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Drilling equipment selection using multi-attribute decision making methods

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Abstract
Drilling and blasting are considered to be the first unit operations in mining. Proper rock fragmentation is the key first element of the ore winning process, as it affects the productivity and economics of processing. To ensure a proper fragmentation is achieved, a lot of factors are considered, among them, 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, efficiency and flexibility is thus an important decision for mining engineers. In this paper, two Multi-Attribute Decision Methods (MADM) are applied to the selection of a Production drill rig. These methods are Yager's method and the Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS) method. 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 forming of AHP pairwise matrices. Yager's and TOPSIS method are then used to rank the alternatives and finally, the most appropriate drill rig was selected. It was shown that Yager's and 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 attribute decision making methods, analytical hierarchy process (AHP), yager's method, and technique for order of preference by similarity to ideal solution (TOPSIS), drill rig

Introduction

Multiple Criteria Decision Making (MCDM) is one of the branches of Decision Making. It implies the making of decisions in the presence of multiple, usually conflicting, criteria. The MCDM are classified into two categories; Multiple Attribute Decision Making (MADM) and Multiple Objective Decision Making (MODM). However, these two are often interchanged 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. Because blasting presents the cheapest method of breaking rock, as compared to crushing or milling, the selection of factors that will present an optimal fragmentation is of great importance to drilling and blasting engineers. This makes the selection of a drill rig a very important decision made by mining 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 has no 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. Kesimal and Bascetin (2002) applied Fuzzy Multi-Attribute Decision Making Methods (FMADM) to the selection of open pit 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) [3] and applied in a South African mine. The AHP-TOPSIS method was applied to loading-haulage equipment selection in open pit mines by Aghajani and Osanloo (Aghajani, Osanloo 2007) [1]. Yavuz (2007) [13] 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) [7] applied the fuzzy analytic hierarchy process (FAHP) approach to selection of an optimal underground mining method. Lidija Zadnik Stirn and Petra Grošelj (2010) [10] applied the Analytic Hierarchy Process method for handling the natural resource problems. The method was applied to land use management in Slovenia. Anupma Yadav and S.C Jayswal (2013) [12] used the Geometric mean method, a mathematical process of Analytical Hierarchy Process (AHP) for analysis of functional layout parameters of a manufacturing plant layout i.e. whether it can be implemented or not under the condition considered. Kun *et al* (2013) [17] applied the AHP and TOPSIS methods to wheel loader selection in a Turkish Marble mine. Through the application of MADM methods, Yazdani-Chamzin (2014) [16] developed an integrated model based on two fuzzy multi-criteria decision making techniques for handling equipment selection.

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), Yager's' 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 Yager's and TOPSIS method.

The remember of this paper is arranged a follows: 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, Yager's method is discussed and applied to the problem to the selection of the optimal drill rig. Section 5 provides a discussion and application of the TOPSIS method to the current problem. The method is subsequently used for carrying out calculations and analysis are done and finally the optimal drill rig is selected. A discussion of the results and a comparison of the 2 methods is given in section 6. A conclusion is given in section 7 which concludes the paper.

Problem Definition

Blu Rock Mining Services is a Zambian Mining and Construction 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 (Enterprise) 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 service decided to acquire a new drill rig that has the following technical features-:

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

Three models of drilling rigs from different manufacturers were considered to be chosen from. 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 structural 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 4 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 3 models is selected.

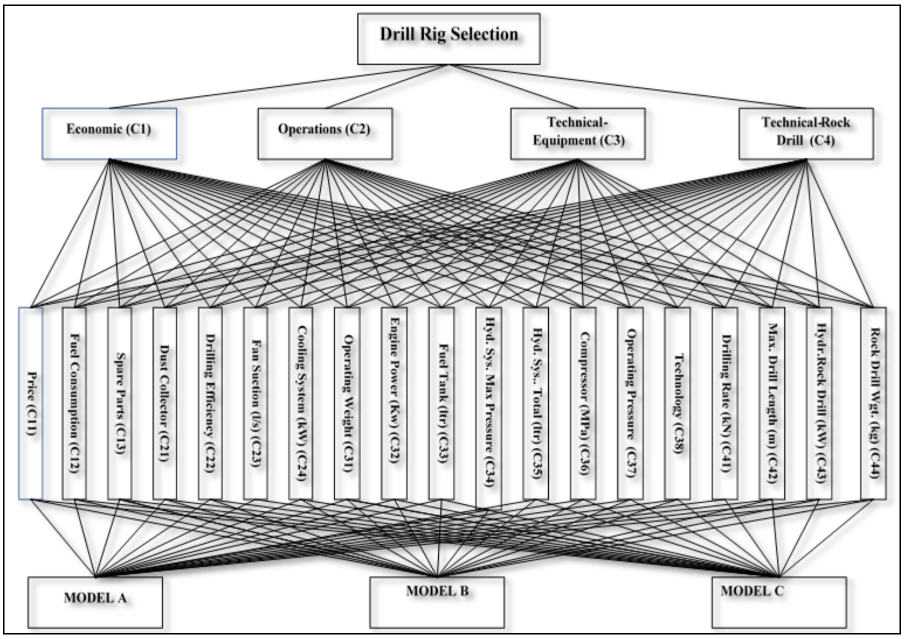

Fig 1: Hierarchy structure for Drill Rig Selection.

Analytical Hierarchy Process

The Analytical Hierarchy Process (AHP) was first proposed in 1980 by Saaty (Saaty, 1980) [8]. It is based on the pairwise comparison of attributes and alternatives. This pairwise comparisons show the level to which one requirement is more important than the other. An *nxn* 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.

Table 3: Scale of Pairwise Comparisons

Intensity of Importance	Definition	Explanation
1	Of equal value	Two requirements are of equal value
3	Slightly morevalue	Experience and judgement slightly favours one requirement over another
5	Essential orstrong value	Experience and judgement strongly favours onerequirement over another
7	Very strong value	A requirement is strongly favouredand 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 paper, the AHP method was used to calculate the weights of the criteria that are latter applied to Yager's and TOPSIS method for eventual ranking of the Alternatives. This is achieved by first decomposing the problem and later perform 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-wise comparison matrix is *A*, then

$$(A- \lambda_{max} \text{ x } I)\ w = 0 \qquad \text{……....1}$$

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:

$$CI = \frac{\lambda_{max} - n}{n-1} \qquad \text{……...2}$$

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

$$CR = \frac{CI}{RI} \qquad \text{……..3}$$

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) [13].

In line with Saaty's recommendations, the attributes are grouped into clusters with less than nine criteria as shown in Table 5. This principle lies in the 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 (Figure 1), 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. Using group decision method, the weight of each main and sub-criteria was assessed by a team of 3 experts. Engineers with an average experience in the drilling industry of more than 8 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 0.5476.

Table 6: Weights of Main criteria

Main	C1	C2	C3	C4	Geo Mean	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

Yager's Method

Yager's method address both multiple objectives and multiple attribute problems. It follows the max-min method of Bellman and Zadeh (1970) [4] with the improvement of the Saaty's method, which considers the use of a reciprocal matrix to express the pairwise comparison criteria and the resulting eigenvector as subjective weights. The weighting procedure employs exponentials based on the definition of linguistic hedges as proposed by Zadeh (1973).

Yager's method assumes the max-min principle approach. The fuzzy set decision is the intersection of all criteria: μD (A) = Min {$\mu C1$ (Ai), $\mu C2$ (Ai), μCn (Ai)}. For all (Ai) ∈ A, the optimal decision is yielded by μD (A*) = Max (μD, (Ai)), where A* is the optimal decision. Because there is limitation to this method, a modified version was proposed by Yavuz (2015) [14] for making proper decisions by taking into consideration the fact that the criteria or alternatives should be grouped so as not to exceed the limitation of human performance (nine criteria/alternatives). In this method, the following steps should be applied to solve the problem in question with Yager's method:

Step1. Group the criteria into clusters with less than nine criteria

Step 2. Perform Saaty's method for the main groups and calculate the weights for each group

Step 3. Perform Saaty's method for all criteria in each group and calculate the weight of each criterion in the group

Step 4. Calculate the final weights of the criteria by multiplying the criteria weights with their own group weights.

Application of Yager's Method

Following the above steps, Yager's method was applied to selection of a drill rig.

Step 1. The Criteria were grouped in clusters as given in Table 5.

Steps 2 and 3 where performed, and the main criterion and sub-criteria weights were calculated. Table 6 shows the calculation of the main criteria using pair-wise comparisons. The calculation of the sub-criteria's is given in appendix 1.

Step 4. The combined weights for the 19 sub-criteria are calculated by multiplying each main criterion weight and each sub-criterion weight separately. The combined weights for each sub-criterion are given in Table 7. It must be note that the sum of the weights of this sub-criterion weight is 1.

Table 7: Combined weights for each sub-criterion

Main Criteria	Sub-Criteria	Sub-criteria weights	Main weights	Combined
Economic (C1)	Price (C11)	0.584	0.5476	0.3199
	Fuel Consumption (C12)	0.281		0.1538
	Spare Parts (C13)	0.135		0.0739
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)	0.254	0.1377	0.0350
	Max. Drill Length (m) (C42)	0.129		0.0178
	Hydraulic Rock Drill (kW) (C43)	0.538		0.0741
	Rock Drill Weight (kg) (C44)	0.079		0.0109
	Sum	4.0000		1.0000

The calculated weight values for each sub-criterion are taken as membership functions of each sub-criteria. The combined weights where taken as the exponential weights (α, where $\alpha>0$) for each sub-criterion.

The general weight values for each sub-criterion where obtained from expert opinions and are given as the 'decision matrix' in Table 8. By using membership levels of alternatives and the weight of criteria for each criterion, the following conclusions were reached using the Equation below:

$\mu_D\ (A_i)= \mathrm{Min}\{(\mu_{C1}\ (A_i))^{\alpha 1}, (\mu_{C2}\ (A_i))^{\alpha 2},\ldots, (\mu_{Cn}\ (A_i))^{\alpha n}\}$.....4

Table 8: Expert opinion and solution

Expert Opinion			General weights		
A	B	C	A	B	C
0.6	0.4	0.8	0.84924	0.74594	0.93111
0.2	0.4	0.6	0.78074	0.86856	0.92445
0.6	0.6	0.6	0.96294	0.96294	0.96294
0.4	0.2	0.4	0.98835	0.97963	0.98835
0.4	0.6	0.4	0.96760	0.98181	0.96760
0.8	0.6	0.4	0.99793	0.99527	0.99153
0.2	0.2	0.6	0.99164	0.99164	0.99734
0.8	0.2	0.6	0.99708	0.97911	0.99332
0.8	0.6	0.4	0.99388	0.98604	0.97510
0.4	0.4	0.2	0.99372	0.99372	0.98900
0.8	0.4	0.4	0.98532	0.94106	0.94106
0.6	0.4	0.4	0.99536	0.99169	0.99169
0.8	0.6	0.4	0.98765	0.97195	0.95025
0.8	0.4	0.6	0.98866	0.95424	0.97422
0.6	0.4	0.2	0.98897	0.98030	0.96566
0.2	0.6	0.6	0.94520	0.98227	0.98227
0.8	0.6	0.6	0.99604	0.99095	0.99095
0.6	0.4	0.8	0.96288	0.93440	0.98361
0.8	0.6	0.4	0.99758	0.99447	0.99010
			0.7807	0.7459	0.9244

Using the Bellman-Zadeh max-min rule, the structure of a decision is reached as follows:

μD (*A*)= {Model A/0.7807, Model B/0.7459, Model C/0.9244,}

The optimal solution is found as follows:

μD (*A**) = *m*ax {*μ*D (*M*odel 1)}=0.9244.

Therefore, '*M*odel C' is found to be the most appropriate drill rig because it displays the highest membership function value. The Models are ranked as C, A then B.

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 [15] 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). Among 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) [15].

The TOPSIS methodology is done following 6 series of consecutive steps as below (Hwang, C. L. and Yoon, K. 1981).

Step 1. Construct a Decision matrix (D)

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

Step 2. Calculate the normalized decision matrix (R). The normalized value r_{ij} of the i_{th} alternative with respect to the j_{th} attribute is calculated as:

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{n} x_{ij}^2}}$$

j=1, 2,3,…..j; i=1,2,3, ….,n

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

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

$$v_{ij} = w_j \text{ x } r_{ij}$$

j=1,2,3,…..j; i=1,2,3, ….,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:

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

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

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

j=1,2,,3 …..,

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*

Application of The Technique

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 is applied here. Firstly, the problem was decomposed into clusters as shown in Table 5.A decision matrix (D) was formed as given in Matrix 1. In this decision matrix, each row denotes alternatives and each column denotes criteria.

D=

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

Matrix 1. The Decision Matrix

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 Matrix 2.

N=

.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

Matrix 2. Normalised Decision Matrix

Step 2. The weights for each criterion were determined using the fuzzy pair-wise matrix. These are the same weights that are used in the Yager's method.

W=
.3199 0.1538 0.0739 0.0128 0.0359 0.0093
0.0052 0.0131 0.0275 0.0069 0.0663
0.0091 0.0557 0.0511 0.0217 0.0350
0.0178 0.0741 0.0109)

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

The weighted normalized decision matrix is constructed as given in Matrix 3.

.2019	.0704	.0500	.0078	.0204	.0055	.0024	.0068	.0204	.0039	.0353	.0049	.0388	.0299	.0146	.0206	.0106	.0400	.0078
.2019	.1173	.0214	.0074	.0194	.0057	.0033	.0075	.0194	.0041	.0322	.0056	.0285	.0272	.0114	.0202	.0100	.0464	.0050
.1442	.0704	.0500	.0069	.022	.0048	.0033	.0084	.022	.0039	.0460	.0053	.0280	.0313	.0114	.0199	.0102	.0416	.0057

Matrix 3. Weighted normalized decision matrix

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

The positive ideal solution was determined as:

A^{+}= [0.1442 0.0704 0.0500 0.0078 0.0223 0.0057 0.0033 0.0084 0.0204 0.0041 0.0460 0.0056 0.0388 0.0313 0.0146 0.0206 0.0106 0.0464 0.0078]

The negative ideal solution was determined as

A= [0.2202 0.1078 0.0166 0.0069 0.0194 0.0048 0.0024 0.0068 0.0124 0.0039 0.0322 0.0049 0.0280 0.0272 0.0114 0.0199 0.0100 0.0400 0.0050]

Step 4: The separation measure values are calculated as:

S_i^{+}= [0.0591 0.0820 0.0180]

S_i^{-}= [0.0569 0.0068 0.0810]

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

C_i*= [0.4904 0.0762 0.8453]

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

Discussion

As mining engineers face decision making in their day to day operation suitable decision-making technique must be used to ensure right decisions are made. Several techniques are available for solving different type of decision problems. In this paper, Yager's and TOPSIS methods which are some of the MADM techniques were 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 compare 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 9 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. Yager's and TOPSIS method was then applied to ranking of the alternative and the most suitable alternative was selected.

Conclusion

The following conclusions are presented:

1. Both Methods presented Drill Model 3 to be the most suitable among the alternative, despite having different ranking orders.
2. The two methods displayed a difference in the ranking of the other 2 models which can be attributed to the input of the experts into the models. Using the Yager's method, the models were listed as C, A and B while TOPSIS ranked as Model C, Model B and lastly Model A.
3. A consistence analysis was no 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.

The result of this work 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.

Conflict of Interest

None

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