Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.3, No.4, pages: 45-55

Evaluation of Wheel Loader Selection Using an Integrated Approach with AHP and TOPSIS

Amir Bahador Moradikhou [1*]***, Mehdi Ravanshadnia*** [2]

[*1] *Ph.D. candidate in Engineering and Construction Management, Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

(amirbahador.moradikhou@srbiau.ac.ir)

[2] *Associate Professor of Engineering and Construction Management, Department of Civil Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran*

(Date of received: 14/08/2021, Date of accepted: 28/11/2021)

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 TOPSIS method for evaluating wheel loader selection were used. In this regard, the Analytic Hierarchy Process (AHP) and the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS), are used in the evaluation procedure. More precisely, AHP is applied to determine the relative weights of evaluation criteria and TOPSIS 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, TOPSIS, 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 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. 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 vlsekriterijumska optimizacija i kompromisno resenje (VIKOR) [8-14]. In this regard, Ghorabaee 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 TOPSIS method for evaluating wheel loader selection were used.

2. Materials and Methods

2.1. The research framework

The research framework is presented in Fig. 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

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.3, No.4, pages: 45-55

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.

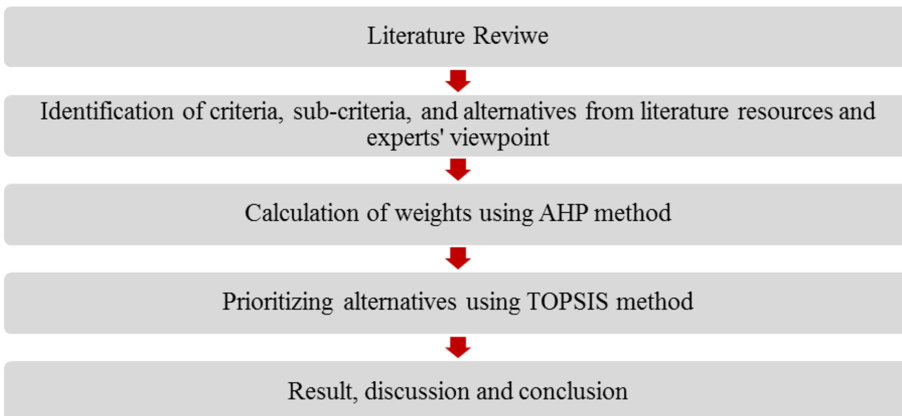

Figure 1. The research framework

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's1-9 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.

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

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.3, No.4, pages: 45-55

Where aij is the relative importance of criterion Ci with respect to criterion Cj. In the matrix, aij = 1 when i = j and aij = 1/aij.

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.

a. Compute the relative weights or eigenvector and λ_{Max} for each matrix of order n

b. Compute the consistency index (CI) for each matrix of order n by 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].

$$CI = \frac{(\lambda Max - n)}{(n-1)} \tag{2}$$

$$CR = \frac{CI}{RI} \tag{3}$$

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. TOPSIS method

TOPSIS which is one of the well-known MCDM methods, was first developed by Hwang et al. TOPSIS is a viable method for the proposed problem and is suitable for the use of precise performance ratings. When the performance ratings are vague and inaccurate, then the fuzzy TOPSIS is the preferred technique. It is a practical and useful technique for ranking and selecting a number of externally determined alternatives through distance measures. It is based upon the concept that the chosen alternative should have the shortest distance from the positive ideal solution (PIS) and the farthest from the negative ideal solution (NIS). The PIS is the solution that maximizes the benefit and also minimizes the total cost. On the contrary, the NIS is the solution that minimizes the benefit and also maximizes the total cost. TOPSIS simultaneously considers the distances to both PIS and NIS. At the end, the ideal solution closest to the PIS and farthest to NIS is obtained.

In this study, the final ranking of wheel loader alternatives is determined by the TOPSIS method. First, the global weights of criteria are calculated using the AHP approach, they are incorporated

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.3, No.4, pages: 45-55

into the decision matrix that contains the performance values of machine alternatives with respect to each related criteria. In the following, the computational steps of TOPSIS are given:

1. Once the decision matrix is formed, the normalized decision matrix is calculated as:

$$r_{ij} = \frac{y_{ij}}{\sqrt{\sum_{j=1}^{J} {y_{ij}}^2}} \quad , i = 1, 2, \dots, n;\ j = 1,2, \cdots, J \tag{4}$$

2. The weighted normalized decision matrix is obtained by multiplying the normalized decision matrix with the weights of the criteria:

$$v_{ij} = w_i \times r_{ij} \quad , i = 1, 2, \dots, n;\ j = 1,2, \cdots, J \tag{5}$$

Where w_i is the weight of the i-th criterion and $\sum_{i=1}^{n} w_i = 1$

3. In this step, the negative and positive ideal solutions are determined. The ideal solution, A*(vi*, i = 1, 2, ..., n), is made of all the best performance scores and the negative ideal solution, $A^-(vi^-$, i = 1, 2, ..., n), is made of all the worst performance scores for the criteria in the weighted normalized decision matrix. They are calculated using equations 6 and 7.

$$A^* = \{v_1^*, v_2^*, \dots, v_n^*\} = \left\{(max_j v_{ij} \middle| i \in I'), (min_j v_{ij} | i \in I'')\right\} \tag{6}$$

$$A^- = \{v_1^-, v_2^-, \dots, v_n^-\} = \left\{(max_j v_{ij} \middle| i \in I'), (min_j v_{ij} | i \in I'')\right\} \tag{7}$$

In these equations, the criteria are divided into two classes: the first class is of an input or cost nature, denoted by the set I', and smaller performance scores for these criteria are preferred; the second class is of an output or benefit nature, denoted by the set I'' and larger performance scores for these measures are preferred.

4. The distance of each alternative from PIS and NIS is calculated using the *n*-dimensional Euclidean distance as follows:

$$D_j^* = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^*)^2} \quad , j = 1, 2, \cdots, J \tag{8}$$

$$D_j^- = \sqrt{\sum_{i=1}^{n} (v_{ij} - v_i^-)^2} \quad , j = 1, 2, \cdots, J \tag{9}$$

5. The next step consists of the calculation of the relative closeness to the ideal solution. The relative closeness of the alternative a_j with respect to A^* is defined as:

$$C_j^* = \frac{D_j^-}{D_j^* - D_j^-}\ , j = 1, 2, \cdots, J \tag{10}$$

6. Rank the preference order in the decreasing order of C_j^* values. In the TOPSIS method, the chosen alternative has the maximum value of $C_j^*$with the intention to minimize the distance from the positive ideal solution and to maximize the distance from the negative ideal solution.

3. Results and Discussion

3.1. Mechanical strengths

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.

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.3, No.4, pages: 45-55

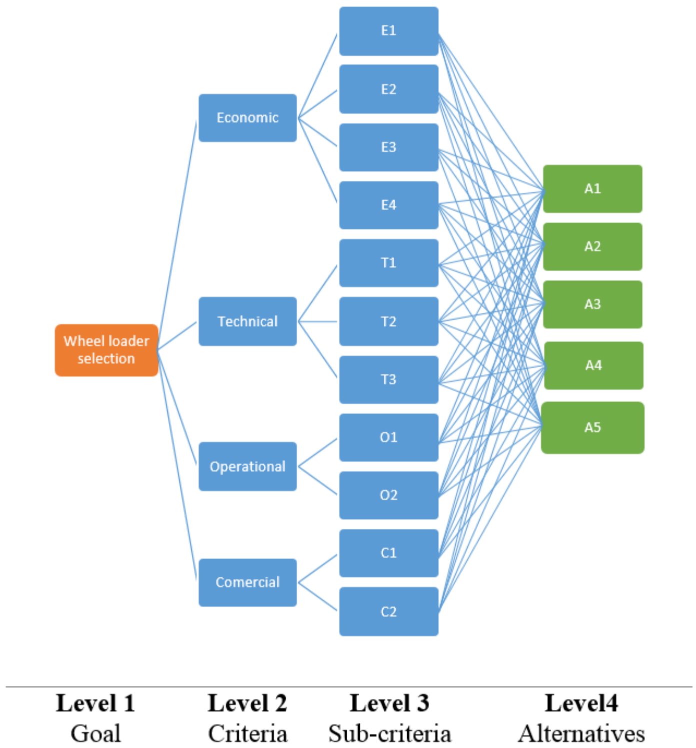

Figure 2. The hierarchical decision-making structure

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

λmax = 4.2249; *CI* = 0.0749; *RI* = 0.9; *CR* = 0.083 ≤ 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 TOPSIS 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

Advance Researches in Civil Engineering
ISSN: 2645-7229, Vol.3, No.4, pages: 45-55

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. TOPSIS 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:

• The performance data of the machines given in Table 6 and the weighted normalized decision matrix is calculated by multiplying the normalized decision matrix with the global weights using Eq. (4) and Eq. (5).

• The positive ideal and negative ideal solutions are obtained using Eq. (6) and Eq. (7).

• The computed distances of each alternative to positive ideal and negative ideal solutions are obtained using Eq. (8) and Eq. (9), respectively and given in Table 7.

• The relative closeness of a particular alternative to the ideal solution is calculated using equation Eq. (10) and shown in Table 8.

• The alternatives are arranged in descending order according to their relative closeness value and the final ranking of the alternatives are shown in Table 8.

Table 6. Decision matrix.

Criteria	**Unit**	**Polarity**	**Alternative**				
			A1	A2	A3	A4	A5
E1	$	-	260000	220000	205000	245000	280000
E2	lt/h	-	30	24	22	22	28
E3	10 scale	+	7	7	7	7	7
E4	$	+	86000	73000	68000	82000	93000
T1	hp	+	322	287	260	303	352
T2	kg	+	33300	25148	23698	29000	33000
T3	10 scale	+	9	7	5	7	9
O1	10 scale	+	9	7	5	7	9
O2	10 scale	+	9	7	5	7	9
C1	10 scale	+	9	9	7	9	9
C2	10 scale	+	9	9	7	9	9

Table 7. The distances of each alternative to the PIS and NIS.

	A1	**A2**	**A3**	**A4**	**A5**
$\boldsymbol{D_j^*}$	0.0295	0.0263	0.0457	0.0267	0.0312
$\boldsymbol{D_j^-}$	0.0453	0.0345	0.0343	0.0342	0.0460

Table 8. The relative closeness and rank of alternatives.

	A1	**A2**	**A3**	**A4**	**A5**
$\boldsymbol{C_j^*}$	0.6057	0.5674	0.4286	0.5610	0.5959
Rank	1	3	5	4	2

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

4. Conclusion

In this study, an integrated approach using AHP and TOPSIS 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, TOPSIS 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 relative closeness values (C_j^*) have been obtained for A1, A5, A2, A4 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.

5. References

[1]- Li, J., Li, H., Umer, W., Wang, H., Xing, X., Zhao, S. and Hou, J., 2020, **Identification and classification of construction equipment operators' mental fatigue using wearable eye-tracking technology**, Automation in Construction, 109, 103000.

[2]- Jahr, K. and Borrmann, A., 2018, **Semi-automated site equipment selection and configuration through formal knowledge representation and inference**, Advanced Engineering Informatics, 38, 488-500.

[3]- Sandanayake, M., Zhang, G. and Setunge, S., 2019, **Estimation of environmental emissions and impacts of building construction – A decision making tool for contractors**, Journal of Building Engineering, 21, 173-185.

[4]- Islam, M. S., Nepal, M. P., Skitmore, M. and Attarzadeh, M., 2017, **Current research trends and application areas of fuzzy and hybrid methods to the risk assessment of construction projects**, Advanced Engineering Informatics, 33, 112-131.

[5]- Waris, M., Shahir Liew, M., Khamidi, M. F. and Idrus, A., 2014, **Criteria for the selection of sustainable onsite construction equipment**, International Journal of Sustainable Built Environment, 3(1), 96-110.

[6]- Naskoudakis, I. and Petroutsatou, K., 2016, **A Thematic Review of Main Researches on Construction Equipment Over the Recent Years**, Procedia Engineering, 164, 206-213.

[7]- Chen, X., Chen, F., Zhou, J., Li, L. and Zhang, Y., 2015, **Cushioning structure optimization of excavator arm cylinder**, Automation in Construction, 53, 120-130.

[8]- Ebrahimian, A., Ardeshir, A., Zahedi Rad, I. and Ghodsypour, S. H., 2015, **Urban stormwater construction method selection using a hybrid multi-criteria approach**, Automation in Construction, 58, 118-128.

[9]- Casanovas-Rubio, M. d. M. and Ramos, G., 2017, **Decision-making tool for the assessment and selection of construction processes based on environmental criteria: Application to precast and cast-in-situ alternatives, Resources**, Conservation and Recycling, 126, 107-117.

[10]- Štirbanović, Z., Stanujkić, D., Miljanović, I. and Milanović, D., 2019, **Application of MCDM methods for flotation machine selection**, Minerals Engineering, 137, 140-146.

[11]- Ebrahiminejad, M., Shakeri, E., Ardeshir, A. and Fazel Zarandi, M. H., 2018, **An object-oriented model for construction method selection in buildings using fuzzy information**, Energy and Buildings, 178, 228-241.

[12]- Bertola, N. J., Cinelli, M., Casset, S., Corrente, S. and Smith, I. F. C., 2019, **A multi-criteria decision framework to support measurement-system design for bridge load testing**, Advanced Engineering Informatics, 39, 186-202.
[13]- Shahtaheri, Y., Flint, M. M. and de la Garza, J. M., 2019, **A multi-objective reliability-based decision support system for incorporating decision maker utilities in the design of infrastructure**, Advanced Engineering Informatics, 42, 100939.
[14]- Figueira, J. R., Greco, S., Roy, B. and Słowiński, R., 2013, **An Overview of ELECTRE Methods and their Recent Extensions**, Journal of Multi-Criteria Decision Analysis, 20(1-2), 61-85.
[15]- Keshavarz Ghorabaee, M., Amiri, M., Zavadskas, E. K. and Antucheviciene, J., 2018, **A new hybrid fuzzy MCDM approach for evaluation of construction equipment with sustainability considerations**, Archives of Civil and Mechanical Engineering, 18(1), 32-49.
[16]- Bascetin, A. and Kesimal, A., 1999, **A new approach in selection of loading-hauling systems in surface mining**; Acik isletmelerde yukleme-tasima sistemi seciminde yeni bir yaklasim,
[17]- Briskorn, D. and Dienstknecht, M., 2019, **Mixed-integer programming models for tower crane selection and positioning with respect to mutual interference**, European Journal of Operational Research, 273(1), 160-174.
[18]- Samanta, B., Sarkar, B. and Mukherjee, S., 2002, **Selection of opencast mining equipment by a multi-criteria decision-making process**, Mining Technology, 111(2), 136-142.
[19]- Elevli, B. and Demirci, A., 2004, **Multicriteria choice of ore transport system for an underground mine: application of PTOMETHEE methods**, Journal of the Southern African Institute of Mining and Metallurgy, 104(5), 251-256.
[20]- Gorcun, O. F., Senthil, S. and Küçükönder, H., 2021, **Evaluation of tanker vehicle selection using a novel hybrid fuzzy MCDM technique**, Decision Making: Applications in Management and Engineering, 4(2), 140-162.
[21]- Moradikhou, A. B. and Ravanshadnia, M., 2021, **Evaluation of CO2 Emissions Reduction Strategies in the Iranian Cement Industry**, Journal of Civil Engineering and Materials Application, 5(3), 108-120.
[22]- Govindan, K., Kaliyan, M., Kannan, D. and Haq, A. N., 2014, **Barriers analysis for green supply chain management implementation in Indian industries using analytic hierarchy process**, International Journal of Production Economics, 147, 555-568.
[23]- Saaty, T. L., 1990, **The Analytic Hierarchy Process**, European Journal of Operational Research, 48, 9-26.