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

Adebimpe, R. A.\textsuperscript{1}, Akande, J. M\textsuperscript{2}, Arum C\textsuperscript{3}

\textsuperscript{1}Dept. of Mineral Resources Engineering. The Federal Polytechnic, Ado-Ekiti, Nigeria
\textsuperscript{2}Dept. of Mining Engineering. The Federal University of Technology, Akure, Nigeria
\textsuperscript{3}Dept. of Civil Engineering. The Federal University of Technology, Akure, Nigeria

Email address: rasheed4u1@yahoo.com (Adebimpe, R. A.)


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-Compliancs [18]. TOPSIS is
more efficient in dealing with the tangibles [8].

5. Location and Geology of Ajabonoko
Iron Ore Deposit

The study area for this project is Ajabonoko, located at
Okene , Kogi State, Nigeria. Ajabonoko Iron Ore deposit is
along longitude 60 15’ 30”N and 60 16’ 50”N and latitudes
70 37’ 25”E and 70 38’ 35”E. Ajabonoko lies 4.5km
Northwest of Itakpe hill.

The Ajabonoko 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 Ajabonoko 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 Ajabonoko 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 Ajabonoko 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 between 18-30m, 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° 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

<table>
<thead>
<tr>
<th>Orebody</th>
<th>Length along strike (m)</th>
<th>Average thickness (m)</th>
<th>Average Fe&lt;sub&gt;tot&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>1100</td>
<td>14.7</td>
<td>40.4</td>
</tr>
<tr>
<td>II</td>
<td>925</td>
<td>10</td>
<td>30.3</td>
</tr>
<tr>
<td>III</td>
<td>750</td>
<td>3.6</td>
<td>37.28</td>
</tr>
<tr>
<td>IV</td>
<td>-</td>
<td>4.3</td>
<td>34.04</td>
</tr>
</tbody>
</table>

Table 2. Itakpe and Ajabanoko Iron Ore Deposits

<table>
<thead>
<tr>
<th>% Mineral Composition</th>
<th>Itakpe Iron Ore</th>
<th>Ajabanoko Iron Ore</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Fe&lt;sub&gt;tot&lt;/sub&gt;</td>
<td>36.00</td>
<td>34.44</td>
</tr>
<tr>
<td>SiO&lt;sub&gt;2&lt;/sub&gt;</td>
<td>19.90</td>
<td>20.19</td>
</tr>
<tr>
<td>Al&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;3&lt;/sub&gt;</td>
<td>42.05</td>
<td>41.99</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>3.20</td>
<td>3.22</td>
</tr>
<tr>
<td>Ore reserve</td>
<td>-</td>
<td>62.104 million tons</td>
</tr>
</tbody>
</table>

Table 3. Parameters of Haulage Road and Catch Bench Design

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum bench width</td>
<td>18m</td>
</tr>
<tr>
<td>Maximum bench width</td>
<td>30m</td>
</tr>
<tr>
<td>Gradient</td>
<td>8%</td>
</tr>
<tr>
<td>Height of berm</td>
<td>2-3.5m</td>
</tr>
<tr>
<td>Berm slope angle</td>
<td>30°</td>
</tr>
<tr>
<td>Non-working berm width</td>
<td>3m</td>
</tr>
<tr>
<td>Working berm width</td>
<td>15m</td>
</tr>
<tr>
<td>Drainage ditch type</td>
<td>v-shaped</td>
</tr>
<tr>
<td>Drainage ditch slope</td>
<td>3:1</td>
</tr>
<tr>
<td>Grade of ditch</td>
<td>3%</td>
</tr>
<tr>
<td>Bench height</td>
<td>15m</td>
</tr>
<tr>
<td>Width of safety bench</td>
<td>10m</td>
</tr>
<tr>
<td>Width of working platform</td>
<td>27.5m</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Numerical assessment</th>
<th>Linguistic Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal Important</td>
</tr>
<tr>
<td>3</td>
<td>Moderately more important</td>
</tr>
<tr>
<td>5</td>
<td>Strong more important</td>
</tr>
<tr>
<td>7</td>
<td>Very strongly important</td>
</tr>
<tr>
<td>9</td>
<td>Extremely more important</td>
</tr>
<tr>
<td>2,4,6,8</td>
<td>Intermediate values of Importance.</td>
</tr>
</tbody>
</table>

DM<sub>xN</sub>=

\[
\begin{bmatrix}
1 & d_{11} & d_{12} & \ldots & d_{1N} \\
2 & d_{21} & d_{22} & \ldots & d_{2N} \\
3 & d_{31} & \ldots & \ldots & d_{3N} \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
M & d_{N1} & \ldots & \ldots & d_{NN}
\end{bmatrix}
\]  \hspace{1cm} (1)

DN<sub>xN</sub>=

\[
\begin{bmatrix}
1 & a_{11} & a_{12} & \ldots & a_{1N} \\
2 & a_{21} & a_{22} & \ldots & a_{2N} \\
3 & a_{31} & \ldots & \ldots & a_{3N} \\
\vdots & \vdots & \ddots & \ddots & \vdots \\
N & a_{N1} & \ldots & \ldots & a_{NN}
\end{bmatrix}
\]  \hspace{1cm} (2)

Step 3: The normalized decision matrix, R<sub>ij</sub>, was obtained using Equation 3

\[
R_{ij} = \frac{d_{ij}}{\sum_{j=1}^{N} d_{2i}}
\]  \hspace{1cm} (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 (w<sub>j</sub>) 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.

\[
GM = \prod_{i=1}^{N} a_{ij}^{0.5}
\]  \hspace{1cm} (4)
and

\[ w_j = GM_i / \sum_{i=1}^{N} GM_i \]  

(5)

The result obtained from \( w_j \) is arranged in a 4x1 matrix = A2/A4.

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

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

\[ \text{Step 5: The weighted normalized matrix } V_{ij} \text{ was obtained.} \]

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

\[ V_{ij} = W_j R_{ij} \]  

(6)

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

\[ V^* = \left[ \sum_{j=1}^{M} V_{ij} \right]^{1/2} \]  

(7)

\[ V^- = \left[ \sum_{j=1}^{M} (V_{ij} - V^-) \right]^{1/2} \]  

(8)

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

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

\[ S^* = \left[ \sum_{j=1}^{M} \left( V^* - V_{ij} \right)^2 \right]^{1/2} \]  

(9)

\[ S^- = \left[ \sum_{j=1}^{M} \left( V_{ij} - V^- \right)^2 \right]^{1/2} \]  

(10)

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

\[ C_i = \frac{S^-}{(S^* + S^-)} \]  

(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 210LC, CAT 325L, TEREX TC 210LC and 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 attributes 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 844H as shown in Table 8. The equipment selection order for bulldozer are HITACHI 2505, CAT D854K, CAT 844H 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.

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.

References


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