Choosing shaft sinking method by using the combination of Fuzzy AHP & Fuzzy TOPSIS approaches

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Abstract
Shaft sinking is one of the main parts in underground mine planning. Shaft has various applications in underground mines e.g. minerals exiting flow, gases entrance or exit way, stope developments for exploitation etc. Considering that this section requires an abundance of expenses, management always following the election is the way that both terms have the technical considerations, economic constraints are also considered. Therefore, selecting shaft sinking method is one of the biggest concerns of underground mines management. There are some methods for this purpose including Delphi, ELECTRE, TOPSIS and AHP. This paper intends to use the combination AHP and TOPSIS methods under fuzzy environment in order to choose a ventilation shaft sinking method for Parvade mine located in coal zone of Tabas. The results indicate that RBM method is the most preferable approach, and drilling-blasting, Alimac, and SBM methods are preferred respectively.

Keywords: Shaft sinking, Tabas Parvade mine, Fuzzy AHP, Fuzzy TOPSIS

1-Introduction
Shafts are the most important of the deep ore bodies’ openings which are used to have access to ore bodies and serve the underground operations. In addition to sink new shafts, deepening available shafts is also desirable in this field. Various shaft applications in underground mines has made shaft sinking one of the most essential parts in underground planning and it is one of the major concerns of mine designers and mangers to decide on an appropriate method for shaft sinking. The most desirable method is one which considers all technical and environmental issues and has the minimum cost. Decision making on choosing the best shaft sinking method gets more complicated as all quantitative and qualitative criteria impact on the sinking method selection and these criteria are often in contrast with each other.

Multi attribute decision making methods like AHP (Analytical hierarchy process) and TOPSIS (Technique for order performance by similarity to ideal solution) are two beneficial approaches in decision making problems which can evaluate quantitative and qualitative criteria and sort the preferences (See table-1). On the other hand, due to uncertainties in data collection, these uncertainties should be used therefore fuzzy theory must also be used in making decisions. Therefore, this paper has tried to apply fuzzy AHP and fuzzy TOPSIS in order to help decision making on the type of shaft sinking of Parvade mine in Tabas coal zone. For this purpose, FAHP has evaluated criteria weight and then fuzzy TOPSIS has prioritized the alternatives.

1. Member of Student Researcher Club
2-Fuzzy theory

This theory has been first introduced by Lotfi A. Zadeh (1965). This theory works under uncertain conditions. This theory can change concepts, variables and systems which are vague and imprecise to mathematical forms and this can provide background for reasoning, inference, control and decision making in uncertainty conditions.

3-FAHP

AHP method has been introduced by Saaty [12]. This method enables decision makers to determine all interaction simultaneous impacts of many complicated situations. This system uses analyzing a problem into some detailed ones to solve the complicated problems. The first level is devoted to the purpose and the second level is the criteria in AHP. If any detailed criteria, they are in lower levels. AHP method was compounded with Fuzzy one in 1996 by Chang [13]. The following covers the steps in this approach.

Step 1- Forming fuzzy decision matrix: $S_k$, which is a fuzzy triangle number in each matrix paired comparison that as follow:

$$S_i = \sum_{j=1}^{m} M_{ij} \otimes \left[ \sum_{g=1}^{n} \sum_{j=1}^{m} M_{ig}^{-1} \right]^{-1}$$  \hspace{1cm} (7)

Where:

$$\sum_{j=1}^{m} M_{ij} = \left( \sum_{j=1}^{m} m_j \sum_{j=1}^{m} u_j \right) \sum_{j=1}^{m} M_{ij}$$  \hspace{1cm} (8)

Where "g" shows the row number, and "i" and "j" show the alternatives and criteria respectively.

Step 2- Finding the degree of possibility $S_g$. If $M_1$ and $M_2$ are two fuzzy triangle numbers, the degree of possibility of $M_1$ to $M_2$ is shown by $V(M_1 \geq M_2)$ and they are defined as:

$$V(M_1 \geq M_2) = \begin{cases} 1, & M_2 \geq M_1 \\ 0, & M_1 \geq M_2 \end{cases}$$

Also:

$$hgt(M_1 \geq M_2) = \frac{S_2 - 1}{(S_2 - 1) + (S_1 - S_2)}$$  \hspace{1cm} (9)

Step 3- Finding the degree of possibility of one fuzzy triangle number from "k" of another fuzzy number. The following equation can be used to determine the degree of greatness:

$$V(M_1 \geq M_2, ..., M_k) = \min[V(M_1 \geq M_2), ..., (M_k \geq M_n)]$$  \hspace{1cm} (10)

Criteria weight is calculated as follows:

$$w^{(S_2)} = \min[V(M_1 \geq S_2), k = 1, 2, ..., n \neq i]$$  \hspace{1cm} (11)

The paired matrix comparison and the criteria resultant will be as the below:

$$w' = [w'(c_1), w'(c_2), ..., w'(c_m)]$$  \hspace{1cm} (12)

3-Fuzzy TOPSIS

This method was offered by Hwang and Yoon in 1981 [14]. This theory asserts that the selected alternative should be in the shortest distance with the positive ideal solution (the best case), and in the biggest distance with the negative ideal solution (the worst case). The following six steps are to solve Fuzzy TOPSIS problems.
Step 1- At first the alternatives should be scored considering different criteria, qualitative concepts should be used to weigh each criterion.

Step 2- This stage establishes a normal weighting fuzzy matrix.

Step 3- Determining the positive ideal solution \((A^+)\) and negative ideal solution \((A^-)\): these positive and negative ideal solutions are defined as the below:

\[
A^* = (\bar{v}_1, \bar{v}_2, \bar{v}_3, \ldots, \bar{v}_n) = \left\{ \max_i v_j \left| i = 1, 2, \ldots, n \right. \right\}
\]

\[
A^- = (\bar{v}_1, \bar{v}_2, \bar{v}_3, \ldots, \bar{v}_n) = \left\{ \min_i v_j \left| i = 1, 2, \ldots, n \right. \right\}
\]

Step 4- Determining the distance of each alternative to positive and negative ideals. This distance of each option from positive ideal \((d_i^+)\) and the distance of each alternative to negative ideal \((d_i^-)\) are calculated as the following:

\[
d_i^+ = \sum_{j=1}^{n} d\left(\bar{v}_{ij}, \bar{v}_j^+\right) , \ i = 1, 2, \ldots, m
\]

\[
d_i^- = \sum_{j=1}^{n} d\left(\bar{v}_{ij}, \bar{v}_j^-\right) , \ i = 1, 2, \ldots, m
\]

Step 5- Determining relative closeness \((CL^*)\) of one alternative to ideal solution can be calculated as the following formula:

\[
CL^* = \frac{d_i^-}{d_i^- + d_i^+}
\]

6) Sorting the alternatives: the bigger \(CL\) is the better.

4- Fuzzy Member Function

The decision maker should compare the alternatives with the criteria and give them a weight. To serve this purpose, some verbal terms can be used. Table 2 illustrates the importance of these verbal terms.

5-Parvade mine (Tabas coal zone)

Tabas coal zone is located in the east of Iran. This zone divided on three parts; Parvade, Nayband and Mezino areas. Nayband and Parvade coals are coke ones And Mezino coal is the thermal one. The area of this zone is 30,000 square meters and Iran's biggest resources are reaching to billions tons are located in this zone. Parvade is 1200 square kilometers. Parvade located on 70 kilometers far from Tabas in the geographical area of 33 and 5 to 32 and 50 and the geographical length is 57 and 15 to 76 and 45. The height of this area is 850 meters above the sea level. Parvade is located between Rostam and Ghoori Chay faults. Some faults with north east tendency and south west ones divide this area into districts I, II, III, IV and eastern.

6- Selection of the shaft sinking method

There are many criteria for determining the most appropriate method for shaft sinking. According to comments of experts, the most important criteria for selection one of the sinking methods Raise Boring Machine (A1), Shaft Boring Machine (A2) and Alimac (A3), and
common methods as Drilling and Blasting (A4), have been chosen. Table 3 demonstrates indicators, symbols, and the way that each parameter influence choosing the shaft sinking methods for Parvade mines. The approach in this paper is using FAHP to obtain the weight of each criterion. Then Fuzzy TOPSIS sorts the alternatives. The criteria have been weighed by 13 experts. On the first FAHP matrix is obtained then Importance degree of each S over other S, has been calculated. Greatness of each fuzzy triangular number compared to other fuzzy triangular numbers and the final weight of FAHP have been shown in table 4. After that importance of each criterion to each alternative is weighed by experts. Normalized weighed fuzzy matrix has been mentioned in table 5. Finally, alternatives have been sorted according to their relative closeness. As it has been indicated in table 6, RBM is the first which means to be the most appropriate method for ventilation shaft sinking applied in Parvade coal mine. Blasting, Alimak and SBM have next ranks respectively.

7- Results
Selection the shaft sinking method is one of fundamental decisions in underground mines that influences designing and planning. There are many methods for decision making which have relative advantages and disadvantages. A combinational method can be used to have the most of advantages and achieve better results. On the other hand, due to uncertainty in decision making has necessitated Fuzzy method. This paper has tried to use a combinational method of Fuzzy AHP and Fuzzy TOPSIS to find out the best method for shaft sinking in Parvade coal mine located inside Tabas coal area. The results indicated that RBM is the best and most appropriate method. Drilling-Blasting, Alimak and SBM have the other ranks.

### Table-1: sample of multiple attribute decision making approach

<table>
<thead>
<tr>
<th>Proposed by</th>
<th>Method used</th>
<th>Year</th>
<th>Application areas</th>
</tr>
</thead>
<tbody>
<tr>
<td>H. Wu et al</td>
<td>TOPSIS, SAW,</td>
<td>2009</td>
<td>evaluating banking performance based on Balanced Scorecard[9]</td>
</tr>
<tr>
<td>Yavuz et al</td>
<td>AHP</td>
<td>2008</td>
<td>The optimum support design selection[10]</td>
</tr>
</tbody>
</table>

### Table 2: verbal terms for fuzzy rates

<table>
<thead>
<tr>
<th>Linguistic terms</th>
<th>Corresponding Fuzzy Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very bad</td>
<td>(0,0,1)</td>
</tr>
<tr>
<td>Bad</td>
<td>(0,1,3)</td>
</tr>
<tr>
<td>Medium bad</td>
<td>(1,3,5)</td>
</tr>
<tr>
<td>Medium</td>
<td>(3,5,7)</td>
</tr>
<tr>
<td>Medium good</td>
<td>(5,7,9)</td>
</tr>
<tr>
<td>Good</td>
<td>(7,9,10)</td>
</tr>
<tr>
<td>Very good</td>
<td>(9,10,10)</td>
</tr>
</tbody>
</table>
Table 3: Effective criteria in choosing the method

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Symbol</th>
<th>Water penetration</th>
<th>Advance rate</th>
<th>Rock mechanic features</th>
<th>Shaft length</th>
<th>Shaft diameter</th>
<th>Safety</th>
<th>Operation cost</th>
<th>Capital cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>effect</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>C1</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 4- final weight obtained of FAHP

<table>
<thead>
<tr>
<th>V(S1&gt;S2,S3,S4,S5,S6,S7,S8)</th>
<th>Local Weight</th>
<th>Global Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.662</td>
<td>0.0979</td>
<td></td>
</tr>
<tr>
<td>V(S2&gt;S1,S3,S4,S5,S6,S7,S8)</td>
<td>0.692</td>
<td>0.103</td>
</tr>
<tr>
<td>V(S3&gt;S1,S2,S4,S5,S6,S7,S8)</td>
<td>0.975</td>
<td>0.1443</td>
</tr>
<tr>
<td>V(S4&gt;S1,S2,S3,S5,S6,S7,S8)</td>
<td>0.785</td>
<td>0.1161</td>
</tr>
<tr>
<td>V(S5&gt;S1,S2,S3,S4,S6,S7,S8)</td>
<td>0.896</td>
<td>0.1326</td>
</tr>
<tr>
<td>V(S6&gt;S1,S2,S3,S4,S5,S7,S8)</td>
<td>0.746</td>
<td>0.1104</td>
</tr>
<tr>
<td>V(S7&gt;S1,S2,S3,S4,S5,S6,S8)</td>
<td>0.999</td>
<td>0.1478</td>
</tr>
<tr>
<td>V(S8&gt;S1,S2,S3,S4,S5,S6,S7)</td>
<td>1</td>
<td>0.148</td>
</tr>
</tbody>
</table>

Table 5- Normalized weighed fuzzy matrix

<table>
<thead>
<tr>
<th>A1</th>
<th>A2</th>
<th>A3</th>
<th>A4</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>0.065</td>
<td>0.081</td>
<td>0.098</td>
</tr>
<tr>
<td>C2</td>
<td>0.067</td>
<td>0.083</td>
<td>0.097</td>
</tr>
<tr>
<td>C3</td>
<td>0</td>
<td>0.035</td>
<td>0.072</td>
</tr>
<tr>
<td>C4</td>
<td>0</td>
<td>0.009</td>
<td>0.014</td>
</tr>
<tr>
<td>C5</td>
<td>0</td>
<td>0.027</td>
<td>0.046</td>
</tr>
<tr>
<td>C6</td>
<td>0.088</td>
<td>0.101</td>
<td>0.111</td>
</tr>
<tr>
<td>C7</td>
<td>0.094</td>
<td>0.111</td>
<td>0.148</td>
</tr>
<tr>
<td>C8</td>
<td>0</td>
<td>0.007</td>
<td>0.016</td>
</tr>
</tbody>
</table>

Table 6- final ranking of alternatives

<table>
<thead>
<tr>
<th>Ranking</th>
<th>CL_i</th>
<th>d_i</th>
<th>d_i'</th>
<th>Alternative</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>0.060250063</td>
<td>0.4836388</td>
<td>7.5435529</td>
<td>SBM</td>
</tr>
<tr>
<td>1</td>
<td>0.067037</td>
<td>0.537782</td>
<td>7.4843801</td>
<td>RBM</td>
</tr>
<tr>
<td>3</td>
<td>0.065938</td>
<td>0.528522</td>
<td>7.486919</td>
<td>Alimac</td>
</tr>
<tr>
<td>2</td>
<td>0.066573</td>
<td>0.5340034</td>
<td>7.487368</td>
<td>Drilling- Blasting</td>
</tr>
</tbody>
</table>

8- Reference


Methods for Equipments Selection in Surface Mining; review

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Abstract
One of the principal costs in mine is related to purchase and application of equipment. Proper fleet selection, in a way that it secures the production needs of a mine as well as minimizes costs of production, is one of the real challenges of mine planners. As such, with the selection of suitable fleet of equipment and their application, could minimize the capital and operational costs. Classifying the equipment selection process into three phases i.e. type of fleet, size of equipment and calculation of required numbers, the present article focuses on different application methods in each of these phases, their advantages and shortcomings.

Keywords: Surface Mining; Equipment Selection; sizing Equipment, Fleet Selection

1. Introduction
The production process in a mine is divided into four parts of drilling, blasting, loading and hauling. The later two aspects i.e. loading and hauling allocate more than half of the total mining cost. The cost related to purchasing loading equipment is more than the vehicles needed for other sections. However, the principal part of the operating costs is related to hauling. Table 1 highlights the share of each of components in the operation costs [1]. With respect to these higher costs, selection and application of type, size and number of equipment could significantly reduce the total production costs.

Equipments selection related to each section is accomplished with respect to existing operation limitation and circumstances as well as production needs. The equipment process in the mine is divided into three phases. First, transportation fleet is determined by taking into account physical and operational conditions of the area and the proposed rate of production. Second, size of suitable machine is distinguished by considering planning parameters. Finally, the required number of each of the equipment is determined in order to secure the proposed production.

2. Equipment Selection in Surface Mining
2.1. Selecting Fleet Type
For ore transportation at a surface mine, different fleets can be used. Shovel- truck and loader-truck are mostly utilized fleets, however; with respect to existing circumstances at the mine, equipments like dragline; bucket wheel excavator; in-pit crusher; and conveyer too could probably be used.

In this selection, multiplicity of parameters and alternatives may possibly lead to a number of complexities hence; selecting accurate equipment needs enough experience as well as taking into account all parameters in connection with each other. By this reason, at this stage, inclination is often toward a procedure where decision is being taken relying on experiences of experts. In this regard, on could point to application of expert system as well as multiple
attribute decision making technique. Fig.1 indicates effective parameters in selection fleet types [2].

**Expert System:** This is one of the first systems planned for selecting equipments in surface mining in 1987. In the proposed project, the main reasons described for using the expert system were the intense need of equipment selection process, past expertise, experiences and some of the effective parameters being qualitative hence; it tried to show the whole process of change of human experiences to an understandable language for computer in the field of mining equipments selection. This system is able to involve the expert knowledge in primary and secondary selection of equipment for surface coal mines [3]. In 1990, another expert system, in order to classify equipment, was planned in the open pit coal mine of Britain with the help of fuzzy logic. This expert system, for primary extraction method, employed drilling and hauling equipments and could receive geological information from software like SUPAC and DATAMINE. Data related to mine equipment is summoned from an external database [4]. The developmental process of expert system continued and in 1992, yet another system was planned for equipment needed for a project with soil conditions that includes 930 rules. This system was able to select equipments necessary for drilling, loading, hauling, placing and compacting earth and the proposed data consisted of bulldozer, scrapper, loader, trucks and compactors. For each type of equipment selected, there are unique qualities that must be considered (such as power, size, application etc.). The developed expert system can be used for earth-moving projects ranging in scope from 10,000 to 4,000,000 bank cu yd [5]. Yet another expert system was presented in 2002 that had basic differences with previous ones such as its interference to the uncertainty related to influential factors in the matter selections. This system was much reflective and apart from calculating uncertainty ratio, it permitted user to determine the rate of important elements in selecting equipments [6]. Some other expert systems have also been proposed for equipments selection, in which, scraper selection system [7] and dragline selector [8] are important.

**Mathematical Modeling:** In 1988, a mathematical model was presented for selecting equipment and analyzing their costs. This particular model is for fleets that principal equipments are excavator and truck. The proposed system consists of two optimum models. The first model is to select equipments for fleet with the aim of minimizing costs of excavating unit. In the second model, equipments with the aim to optimize rate of production are being assessed in the form of a fleet. Constraints to the proposed model include the rate of annual production, diggability, loader haul distances (limited to 150m), and number of passes that lead to fill trucks (limited to 3 to 6 bucket). The uses of the models can be summarized as the -selection of the optimum equipment fleet for a given stripping job, -the determination of the minimum stripping cost, -the evaluation of the contractors fleet from the view point of sufficiency, and -the estimation of the cost of performing the stripping with the contractors fleet [9].

**Genetic Algorithm:** In 1999, a system called XSOME was established on the basis of knowledgebase and using genetic algorithm. This system was designed to solve problems related to equipment selection of opencast mining. In this system, advanced genetic algorithms search techniques to find the input variables that can achieve the optimal cost, and linear programming was used to develop a compound system on the basis of knowledge base and genetic algorithm [10].
Queuing Theory: Using queuing theory, in 2003, a computerized model FLSelector was designed for mining and construction operations. This model was able to select the best fleet combination of loaders and haulers that can complete an earthmoving operation with optimum output (least cost, maximum production, or minimum project duration). These calculations are made on the basis of possible fleet. This system was not designed for selecting the type of fleet and information related to project qualities led it to determine the number of required loaders. In reality, this model was applied for stages after selecting loaders and determining capacity of its bucket [11].

Multiple Attribute Decision Making Techniques: These techniques, in order to select mine equipments, were used for the first time in 2002. In this project, existence of qualitative and quantitative attributes along each other was the principal reason for utilize Analytic Hierarchy Process. The proposed attributes in this research includes mine parameters, technical and production features, performance of equipments, financial consideration, reliability, maintainability, mine life, operating condition, and safety and environment. The selection of fleet type has been accomplished from among five choices [12]. In 2003, a correction about the manner of classification of effective parameters in selecting fleet was presented and the process of equipments selection was carried out in a coal mine in Turkey. In this research, effective attributes are studied in two groups of operational and technical parameters and costs, each of which also includes a bunch of secondary attributes. This selection was accomplished from among four systems of shovel-truck, loader-truck, shovel-truck along with in-pit crusher and conveyor and, shovel and in-pit and conveyor. In this study, AHP method has been used to select suitable fleet [13]. Due to existing weak points in each of MADM methods, other methods including a compound multiple attribute decision technique has been widely used. Process of using compound methods aimed to develop MADM techniques. For instance, a software EQS was developed in 2006 where fuzzy AHP was used to select equipments. This process, to some extent, removed problems of uncertainty hence; some of the required information in this software is determined through expert systems [14]. In recent years, compound methods have been used widely and several other researches have been conducted in this field. For instance, in a research a new weighting method of decision matrix based on Hessian matrix has developed [15]. In another research Combination of Analytical Hierarchy process (AHP) and entropy method applied to calculate global weights of the attributes. The weights then passed to the Technique for order by similarity to ideal solution (TOPSIS) method that the most efficient mining equipment alternative(s) could be appointed through distance measurement so that the best alternative has the nearest (distance) to the ideal solution and farthest from the negative-ideal solution in fuzzy environment [2].

2.2. Selecting Size of Vehicles
After selecting types of equipments for the mine fleet, selection of their size is carried out. As such, first, regarding to hole diameter, loading height are determined and then drill equipment and loader are determined with due attention to their attributes. Thereafter, hauling equipment with respect to loader is selected in a way that their height must have in proportion to each other. The size of equipments is selected with respect to distinguished parameters of each of the machines. The principal factor for drilling equipments is borehole diameter and for hauling and loading machines is their capacity and operation height.
Sensitive parameters that are taken into consideration while selecting size of machines include equipment costs, tires, complexity, matching factor-system approach of machines, loss of production, maintenance, infrastructure and haul roads, dilution and selectivity, possibility of selected extraction, reflectivity and applicability, environmental problems and milling costs.

In this phase, the selection possibility is enough due to diversity of existing equipment. One of the principal policies in selecting size of equipments is with respect to "Economic of Scale" theory. According to this theory, the selection of big equipment would minimize unit cost (per ton). However, this theory to a particular extent continues, which is indicated in Fig.2. As observed in this figure, increase of the size of machines, to the limit of distinguished capacity, has caused to decrease unit cost. By this reason, one of the important points in selecting size of equipment is the knowledge of proposed sizes [16].

Apart from taking into account economic of scale theory, use of optimization tools like mathematical optimization tool, simulation and artificial intelligence techniques would also be proved suitable in this field.

### 2.3. Selecting Required Number and Assignment of Apparatus

At the final stage, with respect to daily production rate and capacity of each of the equipments, the required number of each of machines is calculated. At the first, considering production rate, number of loader is determined and similarly, hauler number are determined with respect to the loader, production rate, hauling distance and transportation condition. Applying queuing theory, assignment and optimization tools, not only waiting period of machines is minimized rather it could, to a larger extent, reduce transportation costs.

### 3. Conclusion

The open pit equipment selection problem is a strategic issue and has significant impacts to the open-pit design and production planning. The cost related to purchasing loading equipment is more than the vehicles needed for other sections. However, the principal part of the operating costs is related to hauling. As a result of new technology, economy of scale will continue to be an extremely important factor in the competitiveness of the mining industry. This implies that both mine size (physical dimensions) and mining equipment will continue to grow.

### References


Table 1- Cost Distribution of Unit Operations (Copper Mines) [1]

<table>
<thead>
<tr>
<th>Unit Operation</th>
<th>Percentage of Total Cost %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drilling</td>
<td>8</td>
</tr>
<tr>
<td>Blasting</td>
<td>8</td>
</tr>
<tr>
<td>Loading</td>
<td>18</td>
</tr>
<tr>
<td>Hauling</td>
<td>47</td>
</tr>
<tr>
<td>General</td>
<td>19</td>
</tr>
</tbody>
</table>
Figure 1: Effective parameters in selection fleet types [2]

Figure 2: Economic of Scale in Mining [16]
Using R-mode factor analysis method and Event probability analysis to determine prospectus areas, Case Study: 1:100000 sheet of Dolat-abad in Kerman province

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Abstract

The main objective of a small scale stream sediments geochemical survey, is to determine areas of geochemical anomaly of the elements to be explored by means of pathfinder elements, to obtain paragenetic relationship among elements by means of correlation analysis, to explore and define mineralization zones and potential areas. In this research, 811 geochemical samples from 1:100000 sheet of Dolat-abad located in Kerman province are studied and 20 elements are analyzed. To achieve the goal, R-mode factor analysis and Even probability analysis (P.N) are used. In R-mode factor the relation among M variables with P uncorrelated factor scores, their maps have been prepared and 9 anomaly areas were detected. Then in order to investigate the accuracy of obtained results from R-mode method, data were studied by P.N method. In Event probability analysis, at first step, threshold value of each interested element within the geochemical sample must be determined. In this paper it is intended to use the occurrence probability of the enrichment factor to detect the anomalous areas. Obtained results of this technique is in good agreement to those acquired.

1- Introduction

Preparation of 1:100000 geochemical maps as one of the most important information layer plays an important role in reconnaissance of promising areas. Dispersal of both old and recent alluviums, fans, diluvial plains, can mentioned as suitable places for exploration of mining deposits. ريكمونن of ultramafic rocks in geochemical states are hopeful regions in geochemical explorations[1]. Classic and modern statistical analysis (multivariate analysis) and also fiscal method of enrichment are done on the outcome raw data of analysis of 811 geochemical samples in 1:100000 sheet of Dolat-abad limit. For data processing, SPSS, Surfer, Auto Cad softwares are used. According to spread of ultrabasic to basic and semi-acidic rocks, all samples are analyzed by means of spectrometer. These considerations cause exploration and introduction of potential zones specially Cr, Co, Ni and partially Cu.

2- Description of study

2-1 general geology of area

The case study is in Kerman province, south-western 1:250000 Haji-abad square and has geographical coordinate as: longitude of 56°30´ - 57°00´ E and latitude of 28°00´ - 28°30´ N. There are different theories about geology situation of this area which situated in ophiolite
belt. But this mentioned belt is mostly reported in relation with Sanandaj-Sirjan or Orumie-Isfandaghe. Oldest rocks of this region belong to Paleozoic and upper Precambrian.

In middle Paleozoic (between upper and lower Devonian) there are though alteration rocks such as Amphibolites of region that spread on North-Western of area and are result of metamorphism. Abshour Complex is Collection of white calcite and brown marmorized dolomite marnoliths and that are Amphibolites. All the mentioned rocks belong to Sanandaj-Sirjan belt. Large parts of area have Mesozoic rocks specially are upper Jurassic and lower Cretaceous.

2-2 Sampling

In studied area, based on dispersion factor of rocky units and fault net, per 3 km$^2$ one sample was selected. In this method we tried to sample from mineral outcrops that specified on the map more (like ultrabasic rocks outcrop) and around faulted areas too. In this project, the number of samples was an important priority in designing sampling points so that there weren’t any rocky outcrop without sample. Stream sediments samples in every station, after checking their geological and geographical situation and recording all geological phenomenon and etc. have passed from 80 mesh sieve in quantity of 200 gr. All geochemical samples and rock samples after preparing for analysis the element have sent to the Iran Geology Organization Spectrometric Laboratory.

Analyzed oxides and elements are: P$_2$O$_5$, TiO$_2$, MnO$_2$, Na$_2$O, K$_2$O, MgO, CaO, Fe$_2$O$_3$, Al$_2$O$_3$, Zn, V, Sr, Sn, Pb, Ni, Cu, Cr, Co, Bi, Ba, B, Ag.

2-3 Preparation of data

There have been investigation to analyze the data:

1) Digitizing the existence topographies in topographic maps such as streams, samples situation, ways, cities and villages, geology structure, etc.

2) Preparation of related raw data to chemical analysis of samples in Excel software.

3) Integration of chemical analysis data with related data to the streams and samples situation.

4) Classification of lithology units according to multiplicity of geology units in studied area and determination of upstream rock( because by increase in geology units, number of upstream rocks invreas and thus make problem in its interpretation, preferably group the existent geology units on the basis of material and then on the basis of age.

5) Processing of determination of upstream rock performing this procedure was based on rocky grouping in prior stage and divided to stony one groups, stony tow groups, stony three groups, stony four groups, stony five groups on the basis of number of upstream rocks per sample and the number of existent samples in each family was specified.

6) Outlier amounts can’t be received in separate classification forms, but we should use them in analysis.

2-4 Univariate statistical studies

Statistical parameters related to chemical analysis of samples in Dolat-abad sheet have shown in table 1. First to third columns of these statistics are mean, mediam, mod that show way of inclination to the center of data. The second group of these statistics which are in next columns show standard deviation and variance that proceed to manner of dispersion and transmittance of data from the mean.

Histogram, normal line diagram at zero level and normal at tow way at zero level were drawn and seen that any raw data don’t follow the normal distribution. Considering that in most
statistical calculations it is a presupposition for next processing, so, normalize the data in two steps:

a) At first step outlier samples on the basis of Box and Whisker method are removed from collection data, then those data converted to the normal distribution by Cox and Box transformation method.

b) In second stage, all data entered into normalization process, so that Outlier data that first had set aside from the calculations, according to the obtained coefficient from the first stage, normalized for each element and added to first stage. Statistical parameters related to the various elements are in table 1.

2-5 Multivariate statistical studies

The aim of multivariate analysis on geochemical data, is geochemical and statistical analysis, configuring the relation between main and secondary elements and probability of use of these correlations to achieve an exploratory model.

Multivariate statistical techniques, analyze several measurements in each observation simultaneously. Every definite group of elements with respect to some environmental conditions shows almost same sensitiveness. Data processing is done in SPSS software and by help of tow method PCA (principle component analysis) and cluster analysis (Fig1)

2-5-1 Determination of correlation coefficient of elements

In this research, to show the genetic relation, correlation coefficient of different elements together used by rank method of Spearman, cluster interpretation and factor analysis method. Correlation matrix of data has shown in table 1

2-5-2 Calculation of KMO quantity

To define the correctness and confirmation of PCA and also number of data being sufficient, both KMO correlation and should be calculated simultaneously. Quantities around 0.9 for KMO is so appropriate for factor analysis, around 0.8 is appropriate, around 0.7 is balanced, around 0.6 is average, around 0.5 is poor, and less than 0.5 is inappropriate. Standard amount of KMO is more than 0.6. As you see, it is 0.767, it means performance of factor analysis can be acceptable.

KMO and Bartlett's Test

<table>
<thead>
<tr>
<th>KMO and Bartlett's Test</th>
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<tbody>
<tr>
<td>Kaiser-Meyer-Olkin Measure of Sampling Adequacy.</td>
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<tr>
<td>Bartlett's Test of Sphericity</td>
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<td>df</td>
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<td>Sig.</td>
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3-5-3 Factor analysis of case study data

One of the major suppositions of factor method is that data should have standard normal probability distribution. In order to do this, at first data were standardized and at first step of factor analysis, correlation coefficients matrix of elements is calculated by means of SPSS software. By help of this matrix, we check quantity of correlation between variables. Then, first P factor are selected by calculation of eigenvalues and by use of one of scales. Unfortunately there is no worldwide opinion about selection criterion of factors number, but there are lots of suggestions such as: percentage of cumulative variance (table 2), eigenvalues greater than one and Scree Plot (fig 2). According to the table 2, there are just 10 eigenvalues
greater than one and furthermore 10 firs factor are able to justify more than 87% 0f variations studied area. Finally, according to the Scree plot (Fig. 2) 5 factor are selected. This research shows that Verimax Rotation yield best results for selecting the factors. According to table of rotated matrix (table 3) and software calculations, 5 main factor are separated.

First factor: This factor mostly is influenced by Co, Mg, Ni, Cr elements.
Second factor: This factor mostly is influenced by Al, Ba, P.
Third factor: This factor mostly is influenced by Al₂O₃, Ba, p.
Forth factor: This factor mostly is influenced by Ca, CaO, Sr, Sn.
Fifth factor: This factor mostly is influenced by Cu, Pb, Zn.

4 Conclusion
1) Presence of geology structure and tectonics characteristics cause close relation between mineralization and geology. Tensile fractures frequency and adaptation of anomaly zones and existence indices confirm control role of tectonic activities.
2) Obtained results of classic and modern statistical calculations show that, at least in exploratory zones the elements, V, Ni, Co, Cr, have rich procreative relation rich genitival relation and perfect geographical overlapping.
3) Base metals, copper, lead, zinc in some parts of exploratory zone have complete adaption and confirm the correlation and multifactor calculations of procreative relation of hydrothermal deposit type.
4) Ba, B, Sr, elements, near relation and probable formation of these elements in relation with sedimentary environment and specially CaO oxide, and in particular dispersion limit of some of these elements seen in many parts of sedimentary rocks.
5) Dispersion of abnormal limits of elements, specially Ni, Co, Cr, V, Cu, and their overlapping with same group rock units and also mines and mine indices specially chromite, show correctness of explorations and probability of achievement to new chromite in abnormal limits.
6) According to the thesaurus got from integration of data, at least 9 promising areas are explored and introduced, that on the basis of developed priorities, should do geochemical semi-detailed exploration on them.

5 References
[1] Hassani Pak, A.A; Geochemical exploration principles; Published in Tehran university; 1383
[2] Hassani Pak, A.A; Exploratory data analysis; Published in Tehran university; 1380
[3] Hassani Pak, A.A; Geostatistic; Published in Tehran university; 1370
Table 1: Correlation matrix of data

Table 2: Total Variance Explained

Table 3: Rotated Component Matrix
Fig. 1: Statistical analysis of data flow sheet

Fig. 2: Scree Plot
Mineralogical studies of various generations of sulfide minerals: A case study of the Gol-e-Gohar iron ore mine, Kerman, Iran

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Abstract

Pyrite is one of the most associated sulfide minerals of the Gol-e-Gohar iron ore mine that has occurred differently within the ore body. In the Gol-e-Gohar iron ore mine, pyrite is observed among the bottom magnetite minerals and to some extent with the top magnetite minerals regarding Eh and pH, temperature and pressure conditions. An extensive mineralogical studies from the Gol-e-Gohar iron ore has confirmed seven generations of pyrite minerals on polished sections. The first generation of pyrite minerals is in the form of subhedral pyrite with silica inclusions. This type of pyrite is to some extent observed among the magnetite and silicate minerals. Some of the pyrite minerals contain magnetite inclusion and even vice versa. This particular texture expresses the syngenetic mineralization and the change in oxygen and sulfur fugacity at the expense of solution precipitation in sedimentary basins. At the end of diagenetic and metamorphic processes of mineral deposit, the euhedral pyrite minerals undergone recrystallization leads to the second generation of pyrite. The layered type of pyrite mineral is the third generation of pyrite which is in the form of interlayer grains among the oxide-silicate minerals. This texture shows syngenetic mineralization of sulfide with silicate and iron oxide minerals. Sometimes these pyrite grains, due to the metamorphic processes exhibit microfolding structures as fourth generation of pyrite. This particular texture states the metamorphic conditions on oxidized minerals, primitive sulfides and silicates. The fifth generation of pyrite minerals is confirmed by fault activities, tectonic and metamorphic processes. In this process, pyrite minerals exhibit breccias and cataclastic textures. These particular textures could have occurred in crushed zones. The Sixth generation of pyrite minerals has occupied the faults and joints in the form of open-space filling which has placed into the fractured and micro-cataclastic magnetites. This texture could happen following the metamorphic processes in the regions with the fault and fracture structures. Sometimes pyrite grains have undergone an extensive weathering and dissolution in the form of martite and hematite which creates the seven generation of pyrite. Chalcopyrite minerals are the other sulfide minerals as an inclusion of magnetite in the Gol-e-Gohar iron ore mine. The first generation of Chalcopyrite is recrystallized along with the hydrothermal solution. The Second generation of chalcopyrite minerals is formed at the expense of pyrite minerals. The Third generation of chalcopyrite minerals is observed in the form of open-space filling along with the fault and veins. The Third sulfide mineral is pyrhhottite which is in the form of elongated and interlayer crystals as compared to the oxide and silicate minerals. Though the abundance of these particular sulfide minerals is rare, but it has shown its unique impact on hematite and magnetite minerals in terms of supgene and oxidized processes that can be started from the margins of oxide minerals.

Keywords: Mineralography; Iron Ore; Textures; Pyrite; Chalcopyrite; pyrhhottite.
Introduction

Mining area of Gol-e-Gohar is located at 55 Km southwest of Sirjan (Kerman province) and is also located at marginal east of Sanandaj-Sirjan zone [1] and has the height of beyond 1700 m with respect to the sea level. The study area is located in the geographical longitude of 55º 10' to 55º 24' and latitude of 29º 03' to 29º 07'. The connection ways are the Sirjan - Niriz - Shiraz asphaltic road and the rail way of Bafq- Bandar-e-Abbas. The climate of the area is dry and wilderness with the less rainfall. Therefore the chemical weathering had less effect on geomorphology of the area. The study of the stratigraphical age shows approximately post protrozoic- pre Paleozoic age for the Gol-e-Gohar ore deposit. Gole-e-Gohar iron ore contain 6 ore bodies and the sequence of the beds in the pit of the mine includes quartzite, top magnetite, middle magnetite and bottom magnetite. The Gol-e-Gohar iron ore mine is one of the most important economic sources of Iran with the proved ore of nearly 900mil/ton iron ore with the assay value of 57.2% Fe, 0.16% P2O5 and 1.85% S. [2]

Discussion

Pyrite as a most important sulfide mineral in the Gol-e-Gohar ore body, contain the numerous primary and secondary shapes. This factor is also due to the vast versatility of the processes that has given to the pyrite mineralization in the ore deposit and has provided different generation of sulfides. The sub-hedral pyrites are of the first generation include mostly of the silica inclusion.(figure1,2) are primary.[3] The pyrite minerals that contain layered structures (figure3,4) are also primary and sometimes are in the form of spongy state (figure5) and seems to be the pyrite intergrowth with fine silicates.[4] The pyrite which found with the magnetite-bearing grains is also of the a state of primary texture of pyrite mineral.[5] Sometimes in some pyrite grains, the recrystalizing (figure 6,7) or folding (figure 8,9) can be visible. In fact these shapes and structures are given due to the effect of metamorphic phenomena in the ore deposits. In areas that the breccias fault are so active, the pyrite minerals exhibit the cataclastic texture (figure10,11) that provides shattered and broken outlook and this is a state of secondary texture of pyrite mineral. The pyrite minerals that precipitate in the form of open-space filling (figure 12) and vein (figure 13) or convert to the hematite and martite (figure 14) due to the weathering effects are also secondary textures of pyrite in the Gol-e-Gohar ore deposit. Chalcopyrite can be named as other sulfide minerals of Gol-e-Gohar iron ore which is in the form of primary and secondary shapes, structures and generation. The calcopyrite minerals which are in the form of calcopyrite-bearing inclusion inside the magnetite minerals as first generation sulfides (figure 15,16) and the chalcopyrite which are in the form of chalcopyrite converted pyrite,(figure 17) or vein- type chalcopyrite (figure 18) are of the secondary state of sulfides.

Conclusion

The pyrite is the most important and versatile sulfide minerals that are included in the Gol-e-Gohar iron ore mine. These sulfide minerals can be formed mostly in the bottom magnetite as compare to the top magnetite zone of the Gol-e-Gohar iron ore deposite. In this work a careful study on pyrite mineral has categorized seven different generations of this particular sulfide minerals. Sub-hedral pyrite mineral is the first generation of pyrite with the silica inclusion. Recrystalized pyrite is the second generation of pyrite. Laminated and layered
pyrite is the third generation of pyrite. Folded pyrite is the fourth generation of pyrite. Cataclastic pyrite is the fifth generation of pyrite. Vein and fractured-filling pyrite is the sixth generation of pyrite and weathered pyrite is the seven generation of pyrite. Chalcopyrite and pyrrhotite minerals are named as the other sulfide minerals of the Gol-e-Gohar iron ore mine.

References

Fig. 7- Recrystalize Py  
Fig. 8- Folding Py  
Fig. 9- Folding Py

Fig. 10- Cataclastic Py  
Fig. 11- Cataclastic Py  
Fig. 12- Open-space filling Py

Fig. 13- Vein of Py  
Fig. 14- Weathering Py  
Fig. 15- Inclusion of Cpy Inside magnetite
Fig. 16- Inclusion of Cpy inside magnetite
Fig. 17- Cpy converted from py
Fig. 18- Open-space filling Cpy