A New Methodology for Prioritizing Mining Strategies

Mohammad Majid Fouladgar, Abdolreza Yazdani-Chamzini, and Siamak Haji Yakhchali

***Abstract*—Mining plays one critical role in most countries and it acts as a foundation for growth and development. It produces raw material for other sectors such as industry, agriculture, etc. So, determining and prioritizing the strategies of mining are so important. Miscellaneous types of tools are offered for determining and evaluating of operational strategies. Analyzing the internal and external environments using SWOT (strengths, weaknesses, opportunities, and threats) helps to determine the current situation and to identify major prospects and challenges that could significantly impact strategy implementation in mining sector. Multi criteria decision making (MCDM) methods are appropriate tools to prioritize under sophisticated and environment. Analytical network process (ANP) and VIKOR (VlseKriterijumska Optimizacija I Kompromisno Resenje) are two hands of MCDM methods that are able to rank alternatives in decision problems with conflicting criteria. The main aim of this paper is to develop an integrated model based on SWOT, ANP, and VIKOR to prioritize the strategies of the Iranian mining sector. We employed the SWOT analysis to determine enforceable strategies; then, ANP was applied in order to obtain the weight of SWOT factors, finally the strategies were ranked by VIKOR technique. The results of proposed model show that improving the ability of exploitation and production outperforms other strategies.**

***Index Terms*—SWOT, ANP, VIKOR, Mining Strategies.**

I. Introduction

Organizations today deal with unprecedented challenges and opportunities in carrying out their vital mission. Managers always look for comprehensive picture of present situation of the organization and a clear understanding of its future organization. For this reason, they need background information of strengths, weaknesses, opportunities, and threats (SWOT) situation of the organization in order to invest the challenges and prospects of adopting organization. SWOT analysis is an effective framework for an organization (or a company) that helps to address the effectiveness of a project planning and implementation [1]. SWOT analysis is used in different sectors such as maritime transportation industry [2], technology development [3], device design [4], food microbiology [5], Hazard Analysis Critical Control Point [6], Environmental Impact Assessment [7], and tourism management [8].

However, the factors that can affect the SWOT are complex and often conflicting. One way to overcome the problem of evaluation performance with respect to various factors is the use of multiple criteria decision making (MCDM). The assumption of independence of criteria is not always correct because in real world, there are criteria that are dependence. Analytical network process (ANP) is an appropriate tool in order to model complex problems with all kinds of relationship, dependency and feedback in the model and draws a systematic figure of the decision making problem. Likewise, VIKOR technique is a suitable tool to evaluate alternatives. In this paper, we applied the SWOT analysis and two multi-attribute evaluation method that are called the analytic network process (ANP) and VIKOR techniques to rank the strategies of Iranian mining sector.

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II. The SWOT Analysis

The SWOT analysis has its origins in the 1960s [2]. It is an environmental analysis tool that integrates the internal strengths/weaknesses and external opportunities/threats.

This method is implemented in order to identify the key internal and external factors that are important to the objectives that the organization wishes to achieve [9]. The internal and external factors are known as strategic factors and are categorized via the SWOT analysis. Based on the SWOT analysis, strategies are developed which may build on the strengths, eliminate the weaknesses, exploit the opportunities, or counter the threats [2].

SWOT maximizes strengths and opportunities, and minimizes threats and weaknesses [10], and transforms the identified weaknesses into strengths, and to take advantage of opportunities along with minimizing both internal weaknesses and external threats. SWOT can provide a good basis for successful strategy formulation [11].

III. Analytical network process (ANP)

Analytical hierarchy process (AHP) was introduced by Saaty (1980) that is a mathematical technique for multi-criteria decision making [12]. This technique is based on pair-wise comparison matrix.

ANP is the general form of the analytic hierarchy process (AHP), which is introduced by Saaty (1996) in order to solve problems involving interaction and feedback among criteria or alternative solutions [13]. This method is able to consider network structures because many real world problems cannot be structured hierarchically. ANP is a general tool that is helpful in assisting the mind to organize its thoughts and experiences and to elicit judgments recorded in memory and quantify them in the form of priorities [14].

Fig. 1 illustrates the deference between hierarchy and network structures. As showed in Fig. 1, a hierarchy is a linear top down structure and network is a non-linear structure that spreads out in all directions.

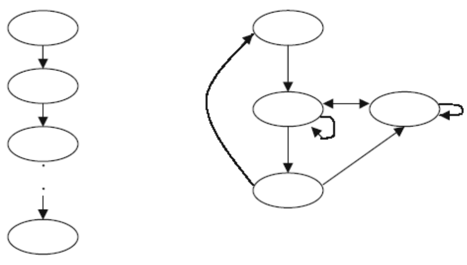


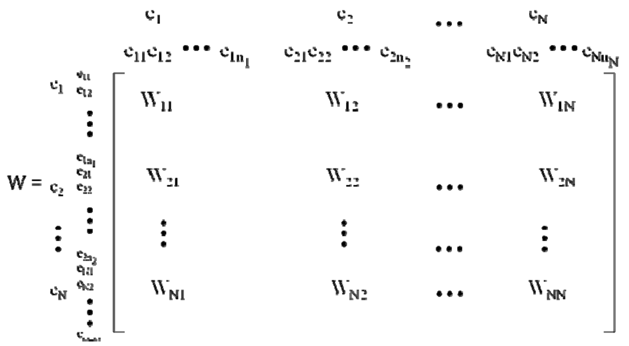
Fig. 1. The difference between a hierarchy (A) and a network (B)

ANP can be described in the following steps [15]:

Step1. Model construction and problem structuring: The derivation of the weights for all n components Cn regarding the dependencies in relevance to an overall criterion, which can be elicited based on expert knowledge.

Step 2. Pair-wise comparison matrices and priority vectors: decision elements at each component are compared Pair-wise with respect to their importance towards their control criterion, and the components themselves are also compared pair-wise with respect to their contribution to the goal.

Step 3. Supermatrix formation: Let the components (clusters) of a decision system be C_h, $h = 1,\ldots n$, and let each component h have m_h elements, denoted by $e_{h1}, e_{h2}, \ldots, e_{hmn}$. The influence of a set of elements belonging to a component, on any element from another component, can be represented as a priority vector by applying pair-wise comparisons in the same way as the AHP. A standard form of a supermatrix is as follows.



where W_{ij} is the principal eigenvector of the influence of the elements compared in the jth component to the ith component. In addition, if the jth component has no influence to the jth component, then $W_{ij} = 0$. The form of the supermatrix relies on the variety of its structure.

Step 4. Selection of the best alternatives: If supermatrix only includes components that are interrelated, additional calculations must be made to obtain the overall priorities of the alternatives. The alternative with the largest weight should be selected, as it is the best alternative as determined by the calculations made using matrix operations.

IV. VIKOR Approach

Opricovic (1998) [16] developed VIKOR (in Serbian: VlseKriterijumska Optimizacija I Kompromisno Resenje) for multicriteria optimization of complex systems [17]. This method determines the compromise solution, and is able to establish the stability of decision performance by replacing the compromise solution obtained with initial weights. The theory of the compromise solution is a feasible solution that is the closest to the ideal solution, and a compromise means an agreement established by mutual concession [2]. The concept of feasible solution (F^c) and the ideal solution (F^*) is shown schematically in Fig. 2.

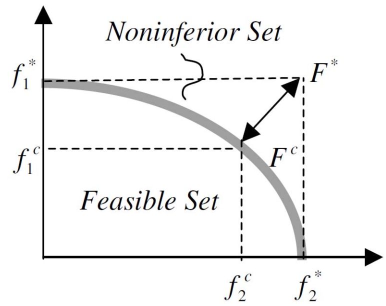


Fig. 2. Ideal and compromise solutions

VIKOR is a helpful tool in multi-criteria decision making, particularly in a situation where the decision maker is not able, or does not know to express his/her preference at the beginning of system design [18,19]. The main procedure of the VIKOR method is described below [19]:

A. Determine the best f_i^* and the worst f_i^- values of all criterion functions, $i = 1, 2, \ldots, n$.

$$f_i^* = \max_j f_{ij}, \; f_i^- = \min_j f_{ij} \cdot \quad (1)$$

If the ith function represents a cost then:

$$f_i^* = \min_j f_{ij}, \; f_i^- = \max_j f_{ij} \cdot \quad (2)$$

B. Compute the values S_j and $R_j, j = 1, 2, \ldots, J,$ by Eqs. (3), (4):

$$S_j = \sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-), \quad (3)$$

$$R_j = \max_i [\sum_{i=1}^{n} w_i (f_i^* - f_{ij}) / (f_i^* - f_i^-)], \quad (4)$$

Where w_i are the weights of criteria, expressing their relative importance.

C. Compute the value $Q_j, j = 1, 2, \ldots, J,$ by Eq. (5):

$$Q_j = v(S_j - S^*) / (S^- - S^*) + (1 - v)(R_j - R^*) / (R^- - R^*) \quad (5)$$

where

$$S^* = \min_j S_j, \quad S^- = \max_j S_j, \quad (6)$$

$$R^* = \min_j R_j, \quad R^- = \max_j R_j,$$

and v is introduced as weight of the strategy of "the majority of criteria" (or "the maximum group utility"), here $v = 0.5$.

D. Rank the alternatives, sorting by the values S, R, and Q, in decreasing order. The results are three ranking lists.

E. Propose as a compromise solution the alternative (a') which is ranked the best by the measure Q (minimum) if the following two conditions are satisfied:

C1. “Acceptable advantage”:

$$Q(a'') - Q(a') \geq DQ \tag{8}$$

where a'' is the alternative with second position in the ranking list by *Q*; $DQ = 1/(J-1)$; *J* is the number of alternatives.

C2. “Acceptable stability in decision making”:

The best alternative, ranked by *Q*, is the one with the minimum value of *Q*. The main ranking result is the compromise ranking list of alternatives, and the compromise solution with the “advantage rate”.

V. Case Study

Mining is one of the most activities so that other activities such as manufacturing, construction, and agriculture, could not exist without primary mineral production. Mining plays a leading social-economic role in Iran. At its various stages –from exploration to production and selling– it generates a significant number of jobs and income for the country. Due to the rising demand for primary minerals by the industrial countries and most rapidly growing economies, mining is becoming increasingly important.

Iran is a country located in the Middle East with a non-federated governmental system. Iran is divided into thirty provinces. Iran has one of the world's largest zinc reserves and second-largest reserves of copper. It also has important reserves of iron, uranium, lead, chromate, manganese, coal and gold.

VI. The Implementation of Proposed Model

The proposed model of this paper uses an integrated method of the SWOT analysis, ANP, and VIKOR to provide a framework for ranking the Iranian mining strategies. In order to implement the model, we first discuss the SWOT, and then the ANP approach is applied to obtain the weight of the SWOT factors. Finally, VIKOR ranks the Iranian mining strategies.

The data of the SWOT analysis are based on the aggregate mining strategy reports of the ministry of industries and mines. The term ‘strengths’ contains advantages and benefits from the adoption of strategic management practices. Similarly, weaknesses would encompass agents and parameters that are difficulties in the efforts of companies to accept any strategic management practices. Moreover, opportunities may include external benefits for companies from the acceptance of strategic management practices. Finally, threats may encompass future problems and difficulties from the prevention of implementing any strategic management practices. We prepared a list of strengths, weaknesses, opportunities, and threats, and then have an interview with the experts in mining strategies of Iran to modify the list. The results of the SWOT analysis based on expert knowledge are presented in Table 1.

TABLE 1. SWOT Analysis and Strategic Recommendations

	SWOT analysis	Recommended strategies
Internal	Strengths: S1. High potential of minerals, S2. Large resources of minerals, S3. Miscellaneous minerals	A1. Improving the ability of exploitation and production. A2. Investing in exploration sector. A3. Investing in the sciences of earth (information, technology, and labor force). A4. Important measures and politics in relevant organizations with mining sector and carrying out research & development (R&D). A5. The privatization of mines and relative industries. A6. The correction of rules and regulations and setting a cadastral system up.
	Weakness: Wn1. The lack of a complete data base, Wn2. Taking time from exploitation to sell, Wn3. Low efficiency in mining sector	
External	Opportunities: O1. Labor force with low wage, O2. Access to energy resource, O3. The strategic location of Iran, O4. Increasing demand for primary materials	
	Threats: T1. Exporting minerals without refining, T2. Non-membership of Iran in WTO, T3. High risk, T4. The fluctuations of row mineral prices	

As shown in Table 1, six strategies are earned from the SWOT analysis. These strategies in order to implement should be ranked because of the lack of finance and time as two limitations. For this reason, we applied the ANP technique and the VIKOR approach in order to obtain the weight of SWOT factors and prioritize strategies respectively. The proposed model is defined as follows:

Step 1: The hierarchy and network model proposed in this study for SWOT analysis is composed of four levels. The goal (best strategy) is indicated in the first level, the criteria (SWOT factors) and sub-criteria (SWOT sub-factors) are found in the second and third levels respectively, and the last level is composed of the alternatives (alternative strategies). The supermatrix of a SWOT hierarchy with four levels is as follows:

$$w = \begin{array}{r} Goal \\ SWOT\ factors \\ SWOT\ sub-factors \\ Alternatives \end{array} \begin{pmatrix} 0 & 0 & 0 & 0 \\ w_1 & W_2 & 0 & 0 \\ 0 & W_3 & 0 & 0 \\ 0 & 0 & W_4 & I \end{pmatrix}$$

Step 2: If assume that there is no dependence among the SWOT factors, pair-wise comparison of the SWOT factors using a 1–9 scale is made with respect to the goal. The importance weights of the criteria determined by twelve decision-makers that are obtained through Eq. (1) are shown in Table 2. The group consistency ratio (GCR) is available in the last row of the matrix.

$$x_{ij} = (\prod_{k=1}^{k} x_{ij}^{k})^{1/k} \quad (1)$$

where x_{ij} is the crisp weight of each criterion that are determined by all experts, k is the number of expert (here, k is equal to 12).

Step 3: Inner dependence among the SWOT factors is extracted by analyzing the impact of each factor on every other factor using pair-wise comparisons. As mentioned, existence of dependence among factors can be modeled through the ANP approach. The pair-wise comparison matrices are formed for the SWOT factors. Based on the computed relative importance weights, the inner dependence matrix of the SWOT factors (W2) is generated. As each factor of the SWOT is affected by two other factors, so that; S factor is affected by W and O factors, W factor is affected by S and T factors, O factor is affected by T and S factors, T factor is affected by W and O factors. The results are calculated as the following:

$$W_2 = \begin{pmatrix} 1 & 0.72 & 0.77 & 0 \\ 0.62 & 1 & 0 & 0.56 \\ 0.38 & 0 & 1 & 0.44 \\ 0 & 0.28 & 0.23 & 1 \end{pmatrix}$$

TABLE 2. PAIRWISE COMPARISON OF SWOT FACTORS WITH ASSUMPTION OF INDEPENDENCE

SWOT factors	S	W	O	T	Relative importance of SWOT factors
S	1	2.37	3.76	3.22	0.49
W	0.42	1	1.25	1.87	0.21
O	0.26	0.8	1	0.69	0.13
T	0.31	0.53	1.45	1	0.15
GCR=0.014					

Step 4: The interdependent weights of the SWOT factors are calculated as follows:

$$w_{factors} = W_2 \times w_1 = \begin{pmatrix} 1 & 0.72 & 0.77 & 0 \\ 0.62 & 1 & 0 & 0.56 \\ 0.38 & 0 & 1 & 0.44 \\ 0 & 0.28 & 0.23 & 1 \end{pmatrix} \times \begin{bmatrix} 0.49 \\ 0.21 \\ 0.13 \\ 0.15 \end{bmatrix} = \begin{bmatrix} 0.38 \\ 0.30 \\ 0.19 \\ 0.13 \end{bmatrix}$$

The results change from 0.49 to 0.38, 0.21 to 0.3, 0.13 to 0.19, and 0.15 to 0.13 for the priority values of factors S, W, O and T, respectively. As observed in the results obtained for the factor weights are difference significantly.

Step 5: The local weights of the SWOT sub-factors are calculated using the pair-wise comparison matrix. The pair-wise comparison matrices, which are weighted by twelve experts and then are calculated by Eq. (1), are presented in Table 3.

TABLE 3. PAIRWISE COMPARISON MATRICES FOR SWOT SUB-FACTORS LOCAL WEIGHTS

S	S1	S2	S3		Local weights
S1	1.00	0.56	3.21		0.331309
S2	1.79	1.00	4.86		0.55957
S3	0.31	0.21	1.00		0.109121
GCR=0.0017					
W	Wn1	Wn2	Wn3		
Wn1	1.00	0.43	0.34		0.158972
Wn2	2.33	1.00	0.71		0.356581
Wn3	2.94	1.41	1.00		0.484446
GCR=0.0007					
O	O1	O2	O3	O4	
O1	1.00	1.12	0.39	0.58	0.176427
O2	0.89	1.00	0.91	2.23	0.289132
O3	2.56	1.10	1.00	0.97	0.304467
O4	1.72	0.45	1.03	1.00	0.229975
GCR=0.073					
T	T1	T2	T3	T4	
T1	1.00	0.66	0.35	1.17	0.179075
T2	1.52	1.00	0.47	0.87	0.204373
T3	2.86	2.13	1.00	0.54	0.32839
T4	0.85	1.15	1.85	1.00	0.288162
GCR=0.097					

Step 6. The overall weights of the SWOT sub-factors are calculated by multiplying the interdependent weights of SWOT factors obtained in Step 4 with the local weights of SWOT sub-factors found in Step 5. The computations of $w_{sub\text{-}factors}$ (global) vector are provided below. The rank of global sub-factors is shown in Figure 5.

Step 7. At this step of the proposed model, the team members were asked to establish the decision matrix by comparing alternatives under each of the SWOT sub-factors. Based on the responses of twelve experts, and using Eq. (1) the obtained results are as shown in Table 4.

Step 8. After forming the decision matrix, according to S1, S2, S3, O1, O2, O3, and O4 criteria are benefit criteria, and Wn1, Wn2, Wn3, T1, T2, T3, and T4 are cost criteria, therefore the best f_i^* and the worst f_i^- values of all criterion functions are determined. Then, the values S_j and R_j are calculated as shown in Table 5.

TABLE 4. IMPORTANT RATING OF EACH ALTERNATIVE

	S1	S2	S3	Wn1	Wn2	Wn3	O1	O2	O3	O4	T1	T2	T3	T4
A1	5.21	7.56	3.43	2.21	3.37	1.67	6.13	7.79	5.24	6.56	6.46	4.93	4.21	3.19
A2	6.11	5.23	2.18	8.14	4.56	3.32	2.27	4.15	5.76	6.33	4.09	6.78	8.47	1.83
A3	5.73	3.67	5.26	7.43	4.12	4.21	4.16	4.77	4.33	5.89	6.24	4.43	6.31	4.15
A4	5.09	3.16	3.78	6.57	5.23	6.42	6.68	3.24	5.67	5.12	6.92	3.25	3.56	3.26
A5	4.13	6.2	4.97	4.31	2.69	1.62	8.06	5.86	5.23	8.47	5.13	5.14	7.49	2.16
A6	5.89	5.14	4.29	4.74	2.34	2.31	4.19	4.89	3.41	5.11	7.65	1.87	6.23	5.57

TABLE 5. THE VALUES S_j AND R_j

	S1	S2	S3	Wn1	Wn2	Wn3	O1	O2	O3	O4	T1	T2	T3	T4	S_j	R_j
A1	0.06	0.00	0.02	0.00	0.04	0.00	0.01	0.00	0.01	0.02	0.02	0.02	0.01	0.01	0.22	0.06
A2	0.00	0.11	0.04	0.05	0.08	0.05	0.03	0.04	0.00	0.03	0.00	0.03	0.04	0.00	0.51	0.11
A3	0.02	0.19	0.00	0.04	0.07	0.08	0.02	0.04	0.04	0.03	0.01	0.01	0.02	0.02	0.60	0.19
A4	0.06	0.21	0.02	0.04	0.11	0.15	0.01	0.05	0.00	0.04	0.02	0.01	0.00	0.01	0.73	0.21
A5	0.13	0.07	0.00	0.02	0.01	0.00	0.00	0.02	0.01	0.00	0.01	0.02	0.03	0.00	0.32	0.13
A6	0.01	0.12	0.01	0.02	0.00	0.02	0.02	0.04	0.06	0.04	0.02	0.00	0.02	0.04	0.43	0.12

Step 9: In this step, the value Q_j is measured with *v*=0.5 (voting by consensus). The results of Q_j and the ranking of alternatives (strategies) are presented in Table 6. According to Q_j values, the ranking of the alternatives in descending order are A1, A5, A6, A2, A3 and A4.

Now, two conditions are investigated as follows. The first condition is given as:

$$0.3237 - 0.0 \geq \frac{1}{6-1} \Rightarrow 0.3237 > 0.2$$

So, the first condition is satisfied. As presented in Table 5, alternative A1 also is the best ranked by S or/and R; therefore, the second condition is satisfied. Proposed model results indicate that A1 is the best alternative with the lowest Q_j .

TABLE 6. RANKING BY VIKOR METHOD

Alternatives	Q_j	Rank
A1	0	1
A2	0.4596347	4
A3	0.7913499	5
A4	1	6
A5	0.3205587	2
A6	0.3937607	3

VII. CONCLUSION

In this study, we proposed an integrated model of the SWOT analysis and ANP approach and VIKOR technique in order to rank feasible strategies. The SWOT analysis constructs a framework, and the weights of SWOT factors and alternatives are calculated via ANP and VIKOR respectively. The SWOT analysis was used in order to define strategies for Iranian mining sector. The SWOT analysis determined six strategies in order to implement in Iran. Then, ANP is employed to obtain the criteria weights and performance ratings when there is interdependence of characteristics. Finally, the VIKOR method is used to prioritize strategies. The results show that A1 has the highest rank. From this result, decision makers or authorities should improve the ability of exploitation and production.

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