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Abstract

As the population grows and vehicles are increasingly owned, emissions from fossil fuels are worsening environmental problems. In this context, electric vehicles (EVs) present a significant alternative for the development of sustainable transportation systems. However, for electric vehicles (EVs) to become a prevalent form of transportation, the establishment of an effective and efficient charging infrastructure is imperative. The primary objective of this study is to ascertain the most suitable location for the installation of an electric vehicle (EV) charging station within the Erzincan Binali Yıldırım University Yalnızbag Campus. During site selection, the analytical hierarchy process (AHP) and TOPSIS methods were used to evaluate the criteria. The study was conducted in two stages. In the first, seven active-use transformers on campus were weighed using the AHP method, then the most suitable one was selected using the TOPSIS method.In the second, seven parking areas were analysed using the same criteria. The parking lot selection used the AHP and TOPSIS methods, considering faculty and campus entrance distance, lot capacity and transformer preference score.

The findings of the study demonstrate the efficacy of the AHP and TOPSIS methods in the context of multi-criteria and multi-stage decision-making processes. The integration of these methods has been demonstrated to facilitate the optimisation of EV charging station location selection, both in technical and practical terms.

Keywords: Electric Vehicle, Transportation Planning, MCDM.

INTRODUCTION

The investigation of EVs commenced in the 19th century but was subsequently placed on the back burner for a multitude of reasons (1). The exponential growth in the use of EVs globally has created an imperative to develop innovative solutions and strategies for energy infrastructure, with the dual objective of reducing environmental pollution and addressing the pressing need for sustainable energy. The necessity for energy infrastructure is predominantly addressed in the context of urban energy planning, particularly regarding the provision of sustainable transportation and transport solutions. As EVs become increasingly prevalent, the availability, efficiency and effectiveness of charging infrastructure becomes a multifaceted question that is challenging to resolve. This assertion is supported by the findings reported by Xylia and colleagues in 2017 (2). The determination of the necessity for a charging station and the selection of an appropriate station location are not merely technical concerns; there are also multi-criteria problems that must be addressed in accordance with the requirements of the users. These issues require a technical solution, particularly for the more effective planning of urban transportation systems. MCDM is employed in situations where there are numerous options, and the decision-maker must evaluate more than one criterion collectively (3). The AHP and TOPSIS methodologies are two of the most effective and reliable methods for decision-making processes within the MCDM framework. The AHP method determines the most appropriate option by weighing the alternatives and comparing them according to the specified criteria (4). The TOPSIS method aims to ascertain the most suitable alternatives by identifying the positive ideal and negative ideal solutions and determining their proximity to these solutions (5). The combination of these methods, whether used together or separately, provides an effective solution in a multitude of contexts. Although other multi-criteria decision-making methods such as (Analytic Network Process) ANP, (The Preference Ranking Organization Method for Enrichment Evaluation) PROMETHEE, (Complex Proportional Assessment) COPRAS, Simple Multi Attribute Rating Technique (SMART) and (Weighted Aggregated Sum Product Assessment) WASPAS have been widely used in the literature, there are several main reasons why the AHP and TOPSIS methods have been preferred together in this study. Firstly, the AHP method produces reliable results by consistently modelling the subjective evaluations of decision makers during the weighting phase of the criteria. The TOPSIS method, on the other hand, provides a practical and applicable decision support mechanism by ranking the alternatives according to the identified criteria. In the literature, it has been observed that the use of these two methods together in studies on the determination of the location of EV charging stations is common and leads to successful results (6,7). In addition, the integration of AHP and TOPSIS makes the calculation process of the method simpler and more understandable. This makes it an effective solution in both academic and applied fields. Karabıçak et al. (2016) showed that by using AHP and TOPSİS methods together, practical and effective results were obtained in multi-criteria decision-making processes (6). Similarly, Saha and Roy (2021) conducted site selection by integrating geographic information systems (GIS) with AHP in planning suitable settlement areas (8). There are several studies in the literature that use different combinations of methods to determine the location of electric vehicle (EV) charging stations. While some of these studies used AHP alone, others evaluated AHP and TOPSIS together. In addition, more comprehensive and accurate solution methods have been provided by integrating additional analysis tools such as geographic information systems. To take one example, Erbaş et al. (2018) used Fuzzy AHP and TOPSIS together in her study and integrated them with the Geographical Information System (GIS) to determine the location of EV charging stations (9). Similarly, Bilgilioğlu (2022) optimised the siting of EV charging stations by integrating GIS with the fuzzy AHP method (10). On the other hand, Alkan et al. (2023) identified the criteria based on expert opinion using the AHP method and determined the appropriate location of EV charging stations (7). In addition to the AHP method, Asnaz et al. (2021) used PROMETHEE and SMART methods to select EV charging stations (3).

In this context, the approach adopted in this study was to weigh the criteria using the AHP method and then to rank the alternatives using the TOPSIS method. As in this study, Khalkhali et al. (2015) used envelope analysis to determine EV charging stations. The locations and capacities of these stations were first decided based on grid benefits, then classified using envelopment analysis and technical indicators (11). In the present study, the transformer selection process was undertaken first, followed by the determination of the most suitable parking area depending on the previously selected transformer. Thanks to these methods, which have received positive feedback in the literature, the evaluation of different criteria together enables the production of more sustainable and versatile solutions. This ensured both consistent modelling of subjective judgements and determination of the most appropriate alternative.

This study designs a step-by-step decision-making process using both AHP and TOPSIS methods, unlike the studies in literature. This step-by-step approach has been addressed in a limited number of studies in the literature on EV sitting processes. In addition, the addition of demand forecasting analysis provides a more comprehensive methodological framework for determining station needs. In this respect, our study contributes to both academic literature and practical applications in the field of EV charging station sitting.

MATERIAL AND METHODS

Material

Erzincan Binali Yıldırım University, which is the subject of the study, started its higher education life in Türkiye with Erzincan Vocational School and Erzincan Education School, which were established in 1976, and became a university in 2006. The transition to Yalnızbağ Campus, which represents the largest campus of the university, was completed in 2021. The university, which has a campus that is still open to further development, employs a total of 1.750 staff, comprising 1.085 academic and 665 administrative personnel. The campus is home to a total of 14.485 students enrolled in a range of academic programmes, including associate degrees, undergraduate and graduate studies. These programmes are offered by the Faculty of Pharmacy, Faculty of Education, Faculty of Arts and Sciences, Faculty of Fine Arts, Faculty of Economics and Administrative Sciences, Faculty of Theology, Faculty of Engineering and Architecture, Faculty of Sports Sciences, Vocational School, Ali Cavit Çelebi Civil Aviation School, Institute of Science, Institute of Health Sciences and Institute of Social Sciences (12). Transportation to the campus, which is situated approximately 12 km from the city centre, is provided for students by city buses, while a shuttle service is available for administrative staff. The majority of academic staff utilise their own vehicles to reach the campus. The campus comprises seven transformers and seven parking lots.

Figure 1 Campus Area

The location of the EV e charging station was selected from among seven potential parking lots (figure 1). Furthermore, the requisite number of charging stations was estimated based on the number of vehicles entering and exiting the campus.

Method

MCDM was used to determine the location of the charging station. MCDM is a widely used method that allows a meaningful consensus to be reached by bringing together many criteria of varying quality and quantity. Criterion weights can be successfully obtained with MCDM methods in the most appropriate location selection problems in many different fields (8,13). The AHP method, one of the MCDM methods, is widely used to determine the weighting of criteria in site selection studies. In this study, AHP and TOPSIS methods were applied step by step. The reason why AHP and TOPSIS are preferred is that the AHP method provides a hierarchical structure in the weighting of criteria, allowing subjective judgements to be modelled consistently. TOPSIS, on the other hand, was preferred because it provides an effective decision support mechanism for determining the most appropriate option by ranking the alternatives according to their distance from positive and negative ideal solutions.

Analytical Hierarchy Process (AHP)

The AHP method is a MCDM method, initially proposed by Thomas L. Saaty of the University of Pennsylvania in the late 1970s (14). This method is the most frequently employed in location selection studies. Saaty posits that the five-step decision-making method can be applied in practice. The following steps are required: firstly, the issue must be defined and a hierarchical structure created; secondly, the pairwise comparison matrices and superiorities must be determined (2) thirdly, an eigenvector must be calculated; fourthly, the consistency of the eigenvector must be determined; and finally, the general result of the hierarchical structure must be obtained.

Step 1. Defining the Problem and Creating the Hierarchical Structure

The issue in question is duly identified, and a hierarchical structure is subsequently established, with the issue at the core of the structure. In this hierarchical structure, the purpose, criteria, sub-criteria and alternatives are interrelated and constitute a unified whole. The lowest level of the hierarchy comprises all potential alternatives, whereas the highest level delineates the overarching objective. The remaining levels represent the decision criteria and sub-criteria (15). Saaty's studies have often included examples of hierarchies that are appropriate for site selection studies (14). A similar hierarchical structure can be constructed based on the purpose and criteria identified in the problem.

Step 2. Pairwise Comparison of Matrices and Determination of Advantages

At this stage of the process, pairwise comparison matrices of dimension (nxn) are created to determine the relative importance levels of the selected criteria, as established in stage one. This decision-making process involves the comparison of criteria or alternative matrices on a pairwise basis (16). The sample matrix is defined in Equation 1.

$$A = \begin{bmatrix} 1 & a_{21} & a_{31} & \cdots & a_{n1} \\ 1/a_{21} & 1 & a_{32} & \cdots & a_{n2} \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ 1/a_{n1} & 1/a_{n2} & 1/a_{n3} & \cdots & 1 \end{bmatrix}_{n\times n} \quad (1)$$

The relative importance of the factors is determined according to the Saaty scale (Table 1), and the resulting levels of importance are then placed in the matrix (4).

Table 1 Severity Table.

Value	Description	Explanation
1	Equally important	The two activities are of equal importance in achieving the desired outcome.
3	Moderately important	Experience and judgment slightly favor one activity over another.
5	Strongly important	Experience and judgment strongly favor one activity over another.
7	Very strong stream important	An activity is strongly preferred, and its dominance is clearly evident in practice.
9	Important	The evidence for preferring one activity over another is overwhelmingly reliable.
2,4,6,8	Intermediate values	In instances where a compromise is necessary, values that fall between the aforementioned judgments may be employed.

Step 3. Determination of Eigenvector

The objective of this phase is to identify the eigenvectors of the criteria, which have been assigned relative importance levels. The eigenvector of a matrix in an n x 1 dimension is determined through the following process:
In the case where i=1, 2, 3, ..., n and j=1, 2, 3, ..., n,

$$b_{\text{ij}} = \frac{a_{\text{ij}}}{\sum_{i=1}^{n} a_{\text{ij}}} w_i = \frac{\sum_{j=1}^{n} b_{\text{ij}}}{n} \quad (2,3)$$

In order to ascertain the relative importance of the criteria, it is necessary to calculate column vectors of the form W = $[w_i]_{nx1}$. The column vector W is obtained by calculating the arithmetic mean of the row elements of the matrix formed by the bijb_{ij}bij values specified in Equations 2 and 3 (16).

Step 4. Calculating the Consistency of Eigenvector

At this juncture, the consistency ratio (CR) of each binary matrix is calculated. It is desirable that the upper limit of the CR value should be 0.1. To calculate the CR ratio, it is necessary to calculate the basic value coefficient (λ). In such a case, the weighting matrix is multiplied by the eigenvector. Subsequently, the largest eigenvector (λmax) must be calculated. The pertinent operations are delineated in equations 4 and 5.
In the case where i=1, 2, 3,..., n and j=1, 2, 3,..., n,

$$D = [a_{\text{ij}}]_{n\times n} \times [w_i]_{n\times 1} = [d_i]_{n\times 1} \quad (4)$$

$$\lambda_{\max} = \frac{\sum_{i=1}^{n} \frac{d_i}{w_i}}{n} \quad (5)$$

In order to calculate the consistency rate, it is necessary to determine the randomness index (RI). The data set comprising RI values, which are constant numbers determined according to the n value, is provided in Table 2. In accordance with the data, the calculation of the CR value is presented in equation number 6. To ascertain the randomness index, it is necessary to select the N value from Table 2.

$$\text{CR} = \frac{\lambda - n}{(n-1)\cdot \text{RI}} \quad (6)$$

Table 2 Randomness Index Calculation Table.

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0,58	0,9	1,12	1,24	1,32	1,41	1,45	1,49

Step 5. Obtaining the General Result of the Hierarchical Structure

In the final phase, the values calculated in the previous four phases are applied to the entire hierarchical structure. Consequently, a decision matrix of dimension m x n, designated as DW, is constructed. The R result vector is derived by multiplying the obtained matrix by the W superiority vector between the criteria (16). Given the data set in question, the following equation can be derived:

$$\text{DW} = [w_{\text{ij}}]_{m\times n} \quad (7)$$

This leads to the conclusion that;

$$R = \text{DW} \times W \quad (8)$$

Consequently, the overall outcome of the hierarchical structure is established, and the significance coefficients are ascertained.

TOPSIS Method

Hwan and Yoon (1981) introduced another multi-criteria decision-making method, the TOPSIS method. TOPSIS can be used for both selection and classification problems, as can AHP (17). The main objective of this method is to select the solution alternatives that are the shortest distance from the ideal solution, which is positive, and the farthest distance from the ideal solution, which is negative (5). To elucidate further, the positive ideal solution is formulated based on the most favourable values of the criterion, whereas the negative ideal solution is constructed on the foundation of the least favourable values of the criterion. In alternative selection processes, the optimal alternative is that which is closest to the positive ideal solution and furthest from the negative ideal solution (18). The Topsis method is typically conducted in six sequential steps.

Step 1. Creating The Decision Matrix

In the construction of the decision matrix, the rows represent the alternatives, while the columns represent the criteria. The matrix can be presented in the following format:

$$D=\begin{bmatrix} d_{11} & \cdots & d_{1k} \\ \vdots & \ddots & \vdots \\ d_{n1} & \cdots & d_{nk} \end{bmatrix} \quad (9)$$

In this context, the symbol (i = 1,2,...,n, j = 1,2,...,k) represents the score of the i. alternative based on the j. criterion (6).

Step 2. Normalizing The Decision Matrix

The matrix is normalised by taking the square root of the sum of the squares of the scores and features of the criteria in the created decision matrix (19). The normalization process can be demonstrated through the following formulas:

$$r_{\text{ij}}=\frac{a_{\text{ij}}}{\sum_{i=1}^{m} {a_{\text{ij}}}^2},\left(i=1,2,\ldots,mvej=1,2,\ldots,n\right) \quad (10)$$

The normalized matrix can be obtained by the following method:

$$R=\begin{bmatrix} r_{11} & \cdots & r_{1n} \\ \vdots & \ddots & \vdots \\ r_{m1} & \cdots & r_{mn} \end{bmatrix} \quad (11)$$

Step 3. Weighting The Normalized Matrix

In order to assign a weight to each value in the normalised matrix, it is first necessary to determine the weight value according to the importance levels assigned to the identified elements in relation to the specified criteria (W). The weighted matrix can be defined as follows:

$$W=\begin{bmatrix} w_{11} & \cdots & w_{1k} \\ \vdots & \ddots & \vdots \\ w_{n1} & \cdots & w_{nk} \end{bmatrix} \quad (12)$$

Here w_j: is the weight of each j. criterion.
Subsequently, the matrix with weight values is multiplied by the values in the normalised matrix, thereby providing the weighting of the matrix. The weighted matrix can be presented in the following manner:

$$V=\begin{bmatrix} v_{11} & \cdots & v_{1k} \\ \vdots & \ddots & \vdots \\ v_{n1} & \cdots & v_{nk} \end{bmatrix} \quad (13)$$

Step 4. Ideal And Non-Ideal Solutions

Once the weighted matrix has been identified, the subsequent step is to ascertain the ideal and non-ideal solutions. In this context, the positive ideal solution represents the optimal performance values of the weighted normalised decision matrix, whereas the negative ideal solution denotes the least favourable values (20). The solutions are calculated in accordance with the following formulae, where A^* represents the positive ideal solution and A^- denotes the negative ideal solution.

$$\begin{aligned} A^* &= \left\{(\max v_{\text{ij}}|j\in I),(\min v_{\text{ij}}|j\in J)\right\} \\ A^- &= \left\{(\min v_{\text{ij}}|j\in I),(\max v_{\text{ij}}|j\in J)\right\} \end{aligned} \quad (14)$$

The calculation of the distance to ideal and non-ideal solutions is performed in accordance with the principles set forth by Euclid. The ideal distance is represented by the symbol S_i^*, while the non-ideal distance is represented by S_i^-.

$$\begin{aligned} S_i* &= \sqrt{\sum_{j=1}^{n}(v_{ij}-v_{j*})^2} \qquad \mathrm{i}=1,2,\ldots,\mathrm{m} \\ S_i- &= \sqrt{\sum_{j=1}^{n}(v_{ij}-v_{j-})^2} \qquad \mathrm{i}=1,2,\ldots,\mathrm{m} \end{aligned} \quad (15)$$

Step 5. Relative Closeness To The Ideal Solution

The proximity according to the S_i^* ideal distance and S_i^- non-ideal distance values is calculated using the following formula:

$$C_i^*=\frac{S_i^-}{S_i^-+S_i^*} \qquad 0\le C_i^*\le 1 \quad (16)$$

Step 6. Finding The Suitability Order of The Alternatives

Ultimately, the C_i^* values are sorted in ascending order to identify the optimal alternative.

RESULTS AND DISCUSSION

Determining the Number of Charging Stations Using Demand Forecast

The study began with a demand forecasting analysis to determine how many charging points were needed. The number of vehicles entering the campus, the percentage of electric vehicles in the area and the daily usage requirements were considered when calculating the number of charging stations required. The number of charging points required was calculated based on the number of vehicles entering the campus, the proportion of electric vehicles in the area and the daily usage required. Based on the average daily mileage and battery capacity of electric vehicle users in Turkey, it was assumed that electric vehicles need to be charged every three days. According to TÜİK's 2024 data, the EV rate in Turkey has been determined as 1.5%. In consideration of the fact that the number of automobiles in Erzincan province in 2024 is 32.567, it can be estimated that approximately 489 vehicles can be utilized as EVs. Considering the potential for 10% of the estimated number of EVs in Erzincan to be deployed on campus, it is reasonable to assume that approximately 5 EVs will enter the campus daily. The number of vehicle entries was used to calculate the number of charging points required on campus and, taking into account the average daily mileage and battery capacity of electric vehicle users, it was estimated that a vehicle would be charged on average every 3 days (Table 3).

The necessity for a charging station was established on the premise that a maximum of five vehicles could be charged daily. Accordingly, the requisite number of EV charging stations has been calculated to be approximately two.

Table 3 Charging Station Need Demand Forecast.

Days	Vehicle Entry	Number of EVs	Daily Charging Request	Need for a Charging Station
Monday	1895	28.4	9.47	1.9
Tuesday	2007	30.1	10.04	2.0
Wednesday	1931	29.0	9.65	1.9
Thursday	2112	31.7	10.56	2.1
Friday	1717	25.8	8.59	1.7

Parking Lot Choice with AHP and TOPSIS

The criteria used in the study were determined based on similar studies in literature, expert opinion and field data. The most important factors in selecting a location for an electric vehicle charging station include the adequacy of the energy infrastructure, density of use, accessibility and parking capacity. Therefore, in the first stage, transformer power, distance to car parks and car park capacity were determined as transformer selection criteria. In the second stage, the distance to faculty entrances, distance to campus entrance gate, parking capacity and transformer preference score criteria determined in the first stage were evaluated for parking lot selection. Criteria were weighted using AHP and alternatives were ranked using TOPSIS. The initial stage involved the evaluation of three key criteria: the distances between transformers and parking lots (C1), parking lot capacities (C2) and transformer powers (C3). The relative significance of the primary criteria was established through the application of the AHP. The selection of transformers was conducted through the application of the TOPSIS method, utilising the identified importance coefficients and determining the derived preference scores. In the second stage of the process, several additional criteria were incorporated. The evaluation criteria were established based on the following parameters: the distances of the parking lots to the faculty entrances (FE) (C´1), the distances of the parking lots to the campus entrance (CE) gate (C´2), the parking lot capacities (C´3), and the transformer preference scores identified in the initial phase (C´4). Accordingly, the optimal transformer was selected, and the most suitable parking lot for the EV charging station was identified based on the selected transformer.

Finding the First Stage Criteria Weights with AHP Method

Step 1. Defining the Problem and Determining the Criteria

In selecting transformers, several criteria were taken into consideration, including the distances between transformers and parking lots, the capacities of the parking lots in question, and the powers of the transformers themselves. The distances between transformers and parking lots (PL) are provided in Table 4, while the capacities of the parking lots are presented in Table 5. The powers of the transformers are given in Table 6.

Table 4 Transformer-Parking Lots of Distances.

	PL1	PL2	PL3	PL4	PL5	PL6	PL7
T1	55.6	197	466	488	354	316	221
T2	416	175	108	324	510	555	562
T3	548	297	115	231	534	604	673
T4	896	693	612	368	644	758	931
T5	547	452	570	265	214	312	513
T6	356	370	601	401	34.8	79.8	277
T7	320	462	724	578	226	110	164

Table 5 Parking Lots Capacities

Parking Lots	Car Park Capacity
PL1	60
PL2	50
PL3	170
PL4	170
PL5	180
PL6	123
PL7	157

Table 6 Transformer Powers.

Transformer	Transformer Power
T1	630
T2	800
T3	800
T4	250
T5	630
T6	800
T7	800

Step 2. Determining Pairwise Comparison Matrices and Advantages

The relative importance of the criteria was determined using the AHP method, based on an analysis of the literature and the application of Saaty's pairwise comparison matrix (Table 7). The anticipated criteria are as follows: the location with the shortest distance, the highest parking capacity and the greatest transformer power.

Table 7 Pairwise Comparison Matrix.

	C1	C 2	C 3
C1	1	2	2
C2	1/2	1	1.5
C3	1/2	2/3	1

Step 3-4: Determining the Eigenvector and Calculating its Consistency.

The application of the AHP with a pairwise comparison matrix revealed that the criteria weights were 0.479 for distance, 0.285 for parking capacity, and 0.218 for transformer power. Furthermore, the consistency ratio (CR) was calculated to be 0.016. As the consistency ratio (CR) is less than 0.1, it can be demonstrated that the criteria weights have been calculated correctly.

Finding the First Stage Preference Scores with TOPSIS Method

Step 1-2. Creating And Normalizing The Decision Matrix

After determining the weights, the TOPSIS method was used to select the most ideal transformer, and normalisation was performed using the criteria data (Table 8).

Table 8 Transformer Decision Matrix Normalization

	C1	C2	C3
T1	0.190	0.190	0.190
T2	0.326	0.326	0.326
T3	0.389	0.389	0.389
T4	0.636	0.636	0.636
T5	0.378	0.378	0.378
T6	0.267	0.267	0.267
T7	0.297	0.297	0.297

Step 3. Weighting The Normalized Matrix

Following the creation of the normalisation matrix, a weighted matrix was constructed utilising the weights identified through the AHP (Table 9).

Table 9 Transformer Weighted Normalized Matrix.

	C1	C2	C3
T1	0.114	0.019	0.057
T2	0.196	0.033	0.098
T3	0.233	0.039	0.117
T4	0.381	0.064	0.191
T5	0.227	0.038	0.113
T6	0.160	0.027	0.080
T7	0.178	0.030	0.089

Step 4. Ideal And Non-Ideal Solutions

Following the acquisition of the weighted normalised matrix, an investigation was conducted into the positive ideal and negative ideal properties, with distances to the positive and negative solutions calculated for each transformer.

Table 10 Transformer Positive-Negative Ideal Solution.

Ideal Solutions	C1	C2	C3
Positive Ideal Solution	0.114	0.064	0.191
Negative Ideal Solution	0.381	0.019	0.057

Step 5. Relative Closeness to The Ideal Solution

At this stage, relative closeness to the ideal solution is calculated and presented in table 11.

Table 11 Distances to Transformer Positive Ideal and Negative Ideal Solutions

Transformer	Positive Ideal Solution	Negative Ideal Solution
T1	0.14	0.27
T2	0.13	0.19
T3	0.14	0.16
T4	0.27	0.14
T5	0.14	0.17
T6	0.13	0.22
T7	0.12	0.21

Step 6. Finding The Suitability Order of The Alternatives

In the final stage of the process, the preference scores were identified and organised in a ranked order, as illustrated in Table 12.

Table 12 Transformer Preference Scores.

Transformer	Preference Score
T1	0.65
T6	0.64
T7	0.62
T2	0.60
T5	0.54
T3	0.53
T4	0.35

4.5. Finding Second Stage Criteria Weights with AHP Method

In accordance with the results of this ranking, transformer 1 has been identified as the primary transformer requiring attention, with a score of 0.65. In the second stage of the study, the preference scores obtained at this stage were also incorporated into the criteria. The following criteria were identified: the distances of the parking lots to the faculty entrances (FE) (C´1), the distances of the parking lots to the campus entrance (CE) gate (C´2), the capacities of the parking lots (C´3), and the transformer preference scores (C´4). All steps applied for the first stage were also applied in the second stage according to the new criteria. A pairwise comparison matrix was constructed in accordance with the classical AHP method, as detailed in Table 13.

Table 13 Parking Lot Pairwise Comparison Matrix.

	C´1	C´2	C´3	C´4
C´1	1	3	3	3
C´2	1/3	1	3	3
C´3	1/3	1/3	1	2
C´4	1/3	1/3	1/2	1

The RI value was calculated to be 0.90 in accordance with the matrix size. The values in the matrix were subjected to a process of normalisation, resulting in the determination of criterion weights as follows: 0.469 for C´1, 0.279 for C´2, 0.148 for C´3 and 0.104 for C´4. Furthermore, the consistency ratio (CR) was determined to be 0.08. Therefore, given that the consistency ratio (CR) is less than 0.1, it can be concluded that the calculated weight is both consistent and accurate.

Finding Second Stage Preference Scores with TOPSIS Method

After the application of AHP, the TOPSIS method was applied in the order of the first stage. Accordingly, the normalised decision matrix was calculated first and is shown in Table 14.

Table 14 Parking Decision Matrix Normalization.

	C´1	C´2	C´3	C´4
PL 1	0.392	0.215	0.182	0.182
PL 2	0.299	0.328	0.152	0.152
PL 3	0.525	0.450	0.379	0.379
PL 4	0.372	0.513	0.364	0.364
PL 5	0.227	0.432	0.546	0.546
PL 6	0.325	0.352	0.379	0.379
PL 7	0.431	0.264	0.476	0.476

The normalised values were weighted in accordance with the weights determined by the AHP method, as detailed in Table 15.

Table 15 Parking Lot Weighted Normalized Decision Matrix.

	C´1	C´2	C´3	C´4
PL 1	118.8	146.0	6.0	0.1
PL 2	90.5	222.8	5.0	0.1
PL 3	159.1	306.0	12.5	0.1
PL 4	112.6	348.8	12.0	0.0
PL 5	68.8	293.6	18.0	0.1
PL 6	98.5	239.6	12.5	0.1
PL 7	130.6	179.6	15.7	0.1

Following the acquisition of the weighted normalised matrix, an investigation was conducted into the positive ideal and negative ideal properties, with the distances to the positive and negative solutions calculated for each parking lot.

Table 16 Parking Lot Positive-Negative Ideal Solution.

	C´1	C´2	C´3	C´4
Positive Ideal Solution	159.12	146.00	5.00	0.07
Negative Ideal Solution	68.80	348.80	18.00	0.03

Table 17 Distances to Parking Lot Positive Ideal and Negative Ideal Solutions

Parking Lots	Positive Ideal Solution	Negative Ideal Solution
PL1	40.29	209.23
PL2	102.98	128.52
PL 3	160.18	100.10
PL 4	208.19	44.17
PL 5	173.53	55.20
PL 6	111.76	113.31
PL 7	45.38	180.13

Finally, the ranking was done by calculating the preference scores for the second stage (Table 18). According to this ranking, PL1 was identified as the first priority car park with a score of 0.84.

Table 18 Parking Lot Preference Scores

Parking Lots	Preference Score
PL1	0.84
PL 7	0.80
PL 2	0.56
PL 6	0.50
PL 3	0.38
PL 5	0.24
PL 4	0.18

Sensitivity Analysis

The present study has undertaken a sensitivity analysis with the objective of examining the effect of changes in the criteria weights on the ranking of the alternatives. The methodology employed in this study is founded upon the principle of re-ranking the alternatives with the TOPSIS method by altering the criteria weights that have been determined with the AHP method under a range of scenarios. For the sensitivity analysis, the criterion weights determined by AHP were taken as the starting point. Three distinct scenarios were formulated:

The distance criterion (C1) is given the greatest weighting: In this scenario, the distance of the parking lots to the faculty entrances and the campus entrance is the most significant criterion.

The significance of parking capacity (C2) is given as follows:

In scenarios characterised by intensive vehicle usage, where capacity is particularly salient, this factor assumes greater significance.

Weighting of transformer preference score (C3): Scenario where energy infrastructure is critical.
New criteria were calculated for each scenario. The criteria weights for each scenario are changed as in Table 9:

Table 19. Scenario Criterion Weights

Scenario	C1 (Distance)	C2 (Capacity)	C3 (Transformer Score)
Default	0.469	0.148	0.104
Distance Priority	0.600	0.100	0.100
Capacity Priority	0.300	0.400	0.100
Transformer Priority	0.300	0.100	0.400

An increase in the weight of C1 was accompanied by a decrease in the weights of the other criteria, thereby achieving a state of normalization. Similarly, when C2 or C3 was weighed, the weights for other criteria were balanced. The alternatives were then subjected to normalisation using the TOPSIS method with new weights. The determination of positive and negative ideal solutions was achieved. New preference scores were obtained by calculating the distances of the alternatives to the ideal solution. With these weights, the distances to the positive and negative ideal solutions were calculated for each alternative using the TOPSIS method (Table 20).

Table 20 Positive And Negative Ideal Solutions

Parking	Default Score	Distance Priority	Capacity Priority	Transformer Score Priority
PL1	0.84	0.86	0.79	0.82
PL2	0.56	0.58	0.60	0.55
PL3	0.38	0.35	0.40	0.37
PL4	0.18	0.15	0.22	0.19
PL5	0.24	0.20	0.30	0.25
PL6	0.50	0.52	0.47	0.51
PL7	0.80	0.82	0.75	0.78

Consequently, the sensitivity analysis demonstrated that, despite alterations in the ranking of the alternatives, the position of the parking lot with the highest score in the ranking remained unaltered. This finding serves to substantiate the model's resilience and dependability. The sensitivity analysis conducted in this study was undertaken to ascertain the impact of alterations in criteria weights on the ranking of alternatives. The criteria determined by the AHP method were subjected to modification under different scenarios, and the alternatives were re-ranked. This analysis resulted in the observation of some changes in the rankings of the alternatives. Specifically, in scenarios where the weight assigned to the distance criterion was augmented, parking lots near faculty entrances emerged as prominent contenders. Conversely, in scenarios where parking capacity was prioritized, larger parking lots were found to confer a distinct advantage. However, it was observed that the parking lot determined as the most suitable alternative maintained its first position. These results demonstrate the model's consistency and reliability in the decision-making process.

CONCLUSION AND DISCUSSION

This study used AHP and TOPSIS to choose the best parking lot for an EV charging station. In the first phase of the study, the distances between transformers and parking lots, parking lot capacities and transformer powers were evaluated for each alternative. The T1 transformer was the best choice after matrix weighting and preference score calculation. In the second stage, the scores from the first stage were used to evaluate the parking lots. Factors such as distance to entrances and gate, and capacity were also considered. The PL1 car park was identified as the optimal location based on the calculated weighting and preference scores at the conclusion of the second stage. The superior features of PL1, namely its advantageous position in terms of distance and the potential for increasing transformer power despite the latter's seemingly low capacity, have resulted in the creation of a competitive solution. The limited capacity of the PL1 car park has resulted in a reduction in the overall weight of the car park due to the comparatively low demand for EV charging stations in comparison to the current situation. Upon evaluation of the preference scores of alternative options, it becomes evident that the PL7 and PL2 car parks, situated near PL1, offer comparable advantages and can be considered for second phase installations as the campus development progresses in future projects. The distance effect in the selection of the PL1 parking lot demonstrates that distance weighting may be open to question in the context of the application scenario. In the case of longer-term projects, it would be prudent to undertake a re-evaluation of parking capacity and energy infrastructure. Considering the campus's relatively youthful status and ongoing development, it is possible to obtain disparate outcomes when environmental factors such as traffic density, user behaviour, parking accessibility and staff density are incorporated into the evaluation process. This situation demonstrates the potential for future expansion of study. To enhance the functionality and satisfaction of future parking facilities, it would be prudent to consider augmenting the parking capacity and utilising a multi-transformer power supply. The reliability of the results may be evaluated through a sensitivity analysis, which entails the consideration of alternative weight scenarios. Furthermore, the long-term sustainability of this study can be enhanced by the development of a more comprehensive model and the incorporation of data such as user demand forecasts and energy cost analysis. The findings of this study indicate that the application of a multi-criteria decision-making methodology would be advantageous in the context of the installation of an EV charging station at the Binali Yıldırım University Yalnızbağ Campus in Erzincan. Nevertheless, a more dynamic model that incorporates environmental factors could offer a more comprehensive framework for future research.

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