APPLICATION OF TOPSIS METHOD TO THE SELECTION OF A PRODUCTION DRILLING RIG

by

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ABSTRACT

Drilling and blasting are considered to be the first unit of operations in mining. proper rock fragmentation is the key first element of the ore winning process, as it affects the economics of processing. To ensure a proper fragmentation is achieved, a lot of factors are considered, one of them being the accuracy and efficiency of drilling. This makes drilling an important part of the rock fragmentation process, and the selection of a drill rig that will result in achieving desired production rate is thus an important decision for mining engineers. In this paper, the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method was applied to the selection of a Production Drill Rig. The methodology involved the application of the Analytical Hierarchy Process (AHP) method in calculation of the weights of the criteria. Expert opinion was used in the formation of AHP pairwise matrices. TOPSIS method was then used to rank the alternatives and finally, the most appropriate drill rig was selected. It was shown that TOPSIS method can be applied in equipment selection as opposed to the traditional trial-and-error methods, which will result in speedy decision making.

Keywords: *Multiple Criteria Decision Making, AHP, TOPSIS, Drill rig.*

INTRODUCTION

Multiple Criteria Decision Making (MCDM) is one of the branches of decision making which implies making decisions in the presence of multiple and usually conflicting criteria. MCDM is classified into two categories; Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). However, these two are often used interchangeable and means the same class of models. Usually, MADM is used when the model cannot be stated in mathematical equations and otherwise MODM is used (Yavuz, 2016).

Drilling and blasting plays an important role in the communition process. This makes the selection of a drill rig a very important decision that is made by mining

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engineers. Drilling has an implication on the overall cost of operation of a mine. Proper drilling to given depth, accuracy, and efficiency has the bearing on the final blast performance. If a selected rig does not have enough power to reach a given depth, toes will form after a blast. This will be a challenge during loading as it will increase loading time of the last slice and affect negatively the loader teeth thus contributing to speedy wear and tear of the equipment. On the other hand, if the rig has excess power, over drilling will result. This will affect the floor contours of the next drill and might result in extra cost, as some form of back filling will become necessary. If centring and drilling is not accurate enough, the blast geometry will be disturbed and thus affect the energy distribution during a blast which may lead to energy loss, fly rock and back breaks.

Several research has been done in the application of MCDM in both engineering and management fields. With particular interest is the application of these methods to the selection of mining equipment. Bascetin (2006) *et al.* used fuzzy logic for selection mining method and surface transportation system. A computer software that uses fuzzy logic for equipment selection in surface mines was proposed by Bascetin et al (Bascetin *et al.* 2006) and applied in a South African mine. Application of AHP-TOPSIS method for loading-haulage equipment selection in open pit mines was used by Aghajani, Osanloo (Aghajani and Osanloo, 2007). Yavuz (2007), applied the AHP method to the selection of a wheel loader at Turkish Coal enterprise. He also applied the TOPSIS method (2015) to the same problem. Naghadeh *et al.* (2009), applied the fuzzy analytic hierarchy process (FAHP) approach to selection of an optimal underground mining method.

The aim of this paper was to compare the many different economic, operation and technical aspects in the selection of the optimal production drill rig for Blu Rock Mining Services. The comparisons have been performed with combination of the Analytical Hierarchy Process (AHP) and TOPSIS method. The AHP method was used in determining the weights of criteria by decision makers. The ranking of criteria has been done by TOPSIS method.

This paper is divided as follows: Section 1 gives a brief introduction of MADM methods and a brief literature review. In Section 2, a problem description is given, and hierarchy structural problem is defined. In Section 3 the AHP method is briefly discussed and is applied to determine the weights of the criteria. In Section 4, TOPSIS method is illustrated. The method is subsequently used for carrying out calculations and analysis are done and finally the optimal drill rig is selected. The results are presented in Section 5 which concludes the paper.

Problem definition

Blu Rock Mining Services is a Zambian contractor that is specialised in exploration and production drilling. The company is headquartered in the City of Kitwe of the Copperbelt Province of Zambia. The company has contractual operations for production drilling with Mopani Copper Mines open pit in Kitwe and First Quantum's Kalumbila Mine (Intrepid) in Kalumbila. The company has also undertaken several exploration drilling applying both Diamond Drilling and Reverse Circulation (RC) methods. In a bid to increase its drilling fleet, Blu Rock Mining Services decided to acquire a new drill rig that has the following technical features-:

(a) Operating weight of between 15 and 25 tonnes;
(b) Drill feed rate of between 25 and 30 kN;
(c) Maximum hydraulic pressure of above 200 bars;
(d) Compressor capacity of above 1 MPa;
(e) Fitted with dust collector and Colling system;
(f) Rock drill weight of between 300 and 450 kg;
(g) High percussion rate and drilling efficiency;
(h) Fitted with modern cabin technology; and
(i) Maximum hydraulic rock drill power of between 45 and 60 kW.

MATERIALS AND METHODS

Three models of drilling rigs from different manufacturers were chosen. A full list of technical features is given in Table 1.

Table 1: **Alternatives and Attributes for the drill rig**

Attributes	Alternatives		
	Model A	**Model B**	**Model C**
Operating Weight (tonne)	24	15.93	19.6
Engine Power (Kw)	328	220	185
Cooling System (kW)	5.5	5.2	4.9
Max. Drill Length (m)	42	45	30
Rod Length (m)	3.6	3.66	3.05
Drilling Rate/Feed Rate (kN)	29	28.5	28
Fuel Tank (ltr)	975	330	400
Hydraulic System Max Pressure (Bar)	230	210	200
Fan Suction (l/s)	125	130	110
Hydraulic Rock Drill (kW)	50	58	45
Compressor (MPa)	1.4	1.03	1.01
Dust Collector/Filter Area (m^3/min)	21	20	23
Hydraulic System Total (ltr)	500	300	350
Operating Pressure (Bar)	220	200	230
Rock Drill Weight (kg)	468	300	345
Technology	VH	H	H
Price	VH	H	H
Fuel Consumption	M	MH	M
Drilling Efficiency	MH	H	H
Spare Parts	H	M	H

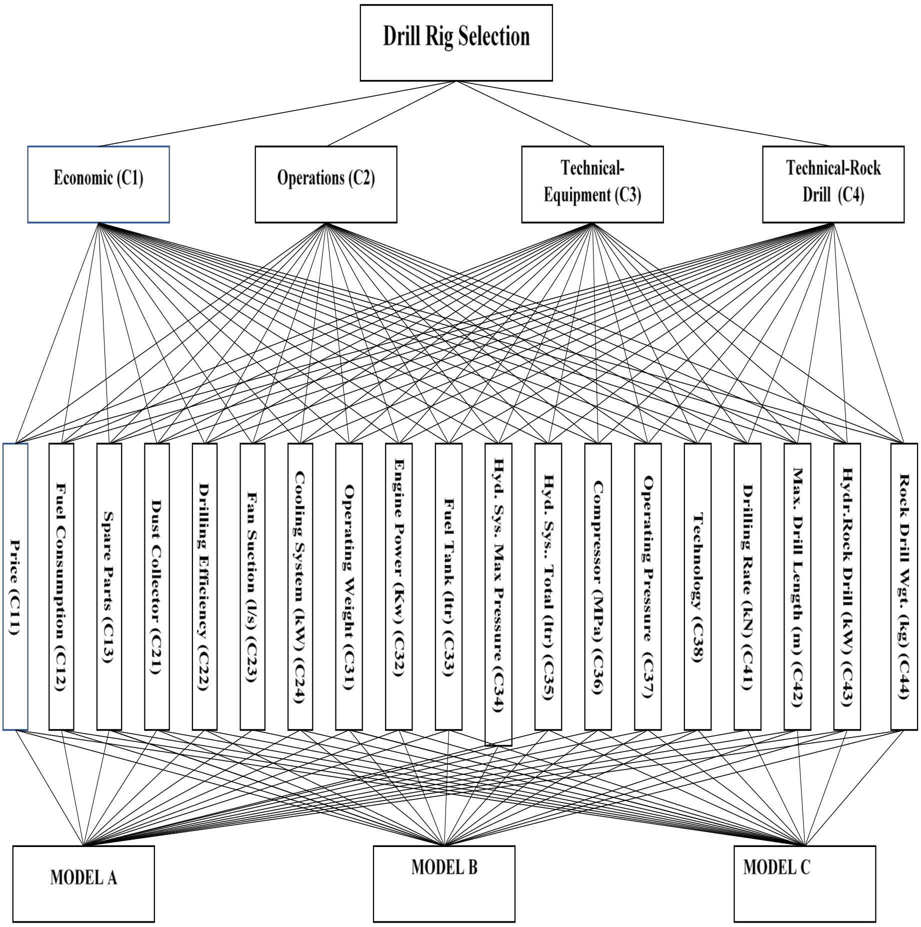
In this study, a numerical value is assigned to each linguistic variable using the scale explained in Table 2.

Table 2: **Assigned Numerical Values of Linguistic Variables**

Utility Based model	**Relative Intensity**	**Cost Based**
Low (L)	1	Very High
Medium (M)	3	High
Medium High (MH)	5	Medium High
High (H)	7	Medium
Very High (VH)	9	Low

The hierarchy structure of the problem is given in Figure 1. All decisions have a common hierarchical structure whereby options are evaluated against the various criteria that promote the ultimate decision objective. The main objective being the selection of a drill rig based on the four main criteria given. These main criteria are then divided into sub-criterion that are compared to each other depending on their importance and eventually an optimal alternative from the three models is selected.

Figure 1. **Hierarchy structure for Drill Rig Selection.**



Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) was first proposed in 1980 by Saaty (Saaty,1980). It is based on the pairwise comparison of attributes and alternatives. This pairwise comparison shows the level to which one requirement is more important than the other. A *n*x*n* pairwise comparison matrix is constructed, where *n* is the number of elements to be compared. This matrix is constructed for each level and each judgment is assigned a number on a scale. The most used scale is that of Saaty shown in Table 3 below.

Table 3: Scale of Pairwise Comparisons

Intensity of Importance	**Definition**	**Explanation**
1	Of equal value	Two requirements are of equal value
3	Slightly more value	Experience and judgement slightly favours one requirement over another
5	Essential or strong value	Experience and judgement strongly favours one requirement over another
7	Very strong value	A requirement is strongly favoured and its dominance is demonstrated in practice
9	Extreme value	The evidence favouring one over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed

In this article, the AHP method was used to calculate the weights of the criteria that were latter applied to TOPSIS method for eventual ranking of the Alternatives. This was achieved by first decomposing the problem and later performing the pairwise comparisons in order to obtain the needed weights. The relative priorities were determined using the theory of eigen vectors. For example, if a pair comparison matrix is A, then

$$(A - \lambda_{max} \text{ x } I)\, w = 0$$

To calculate the eigenvalue "λ_{max}" and eigenvector *w=(w1, w2,..., wn)*, weights can be estimated as relative priorities of criteria or alternatives. A consistency ratio (CI) of the comparison matrix is calculated in order to ensure the accuracy of selection. CI is calculated as:

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

where λ_{max} is maximal or principal eigenvalue, and n is the matrix size. The consistency Ratio (*CR*) is calculated as:

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

where "*RI*" Random Consistency Index. Random consistency indices are given in Table 4.

Table 4: **The consistency indices of randomly generated reciprocal matrices.**

Order of the Matrix	RI Values	Order of the Matrix	RI Values
1, 2	0	9	1.45
3	0.58	10	1.49
4	0.90	11	1.51
5	1.12	12	1.48
6	1.24	13	1.56
7	1.32	14	1.57
8	1.41	15	1.59

Generally, a consistency ratio of "0.10" or less is considered acceptable. In practice, however, consistency ratios exceeding "0.10" occur frequently (Yavuz, 2007).

The attributes are grouped into clusters with less than nine criteria as shown in Table 5. This is in line with Saaty's recommendations. This principle is used because of limitation of human performance in abstract thinking, as making more than 9 pairwise comparison becomes tedious and a lot of error is introduced. (Saaty, 2003).

Table 5: **Group clusters of criteria**

Economic (C1)	Price **(C11)**
	Fuel Consumption **(C12)**
	Spare Parts **(C13)**
Operations (C2)	Dust Collector/Filter Area (m^3/min) **(C21)**
	Drilling Efficiency **(C22)**
	Fan Suction (l/s) **(C23)**
	Cooling System (kW) **(C24)**
Technical-Equipment (C3)	Operating Weight **(C31)**
	Engine Power (Kw) **(C32)**
	Fuel Tank (ltr) **(C33)**
	Hydraulic System Max Pressure (Bar) **(C34)**
	Hydraulic System Total (ltr) **(C35)**
	Compressor (MPa) **(C36)**
	Operating Pressure (Bar) **(C37)**
	Technology **(C38)**
Technical-Rock Drill (C4)	Drilling Rate/Feed Rate (kN) **(C41)**
	Max. Drill Length (m) **(C42)**
	Hydraulic Rock Drill (kW) **(C43)**
	Rock Drill Weight (kg) **(C44)**

After structuring the hierarchy as shown in Figure 2, a pairwise comparison matrix for each level was constructed. During the pairwise comparison, the nominal scale given in Table 3 was used to rank the importance of each attribute with respect to the other. The weight of each main and sub-criteria was assessed by a team of three expert Engineers with an average experience in the drilling industry of more than eight years.

The pairwise calculations for the main criteria are given in Table 6. The calculation for the rest comparisons are attached in Appendix 1. It is evident that the Economic Main Criteria is the most important among the main criteria with the weight of 0.5477.

Table 6: **Weights of Main criteria**

Main	***C1***	***C2***	***C3***	***C4***	**GeoMean**	**Weight**	**A*W**	**Eigen max**	**CI**	**CR**
C1	1.000	5.000	3.000	5.000	2.943	***0.5476***	2.307	4.212	0.071	0.079
C2	0.200	1.000	0.200	0.333	0.340	0.0632	0.269	4.253	0.084	0.094
C3	0.333	5.000	1.000	2.000	1.351	0.2514	1.026	4.079	0.026	0.029
C4	0.200	3.000	0.500	1.000	0.740	0.1377	0.563	4.086	0.029	0.032
					5.374	**1.000**	1.041	4.157	**0.052**	**0.058**

λ_{max}=*4.157 CI= 0.052 and CR=0.058≤1, ok*

The calculated weight values for each sub-criterion are multiplied by the weight of the main criteria to form the combined weights indicated in Table 7 that was used in weighing the normalised matrix in TOPSIS (Refer to Stage 3 in TOPSIS).

Table 7: The combined weights for each sub-criterion

Main Criteria	Sub-Criteria	Sub-criteria weights	Main weights	Combined
Economic (C1)	Price **(C11)**	0.637	0.5476	0.3488
	Fuel Consumption **(C12)**	0.258		0.1414
	Spare Parts **(C13)**	0.105		0.0574
Operations (C2)	Dust Collector **(C21)**	0.202	0.0632	0.0128
	Drilling Efficiency **(C22)**	0.568		0.0359
	Fan Suction (l/s) **(C23)**	0.147		0.0093
	Cooling System (kW) **(C24)**	0.083		0.0052
Equipment Technical (C3)	Operating Weight **(C31)**	0.052	0.2514	0.0131
	Engine Power (Kw) **(C32)**	0.109		0.0275
	Fuel Tank (ltr) **(C33)**	0.027		0.0069
	Hydraulic System Max Pressure (Bar) **(C41)**	0.264		0.0663
	Hydraulic System Total (ltr) **(C35)**	0.036		0.0091
	Compressor (MPa) **(C36)**	0.221		0.0557
	Operating Pressure (Bar) **(C37)**	0.203		0.0511
	Technology **(C38)**	0.086		0.0217
Rock Drill Technical (C4)	Drilling Rate/Feed Rate (kN) **(C41)**	0.253	0.1377	0.0349
	Max. Drill Length (m) **(C42)**	0.074		0.0102
	Hydraulic Rock Drill (kW) **(C43)**	0.536		0.0738
	Rock Drill Weight (kg) **(C44)**	0.136		0.0188
	Sum	4.0000		1.0000

TOPSIS Method

The Technique for Order of Preference by Similarity to Ideal Solution (**TOPSIS**) is a multi-criteria decision analysis method, which was originally developed by Hwang and Yoon in 1981 with further developments by Yoon in 1987, and Hwang, Lai and Liu in 1993. The basic idea of TOPSIS is that the ideal alternative will have the shortest distance from the Positive Ideal Solution (PIS) and the furthest from the Negative Ideal Solution (NIS). Some of the advantages of TOPSIS are to logically represent the rational of human choice by considering both the best and the worst attributes of alternatives simultaneously, represented by a scalar value, and the simplicity on computation and presentation (Hwang, C. L. and Yoon, K., 1981).

TOPSIS Methodology

The TOPSIS methodology is done following a series of six consecutive steps as shown below (Hwang, C. L. and Yoon, K. 1981).

Step 1. Construct a Decision matrix (D)

$$A_{ij}= \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ . & & & . \\ . & & & . \\ x_{m1} & x_{m2} & \cdots & x_{mn} \end{bmatrix}$$

Step 2. Calculate the normalized decision matrix (R). The normalized value r_{ij} of the i_{th} alter $r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$ spect to the j_{th} attribute is calculated as:

j=1,2,3,….j; i=1,2,3, ….,n

$$R_{ij}= \begin{bmatrix} r_{11} & r_{12} & \cdots & r_{1n} \\ r_{21} & r_{22} & \cdots & r_{2n} \\ . & & & . \\ . & & & . \\ r_{m1} & r & \cdots & r_{mn} \end{bmatrix}$$

Step 3: Calculate the weighted normalised decision matrix. The weighted normalised value

$$v_{ij} = w_j \text{ x } r_{ij} \qquad j=1,2,3,\ldots.j;\ i=1,2,3,\ \ldots.,n$$

Where w_j is the weight of the j_{th} attribute and $\sum_{i=1}^{j} w_j = 1$

Step 4: Determine the ideal and negative ideal solution:

$A^{+}= \{V_1^{+},\ldots\ldots,V_j^{+}\} = \{(\max(or \min)\ v_{ij}\ |\ j\in J)\quad j=1,2,3,\ldots.j;\ i=1,2,3,\ \ldots,n$

$A^{-} = \{V_1^{-},\ldots\ldots,V_j^{-}\} = \{(\max(or \min) v_{ij}\ |\ j\in J)\ j=1,2,3,\ldots.j;\ i=1,2,3,\ \ldots,n$

Step 5: Calculate the separation measures, using the n-dimension Euclidean distance. The separation of each alternative form the ideal solution is given as:

j=1,2,,3 …..,J

$$S_i^{+} = \sqrt{\sum_{j=1}^{i}(v_{ij}-v_j^{+})^2} \qquad S_i^{-} = \sqrt{\sum_{j=1}^{i}(v_{ij}-v_j^{-})^2}$$

Step 6: Calculate the relative closeness to the ideal solution. The relative closeness of A_i with respect to A is defined as:

$$C_i^{*} = \frac{S_i^{-}}{S_i^{+}+S_i^{-}}$$ where $0< C_i^{+}<1$ i= 1,2, 3,…..,n

It is clear that $C_i^{*}=1$ if $A_i=A^{+}$ and $C_i^{*}=0$ if $A_i=A^{-}$, therefore a preferable option is the one that poses the value closer to 1 (Maximum value)

Step 7: Rank the preference order based on the descending order of C_i*

RESULTS AND DISCUSSION

The TOPSIS technique was used to select a production drill rig according to the provided attributes using the specifications given in Table 1. The same linguistic variables for assigning numerical value given in Table 2 was applied here. Firstly, the problem was decomposed into clusters as shown in Table 5.

A decision matrix (D) was formed as given in Figure 2. In this decision matrix, each row denoted alternatives and each column denoted criteria.

Figure 2. The Decision Matrix

$$D=\begin{bmatrix} 7 & 3 & 7 & 5.5 & 21 & 125 & 5 & 19500 & 328 & 700 & 230 & 350 & 1.4 & 220 & 9 & 29 & 73 & 50 & 468 \\ 7 & 5 & 3 & 5.2 & 20 & 130 & 7 & 21500 & 220 & 720 & 210 & 400 & 1.03 & 200 & 7 & 28.5 & 69 & 58 & 300 \\ 5 & 3 & 7 & 4.9 & 23 & 110 & 7 & 24000 & 200 & 690 & 300 & 380 & 1.01 & 230 & 7 & 28 & 70 & 52 & 345 \end{bmatrix}$$

In this matrix,19 different criteria for 3 alternatives have been evaluated. The steps described above are followed in the application of this technique.

Step 1. Normalised Decision Matrix was constructed as shown in Figure 3.

Figure 3. Normalised Decision Matrix

N=

$$\begin{bmatrix} .6312 & .4575 & .6767 & .6100 & .5674 & .5617 & .4508 & .5177 & .7409 & .5745 & .5319 & .5357 & .6964 & .5853 & .6727 & .5874 & .5962 & .5402 & .7153 \\ .6312 & .7625 & .2900 & .5767 & .5403 & .6154 & .6312 & .5709 & .4969 & .5909 & .4856 & .6122 & .5124 & .5321 & .5232 & .5773 & .5636 & .6266 & .4585 \\ .4508 & .4575 & .6767 & .5434 & .6214 & .5207 & .6312 & .6372 & .4518 & .5663 & .6937 & .5816 & .5024 & .6119 & .5232 & .5672 & .5717 & .5618 & .5273 \end{bmatrix}$$

Step 2. The weights for each criterion were determined using the fuzzy pair-wise matrix, performed in Section 2.

W = 0.3488 0.1414 0.0574 0.0128 0.0359 0.0093 0.0052 0.0131 0.0275 0.0069 0.0663 0.0091 0.0557 0.0511 0.0217 0.0349 0.0102 0.0738 0.0188)

$$\sum_{j=1}^{19} w_j = 1$$

Figure 4: Weighted normalized decision matrix

$$\begin{bmatrix} .2202 & .0064 & .0388 & .0078 & .0204 & .0055 & .0024 & .0068 & .0204 & .0039 & .0353 & .0049 & .0388 & .0299 & .0146 & .0205 & .0061 & .0399 & .0134 \\ .2202 & .1078 & .0166 & .0074 & .0194 & .0057 & .0033 & .0075 & .0194 & .0041 & .0322 & .0056 & .0285 & .0272 & .0114 & .0202 & .0058 & .0463 & .0086 \\ .1573 & .0647 & .0388 & .0069 & .022 & .0048 & .0033 & .0084 & .022 & .0039 & .0460 & .0053 & .0280 & .0313 & .0114 & .0198 & .0059 & .0415 & .0099 \end{bmatrix}$$

Step 3. In each column of the weighted normalised decision matrix, the minimum and maximum values are marked. Maximisation and minimisation was applied to the benefit-based model and cost-based model respectively.

The positive ideal solution was determined as:

$$A^{+} = [0.1573 \quad 0.0647 \quad 0.0388 \quad 0.0078 \quad 0.0223 \quad 0.0057 \quad 0.0033 \quad 0.0084 \quad 0.0204 \quad 0.0041 \quad 0.0460 \quad 0.0056 \quad 0.0388 \quad 0.0313 \quad 0.0146 \quad 0.0205 \quad 0.0061 \quad 0.0463 \quad 0.0134]$$

The negative ideal solution was determined as

$$A^{-} = [0.2202 \quad 0.1078 \quad 0.0166 \quad 0.0069 \quad 0.0194 \quad 0.0048 \quad 0.0024 \quad 0.0068 \quad 0.0124 \quad 0.0039 \quad 0.0322 \quad 0.0049 \quad 0.0280 \quad 0.0272 \quad 0.0114 \quad 0.0198 \quad 0.0058 \quad 0.0399 \quad 0.0086]$$

Step 4: The separation measure values are calculated as:

$$S_i^{+} = [0.0642 \quad 0.0819 \quad 0.0151] \qquad S_i^{-} = [0.0509 \quad 0.0067 \quad 0.0808]$$

Step 5: The relative closeness to the ideal solution is calculated as:

$$C_i^{*} = [0.4420 \quad 0.0716 \quad 8426]$$

Step 6: The alternatives are ranked based on the descending order of preference. The ranks are as follows: Alternative 3, Alternative 1, and Alternative 2. As a result of this evaluation, the best choice is Alternative 3 (Model C) because it has the shortest distance to the ideal solution.

As mining engineers face decision making in their day to day operation, a suitable decision-making techniques must be used to ensure right decisions are made. Several techniques are available for solving different types of decision problems. In this paper, TOPSIS methods which is one of MADM techniques was used to solve a drill rig selection problem. A suitable drill rig was to be selected from an alternative of three models. Each model was compared to each other with respect to the provided technical specifications. The criteria of the machines were grouped into clusters with each cluster having less than nine entries. These criteria were then subdivided into sub-criteria that aided the determination of the weights with respect to each other. The AHP method was applied to calculate these weights of relevance. TOPSIS method was then applied to ranking of the alternative and the most suitable alternative was selected.

CONCLUSION

1. Using TOPSIS method, Drill Model 3 was determined to be the most suitable solution as it has the closed distance to the ideal solution. The models were thus ranked as Model A, Model B and lastly Model C.
2. A consistence analysis was not done because the difference between the ideal solutions was big and it can therefore be concluded that the decision can barely change even if the values of some of the attributes was to be changed.
3. The result of this exercise shows that MADM methods can assist engineers to effectively select equipment based on several alternatives. These methods are faster and less tedious than the traditional trial-and-error methods, that can result in colossal loss of resources should a wrong decision be made.

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