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Mine equipment selection for Ajabanoko iron ore deposit, Kogi State, Nigeria

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Abstract: Mine equipment selection is an integral part of mine planning and design. This study carried out mine equipment selection using combined multiple attributes decision - making method (MADM). Various models of five major mine equipment (dump trucks, wheel loaders, crawler excavators, bulldozers and blast hole drilling rigs) were considered for selection. The attributes considered for the equipment selection where appropriate are cost/unit, operating weight, payload capacity, bucket capacity, maximum digging depth and power. The mine equipment selection order for dump truck, wheel loader, excavator, bulldozer and drilling rig at the Ajabanoko iron ore deposit is EUCLID R90, CAT IT 62H, TEREX TC 225 LC, HITACHI 2505 and TEREX SKT-12 respectively. The study further established the importance of the attributes in the selection of the appropriate model of mine equipment.

Keywords: Mine Equipment, Attributes, Selection Order, MADM, Models

1. Introduction

Mine equipment selection is among the important decisions that must be taken during the planning stage of a new mine. It is pertinent to consider the attributes that will have positive contribution to the overall performance of the equipment. The purpose of equipment selection is to select optimum equipment with minimum cost [1]. The cost of the equipment selected must also consider expected maintenance and running cost. However mine specific factors and not generalities drive mine equipment and machinery selection [2]. Proper equipment selection lowers mining costs and may even change the optimized pit limits, therefore equipment optimization and pit optimization are strongly interrelated [3]. Mine equipment selection is a dynamic process and continues throughout the life of the mine. Equipment affects economic consideration in open pit design, specifically overburden waste rock and ore mining cost and cost escalation parameter as a function of plan location and depth [4]. The problem of equipment selection in a mine is complex [5]. Therefore the attributes of the mine equipment need to be studied carefully in order to select equipment that would operate optimally within the overall mine plan. The term optimum here reflects that the equipment selected must comply with the mining conditions/limitations and meet the basic requirements and preferences of the mine [4, 6]. Many features, restrictions and criteria need to be considered [7]. Therefore the objective of the study is to select some of the mine equipment necessary to exploit the Ajabanoko iron ore deposit.

2. Multiple Attribute Decision Making (MADM)

A MADM method is a procedure that specifies how attribute information is to be processed in order to arrive at a choice [8]. MADM deals with the problem of choosing an alternative from a set of alternatives which are characterized in terms of their attributes [4]. The engineering level of the MADM process defines alternatives and points out the consequences of choosing any of them from the standpoint of various criteria [9]. MADM refers to an approach that is employed to solve problems involving selection from among a finite number of alternatives [8]. Usually consist of a single goal, but this may be of two different type: (i) the first is where to select an alternative from a set of scored ones based on the values and importance of the attributes of each alternative (ii) the second type of goal is to classify alternatives, using a kind of role model or similar cases [4]. The main steps of multi criteria decision making are the following [9]. (i) establishing system evaluation criteria that relates system capabilities to goals (ii) developing alternatives systems for attaining the goals (generating alternatives) (iii) evaluating alternatives in terms of criteria (the values of the criteria functions) (iv) applying a normative multi criteria analysis method (v) accepting one alternative as "optimal" (preferred) (vi) if the final solution is not accepted, gather new information and go into the next iteration of multi criteria optimization.

3. Analytical Hierarchy Process (AHP)

AHP is a multi-criteria decision making (MCDM) procedure which has proven to contribute in several research studies [10]. The following ways are used to generate priorities in making decision:(i) Define the problem and determine the kind of knowledge sought (ii) Structure the decision hierarchy from the top with the goal of the decision objectives from a broad perspective, through the intermediate level (criteria on which subsequent element depend) to the lowest level (which usually is a set of the alternatives) (iii) Construct a set of pairwise comparison matrices. Each of the elements in any level is used to compare the elements in the level immediately below (iv) Use the priorities obtained from the comparisons to weigh the priorities. Do these for every element .Then for each element in the level below add its weighed values and obtain its overall weight. Continue this process of weighing and adding until the final priorities and alternatives in the bottom most level are obtained [11].

The AHP structures the decision problem in levels which correspond to ones understanding of the situation: goals, criterion, sub-criterion, and alternatives [12]. By breaking the problems into levels, the decision-maker can focus on smaller sets of decisions. In the traditional formulation of the AHP, human judgments are represented as crisp values [12]. AHP method considers the use of a reciprocal matrix to expose the pairwise comparison criteria and the resulting eigen vector as subjective weights [13]. The disadvantages of the AHP technique is that it focuses mainly on the decision maker who has to make pair-wise comparisons to reach a decision, while possibly using subjective preference [14]. The AHP is unique in that it allows the quantification of intangible through the construction of the problem in a visual hierarchical manner [10]. This allows relationships between the ultimate goal, the criteria of choice and the alternatives to be clearly delineated in the decision making process [15].

4. Technique for Order Preferences by Similarity to an Ideal Solution (TOPSIS)

TOPSIS was first proposed by Hwang and Yoon [16]. The ideal solution is the solution that maximizes the benefit criteria and minimizes the cost criteria; whereas the negative ideal solution maximizes the cost criteria and minimizes the benefit criteria [16]. The optimal alternative is the one which is closest to the ideal solution and farthest to the negative ideal solution [17]. Schinas identified the advantages the algorithm of TOPSIS offers to decision maker (i) it offers a Euclidean solution, i.e it is easily conceivable (ii) TOPSIS does not use any specific preference scale (iii) all calculations can easily be performed on a normal PC-Compatibles [18]. TOPSIS is more efficient in dealing with the tangibles [8].

5. Location and Geology of Ajabanoko Iron Ore Deposit

The study area for this project is Ajabanoko, located at Okene , Kogi State, Nigeria. Ajabanoko Iron Ore deposit is along longtitude 60 15' 50"N and 60 16' 50"N and latitudes 70 37' 25"E and 70 38' 35"E. Ajabanoko lies 4.5km Northwest of Itakpe hill.

The Ajabanoko deposit area falls within the Nigerian Precambrian basement complex, a suite of crystalline rocks exposed in over nearly half of the country extending west into Dahomeyan of Benin Republic and east into Cameroon [19]. The Ajabanoko area consists of a set of three closely related hills of basement rocks in which some large bands of iron ore occur. These three hills which mark the southern, central and northern ore zones are made up mainly of migmatite and biotite gneisses which trend in a northeast-southwest direction and dip mostly westwards. The dominant lithologic units of Ajabanoko deposit area are gneiss of migmatite, biotite and granite, ferruginous quartzites, granites and pegmatite [19].The ferruginous quartzite is the source of the iron ore mineralization in the area [20].

The nature of Ajabanoko iron ore deposit and the associated rocks indicate that they are residual concentrates derived from iron rich sediment, a volcanogenic sedimentary material [21]. This suggests that all the rocks in the area including the high grade metamorphic ones such as the gneisses and the low grade metamorphic ones such as the quartzites may have been derived from sedimentary materials which in turn were probably derived from an ancient volcanic source [22]. Four principal ore layers have been identified for the different ore zones [23]. Four thick bands ranging from 1 to 5m in thickness and measuring 1.22km along strike have been identified in the deposit, and are classified as ore body I, ore body II, ore body III and ore body IV as shown in Table 1 [22]. Petrological studies of the ore have revealed four major types of ore composition similar to Itakpe Hill: (i) magnetite quartzites (ii) magnetite-hematite quartzites (iii) hematite-magnetite quartzite (iv) hematite-quartzite. The sum total of iron ore reserves in the entire deposit is 62.104 million tons in the C1 category and 25.952 million tons in the C2 category as shown in Table 2.

6. Bench Geometry

The capacity of dump trucks to be used for the proposed mine is 100 tons while the maximum sustained grade for the access road of the mine is 8%. The haulage road width varies between18-30m, this is sufficient to allow easy movement of trucks and other haulage equipment as indicated in Table 3. The slope of the safety berm used for this study is 30^0 which is sufficient to ensure its stability. The height of the safety berm varies from 2-3.5m while the bench height is 15m.

Table 1. *Parameters of the Main Ore Layer Of Ajabanoko Iron Ore Deposit*

Ore layer	Length along strike(m)	Average thickness(m)	Average Fe_{tot}
Orebody I	1100	14.7	40.4
Orebody II	925	10	30.3
Orebody III	750	3.6	37.28
Orebody IV	-	4.3	34.04

National Steel Raw Material Exploration Agency (1994)

Table 2. *Itakpe and Ajabanoko Iron Ore Deposits*

% Mineral Composition	Itakpe Iron Ore	Ajabanoko Iron Ore
Average Fe_{tot}	36.00	34.44
Fe_{mag}	19.90	20.19
SiO_2	42.05	41.99
Al_2O_3	3.20	3.22
P_2O_5	-	0.17
Ore reserve	200million tons	62.104million tons

Table 3. *Parameters of Haulage Road and Catch Bench Design*

Parameter	Value
Minimum bench width	18m
Maximum bench width	30m
Gradient	8%
Height of berm	2-3.5m
Berm slope angle	30^0
Non-working berm width	3m
Working berm width	15m
Drainage ditch type	v-shaped
Drainage ditch slope	3:1
Grade of ditch	3%
Bench height	15m
Width of safety bench	10m
Width of working platform	27.5m

7. Methodology

The methodology of the TOPSIS and AHP was adopted for this study and the procedure is as expressed by Saaty [24]. and Rao [8]. A software program named EQUIPSELECTOR was written for the equipment selection based on the procedure established by Rao [8]..

The methodology of the combined TOPSIS (Technique for Order Preference by Similarity to Ideal Solution and AHP (Analytic Hierarchy Process) is as follows [8].:

Step 1: The objective and evaluation attribute was determined

Step 2: A matrix form of all the information available of the attribute was represented. Such a matrix is called the decision matrix as shown in Equation 1. Table 4 represents the verbal judgment of the attributes when compared with each other. The pairwise comparison of the attributes was carried out using Equations 1 and 2.

Table 4. *Fundamental Scale of Absolute Numbers*

Numerical assessment	Linguistic Meaning
1	Equal Important
3	Moderately more important
5	Strong more important
7	Very strongly important
9	Extremely more important
2,4,6,8	Intermediate values of Importance.

$$DMxN=\begin{array}{c} \\ 1 \\ 2 \\ 3 \\ - \\ - \\ - \\ M \end{array}\begin{pmatrix} 1 & 2 & 3 & - & - & N \\ d_{11} & d_{12} & d_{13} & - & - & d_{1N} \\ d_{21} & d_{22} & d_{23} & - & - & d_{2N} \\ d_{31} & d_{32} & d_{33} & - & - & d_{3N} \\ - & - & - & - & - & - \\ - & - & - & - & - & - \\ - & - & - & - & - & - \\ d_{M1} & d_{M2} & d_{M3} & - & - & d_{MN} \end{pmatrix} \quad (1)$$

$$DNxN=\begin{array}{c} \\ 1 \\ 2 \\ 3 \\ - \\ - \\ - \\ - \\ N \end{array}\begin{pmatrix} 1 & 2 & 3 & - & - & N \\ a_{11} & a_{12} & a_{13} & - & - & a_{1N} \\ a_{21} & a_{22} & a_{23} & - & - & a_{2N} \\ a_{31} & a_{32} & a_{33} & - & - & a_{3N} \\ & & & & & \\ - & - & - & - & - & \\ - & - & - & - & - & - \\ - & - & - & - & - & - \\ a_{N1} & a_{N2} & a_{N3} & - & - & a_{NN} \end{pmatrix} \quad (2)$$

Step 3: The normalized decision matrix, Rij, was obtained using Equation 3

$$Rij = d_{ij} / \sqrt{\sum_{j=1}^{m} d \; d2i} \quad (3)$$

Step 4: The relative of different attributes with respect to the following objective was obtained.

The attribute values were obtained from equipment manufacturers and suppliers as shown in Tables 5-9

The relative normalized weight (wj) of each attribute was obtained by (i) calculating the geometric mean of the ith row, and (ii) normalizing the geometric mean of rows in the comparison matrix using Equations 4 and 5.

$$GM=[\prod_{i=1}^{N} aij\,]0.5 \quad (4)$$

and

$$w_j = GMi \quad / \sum_{i=1}^{N} GM\ i \tag{5}$$

The result obtained from w_j is arranged in 4x1 matrix = $A2_{4X1}$.

Matrix A3 and A4 such that A3 = A1.A2 and A4 = A3/A2 was calculated

The maximum eigen value λ_{max} which is the average of matrix A4 was obtained. The consistency index (I =(A_{max} – N) / (N-1) was obtained. The smaller the value of CI, the smaller is the deviation from consistency. The Consistency ratio CR = CI/RI was obtained.

Table 5. *Attribute Values for Dump Truck Selection*

S/No	Model	Power(hp)	Operating weight(kg)	Payload capacity(tons)	Cost ($/unit)
i	HITACHI 1700-3	1050	171000	100	640000
ii	CAT 773E	682	39390	100	800000
iii	EUCLID R90	1050	201110	100	540000
iv	TR. 100	1050	166320	100	510000

Table 6. *Attribute Values for Mid-size Wheel Loader Selection*

S/No	Model	Power(hp)	Operating weight(kg)	Bucket capacity(m3)	Cost ($/unit)
i	CAT IT 38H	180	15055	3.0	365000
ii	CAT IT 62H	211	19400	4.25	400000
iii	TL 210	162	12500	3.4	360000
iv	CAT 962H	211	19369	3.8	420000

Table 7. *Attribute Values for Crawler Excavator Selection*

S/No	Model	Power(hp)	Operating weight(kg)	Max. digging depth(m)	Cost ($/unit)
i	TEREX TC 210LC	165	19958	5.6	380000
ii	TEREX TC 225LC	156	21682	7.58	410000
iii	TEREX TC 260LC	168	24132	7.69	425000
iv	CAT 325L	168	25520	5.60	450000

Table 8. *Attribute Values for Bulldozer Selection*

S/No	Model	Power(hp)	Operating weight(kg)	Equipment capacity(m^3)	Cost($/unit)
i	HITACHI 1905	765	185900	15.0	435,000
ii	HITACHI 2505	1007	242000	16.5	460,000
iii	CAT D854 K	904	98101	15	580,000
iv	CAT 844 H	687	70816	15	520,000

Table 9. *Attribute Values for Rotary Drill Selection*

S/No	Model	Max. hole size(mm)	Max. hole depth(mm)	Max. bit load(kg)	Cost ($/unit)
I	ATLAS COPCO DML-SP	251	51500	24500	790000
ii	ATLAS COPCO DML	270	52500	27200	810000
iii	TEREX SKF-15	269.9	23470	22679.6	780000
iv	TEREX SKF-12	269.9	55474	22679.6	820000

Step 5: The weighted normalized matrix Vij was obtained.

This is obtained by the multiplication of each element of the column of the matrix Rij with its associated weight wj using Equation 6. Hence

$$V_{ij} = W_j R_{ij} \tag{6}$$

Step 6: The ideal (best) and negative ideal (worst) solutions was obtained using Equations 7 and 8 respectively.

$$V^* = \left[\max_i Vij / j \in J\right] \left[\sum_i^{\min} Vij / j \in J'\right] / I=1,2,\ldots,M \ ]$$

$$=(v^*_1, V^*_2, V^*_3, \ldots, V^*_N) \tag{7}$$

$$V\text{-}=\left(\sum_i^{\min} Vij / j \in J\right)\left(\sum_i^{\max} Vij / j \in J'\right) / i=1,2,\ldots,m \ ]$$

$$=(V\text{-}1, V\text{-}2, V\text{-}3, \ldots, V\text{-} N) \tag{8}$$

Where J=(j=1,2,…N)/j associated with beneficial attributes and J'=(j=1,2,…N)/j associated with non-beneficial attributes.

Sept 7: The separation measure was obtained using Equations 9 and 10.

$$S^*_{i.} = \left[\sum_{j=i}^{N} \left(Vij -_v Vj\ \right)^2 \ \right]^{0.5} \tag{9}$$

$$S^-_{=} \left[\sum_{j=i}^{N} \left(Vij - V_i^-\right)^2 \ \right]^{0.5} \tag{10}$$

Step 8: The relative closeness of a particular alternative to the ideal solution is obtained using Equation 11.

$$C_i^* = \frac{S_i^-}{\left(S_i^* + S_i^-\right)} \tag{11}$$

8. Results and Discussion

The attributes used in the selection of mine equipment for Ajabanoko iron ore deposit are power, operating weight, payload capacity, bucket capacity, maximum digging capacity, maximum hole size, maximum hole depth, maximum bit load and cost. The equipment considered in this study are dump trucks, wheel loaders, bulldozers, crawler excavators and drilling rigs .The equipment attributes were evaluated for the equipment identified above. The equipment models identified for dump truck are TR 100, HITACHI EH 1700-3, CAT 773E and EUCLID R90 as shown in Table 5. The attributes considered for the dump truck selection are power, operating weight, payload capacity and cost/unit. The selection order obtained using EQUIPSELECTOR is, EUCLID R90, CAT 773E, TR100 and HITACHI EH 1700-3 . The values obtained for this selection decrease from 0.6590 for EUCLID R90 and reached a lower limit of 0.4001 for HITACHI EH 1700-3 as shown in Table 10. This indicates that EUCLID R90 is the most acceptable dump truck based on the attributes listed above while HITACHI EH 1700-3 is the least acceptable dump truck as shown in Table 10. The models considered for wheel loaders are CAT IT 38H, CAT IT 62H, TEREX TL 210 and CAT 962H as shown in Table 6. The attributes considered for wheel loaders selection are power, operating weight, bucket capacity and cost/unit.

The equipment selection order obtained from the EQUIPSELECTOR package are CAT IT 62H, CAT IT 38H , TEREX TL 210 and CAT 962H and the corresponding values attached to the selection order are 0.8777, 0.8095, 0.7364 and 0.2636 respectively. This indicates that the model CAT IT 62H is the most acceptable loading machine while the least acceptable is CAT 962H as shown in Table 11 .The attributes values for crawler excavator are power, operating weight, maximum digging depth and cost/unit. The models considered for selection are TEREX TC 210LC, TEREX TC 225LC, TEREX TC 260LC and CAT 325L as shown in Table 7. The selection order obtained for the crawler excavator are TEREX TC 260LC,CAT325L, TEREX TC 210LC,TEREX TC 225LC with corresponding values of 0.7947, 0.5699, 0.4494 and 0.2670 respectively as shown in Table 12. Also the maximum digging depths are 7.69m, 5.60m, 5.60m and 7.58m respectively as shown in Table 7.

The attribute values for bulldozers considered for this study are model, power, operating weight, equipment capacity and cost/unit while the models considered are HITACHI 1905, HITACHI 2505, CAT D854K and CAT 844 H as shown in Table 8. The equipment selection order for bulldozer are HITACHI 2505, CAT D854 K, , CAT 844 H and HITACHI 1905 with values 0.5694, 0.5239, 0.5037 and 0.4554 respectively as shown in Table 13 . The attributes values used for rotary drilling rig are maximum bit load and cost/unit while the models considered for selection are ATLAS COPCO DML-SP, ATLAS COPCO DML, TEREX SKF-15 and TEREX-SKF-12 as shown in Table 9. However the selection order obtained with the package are TEREX SKT-12, ATLAS COPCO DML, ATLAS COPCO DML-SP and TEREX SKT-15 with corresponding selection values of 0.8410, 0.8276, 0.7646 and 0.2533. This shows that TEREX SKF-12 is the most acceptable while TEREX SKT-15 is the least acceptable as shown in Table 14.

Table 10. *Selection Order for Dump Truck*

S/No	Model	Value
i	EUCLID R90	0.6590
ii	CAT 773E	0.5837
iii	TR 100	0.5461
iv	HITACHI EH 1700-3	0.4001

Table 11. *Selection Order for Loading Machine*

S/No	Model	Value
i	CAT IT 62H	0.8777
ii	CAT IT 38H	0.8095
iii	TEREX TL 210	0.7364
iv	CAT 962H	0.2636

Table 12. *Selection Order for Crawler Excavator*

S/No	Model	Value
i	TEREX TC 225LC	0.7947
ii	TEREX TC 260 LC	0.5699
iii	CAT 325 L	0.4494
iv	TEREX TC 210LC	0.2670

Table 13. *Selection Order for Bulldozer*

S/No	Model	Value
i	HITACHI 2505	0.5694
ii	CAT D854 K	0.5239
iii	CAT 844 H	0.5037
iv	HITACHI 1905	0.4554

Table 14. *Selection Order for Rotary Drill Rig*

S/No	Model	Value
i	TEREX SKT-12	0.8410
ii	ATLAS COPCO DML	0.8276
iii	ATLAS COPCO DML-SP	0.7646
iv	TEREX SKT-15	0.2533

9. Conclusions and Recommendations

The equipment selection order is EUCLID R90 model for dump truck; CAT IT 62H model for loading machine; TEREX TC 225 LC model for crawler excavator; HITACHI 2505 for bulldozer and TEREX SKT-12 for rotary drilling rig.

Mine equipment selection order using their attributes should be used when selecting mine equipment for the optimal exploitation of the deposit

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