



Evaluation of Wheel Loader Selection using AHP and Promethee Hybrid Method

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ABSTRACT

Considering the growth of industrialization for construction works, the role of on-site equipment and machinery in enhancing productivity and efficiency as well as improving working standards of construction. Hence, selecting the proper construction equipment is a challenging task owing to a wide range of available types as well as a host of criteria to be considered during decision making. However, the selection may result in incorrect decision-making or neglection of factors that are as important as cost or technical features. For this reason, nowadays the decision makers use multi-criteria decision making (MCDM) methods to make the most suitable or beneficial decision on machine and equipment selection. One of the most widely used construction equipment is wheel loader. This machine is widely used in all fields of construction. Therefore, proper selection based on the real needs of the project seems necessary. Hence, in this study, the selection of a suitable wheel loader was studied using MCDM methods. In this regard, an integrated approach using AHP and PROMETHEE method for evaluating wheel loader selection were used. In this regard, the Analytic Hierarchy Process (AHP) and the preference ranking organization method for enrichment evaluation (PROMETHEE), are used in the evaluation procedure. More precisely, AHP is applied to determine the relative weights of evaluation criteria and PROMETHEE is applied to rank the wheel loader alternatives. The proposed approach also provides a relatively simple and very well suited decision making tool for this type of decision making problems.

Keywords:

Wheel loader selection, AHP, PROMETHEE, MCDM, Construction equipment selection.



1. Introduction

Considering the growth of industrialization for construction works, the role of on-site equipment and machinery in enhancing productivity and efficiency as well as improving working standards of construction. For many construction projects, the acquisition of heavy mechanized equipment is quite capital intensive as it occupies around 36 percent of the total project cost [1]. The proper selection of construction equipment is essential for both the quality and duration of a construction project and can lead to maximizing construction efficiency, especially for infrastructure work [2]. Therefore, selection of construction equipment is a challenging task and also one of the most important issues for any construction company. Given the importance of purchasing the right type of construction equipment, practitioners seem to be confused when confronted with an increasing number of alternatives that serve the same purpose with various features [3,4]. During the selection of proper equipment, many purchasers tend to give a priority to the expense, as it is aligned with profit-oriented goals of a construction company [5]. Also, some may emphasize technical aspects of equipment selection or a trade-off between cost and technology [6,7]. However, the selection may result in incorrect decision-making or neglect of factors that are as important as cost or technical features. For this reason, nowadays the decision makers use multi-criteria decision making (MCDM) methods to make the most suitable or beneficial decision on machine and equipment selection. In previous studies in this field, various MCDM techniques were applied for the proper selection of construction equipment, such as analytical hierarchy process (AHP), simple additive weighting (SAW), preference ranking organization method for enrichment evaluation (PROMETHEE), elimination et choice translating reality (ELECTRE), technique for order preference by similarity to an ideal solution (TOPSIS) and vlskriterijumska optimizacija i kompromisno resenje (VIKOR) [8-14]. In this regard, Ghorabae et al [15] proposed a new hybrid fuzzy MCDM approach for evaluation of construction equipment based on extended step-wise weight assessment ratio analysis (SWARA), criteria importance through intercriteria correlation (CRITIC) method and evaluation based on distance from average solution (EDAS) method. Bascetin et al [16] also used the AHP method for machinery and equipment selection in mining. Also, Briskorn et al [17] applied mixed-integer programming models for tower crane selection. Samanta et al [18] incorporated the AHP method to the selection of open cast mining equipment. Elevli et al [19] also used PROMETHEE technique to decide on an underground transport system in a chrome mine. Gorcun et al [20] used a novel hybrid fuzzy MCDM technique (SWARA) for tanker vehicle selection. One of the most widely used construction equipment is wheel loader. This machine is widely used in all fields of construction. Therefore, proper selection based on the real needs of the project seems necessary. Hence, in this study, the selection of a suitable wheel loader was studied using MCDM methods. In this regard, an integrated approach using AHP and PROMETHEE method for evaluating wheel loader selection were used.

2. Methods

2.1. The research framework

The research framework is presented in Figure 1. The proposed approach helps to decompose this unstructured problem into a reliable hierarchical structure that includes various criteria, sub-criteria, and alternatives. The research started with identification various criteria, sub-criteria, and alternatives. Then, AHP method was applied to find the relative importance weights of the evaluation criteria in the decision hierarchy. Finally, TOPSIS method uses these weights for determining the overall ranking scores of the machines. In the proposed methodology, the TOPSIS



approach is used to achieve the final ranking of the wheel loaders. The evaluation procedure consists of the following three main steps:

- 1- Identify the wheel loader evaluation criteria that are considered to be the most important.
- 2- Build criteria hierarchy and determine the criteria weights with the AHP method.
- 3- Use the TOPSIS method to establish a ranking of potential machines

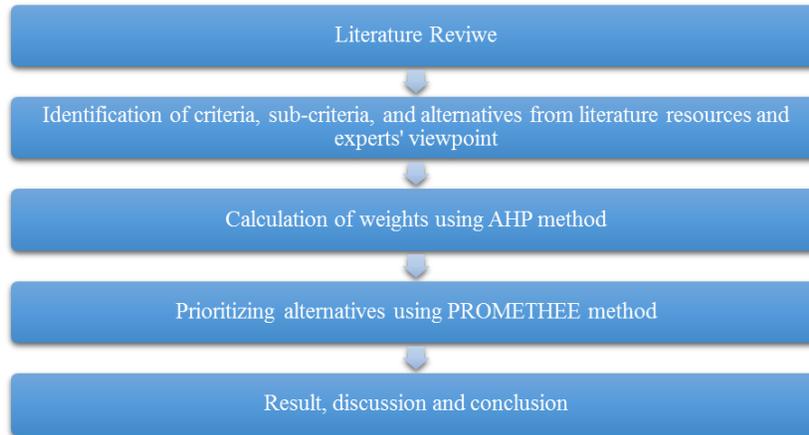


Figure 1. The research framework

2.2. AHP Method

AHP initially developed by Saaty is a well- accepted technique to handle complicated MCDM complications including multiple quantitative and qualitative factors. AHP is used to derive quantitative scales from both discrete and continuous paired comparisons and using Saaty's 1-9 scale (Table 1) based on the opinions of experts who are allowed to specify their liking. This scale is very helpful for an individual or for experts to generate a decision. Giving importance weights for each criteria and sub-criteria is the purpose of AHP [21]. Essential steps of the AHP method include:

- 1- Identifying main factors and sub-factors and establishing a hierarchy prioritization model.
- 2- Developing a questionnaire and then collect the opinion of experts.
- 3- Construct pairwise comparison matrices (A) among the main criteria and the sub-criteria with respect to their corresponding main criteria.

$$A = \begin{matrix} & \begin{matrix} C1 & C2 & C3 & \dots & Cn \end{matrix} \\ \begin{matrix} C1 \\ C2 \\ C3 \\ \vdots \\ Cn \end{matrix} & \begin{bmatrix} 1 & a_{12} & a_{13} & \dots & a_{1n} \\ a_{21} & 1 & a_{23} & \dots & a_{2n} \\ a_{31} & a_{32} & 1 & \dots & a_{3n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & a_{n3} & \dots & 1 \end{bmatrix} \end{matrix} \quad (1)$$

Where a_{ij} is the relative importance of criterion C_i with respect to criterion C_j . In the matrix, $a_{ij} = 1$ when $i = j$ and $a_{ij} = 1/a_{ji}$.

- 4- Determine normalized weights for each of the main factors and sub-factors.
- 5- Examine the consistency ratio (CR).



The CR is determined to measure inconsistencies in the pairwise assessments. Consistency ratio is determined by the following steps.

- Compute the relative weights or eigenvector and λ_{Max} for each matrix of order n
- Compute the consistency index (CI) for each matrix of order n by Eq. (2), The CR, then calculated by Eq. (3). Depending on the value of n the value of random consistency index (RI) is obtained from Table 2. If CR is less than 0.1, the result obtained is considered as consistent [22].

$$CI = \frac{(\lambda_{Max} - n)}{(n - 1)} \quad (2)$$

$$CR = \frac{CI}{RI} \quad (3)$$

Table 1. Significance of scores in AHP [23].

Score	Definition
1	Both factors are equally important
3	One factor moderately important over another
5	One factor strongly important over another
7	One factor very strongly important over another
9	One factor extremely important over another
2, 4, 6, 8	Intermediate value between two adjacent judgments

Table 2. Random consistency index (RI) [23].

Order of matrix (n)	1	2	3	4	5	6	7	8	9	10
Random index (RI)	0.00	0.00	0.52	0.89	1.11	1.25	1.32	1.41	1.45	1.49

2.3. Promethee Method

The PROMETHEE is a MCDM method developed by Brans et al [24, 25]. It is a quite simple ranking method in conception and application compared with other methods used for multi-criteria analysis. It is well adapted to problems where a finite number of alternatives are to be ranked according to several, sometimes conflicting criteria. The implementation of PROMETHEE requires two additional types of information:

- Information on the relative weight of the criteria considered.
- Information on the decision-maker's preference function, which he/she uses when comparing the contribution of the alternatives in terms of each separate criterion. The weights coefficients can be determined according to various methods. AHP method is used to determine the criteria weights in this study. The PROMETHEE method is appropriate to treat the multi-criteria problem of the following type:

$$\max\{f_1(a), f_2(a), \dots, f_n(a) \mid a \in A\} \quad (4)$$

Where A a finite is set of possible alternatives $\{a_1, a_2, \dots, a_n\}$, and f_j denotes n criteria to be maximized. When two alternatives $(a, b \in A)$ are compared, the results of these comparisons should be expressed in in terms of preference. As a result, the preference function (P) is considered (Eq.s (5, 6 and 7)). The preference structure of PROMETHEE is based on pairwise comparisons. In this case the deviation between the evaluations of two alternatives on a particular criterion is considered.



$$P_j(a, b) = G_j [d_j(a, b)]; \forall a, b \in A \quad (5)$$

Where G_j is a non-decreasing function of the observed deviation (d_j) between $f_j(a)$ and $f_j(b)$

$$d_j(a, b) = f_j(a) - f_j(b) \quad (6)$$

And for which:

$$0 \leq P_j(a, b) \leq 1 \quad (7)$$

In case of a criterion to be maximized, this function is giving the preference of a over b for observed deviations between their evaluations on criterion f_j . For criteria to be minimized, the preference should be reversed or alternatively given by:

$$P_j(a, b) = G_j [-d_j(a, b)] \quad (8)$$

PROMETHEE permits the computation of the following quantities for each alternative a and b :

$$\pi(a, b) = \frac{\sum_{j=1}^n w_j P_j(a, b)}{\sum_{j=1}^n w_j} \quad (9)$$

$$\phi^+(a, b) = \sum_{x \in A} \pi(x, a) \quad (10)$$

$$\phi^-(a, b) = \sum_{x \in A} \pi(a, x) \quad (11)$$

$$\phi(a) = \phi^+(a) - \phi^-(a) \quad (12)$$

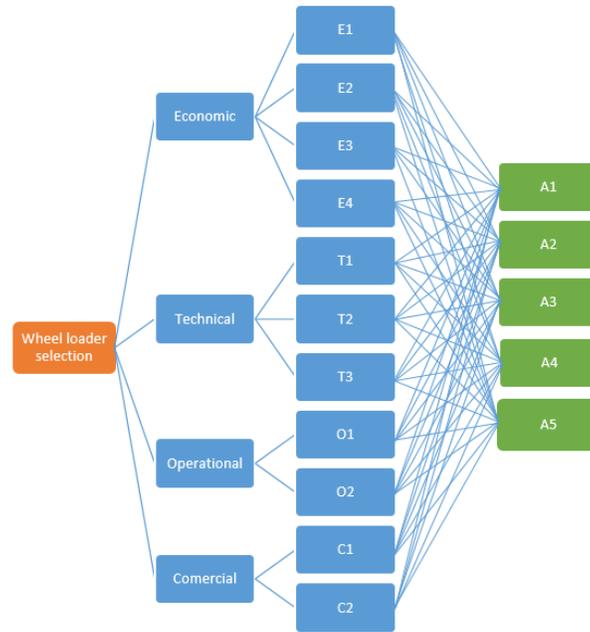
For each alternative a , belonging to the set A of alternatives, $\pi(a, b)$ is an overall preference index of a over b . The leaving flow $\phi^+(a)$ is the measure of the outranking character of a (how a dominates all the other alternatives of A). Symmetrically, the entering flow $\phi^-(a)$ gives the outranked character of a (how a is dominated by all the other alternatives of A). $\phi(a)$ represents a value function, whereby a higher value reflects a higher attractiveness of alternative a and is called net outranking flow. PROMETHEE uses net outranking flow (ϕ) to rank alternatives. The alternative with the higher net flow is assumed to be superior.

3. Results and Discussions

The research started with identification of main criteria and sub-criteria and alternatives from literature resources and experts' viewpoint. 5 alternatives (A1, A2, ..., A5) have been specified. Economic, technical, operational, and commercial criteria are defined as main criteria in this study. Each of these main criteria is divided into sub-criteria. The hierarchy design of the evaluation procedure is illustrated in Figure 2 and Table 3 with the main and sub-criteria definitions and their symbolic notations. Initially, the local weights of the main criteria are determined. The questionnaire was created to obtain experts' opinions. Before data collection, objective and utility of the research were explained to each expert. Expert Choice software was used to prioritize the identified strategies, according to AHP technique. Next, the pairwise evaluation matrix for the main criteria was constructed based on the Saaty's scale, by each expert. After receiving the



questionnaire from each of the experts, the CR was calculated and if it was more than 0.1, the questionnaire was returned to the expert for review. Table 4 shows the importance weight of main criteria. The local weights of the sub-criteria are calculated in the same manner using the AHP approach. Subsequently, the global weights of the sub-criteria are calculated by multiplying the local weight of each sub-criterion with the local weight of its respective main criteria given in Table 5. It should be noted that according to table 4, CR of main factors paired comparisons was calculated as 0.0084, which is less than 0.10, so the results of this section are acceptable.



Level 1	Level 2	Level 3	Level 4
Goal	Criteria	Sub-criteria	Alternatives

Figure 2. The hierarchical decision-making structure

Table 3. Description of main criteria and sub-criteria.

Main criteria	Sub-criteria	ID
Economic	Investment	E1
	Fuel expense	E2
	Spare part	E3
	Second-hand value	E4
Technical	Gross power	T1
	Operating weight	T2
	Economical life	T3
Operational	Block size	O1
	Operational capacity	O2
Commercial	Term of service	C1
	Warranty terms	C2



Table 4. Proportionate ranks and their relative importance weights of the main criteria.

Main criteria	Relative importance weights	Ranks
Economic	0.464	1
Technical	0.242	2
Operational	0.225	3
Commercial	0.069	4

$$\lambda_{\max} = 4.2249; CI = 0.0749; RI = 0.9; CR = 0.083 \leq 0.1$$

Table 5. Proportionate ranks and their relative importance weights of the sub-criteria.

Main criteria	Relative importance weights	Sub-criteria	Relative importance weights	Relative Rank	Global importance weights	Global Rank
Economic	0.464	E1	0.42	1	0.193	1
		E2	0.33	2	0.154	2
		E3	0.16	3	0.072	8
		E4	0.10	4	0.045	9
Technical	0.242	T1	0.36	1	0.087	5
		T2	0.33	2	0.081	6
		T3	0.31	3	0.075	7
Operational	0.225	O1	0.56	1	0.125	3
		O2	0.44	2	0.100	4
Commercial	0.069	C1	0.60	1	0.042	10
		C2	0.40	2	0.028	11

According to the results of Table 4, among the main criteria, Economic obtained the highest priority as it holds the first rank, followed by Technical, Operational and Commercial. The results seem reasonable considering the financial status of construction projects. Regarding the sub-criteria according to Table 6, the four sub-criteria associated with Economic as the most important main factor in this study, are organized as per their relative rank, given as $E1 > E2 > E3 > E4$. The obtained results showed that E1 (Investment) is the most important sub-criteria in this category. The three Technical-related sub-criteria are prioritized in $T1 > T2 > T3$, respectively. In this category, T1 (Gross power) is at the top of the relative rankings, indicating the importance of this strategy. Regarding Operational sub-criteria as the other main criteria in this study, sub-criteria are ranked as $O1 > O2$, respectively. C1 and C2 are also the first and second sub-criteria of the Commercial category in terms of relative weight, respectively. Considering the global ranking of sub-factors, the overall importance weights of Investment (E1) and Fuel expense (E2) were calculated 0.193 and 0.154, respectively. As these sub-criteria are ranked at first and second position in global rank. The O1 (Block size) and O2 (Operational capacity) sub-criteria with final weights of 0.125 and 0.100 are the third and fourth most effective wheel loader selection in the global ranking, respectively. E4 (Second-hand value), C1 (Term of service) and C2 (Warranty terms) with final weights of 0.045, 0.042 and 0.028, are ranked as the least effective sub-criteria among all wheel loader selection sub-criteria, respectively. As the first step of PROMETHEE method, the performance values of the machines with respect to the evaluation criteria are collected and the decision matrix is constructed using the data given in Table 6. These data can be either quantified performance such as motor power and fuel cost or qualified performance such as economic life and after sale service. Qualified performance is a score which is determined



subjectively by the experts ranging from 1 to 10 points and the higher the score the better is the performance. The PROMETHEE will then use the global weights of criteria obtained by the AHP method and the decision matrix in the computations and the remaining steps of the methodology will be applied as follows:

- 1- The performance data of the machines are given in Table 6.
- 2- The computed preference matrix of alternatives are obtained using Eq. (9-11), respectively and given in Table 7.
- 3- The positive flow (ϕ^+), negative flow (ϕ^-), net out ranking flow (ϕ) values (using Eq. (12)) and ranking of alternatives obtained from tis evaluation are given in Table 8.

Table 6. The decision matrix.

Criteria	Global importance weights	Unit	Polarity	Alternative				
				A1	A2	A3	A4	A5
E1	0.193	\$	-	260000	220000	205000	245000	280000
E2	0.154	lt/h	-	30	24	22	22	28
E3	0.072	10 scale	+	7	7	7	7	7
E4	0.045	\$	+	86000	73000	68000	82000	93000
T1	0.087	hp	+	322	287	260	303	352
T2	0.081	kg	+	33300	25148	23698	29000	33000
T3	0.075	10 scale	+	9	7	5	7	9
O1	0.125	10 scale	+	9	7	5	7	9
O2	0.100	10 scale	+	9	7	5	7	9
C1	0.042	10 scale	+	9	9	7	9	9
C2	0.028	10 scale	+	9	9	7	9	9

Table 7. The preference matrix.

	A1	A2	A3	A4	A5	leaving flow ϕ^+
A1	0	0.513	0.583	0.513	0.274	1.883
A2	0.154	0	0.583	0.193	0.347	1.277
A3	0.347	0.347	0	0.193	0.347	1.234
A4	0.347	0.367	0.583	0	0.347	1.644
A5	0.286	0.513	0.583	0.513	0	1.895
entering flow ϕ^-	1.134	1.74	2.332	1.412	1.315	

Table 8. The relative closeness and rank of alternatives.

Alternatives	ϕ^+	ϕ^-	$\phi^+ - \phi^-$	Ranking
A1	1.883	1.134	0.749	1
A2	1.277	1.74	-0.463	4
A3	1.234	2.332	-1.098	5
A4	1.644	1.412	0.232	3
A5	1.895	1.315	0.58	2



Finally, the wheel loader A1 is chosen as the best alternative with the highest ϕ value of 0.6057, followed by the A5, A4, A2 and A3, respectively.

4. Conclusions

In this study, an integrated approach using AHP and PROMETHEE method for evaluating wheel loader selection were used. The proposed approach helps to decompose this unstructured problem into a reliable hierarchical structure that includes various criteria, sub-criteria, and alternatives. It starts with applying the AHP method to find the relative importance weights of the evaluation criteria in the decision hierarchy. Then, the PROMETHEE method uses these weights for determining the overall ranking scores of the machines. The most common wheel loader alternatives used in construction project have been evaluated using the proposed approach. The highest net outranking flow values (ϕ) have been obtained for A1, A5, A4, A2 and A3 wheel loaders, respectively. The best loader alternative chosen, A1, is relatively preferable due to its higher operating weight, operational capacity, gross power and block size compared to the other alternatives with better evaluations such as less investment.

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