1,1,1)	0.000

O4	**SO**	(1,1,1)	(3,4.33,6)	(0.5,1.83,3)	(3,5.67,8)	0.534
	ST	(0.167,0.231,0.33)	(1,1,1)	(0.17,0.39,0.5)	(0.5,1.17,2)	0.037
	WO	(0.33,0.545,2)	(2,2.57,6)	(1,1,1)	(3,3.67,5)	0.404
	WT	(0.125,0.17,0.33)	(0.5,0.857,2)	(0.2,0.273,0.33)	(1,1,1)	0.025
T1	**SO**	(1,1,1)	(0.17,0.29,0.5)	(0.25,0.36,0.5)	(0.13,0.24,0.33)	0.000
	ST	(2,3.462,6)	(1,1,1)	(2,3,4)	(0.17,0.56,1)	0.373
	WO	(2,2.769,4)	(0.25,0.33,0.5)	(1,1,1)	(0.17,0.19,0.25)	0.111
	WT	(3,4.235,8)	(1,1.8,6)	(4,5.143,6)	(1,1,1)	0.517
T2	**SO**	(1,1,1)	(0.17,0.25,0.33)	(0.17,0.33,0.5)	(0.11,0.17,0.25)	0.000
	ST	(3,4,6)	(1,1,1)	(0.5,0.83,1)	(0.2,0.24,0.33)	0.202
	WO	(2,3,6)	(1,1.2,2)	(1,1,1)	(0.17,0.31,0.5)	0.233
	WT	(4,5.95,9)	(3,4.09,5)	(2,3.273,6)	(1,1,1)	0.565
T3	**SO**	(1,1,1)	(0.33,0.78,1)	(0.14,0.18,0.2)	(0.14,0.18,0.2)	0.000
	ST	(1,1.286,3)	(1,1,1)	(0.2,0.34,0.5)	(1,1.33,2)	0.112
	WO	(5,5.526,7)	(2,2.9,5)	(1,1,1)	(0.33,0.61,1)	0.471
	WT	(5,5.53,7)	(0.5,0.75,1)	(1,1.636,3)	(1,1,1)	0.416
T4	**SO**	(1,1,1)	(1,1.33,2)	(0.11,0.12,0.14)	(0.13,0.14,0.17)	0.000
	ST	(0.5,0.75,1)	(1,1,1)	(0.11,0.15,0.2)	(0.13,0.15,0.2)	0.000
	WO	(7,8.22,9)	(5,6.879,9)	(1,1,1)	(0.5,0.83,1)	0.523
	WT	(6,6.904,8)	(5,6.667,8)	(1,1.2,2)	(1,1,1)	0.477
T5	**SO**	(1,1,1)	(0.13,0.14,0.14)	(0.25,0.31,0.33)	(0.11,0.13,0.17)	0.000
	ST	(7,7.3,8)	(1,1,1)	(3,5,7)	(0.33,0.78,1)	0.491
	WO	(3,3.273,4)	(0.143,0.2,0.333)	(1,1,1)	(0.13,0.22,0.33)	0.000
	WT	(6,7.714,9)	(1,1.286,3)	(3,4.557,8)	(1,1,1)	0.509

Table 11. Priority weights of SWOT factors, sub-factors and alternative strategies

SWOT factors & their priorities		**SWOT sub-factors & their priorities**		**Alternative Strategies**			
				SO	**ST**	**WO**	**WT**
Strengths	0.171	S_1	0.304	0.581	0.419	0.000	0.000
		S_2	0.244	0.398	0.399	0.146	0.057
		S_3	0.106	0.336	0.348	0.249	0.067
		S_4	0.346	0.529	0.471	0.000	0.000
Weaknesses	0.312	W_1	0.184	0.000	0.000	0.701	0.299
		W_2	0.258	0.000	0.000	0.401	0.599
		W_3	0.114	0.000	0.000	0.733	0.267
		W_4	0.266	0.000	0.000	0.767	0.233
		W_5	0.178	0.000	0.000	0.511	0.489
Opportunities	0.211	O_1	0.319	0.601	0.000	0.399	0.000
		O_2	0.215	0.615	0.000	0.385	0.000
		O_3	0.312	0.358	0.276	0.366	0.000
		O_4	0.154	0.534	0.037	0.404	0.025
Threats	0.306	T_1	0.296	0.000	0.373	0.111	0.517
		T_2	0.113	0.000	0.202	0.233	0.565
		T_3	0.231	0.000	0.112	0.471	0.416
		T_4	0.281	0.000	0.000	0.523	0.477
		T_5	0.080	0.000	0.491	0.000	0.509
Weights				0.193	0.144	0.366	0.254

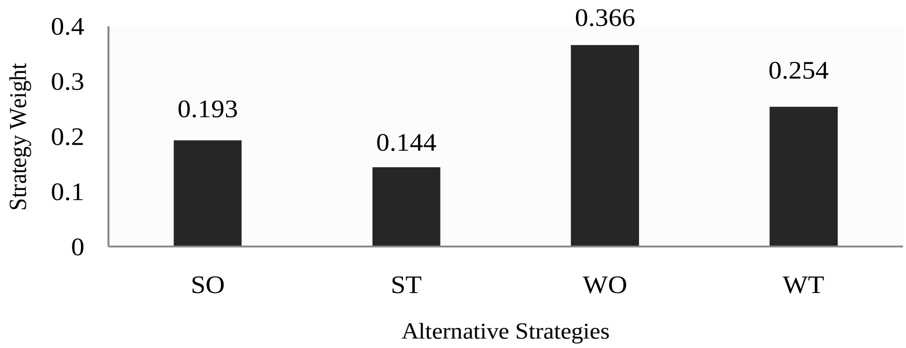

Figure 5. Ranking of the strategies

The results obtained from the SWOT-FAHP analysis are shown in Figure 5. According to the analysis, alternative strategies are ordered as WO, WT, SO and ST. The results indicate that WO is the best strategy group with an overall priority value of 0.366.

5. Discussion and conclusions

Considering the valuable stone deposits in Iran, analyzing strategic factors and developing appropriate strategies for the dimensional stone mines require special attention. In this study, the SWOT-FAHP hybrid method has been used to prioritize the alternative strategies and select the best strategy for these mines. In the SWOT analysis, strategic alternatives are selected in the view of the strengths, weaknesses, threats and opportunities as determined through internal and external environment analysis. FAHP is used in the SWOT approach to eliminate the weaknesses in the measurement and evaluation steps of the SWOT analysis.

An environment analysis was performed and the SWOT sub-factors, which have significant effect on the quarries, were identified. The factors from the SWOT analysis and the alternative strategies based on these factors were transformed into an FAHP model. The first four levels of the FAHP model consist of a goal (determining the best strategy group), 4 SWOT factors, 18 SWOT sub-factors and, 4 alternative strategies respectively. The relative importance of the alternative strategies and the overall priorities of the alternative strategies were calculated. According to the FAHP analysis, alternative strategies are ordered as WO, WT, SO and ST. The results indicate that WO is the best strategy for Iran's quarries. Therefore, according to the SWOT matrix, using mechanized systems and automation to improve production efficiency, develop the scientific management in the stone mines and replace worn out machineries were determined as proper strategies.

The research results emphasize the importance of using new technologies, mechanized systems and automation. Furthermore, it is essential that scientific management improve performance and productivity in the quarries.

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Appendix A.

The triangular fuzzy numbers

A tilde '~' will be placed above a symbol if the symbol represents a fuzzy set. A triangular fuzzy number (TFN), $\tilde{M}$ is shown in Figure 6. A TFN is denoted simply as $(l|m, m|u)$ or (l,m,u). The parameters l, m and u, respectively, denote the smallest possible value, the most promising value, and the largest possible value that describe a fuzzy event.

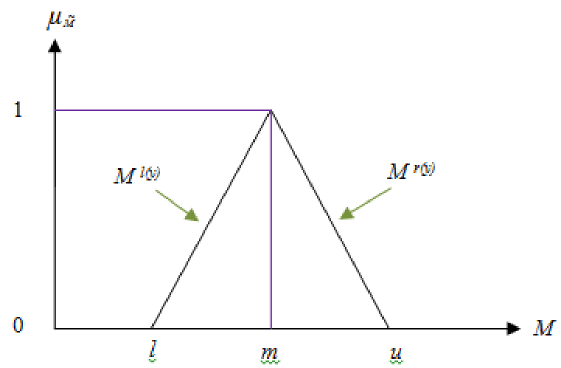

Figure 6. A triangular fuzzy number, $\tilde{M}$

Each TFN has linear representations on its left and right side such that its membership function can be defined as

$$\mu(x|\tilde{M}) = \begin{cases} 0 & x < l \\ (x-l)/(m-l) & l \le x \le m \\ (u-x)/(u-m) & m \le x \le u \\ 0 & x > u \end{cases} \quad (2)$$

A fuzzy number can always be given by its corresponding left and right representation of each degree of membership:

$$\tilde{M} = (M^{l(y)}, M^{r(y)}) = (l+(m-l)y, u+(m-u)y), \quad y \in [0,1], \quad (3)$$

Where $l(y)$ and $r(y)$ denote the left side representation and the right side representation of a fuzzy number, respectively. Many ranking methods for fuzzy numbers have been developed in the literature. These methods may give different ranking results and most methods are tedious in graphic manipulation requiring complex mathematical calculation.

Appendix B.

Chang's extent analysis method

Let $X = \{x_1, x_2, x_3, ..., x_n\}$ an object set, and $G = \{g_1, g_2, g_3, ..., g_n\}$ be a goal set. According to the method of Chang's extent analysis, each object is taken and extent analysis for each goal performed respectively. Therefore, m extent analysis values for each object can be obtained, with the following signs:

$$M_{gi}^1, M_{gi}^2, ..., M_{gi}^m, \qquad i = 1, 2, ..., n,$$

Where $M_{gi}^j \; (j = 1, 2, ..., m)$ all are TFNs. The steps of Chang's extent analysis can be given as in the following:

Step 1. The value of fuzzy synthetic extent with respect to the i th object is defined as:

$$S_i = \sum_{j=1}^{m} M_{gi}^j \otimes \left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} \quad (4)$$

To obtain $\sum_{j=1}^{m} M_{gi}^j$, the fuzzy addition operation of m extent analysis values for a particular matrix is performed such as:

$$\sum_{j=1}^{m} M_{gi}^j = \left(\sum_{j=1}^{m} l_j, \sum_{j=1}^{m} m_j, \sum_{j=1}^{m} u_j \right) \quad (5)$$

and to obtain $\left[\sum_{j=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1}$, the fuzzy addition operation of $M_{gi}^j \; (j = 1, 2, ..., m)$ values is performed such as:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j = \left(\sum_{i=1}^{n} l_i, \sum_{i=1}^{n} m_i, \sum_{i=1}^{n} u_i \right) \quad (6)$$

and then the inverse of the vector above is computed, such as:

$$\left[\sum_{i=1}^{n} \sum_{j=1}^{m} M_{gi}^j \right]^{-1} = \left(\frac{1}{\sum_{i=1}^{n} u_i}, \frac{1}{\sum_{i=1}^{n} m_i}, \frac{1}{\sum_{i=1}^{n} l_i} \right) \quad (7)$$

Step 2. As $M_1 = (l_1, m_1, u_1)$ and $M_2 = (l_2, m_2, u_2)$ are two triangular fuzzy numbers, the degree of possibility of $M_2 = (l_2, m_2, u_2) \ge M_1 = (l_1, m_1, u_1)$ is defined as:

$$V(M_2 \ge M_1) = \sup_{y \ge x} \left[\min(\mu_{M_1}(x), \mu_{M_2}(y)) \right] \quad (8)$$

and can be expressed as follows:

$$V(M_2 \ge M_1) = hgt(M_1 \cap M_2) = \mu_{M_2}(d) \quad (9)$$

$$= \begin{cases} 1 & \text{if } M_2 \ge M_1 \\ 0 & \text{if } l_1 \ge u_2 \\ \dfrac{l_1 - u_2}{(m_2 - u_2) - (m_1 - l_1)} & \text{otherwise} \end{cases} \quad (10)$$

Figure 7. illustrates Eq. (9) where d is the ordinate of the highest intersection point D between μ_{M_1} and μ_{M_2} to compare M_1 and M_2, we need both the values of $V(M_1 \ge M_2)$ and $V(M_2 \ge M_1)$.

Step 3. The degree possibility for a convex fuzzy number to be greater than k convex fuzzy $M_i \;\; (i = 1, 2, ..., k)$ numbers can be defined by:

$$V(M \ge M_1, M_2, ..., M_k) = V\begin{bmatrix} (M \ge M_1) \text{ and } (M \ge M_2) \\ \text{and ... and } (M \ge M_k) \end{bmatrix} = \min V(M \ge M_i), \quad i = 1, 2, 3, ..., k \quad (11)$$

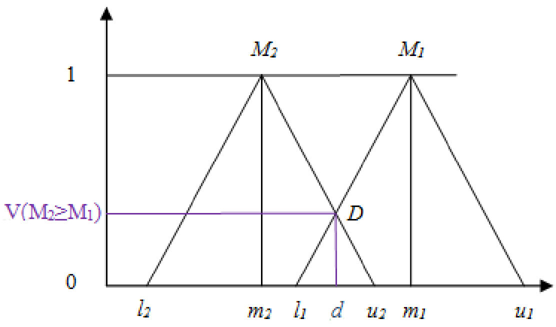

Figure 7. The intersection between M_1 and M_2

Assume that $d(A_i) = \min V(S_i \geq S_k)$ for $k = 1, 2, ..., n;\ k \neq i$. Then the weight vector is given by:

$$W' = (d'(A_1), d'(A_2), ..., d'(A_n))^{\mathrm{T}} \qquad (12)$$

where $A_i\ (i = 1, 2, ..., n)$ are n elements.

Step 4. Via normalization, the normalized weight vectors are:

$$W = (d(A_1), d(A_2), ..., d(A_n))^{\mathrm{T}} \qquad (13)$$

where W is a non-fuzzy number.

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