Selection of Equipment for Construction of a Hilly Road using Multi Criteria Approach

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Abstract

Planning and construction of a road in hilly region is very challenging which involves complex processes such as reconnaissance and survey to fix the alignment, formation work and construction of various layers of pavement. It has always been a daunting task for implementing agencies to select proper equipments effectively during construction of a road by taking into consideration of both tangible and intangible factors so as to maximize the benefits of the limited resources. An application of five multi-criteria decision making (MCDM) techniques to a typical selection of equipments used for hilly road construction is presented. Three criteria representing earthwork operations, operational efficiency and convenience of manager have been considered with six sub criteria each for selection of seven different construction equipment alternatives. Five MCDM techniques: Analytical Hierarchy Process (AHP), Simple Additive Weights Method (SAW), Distance Based Method (DBM), Preference Ranking Organization Method (PROMETHEE) and Elimination Et Choice Translating Reality (ELECTRE) methods are examined as potential decision-aid tools to select the appropriate management scheme. Comparison of the results shows that these quite different MCDM techniques lead to a similar subset of recommended solutions. Finally, a case study of Katra-Reasi road of 26 Km length has been carried out to evaluate correct equipments/machinery used for construction of the road hereby optimizing the output. The study clearly demonstrates that alternative dozer D80 is the best choice among the alternatives which has maximum output of 48 cum/hr.

Keywords: Decision Maker (DM); Formation work; Hill road; MCDM Techniques; Equipment Selection.

1. Introduction

Construction of hilly roads involves a number of operations such as earthworks, excavating, hauling, placing, and compacting. Earthworks become more important in context to the construction of hilly roads due to occurrence of land-sliding and non-availability of sufficient quantity of desired materials due to higher transportation cost. Moreover, the operations require expensive heavy equipment as well as manpower. Thus,

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selection of proper equipments is very important step during the construction of the hilly roads which not only to
ensure the usefulness of proper equipment but also should be cost effective and less time consuming process
during construction. It will enable decision makers to improve the efficiency of earthmoving operations from the
point of view of the project management. Therefore, this paper presents a methodology for selection of proper
equipments to be used for construction of a hilly road especially with regard to earthmoving operations. The
well-known multi-criteria techniques have been employed to evaluate the most appropriate equipments. A
complete flowchart has been presented to demonstrate the methodology involved in the process. The evaluation
process is performed to compare the optimal selection of equipments used for construction operations through a
case study using five different MCDM methods, viz. Analytical Hierarchy Process (AHP), Simple Additive
Weights Method (SAW), Distance Based Method (DBM), Preference Ranking Organization Method
(PROMETHEE), ELECTRE Methods. The criteria are defined to express the performance of particular
alternatives relevant for a Decision-Maker (DM), in this case the Border Road Organization (BRO). In addition
to illustration of five methods, this study is intended to lead to a preliminary judgment about the usefulness of
MCDM methods as supplementary decision-making tools for eventual practical use. The case study shows that
the proposed methodology can effectively allocate an optimal equipment selection for different construction
operations and hence serve as an efficient tool for construction management.

In this study a 26 Km Katra-Reasi hilly road stretch has been considered which was to be upgraded by the
BRO. The existing width of pavement of 3.6m was proposed to be widened by 10 m. It is proposed to provide
1.0m wide shoulders along both sides of road to serve as an emergency lane for vehicles which leads a total of 12
m wide formation width. The formation work was planned to perform using 7 different equipments as
alternatives: dozer D80 (A1), dozer BD50 (A2), JCB (A3), rock breaker (A4), wheel loader (A5), tippers (A6),
blasting (A7). The suitability of these seven alternatives has been evaluated with respect to 3 important criteria.
These are earthwork operations, operational efficiency and convenience of manager.

2. Description of Equipment Selection Process

An earthmoving operation consists of the preparation of material, the loader/truck loading cycle, haulage of
trucks to the disposal place, the deposition of the material and the trucks’ return trip to the loading station to start
another load-and-haul cycle. The most common method in earthmoving operations is to employ a number of
rock-breakers/excavators, wheel loaders and haulers to prepare, excavate, load and transport soil. Depending on
the scope and working condition of each project, different operation methods and machine types should be
selected to maximize the overall performance of the operation. The equipment selection process involves various
factors for choosing best alternative of equipment as given in Table 1. There are some commonly used methods
of choosing heavy equipment such as mechanistic, empirical (e.g. means estimating manuals), and discrete event
simulation (e.g. Goldenberg et al., 2007; Peurifoy et al., 2006; Shapira et al., 2007). A simulation tool named site
simulation is also being used by the some agencies now days to recommend to customers a suitable set of
machines and their configuration for relatively simple earthworks. However, these methods do not adequately
catch up with the rapid product development taking place throughout world. Moreover, the applicability of these
methods is limited and it is not possible to evaluate effectively when the site operations grow large and complex.
Fig. 1 depicts a flowchart wherein decision factors are organized in a hierarchy-type structure so that the
complexity of the problem can be decomposed. The main goal of the problem i.e., the selection of equipments
for construction of a hill road is at the top level of the hierarchy-structure, followed by a number of attributes that
are organized at different hierarchy levels. For example, three criteria representing earthwork operations (C1),
operational efficiency (C2) and convenience of manager (C3) have been considered with six sub-criteria each for
selection of seven different equipment alternatives viz. dozer D80 (A1), dozer BD50 (A2), JCB (A3), rock
breaker (A4), wheel loader (A5), tippers (A6), blasting (A7). A second-level attribute set deals with the
secondary goals that together contribute to achieving the top-level goal (e.g., type of earthwork operations, operational efficiency of the equipment, and convenience of manager). At the lowest hierarchy level is a set of feasible alternatives that are to be evaluated. These alternatives are inter-connected to all of the attributes which can be defined within the framework of a construction project as mentioned in Fig. 1.

Table 1. Various factors considered for selection of equipment during hill road construction

| Sr. no. | Convenience of Project Manager | Operational Efficiency | Limitations of Terrain | Safety and Security | Miscellaneous |
|---------|--------------------------------|------------------------|------------------------|---------------------|---------------|
| 1       | Past experience with equipment | Output per hour         | Type of soil (soft/hard rock, soil mixed with boulders) | Landslide prone area | Financial constraints |
| 2       | Availability of number of machines of each type | Availability of trained operators | Season (Rainy/snowfall/summer) | Slippery surface for plying of tippers (hill driving experience of drivers) | Supply of fuel to site for equipments |
| 3       | Time constraint for completion of project | Maintenance and repair required in equipment | Type of vegetation (whether forest clearance required) | Movement of traffic on existing road | Experienced drivers availability |
| 4       | Management of manpower & resources | Availability of spares | Location for dumping site for soil, haulage distance | Track width/ wheel base | Explosive handling experts for blasting |
| 5       | Simultaneous running projects and maintenance | Turning radius of each equipment | Site congestion | Braking system and work mechanism | Cost of human labour vs cost of machine operation |
A number of commonly used attributes that govern the equipment-selection decision can be classified based on the considerations of site conditions, type of equipment, scope and amount of work, available time to complete the work, job conditions and economics of the equipment. The job conditions include factors such as soil conditions, availability of loading and dumping area, accessibility of site, traffic flows and weather conditions at site (Alkass and Harris 1988). The type of supervision and the duration of working hours are also important for the selection of a particular type of earthmoving equipment. The soil and profile of a site may be the deciding factor whether to go for crawler-mounted equipment or wheel-mounted equipment. Similarly, climatic conditions such as the heavy rains, snowfall, and winds speed and visibility level may affect decision on equipment-selection. Heavy traffic congestion near a site may lead to a decision to clear the debris at site and, hence, selecting dozing rather than relying loading and haulage. Generally, most of the construction equipments come with high price which is dependent on size and efficiency of the respective equipments. In addition, a few other important attributes can also affect the decision making process of selection of equipments at greater length. These may include economics of equipment, scheduling process, effectiveness of the outcome and safety during the project work as explained in Table 1. These, in turn, are directly affected by all of the attributes in the set located one level lower e.g., safety may be affected by landsliding, equipment overlapping, night work, etc. as can be experienced from the nature of the problem.

2.1 Equipment Alternatives

Based on the economical, technical, and physical ease to implement and achieve the desired objectives, the results from preliminary discussions with the stakeholders and authorities, seven alternatives are considered as follows: Alternative 1 (A1) is dozer D80 (Make Komatsu) which consists of operating weight of 20000 Kg along with 224 HP of power capacity. It dozes off 3.1 cu m of earthwork from its blade. Alternative 2 (A2) is dozer BD50 (Make BEML) which has operating weight of 11000 Kg with 90 HP of power capacity. BD50 dozes off about 1.8 cu m earthwork. Alternative 3 (A3) is a JCB with bucket capacity of 0.15-0.2 cu m. Alternative 4 (A4) is Rockbreaker/excavator which has hourly output of 60 cu m. Alternative 5 (A5) is a wheel loader with bucket capacity of 1.5 cu m. Alternative 6 (A6) is tippers/dumpers used for hauling and has the capacity of 4.5 cu m /9.6 cu m. Alternative 7 (A7) is blasting which is used on hard rock. It may be noted that blasting may affect the characteristics of the earth materials, composition, texture impact developed in the process. This may lead cracks in the rocks and may ultimately reduce the shear strength. These alternatives of equipments are being used in earthwork operations at various projects part of inventory of BRO as given in Table 2.

Table 2: Inventory of equipment deployed in a BRO Project for Katra-Reasi road

| Equipment                  | Hourly output/capacity | No of Machines Available for the Project | Remarks                                    |
|----------------------------|------------------------|-----------------------------------------|--------------------------------------------|
| Dozer D80                  | 48 cu m                | 2                                       | SMB(soil mixed with boulders)& SR(soft rock) |
| Dozer BD50                 | 28.32 cu m             | 2                                       | SMB(soil mixed with boulders) & SR(soft rock) |
| JCB                        | 30 cu m (loading)      | 2                                       | SMB(soil mixed with boulders) & SR(soft rock) |
| Rockbreaker/Excavators     | 60 cu m                | 4                                       | SR(soft rock) & HR(hard rock)              |
| Wheel loader               | 40 cu m                | 2                                       | SMB (soil mixed with boulders)             |
| Tippers and Dumpers        | 4.5 cu m and 9.6 cu m  | 13 and 2                                | Hauling                                    |
| Air compressor with jack   | 20 cu m                | 1                                       | Rarely used (depends on soil strata, preferred in hard rocks) |
2.2 Criteria for selection of equipments

The construction manager (DM) is assumed to select equipment among several alternatives as potential choice for earthwork operations during the construction of a hilly road. The DM is assumed to try to evaluate their convenience by defining a set of criteria (attributes) which reflect their relevant performance. The equipments are selected with diligence and deliberate process with focus on performance enhancement. The selection process considered the type of earthwork operations, operational efficiency and convenience of manager as basic criteria for application of MCDM techniques. Based on discussions held with stakeholders, total eighteen sub-criteria were adopted to be used in the evaluation of the alternatives. The type of earthwork operations include formation cutting (C11), rock cutting (C12), filling (C13), dozing (C14), loading (C15), transportation (C16) as sub criteria. The sub criteria for operational efficiency are output per hour (C21), availability of trained operators (C22), maintenance, repair required in equipment and availability of spares (C23), fuel consumption (C24), mobility (C25), safety (C26). The sub criteria considered for convenience of manager are past experience with equipment (C31), availability of number of machines of each type (C32), time constraint for completion of project (C33), management of manpower and resources (C34), simultaneous running projects and maintenance (C35) and consistence of machine (C36). Table 1 lists the criteria, specifying for each criterion the units and its direction of preference (increasing or decreasing preference). The criteria (attributes) of performance of equipment can be quantified by using different methods.

2.3 The basic structure of the chosen MCDM methods

A number of researchers have worked to develop a method to assist in equipment selection and, consequently, different models have evolved over the years. For example, there are optimization model, graphics model and database-centered models. Different expert systems have also been developed to assist in equipment selection using artificial intelligence-based models (Alkass and Harris, 1988). Harris and McCaffer (2001) have developed their equipment selection model based on multi-attribute decision-making. A number of computer programs have been developed to assist in the equipment-selection process. Similarly, commercial software is available that offers solutions for the selection of a specific compactor model. Some of the software packages are also commonly used by engineering and construction firms, such as Compu-Crane and LPS (NCI 2006).

Five discrete MCDM methods are chosen to deal with the problem of selecting appropriate equipments (Hwang and Yoon, 1981; Saaty, 1990; Singh and Dubey, 2012). Essentially, each method reflects a different approach to solve a given discrete MCDM problem of choosing the best among several preselected alternatives. All five methods require the pre-selection of a countable number of alternatives and the use of a countable number of quantifiable (conflicting and non commensurable) performance criteria. The SAW method is selected as the simplest and clearest method. It is often used as a benchmark to compare the results obtained from this and other discrete MCDM methods when applied to the same problem. The distance based methods are generally selected because of their unique but also very logical way of approaching the discrete MCDM problems. The AHP method can be used for its specificity. It offers freedom to the DM to express his/her preferences for particular criteria by using the original AHP measurement scale. For these methods, the weights used to express the relative importance of criteria can be determined either analytically or empirically by the DM himself. The AHP method, does not require such explicit quantification of criteria, but it needs specific hierarchical structuring of the MCDM problem. The method itself then generates the weights of the criteria by using the AHP measurement scale according to a specified procedure. The two outranking methods, viz. PROMETHEE II and ELECTRE III, can be recommended for situations, where a finite number of discrete alternatives are to be chosen by taking into consideration of large number of decision criteria and decision makers. An important advantage of outranking methods, when compared to other decision support techniques most often applied, is the ability to
deal with ordinal and more or less descriptive information on the alternative plans to be evaluated. In PROMETHEE II and ELECTRE III outranking methods, the criteria are treated as pseudo-criteria (Brans et al. 1986). In the next sub-sections, the basic structures of five MCDM methods and the procedures for assigning weight to the criteria are described.

2.3.1 Analytical Hierarchy Process (AHP)

The analytical hierarchy process was developed by Saaty (1980) which is based on additive weighting process. Over the years, it has been widely reviewed and applied in the area of construction management, and its use is supported by several commercially available, user-friendly software packages (Hastak 1998). AHP formalizes the conversion of the attribute weighting problem into the more tractable problem of making a series of pairwise comparisons among competing attributes. The AHP algorithm is composed of following steps:

- An hierarchy of decision criteria (attributes) is developed and the alternative courses of actions are defined by developing interrelationships among these attributes. Once interrelationships between attributes are developed by the hierarchy, relative weights of the attributes are evaluated by comparing them in pairs, separately for each set in the hierarchy.
- The next step is the calculation of a list of the relative weights, importance, or value, of the factors which can be evaluated by normalizing each column of the “decision matrix”. The algebraic average of the columns of the normalized matrix will provide the relative weights. Once relative weights are calculated for each criterion at every level of the hierarchy and respective local priority vectors are produced, the overall score of each alternative, representing the preference of one alternative over another, can be obtained. Aggregation is achieved by multiplying local priority vectors of each set of attributes by the relative weights of the attributes immediately above them.
- The above evaluation process must satisfy the condition of “Consistency Ratio” (CR) which is a measuring tool for controlling the consistency of pair-wise comparisons. Based on numerous empirical studies, it is suggested that to be acceptable (i.e., for tolerable inconsistency), the CR must be less than or equal to 0.10.

2.3.2 Simple Additive Weights (SAW) method

In the Simple Additive Weighting (SAW) method, the score of an alternative is equal to the weighted sum of its preference ratings, where the weights are the importance weights associated with each criterion. The resulting scores for each alternative can be used to rank, screen, or choose an alternative. It consists of quantifying the values of criteria (attributes) for each alternative by constructing a decision matrix. The DM constructs a new objective function, which is the weighted average of the evaluation values with respect to the different criteria. The SAW algorithm for N alternatives and M criteria can be explained with following steps:

- The criteria for the problem are identified and hierarchy of decision criteria is developed.
- The weight for each criteria is determined. The weight can be obtained via survey, AHP, etc.
- The score of alternative (option) are obtained using each criteria “i” for all alternatives “j”.
- The sum of the weighted score for each alternative is computed using following equation:

\[ S_i = \sum_{j=1}^{M} w_j r_{ij} \text{ for } i = 1, 2, ..., N \]  

where, \( S_i \) is the overall score of the ith alternative; \( r_{ij} \) is the normalized rating of the ith alternative for the jth criterion, \( w_j \) is the importance weight of the jth criterion. The option with the best score is selected.

2.3.3 Distance Based Methods (DBM)

This method is also called Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) method. There are two fundamentally different versions of this method. In the first case the DM specifies the ideal point,
the components of which are the subjective or computed best values of the different criteria. The ideal point is an n-dimensional vector, and the evaluation vector $X_j$ of each alternative is compared to the ideal point by computing their distance. The alternative with the smallest distance is considered the best. In the second approach the DM specifies/computes the nadir, the components of which are the subjective or computed worst values of the criteria. The nadir is also an n-dimensional vector. Each alternative “$j$” will be compared to the nadir by computing the distance of the evaluation vector $X_j$ from the nadir. The alternative with the largest distance is then selected as the best choice. In order to avoid the difficulties resulting from the different units of the criteria, all criteria are normalized, so the components of the ideal point, the nadir and the evaluation vectors are all normalized. Let $a_{i*}$ denote the $i$th component of the ideal point and $a_{i*}$ be the $i$th component of the nadir, and assume that linear transformation is used for normalizing. Then the distance of alternative $j$ from the ideal point is given by equation (2):

$$D_j^p = \left\{ \sum_{i=1}^{n} \left( w_i \frac{a_{ij} - a_{ip}}{a_{i*} - a_{i*}} \right)^p \right\}^{1/p}$$

(2)

where $p \geq 1$ is a positive user-selected model parameter. Similarly the distance of alternative $j$ from the nadir is defined by relation given by equation (3):

$$D_j^p = \left\{ \sum_{i=1}^{n} \left( w_i \frac{a_{ij} - a_{ip}}{a_{i*} - a_{i*}} \right)^p \right\}^{1/p}$$

(3)

The selection of parameter $p$ is very important, since it has a significant effect on the final choice. If $p = 1$, it corresponds to simple averaging, $p = 2$ to squared averaging.

2.3.4 PROMETHEE Methods

This method has two steps. (a) Building the outranking relation (b) Exploiting the outranking relation with regard to the chosen statement of the problem. In step 1, DM chooses a generalized criterion and fixes the necessary parameters related to the selected criterion: a preference function is defined for each attribute. Multi-criteria preference index is defined as the weighted average of the preference functions. This preference index determines a valued outranking relation on the set of alternatives. In step 2, for each alternative, a leaving and an entering flow are defined. A net flow is also considered. A complete preorder (PROMETHEE II) has been proposed in this case study, the details of which can be referred elsewhere.

2.3.5 ELECTRE III Method

The extensive methodological development and refinements have been made to use ELECTRE (for Elimination and Choice Translating Reality; English translation from the French original) in multi-criteria decision making process by many investigators (Massam and Askew, 1982; Roy, 1971). ELECTRE uses four different threshold levels namely strong preference threshold, weak preference threshold, indifference threshold, veto threshold (Vincke, 1999). Through a series of consecutive assessments of the outranking relations of the alternatives, ELECTRE finds the so-called concordance index, defined as the amount of evidence to support the conclusion that alternative ‘a’ outranks, or dominates, alternative ‘b’, as well as the discordance, the counter-part of concordance index.

3. Application of the Proposed MCDM Methods

The application of the five MCDM methods is carried out under the assumption that the project manager has sufficient knowledge about characteristics of different equipments. Evidently, such information makes the project manager’s intentions to look for the best alternative. The seven alternatives (equipments) are selected as potential
equipments as described earlier. In order to determine the relative weights of each parameter, pair-wise comparisons have been made by taking into consideration of the opinion of 5 operators/supervisors working in this area through a structured questionnaire survey. The five different MCDM methods have been applied which are demonstrated in subsequent paragraphs based on the experts opinion on weights of these criteria.

(i) Application of Analytical Hierarchy Process (AHP)

Using AHP, the relative weights have been evaluated by performing pairwise comparisons among all six sub-criteria of criterion 1 for the present case study. Similarly pairwise comparisons of sub-criteria associated with other two criteria have also been performed to evaluate weights of all the sub-criteria. In order to determine the relative weights of each parameter, pair-wise comparisons have been made by taking into consideration of the opinion of 5 operators/supervisors. The second column of Table 3(a)-(c) represents the relative weights of different criteria evaluated by the AHP by using appropriate aggregation function.

(ii) Application of SAW method

The evaluation vectors for seven equipment alternatives have been assigned as given in Table 3(a), 3(b), 3(c) with respect to earthwork operations, operational efficiency and convenience of manager respectively. It summarizes the input evaluation matrix for the computation of the score of all seven alternatives which is equal to the weighted sum of its cardinal evaluation/preference ratings. Table 3(a) shows the alternative systems versus criteria array for earthwork operations. All the criteria considered were estimated quantitatively. It is assumed that the “true ideal point” is not known so that the approach of “displaced ideal” is used. The weights for each criterion have been evaluated from AHP after discussions with DMs. The numerical values of importance weights for the given criteria are given in second column of table 3. The score of alternative j using each criterion i for all i and j has been obtained and sum of weighted score for each option has been computed using SAW method as explained earlier. The ranking has been provided to all alternatives based on descending value of sum of weighted score. The results obtained by SAW method of MCDM are appended in Table 4.

(iii) Use of DBM/TOPSIS method

By considering again the data of the case study discussed earlier, the ideal point components (the maximum values), and the components of the nadir (the actual minimum values) have been set with respect to all criteria. Using the distance equation (3) with p = 2 and weights as mentioned in Table 3 as before, the distances can be calculated as given in Table 4. For example, in case of the type of earthwork operations, when all alternatives A1-A7 are evaluated with respect to six criteria, the final score in terms of distances are 0.213, 0.260, 0.421, 0.377, 0.406, 0.451, 0.455 respectively. The first alternative gives the smallest distance (i.e. 0.213), so it is the best choice. The ranking of the alternatives with respect to type of earthwork operations can be obtained by ordering them in increasing distances. Thus order of equipment to be selected with respect to earthwork operations is A1 >A2>A4>A5>A3>A6>A7. Similarly, the ranking of the alternatives with respect to other two criteria viz. operational efficiency and convenience of manager can be obtained. The final scores evaluated using DBM/TOPSIS method are given in Table 4.

(iv) Use of PROMETHEE II and ELECTRE III

By taking the opinion of stakeholders and developing outranking relationships using different criteria as described earlier, PROMETHEE II and ELECTRE III has been applied and results are presented in Table 4.

The results obtained from different MCDM methods, viz. SAW, DBM, PROMETHEE II, ELECTRE III have been integrated to evaluate a single value for each alternative using SAW method. The comprehensive ranking of all alternatives is given in Table 5.
Table 3(a): Evaluation Matrix for different alternatives vs. criteria earthwork operations

| Criteria | Weights | A1 | A2 | A3 | A4 | A5 | A6 | A7 | Best | Worst |
|----------|---------|----|----|----|----|----|----|----|------|-------|
| C11      | 0.319   | 52.00 | 35.00 | 1.00 | 8.00 | 2.00 | 0.00 | 1.00 | 52.00 | 0.00  |
| C12      | 0.215   | 15.00 | 10.00 | 3.00 | 65.00 | 2.00 | 0.00 | 5.00 | 65.00 | 0.00  |
| C13      | 0.092   | 5.00  | 5.00  | 20.00 | 0.00 | 30.00 | 40.00 | 0.00 | 40.00 | 0.00  |
| C14      | 0.222   | 45.00 | 30.00 | 10.00 | 0.00 | 15.00 | 0.00 | 0.00 | 45.00 | 0.00  |
| C15      | 0.079   | 0.00  | 0.00  | 45.00 | 0.00 | 55.00 | 0.00 | 0.00 | 55.00 | 0.00  |
| C16      | 0.073   | 0.00  | 0.00  | 5.00  | 0.00 | 5.00  | 90.00 | 0.00 | 90.00 | 0.00  |

Table 3(b): Evaluation Matrix for different alternatives vs. criteria Operational Efficiency

| Criteria | Weights | A1 | A2 | A3 | A4 | A5 | A6 | A7 | Best | Worst |
|----------|---------|----|----|----|----|----|----|----|------|-------|
| C21      | 0.263   | 48.00 | 28.00 | 18.00 | 25.00 | 45.00 | 4.50 | 20.00 | 48.00 | 4.50  |
| C22      | 0.204   | 60.00 | 60.00 | 80.00 | 15.00 | 75.00 | 98.00 | 10.00 | 98.00 | 10.00 |
| C23      | 0.088   | 20.00 | 20.00 | 30.00 | 5.00  | 25.00 | 80.00 | 98.00 | 98.00 | 5.00  |
| C24      | 0.102   | -18.0 | -12.0 | -8.00 | -16.0 | -12.0 | -5.00 | -12.0 | -5.00 | -18.0 |
| C25      | 0.132   | 90.00 | 80.00 | 95.00 | 90.00 | 90.00 | 75.00 | 90.00 | 95.00 | 75.00 |
| C26      | 0.211   | 80.00 | 80.00 | 90.00 | 35.00 | 75.00 | 60.00 | 20.00 | 90.00 | 20.00 |

Table 3(c): Evaluation Matrix for different alternatives vs. criteria convenience of project manager

| Criteria | Weights | A1 | A2 | A3 | A4 | A5 | A6 | A7 | Best | Worst |
|----------|---------|----|----|----|----|----|----|----|------|-------|
| C31      | 0.108   | 90.00 | 75.00 | 60.00 | 40.00 | 70.00 | 60.00 | 25.00 | 90.00 | 25.00 |
| C32      | 0.221   | 50.00 | 50.00 | 60.00 | 20.00 | 40.00 | 70.00 | 80.00 | 80.00 | 20.00 |
| C33      | 0.164   | -20.0 | -45.0 | -60.0 | -75.0 | -35.0 | -25.0 | -80.0 | -20.0 | -80.0 |
| C34      | 0.164   | 80.00 | 80.00 | 98.00 | 30.00 | 70.00 | 100.0 | 40.00 | 100.0 | 30.00 |
| C35      | 0.061   | 95.00 | 90.00 | 65.00 | 45.00 | 75.00 | 98.00 | 95.00 | 98.00 | 45.00 |
| C36      | 0.282   | 90.00 | 85.00 | 85.00 | 75.00 | 85.00 | 90.00 | 10.00 | 90.00 | 10.00 |

Table 4: Final Score using Normalized evaluations and weights by different methods

| Criteria | A1 (Dozer D80) | A2 (Dozer BD50) | A3 (JCB) | A4 (Rock breaker) | A5 (Wheel Loader) | A6 (Tippers) | A7 (Blasting) |
|----------|----------------|-----------------|----------|-------------------|-------------------|--------------|--------------|
| SAW Method | 0.705          | 0.554           | 0.525    | 0.276             | 0.545             | 0.521        | 0.217        |
| DBM Method | 0.164          | 0.202           | 0.255    | 0.342             | 0.233             | 0.274        | 0.390        |
| PROMETHEE II | 0.644         | 0.998           | 0.948    | 0.912             | 0.938             | 0.929        | 0.970        |
| ELECTRE III | 2.333          | 4.667           | 4.000    | 4.667             | 3.00              | 2.000        | 6.333        |
Table 5: The comprehensive ranking of all alternatives

| Alternatives         | A1 (Dozer D80) | A2 (Dozer BD50) | A3 (JCB) | A4 (Rock-breaker) | A5 (Wheel Loader) | A6 (Tippers) | A7 (Blasting) |
|----------------------|----------------|-----------------|----------|-------------------|-------------------|--------------|--------------|
| Earth Operations     | 1              | 2               | 5        | 4                 | 3                 | 5            | 7            |
| Operational efficiency| 4              | 3               | 2        | 7                 | 1                 | 5            | 6            |
| Convenience of manager| 2              | 4               | 3        | 7                 | 5                 | 1            | 6            |
| Overall Ranking      | 1              | 3               | 4        | 6                 | 2                 | 5            | 7            |

4. Conclusion

The model presented herein offers a comprehensive solution for the systematic evaluation of both qualitative and quantitative decision factors alongside a mechanism for the overall integrative evaluation of criteria. The analysis clearly demonstrates that dozer D80 (A1) scores the first rank and blasting (A7) being the last. Sequence of most preferred to least preferred is dozer D80 (A1), wheel loader (A5), dozer BD50 (A2), JCB (A3), tippers (A6), rock breaker (A4), blasting (A7). During road construction the alternative selection procedure results were verified and testimony was the timely completion of earth operations of the road construction. However, the choice for equipment will vary case by case depending upon terrain, task, time of completion of project and construction cost. These tools have proven to be very comprehensive in making decisions where human interpretations and bias may spoil the show. Hence it makes a strong case for recommendation of utilization of multi-criteria tools and adopts a more scientific approach.

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