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Cover Page Footnote

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Abstract

Mine designers often face difficulties in selecting an appropriate mining method; however, such a method should be selected based on ore and rock characteristics. The selection of mining methods can be considered a type of multi-criteria decision making, and this depends on many factors used in the selection process. The general method used in this field is the University of British Columbia (UBC) method, which determines the criteria of the properties that are compared to determine the best and worst of several mining methods. In this paper we used as new technique which defines as Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS). The criteria considered in the UBC method include general shape, ore thickness, ore plunge, and grade distribution, beside the rock quality designation (RQD), and the rock substance strength (RSS). This paper presents an improved TOPSIS method based on experimental design. Additionally, this paper will introduce a modified version of the UBC method that can be employed based on Excel sheet. The best mining methods is cut and fill stoping and top slicing with the same rank equal 0.72, and the second-best mining method is square set stoping with rank equal 0.65.

Keywords: TOPSIS, UBC method, mining methods selection, multiple-criteria decision making

1. Introduction

O re extraction processes are designed with regard to surface or underground mining methods. These techniques depend on the depth, stripping ratio, and other parameters. Furthermore, the optimal use of underground resources is related to the choice of underground mining methods; many factors are taken into consideration in underground mining method; these include safety, mine planning, ventilation system, reduced maintenance costs, and planning production [1,2]. According to the criteria of University of British Columbia (UBC) method for selecting appropriate mining methods, a good selection will be made. Another issue pertains to the manner in which the methodology should be used to achieve high accuracy and easy application. All results should be aggregated to analyse the decision before it is applied. Many conventional methods consider only a limited number of criteria; therefore, in the decision-making process; there is a need for alternative methods, that can consider all known criteria related to selecting underground mining methods. This is because once a mining method is selected, it is nearly impossible to change it owing to the high costs and losses entailed. Thus, it is very important to re-analyse a decision before it is carries out [3,4]. The method that decision makers generally use for this is a sensitivity analysis of the final decision. Mining method selection underlies every mining operation and is essential for estimating the capital and operating costs of alternatives such that economic returns are maximized. This selection is also an important task in

mine management because of its effect on operational cost; it is also an integral part of mine planning and design. Most importantly, using the appropriate mining method increases the safety of employees and secures production [5]. Despite this, mining method selection is not a well-defined process because it involves the interaction of several subjective factors or criteria. In this process, several controllable and uncontrollable parameters should be accounted for [6], and they should be determined according to scientific and technical studies for individual ore deposits [7—10]. The numerous effective factors involved in the selection of an appropriate mining method, complicate this process. The selection method for exploiting fluorine deposits, similar to those used for other deposits, includes modelling followed by examining alternative for mining treatment. Several qualitative and quantitative methods have been developed to evaluate suitable mining methods for ore deposits based on their geometry (depth, shape, thickness, dip), rock quality (ore zone and host rock competency, i.e., structures, stress, stability), ore variability (uniformity, continuity, grade distribution) and related economics factors (ore recovery, ore value and mine recovery, productivity, capital, operating costs) [11—13]. Many citations are provided herein regarding the main sequences employed in all mining methods and the related criteria. This study will focus on the modification of the UBC method using the function in an Excel sheet integrated with the UBC criteria for all mining methods. All criteria indexes from the UBC method will be defined in Excel sheets related to all rock characterizations and mining methods. In this regard [14], the use of multi-criterion decision-making overcomes

many of the shortcomings of the aforementioned studies [15—19].

In this article we applying the TOPSIS technique, TOPSIS is defined related to the main concept of the best decision making which lead to selected the closed ideal solution and faraway from the non-ideal solution as mentioned This technique depends on one that maximum or minimum for the benefit criteria which related to positive or negative ideal solutions. TOPSIS is compare between positive and negative solution to find out the distance between alternative solutions. There are many researchers developed the TOPSIS from Ref. [20]. They are focused on creating the weight for each criterion, scoring normalization for each criterion and estimating the geometric distance between each alternative and the ideal alternative, to a carried out the best value for each criterion.

2. Site investigation and data collection

Geotechnical characterization of the Boleo mine (Mexico) field involved evaluating its various geological structural features and depositional environments. The mineral-bearing zones of interest in the area are bedded clay seams with a slight dip known locally as mantos and an overlying brecciated zone. There are three mines denoted M303, M303S, and M303C, at this site. To circumvent the area of Manto 3, step mining was used to reach the ore body after excavation through its upper interburden. Severe abrasions and pillar damage were caused when conglomerate and repeated grading were supporting the lateral pressure of the mine. Crack displacements and cement injections were measured. In addition, water did not penetrate through cracks during the rainy season. For short wall mining, the main gateway was excavated in the Manto 3 layer; this mine has two panels. One section of panel SW1 was 80 m width and 2.4 m high; currently, it is approximately 90 m length, and thus produces a volume of approximately 17,280 m³ of

Table 1. Characterization of rock collected from the mine site.

Ore property		Description	Magnitude
General shape		T, Tabular	—
Ore thickness, m		N, Narrow	15
Ore plunge, degree		—	70
Grade distribution		G, Gradational	—
Depth below surface, m		SH, Shallow	100
Rock quality designation (RQD, %)	Ore zone	M, Moderate	60
	Hanging wall	VW, very weak	35
	Foot wall	VW, very weak	35
Rock substance strength (RSS)	Ore zone	VW, very weak	35
	Hanging wall	W, weak	25
	Foot wall	W, weak	35

extracted ore. Table 1 lists the proprieties of the rock in the studied area, including data on ore thickness, shape, ore plunge, grade distribution, depth, and rock mass classification.

3. Methodology

The UBC method was devolved and established and developed by Miller to address the need to improve the Nicholas technique. New additions by Miller include assigning a −10 value a negative weight without completely discarding any alternative. Rock characterizations particularly the mechanical values were also modified. Tomich provides more details as shown in Fig. 1 [15]. We are converted the UBC criteria to weight and rate, the weight depends on the properties to mining methods (highest weight is advantages and lowest is disadvantages corresponding to mining methods) and the rate depends on the real geo-technical geometric, and economic factors related to mine filed investigation, all criteria are presented Tables 2 and 3.

TOPSIS technique assumes that monotonous criteria increase or decrease. Which depends on normalization as a basic factor even though takes in consideration an odd dimension in multi-criteria cases. TOPSIS technique is good method to comparison between criteria as considered poor results in other issue. That results provide us in realistic form of modelling than other methods, take in consideration the alternatives related to include or exclude alternative solutions.

One model uses a total of 36 criteria that were classified into six main groups by Hartman and Mutmansky to analyse an underground mining method selection (UMMS) problem in detail [3]. These criteria are listed in Table 3. However, using this model, also increased the number of pair-wise comparison matrices. The alternatives of the Analytical Hierarchy Processing (AHP) models and the fuzzy multiple attribute decision-making (FMADM) are determined based on the UBC approach used by various researcher [21−34]. The UBC approach is simply a modified version of the Nicholas approach; it numerically ranks the characteristics of the ore geometry and rock mechanics for the ore zone, footwall, and hanging wall of the target deposits. The rankings are then summed where the higher rankings correspond to the more favourable methods. Each ranking consists of a number, such as a number from "0 to 6" or "10, −49". A rank of "-49" corresponds to a mining method that is not feasible and the methods is therefore eliminated; a rank of "0" suggests strongly that a particular characteristic makes given mining method less attractive than others; and a rank of "6" indicates that the corresponding mining methods possesses a very favourable characteristic. To determine the set of valid alternatives, the underground mining method selection (UMMS) uses the final UBC ranking.

4. Modifications to the University of British Columbia (UBC) method

The discussion and illustration of the UBC method in the prior section clarify it before the modifications are discussed in this section. The main criterion for this technique is measuring the stratification of all mechanical and other properties
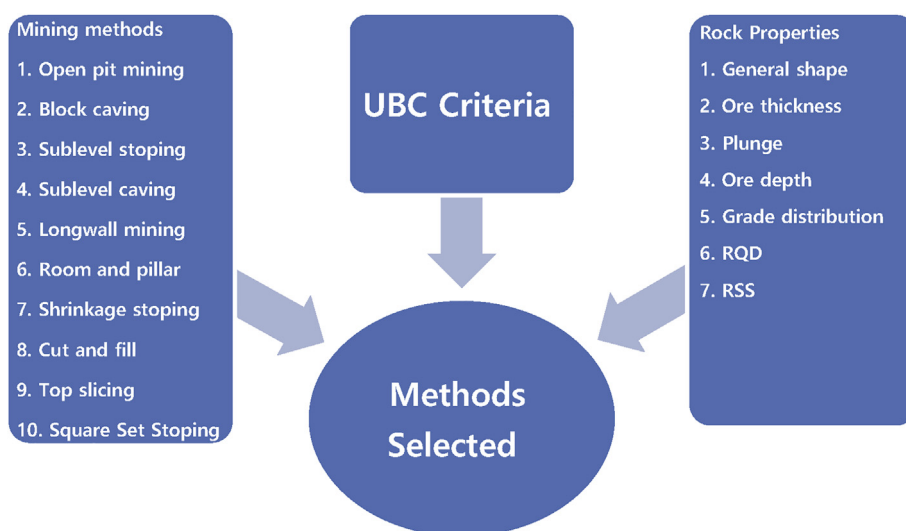

*Fig. 1. All criteria and mining methods. *RQD − rock quality designation, RSS − rock substance strength.*

Table 2. Assignment of the weights of the various parameters according to mining methods.

	Parameter/mining methods	Open pit	Block caving	Sublevel stoping	Sublevel caving	longwall	Room and pillar	Shrinkage stopping	Cut and fill stoping	Top slicing	Square set stoping
1	General shape	0.8	0.8	0.6	0.6	0	0	0	0.2	0.2	0
2	Ore thickness, m	0.8	0.8	0.6	0.8	0	0	0	0	0.2	0
3	Grade distribution	0.6	0.6	0.8	0.6	0.8	0.8	0.6	0.4	0.4	0
4	Depth below surface, m	0.8	0.4	0.6	0.6	0.4	0.6	0.6	0.4	0.4	0.2
5	Plange	0.2	0.8	0.8	0.8	0	0	0.8	0.8	0	0.4
6	RQD Ore zone	0.6	0	0.8	0	0.4	09	0.6	0.6	0	0
7	Hanging wall	0.8	0.4	0.8	0.4	0.6	0.9	0.8	0.6	0.6	0
8	Foot wall	0.8	0.4	0.6	0.6	0	0	0.6	0.4	0.4	0 00
9	RSS Ore zone	0.6	0	0.8	0.4	0.2	0.9	0.8	0.6	0	0
10	Hanging wall	0.8	0	0.6	0.250	0.4	0.9	0.8	0.4	0.4	0
11	Foot wall	0.8	0.2	0.6	0.4	0	0	0.6	0.4	0.25	0

Table 3. Assigned ratings to the different ranges of parameters.

Parameter		Rating				
		0	0.4	0.6	0.8	1
General shape		Irregular	Platy/Tabular W/Depth no exceed 35 m	Platy/Tabular W/Depth no exceed 30 m	Platy/Tabular W/Depth no exceed 25 m	Equal dimensions
		Very low	low	Medium	High	Very high
Ore thickness, m		<3	3–10	10–30	30–100	>100
		Very narrow	Narrow	Intermediate	thick	Very thick
Plunge		>55	45–55	35–45	20–35	<20
		steep	Sami steep	Intermediate	Sami flat	flat
Depth below surface, m		>600	300–600	150–300	70–150	<70
		Deep	Sami deep	Intermediate	Sami shallow	shallow
Grade distribution, %		<50	50–70	70–80	80–99	100
		erratic	un Uniformed	Medium	Sami Uniformed	Uniformed
RQD, %	Ore zone	<20	30–40	40–60	60–80	80–100
		Very weak	Weak	Moderate	strong	Very strong
RSS, %	Ore zone	<5	5–10	10–15	15–20	20
		Very weak	Weak	Moderate	strong	Very strong

of the bedrock such that can be added to a new Excel sheet and linked with phenomena corresponding to all mining methods by using the TOPSIS technique, which can easily connect all the characterization bed layers e.g., thickness, plunge, depth, rock mass rating (RMR). The following example shows the manner in which the function and active link to all parameters can be prepared. Table 4 illustrate the weight and rate for every property, the weight mean if this property as advantages or disadvantages for mining methods as mention in UBC method, and the rate mean the actual property based on UBC scheme.

The final value will appear in the next file in the same Excel sheet as shown in Table 6. Decision makers can decide which method is suitable able to decide for a given mine based on the fact that a high value (nearest from 1) is assigned to the most preferred method, less to the next preference, and

so on. All methods will be formulated according to the UBC method and linked cell in excel sheet with all properties. MCDM assume that, the issue was obeyed to m alternative, denotes the value assigned to the jth criterion of the ith alternative, x_{ij} is the decision matrix. The equivalent weight of property has mentioned by w_1, w_2, ….w_n, beside the TOPSIS processes are find out as five steps which follows by equations (1)–(5). Table 4 illustrated transformed approach criteria from UBC criteria all properties were weighted to near from 1. Table 5 is given the calculation normalized matrix according to Equation No. 1. Table 6 summarized the results of variables X multiplied with weighted index for every property. Table 7 illustrated the positive ideal and negative ideal solutions and finally Table 8 is given the final results according to the Euclidean distance from the ideal worst and ranking.

Table 4. Conversion the UBC criteria to new approach of weight and rate.

| weights/rates | 0.1 | 0.4 | 0.6 | 0.8 | 1 | 0.3 | 0.4 |
	General shape	Ore thickness, m	Grade distribution	Depth below surface, m	Plunge	RQD	RSS
Open pit mining	0.4	0.8	0.6	0.6	0.6	0.1	0.1
Block caving	0.8	0.8	0.6	0.8	0.1	0.1	0.1
Sublevel stoping	0.6	0.6	0.8	0.6	0.8	0.8	0.6
Sublevel caving	0.8	0.4	0.6	0.6	0.4	0.6	0.6
Longwall	0.2	0.8	0.8	0.8	0.1	0.1	0.8
Room and pillar	0.6	0.1	0.8	0.1	0.4	9	0.6
Shrinkage stoping	0.1	0.4	0.8	0.4	0.6	0.9	0.8
Cut and fill stoping	0.8	0.4	0.6	0.6	0.1	0.1	0.6
Top slicing	0.6	0.1	0.8	0.4	0.2	0.9	0.8
Square set stoping	0.8	0.1	0.6	0.25	0.4	0.9	0.8

Table 5. Normalized matrix.

	General shape	Ore thickness, m	Grade distribution	Depth below surface, m	Plunge	RQD	RSS
Open pit mining	0.203858877	0.478947472	0.268328157	0.340092121	0.4341	0.0109	0.0499
Block caving	0.407717753	0.478947472	0.268328157	0.453456161	0.0724	0.0109	0.0499
Sublevel stoping	0.305788315	0.359210604	0.357770876	0.340092121	0.5789	0.087	0.2993
Sublevel caving	0.407717753	0.239473736	0.268328157	0.340092121	0.2894	0.0653	0.2993
Longwall	0.101929438	0.478947472	0.357770876	0.453456161	0.0724	0.0109	0.399
Room and pillar	0.305788315	0.059868434	0.357770876	0.05668202	0.2894	0.9792	0.2993
Shrinkage stoping	0.057259833	0.325515384	0.386694596	0.275208366	0.4835	0.0979	0.4
Cut and fill stoping	0.407717753	0.239473736	0.268328157	0.340092121	0.0724	0.0109	0.2993
Top slicing	0.305788315	0.059868434	0.357770876	0.226728081	0.1447	0.0979	0.399
Square set stoping	0.407717753	0.059868434	0.268328157	0.14170505	0.2894	0.0979	0.399

Table 6. Calculate Normalized Matrix multiplied with rate for every property.

Methods/properties	General shape	Ore thickness, m	Grade distribution	Depth below surface, m	Plunge	RQD	RSS
Open pit mining	0.020385888	0.191578989	0.160996894	0.272073697	0.4341	0.0033	0.02
Block caving	0.040771775	0.191578989	0.160996894	0.362764929	0.0724	0.0033	0.02
Sublevel stoping	0.030578831	0.143684242	0.214662526	0.272073697	0.5789	0.0261	0.1197
Sublevel caving	0.040771775	0.095789494	0.160996894	0.272073697	0.2894	0.0196	0.1197
Longwall	0.010192944	0.191578989	0.214662526	0.362764929	0.0724	0.0033	0.1596
room and pillar	0.030578831	0.023947374	0.214662526	0.045345616	0.2894	0.2938	0.1197
Shrinkage stoping	0.005725983	0.130206153	0.232016757	0.220166693	0.4835	0.0294	0.16
Cut and fill stoping	0.040771775	0.095789494	0.160996894	0.272073697	0.0724	0.0033	0.1197
Top slicing	0.030578831	0.023947374	0.214662526	0.181382464	0.1447	0.0294	0.1596
Square set stoping	0.040771775	0.023947374	0.160996894	0.11336404	0.2894	0.0294	0.1596

Table 7. The positive ideal and negative ideal solutions.

| V+ | 0.005725983 | 0.023947374 | 0.160996894 | 0.045345616 | 0.0724 | 0.0033 | 0.02 |
| V- | 0.040771775 | 0.191578989 | 0.232016757 | 0.362764929 | 0.5789 | 0.2938 | 0.16 |

Table 8. Euclidean distance from the ideal worst and ranking.

S_i^+	S_i^-	P_i	Rank	
0.4589	0.3723	0.45	7	Open pit mining
0.3607	0.6046	0.63	3	Block caving
0.5799	0.2902	0.33	9	Sublevel stoping
0.3393	0.4278	0.56	5	Sublevel caving
0.3889	0.585	0.60	4	Longwall
0.3807	0.4633	0.55	6	Room and pillar
0.486	0.323	0.40	8	Shrinkage stoping
0.2603	0.6564	0.72	1	Cut and fill stoping
0.2178	0.5655	0.72	1	Top slicing
0.2705	0.499	0.65	2	Square set stoping

1. Normalize the decision matrix:

$$\overline{X}_{ij} = \frac{X_{ij}}{\sqrt{\sum_{i=1}^{n} X_{ij}^2}} \qquad (1)$$

$ri\,j = xi\,j - mk = 1\,x2\,k\,j,\ i = 1, \ldots, m;\ j = 1, \ldots, n$ where $ri\,j$ denotes the normalized value of jth criterion for the ith alternative Ai.

2. Calculate the weighted normalized decision matrix:

$$V_{ij} = \overline{X}_{ij} \times W_j \qquad\qquad (2)$$

$vi\,j = wj\,ri\,j$, $i = 1, ..., m$; $j = 1, ..., n$ (2), where w_j is the weight of the jth criterion or attribute.

3. Determine the positive ideal and negative ideal solutions:

$$S_i^+ = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^+ \right)^2 \right]^{0.5} \qquad (3)$$

4. Calculate the Euclidean distance from the ideal worst

$$S_i^- = \left[\sum_{j=1}^{m} \left(V_{ij} - V_j^- \right)^2 \right]^{0.5} \qquad (4)$$

5. Calculate Performance Score and ranking

$$P_i = \frac{S_i^-}{S_i^+ + S_i^-} \qquad\qquad (5)$$

5. Conclusion

The results showed that, selecting a mining method would depend on many criteria, all of which are related to safety and economic considerations. The modification of the UBC method focused on linking all parameters related to all criteria in a simple manner and obtaining accurate final results. The final results provide indicators using which decision makers can choose between different mining methods based on the total points given to all ore properties. The best mining methods is cut and fill stoping and top slicing with the same rank equal 0.72, and the second-best mining method is square set stoping with rank equal 0.65, the pattern continues as shown in Table 8. This modified method was applied to other case and good results were obtained; further, it is easy input and output all data and solutions.

Ethical statement

The authors state that the research was conducted according to ethical standards.

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Conflicts of interest

None declared.

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