

Selection of optimal electric vehicle charging station location using AHP-fuzzy TOPSIS approach

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Abstract. Electric vehicles have developed into one of the most desirable transportation alternatives in recent times. India and many countries such as the USA and the UK are working on various projects and policies to increase the amount of electrically powered vehicles onto their roads soon to deal with continuously rising fuel prices and CO₂ emissions. For effective implementation of such plans, suitable charging infrastructure requires supplying the electrical fuel to these vehicles. In this paper, we studied and different types of factors, such as traffic density, weather, parking space, solar power capacity, and many other factors, to identify the optimum location for public charging stations within a specified area with the help of AHP-fuzzy TOPSIS approach.

Keywords: electric vehicles; optimum location; AHP; Fuzzy TOPSIS.

1 Introduction

The concept of electric cars first came into existence in the mid-nineteenth century. The rising awareness about carbon footprint and other environmental impacts of fossil-fuel-based vehicles increased their popularity. Therefore, such vehicles act as a possible replacement for current-generation automobiles due to technological developments and even as the “green saviour,” to counter the rising problems of pollution, global warming, depletion of natural resources, etc. [1]. Electric vehicles run at low maintenance costs as they have less moving parts and no requirement for lubricating the engine. They also reduce noise pollution; therefore, they produce less noise and are smooth driven [2]. However, the sales figures for EVs around the globe show limited adoption of electric vehicles. The prime reasons for this are the high cost of EVs and short driving ranges. Besides, insufficient battery technologies and long-time consumption during charging make them less attractive to the market. Furthermore, adopting the latest technology and the lack of faith in electricity, as fuel is also one of the reasons people are not willing to make these changes [1].

In India, the government has been working on the projects and policies for the development of electric vehicles for around a decade.

Analytic Hierarchy Process is one of the popular analytic methods for complex decision-making problems developed by SATTY, which breakdowns the decision-making problem into a structured system of hierarchy of objectives, criteria, and alternatives. Hwang and Yoon developed the TOPSIS method in 1981. It is based on the approach that the chosen decision should have the minimum Euclidean distance from the ideal solution and maximum from the negative ideal solution [3].

2 Literature review

Muniamuthu et al. pointed out the rise in demand for electric vehicles, their sales, increasing their adoption, and the increase in government policies to promote the usage of electric vehicles. Showing the widespread determination to shift from pollution-causing conventional automobiles to electric vehicles [4]. Lie et al. explained about the evolution of electric cars, pros and cons, their sources of supply, their classification and constituents [5] and for the charging of electric cars, Somudeep et al. explained about the various categories of public charging sites and factors involved in the picking the most suitable location for installation of a public charging infrastructure in urban areas or developed cities [6]. The charging station model needs planning before establishment to minimise investments and operating costs. Zhang et al. considered that thoughtful outlining and massive scale development of charging facilities is a prerequisite for the popularisation and application of electric vehicles and to solve the problem of energy shortage and environmental pollution [7]. Khooi et al. talked about the methods of planning and strategic management of electric vehicle charging sites in the research and how effective planning and management play an essential role in the replacement of fossil fuel by hybrid or electric vehicles [8]. Yin et al. introduced a planning model charging infrastructure by combining aspects of the networks of road, traffic flow, and space constraints to determine the charging demands of the traffic flow and optimise the charging facility location accordingly [9].

González et al. studied the daily dimensional behaviour of electric vehicles (EV) and trip durations to design an algorithm for the identification of optimal locations and identify the most overloaded area [10]. Erbaş et al., with the help of Geographic Information Systems (GIS), a decision support system, and the Analytical Hierarchy Process (AHP), constructed a study to determine the best location for charging from the selected area of Istanbul, Turkey [11]. Wu et al., in his paper, proposed a decision system based on Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE) method and merged it with the cloud model to simplify the task of selection of an ideal site for the electric vehicle charging station. The technique used in this paper also makes up for the flaws in the traditional MCDM methods [12]. Andrenacci et al. analysed an extensive collection of vehicle movement data to carry out a strategy for the best possible location of the charging station to meet the demand [13]. Viswanathan et al. studied the real traffic flow and road system data and the movement of each vehicle plying on the road to determine the charging station framework [14].

3 Research methodology

First, we studied the importance of electric vehicle charging stations and why they need preference in the future. The primary component of the electric vehicle system is the charging station location. Thus, we need to determine factors, which will help in deciding the optimum location for the charging station. We talked with various experts from the automobile department in Hyundai, Tata Motors, and Mahindra. Next, we determined the factors based on the experience of different automobile professionals from various sectors. Experts mentioned above further reviewed our analysis and which helped us to draw necessary outcomes for the establishment of factors affecting the electric vehicle charging station. For choosing the most appropriate locations for charging stations, we employed AHP to obtain the weights of the criteria, while TOPSIS determines the priorities of alternatives.

4 Factors affecting the location of the electric vehicle charging station

While deciding a place for the installation of an electric vehicle, it is vital to consider the following factors to develop an electric vehicle charging station, which is economically viable and readily accepted.

- *Area of electric vehicle station*

Larger the useful space of the electric vehicle station, a number of the vehicle can be accommodated and charged, and new equipment placed quickly. The designer generally recommends parking lot either perpendicular or angled to traffic flow as it has high spatial efficiency. Angled parking lot creates unused triangular spaces suitable for electric vehicle supply equipment [15].

- *Charging duration*

Charging duration means “how long does it take to charge the electric vehicle.” The electric vehicle charging station can be located at places which are accessible to people such as shopping malls, educational organisations, and workplaces so that less time of people will be wasted for their electric vehicles to charge [6]. Level 1, level 2, level 3 charging equipment used depends upon the time the car spends in the charging station.

- *Traffic density*

Traffic density is an essential factor as it is directly proportional to the number of users. With an increase in traffic density, many users can use the charging station for their electric vehicle charging. With the installation of fast charging equipment, a large number of vehicles get charging, thus fulfilling the need for more users. Since densely populated location has costly land value, it is challenging to build a charging station, but places like a shopping centre, workplace, and government offices can work. Multiple floors charging stations can make to incorporate many users. Thus, it is more favourable to build a charging station where traffic density is more.

- *Integrating with existing infrastructure*

Electric vehicle charging is generally located in place, having a mix of buildings, other structures, walkways, and parking lots. Hence, proper formal and informal Pedestrians should have designed before placing the electric vehicle charging station so that cables do not create a tripping hazard. Vandalism and personal safety are essential characteristics of which care must take for enhanced utilisation of electric vehicle stations. Electric vehicle stations should accommodate the person with disabilities.

- *Surrounding vehicle movement*

Public electric vehicle charging stations cause various effects on the environment around them. The location of the charging station should be as such that the charging vehicles must not hinder the normal flow of traffic. Moreover, the incoming charging vehicles should not become a hurdle for pedestrian traffic and other vehicles and do not cause any accident or vandalism. One of the best ways of the implication of the charging station is along the street side parking bays [6].

- *Communication*

Information and technology support, control, manage the energy transfer between the electric vehicle and power grid varying in time and space. Technology further needed for management, billing, information, and authorisation for energy transfer. Internet technology plays a vital role in load management, thus leading to the optimisation of resources. Facilities like free Wi-Fi and app-connected electric vehicle charging stations can attract the consumer. Therefore adequate information technology is required for the general and more accessible operation of electric vehicle charging stations. Proper Network communication needs to display information on the screen, manage demand-supply and report faulty equipment, etc.

- *Weather*

The weather must not hinder the functioning of electric vehicles. In winter, the location must not be affected by snow, fog, ice, etc. Snow, ice can damage the equipment and impede the operation. Fog reduces the visibility level, thus leading to accidents. For this, the closed and covered type charging station work and should use photovoltaic charging technology [16].

- *Visibility*

Visibility of the charging station is an essential factor in encouraging the use of the station by the drivers and increases the number of users. The charging station should be easily visible to the drivers from distant places, as it will help the users in locating charging stations quickly and attracting more users. The visibility of the charging station can enhance with the help of signboards and indicators [6].

5 Analytic Hierarchy Process (AHP)

AHP is the most comprehensive system considered deciding with multiple criteria because this method gives to formulate the problem as hierarchical. The step by step approach given below:

Step 1: Define the objective and their decision criteria and sub-criteria.

Step 2: Construct a pairwise comparison matrix having (k) elements by comparing the importance of each criterion with all other criteria's with the help of a specified scale of preference ranging from 1 to 9, as shown in Table 1 [17].

Table 1. Scale of preference

Weights	Meaning
1	Equally important
3	Moderate
5	Strong
7	Very strong
8	Extreme
2,4,6,8	Intermediate values
Reciprocals	Reciprocals of opposite evaluation

Step 3: Normalised pairwise comparison matrix is calculated by dividing all elements of a column by the sum of the column. Now criteria weights are calculated by averaging all elements in a row. Now maximum Eigen value λ_{\max} of the matrix is calculated. The consistency index (CI) calculated as:

$$CI = \frac{(\lambda_{\max} - k)}{(k-1)}. \quad (1)$$

Step 4: To calculate random index (RI) use Table 2 [17] and the following relation obtains consistency ratio (CR):

$$CR = \frac{CI}{RI}. \quad (2)$$

If (CR) is ≤ 0.1 , then the matrix is consistent and acceptable. If the (CR) is ≥ 0.1 , the matrix is inconsistent, and judgment is not accurate.

Table 2. Values of random index

No.of attribute (k)	1	2	3	4	5	6	7	8	9	10
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

6 The Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)

TOPSIS compares a set of choices by identifying weights of each criterion, then normalising the value of each of them and determining the geometric distance between each alternative and ideal alternative, which is the optimal value in each criterion. The step by step approach given below:

Step 1: Generate feasible alternatives and determine the evaluation criteria. Assume that there are 'a' alternative and 'b' evaluation criteria.

Step 2: Choose the linguistic ratings for alternatives concerning standards from Table 3 [18].

Table 3. Linguistic terms and fuzzy numbers

Linguistic term	Fuzzy number
Very low	(0.0,0.1,0.3)
Low	(0.1,0.3,0.5)
Medium	(0.3,0.5,0.7)
High	(0.5,0.7,0.9)
Very high	(0.7,0.9,1.0)

Step 3: Construct the fuzzy decision matrix as given below.

$$M = \begin{bmatrix} z_{11} & z_{21} & z_{31} & \dots & \dots & z_{1b} \\ z_{21} & z_{22} & z_{32} & \dots & \dots & z_{2b} \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ \dots & \dots & \dots & \dots & \dots & \dots \\ z_{a1} & z_{a2} & z_{a3} & \dots & \dots & z_{ab} \end{bmatrix}. \quad (3)$$

Where $z_{ij} = (e_{ij}, f_{ij}, g_{ij})$ is the fuzzy number, $i = 1, 2, \dots, a$ represents the alternatives and $j = 1, 2, \dots, b$ represents the criteria.

Step 4: Now neutralise the weights of the matrix and generate the un-weighted matrix (S). Matrix S is obtained using the following relationship:

$$S = [s_{ij}]_{a \times b}; s_{ij} = \left(\frac{e_{ij}}{d_j^*}, \frac{f_{ij}}{d_j^*}, \frac{g_{ij}}{d_j^*} \right) \quad \text{where } d_j^* = \max d_i. \quad (4)$$

Step 5: Calculate the normalized weighted decision matrix as given below

$$H = [h_{ij}]_{a \times b}; i = 1, 2, \dots, a; j = 1, 2, \dots, b. \quad (5)$$

The normalized weighted value h_{ij} given as:

$$h_{ij} = s_{ij} \times w_j. \quad (6)$$

Here w_j denotes the weight of the j^{th} criteria as calculated above.

Step 6: Obtain the ideal positive and negative solution:

$$D^+ = \{u_1^+, u_2^+, \dots, u_n^+\} \& D^- = \{u_1^-, u_2^-, \dots, u_n^-\}. \quad (7)$$

The positive and negative ideal solution is given below:

$$u_j^+ = (1,1,1) \text{ \& } u_j^- = (0,0,0) . \quad (8)$$

Step 7: Determine the distances from D^+ and D^- for every factor by using

$$d(D1 - D2) = \sqrt{\frac{1}{3} [(e_2 - e_1)^2 + (f_2 - f_1)^2 + (g_2 - g_1)^2]} . \quad (9)$$

Step 8: Calculate the relative closeness coefficient given by:

$$CC_j = \frac{D_j^-}{D_j^+ + D_j^-}, \quad j = 1, 2, \dots, b . \quad (10)$$

Step 9: Now rank the alternatives in descending order based on values of CC_j .

7 Numerical application

AHP-TOPSIS approach is utilised in the problem for the selection of optimal charging station locations. The problem is demonstrated in the hierarchy of three stages, as shown in Figure 1. The first stage shows the problem objectively. The next step defines the criteria about the top stage, and the last step shows the alternatives.

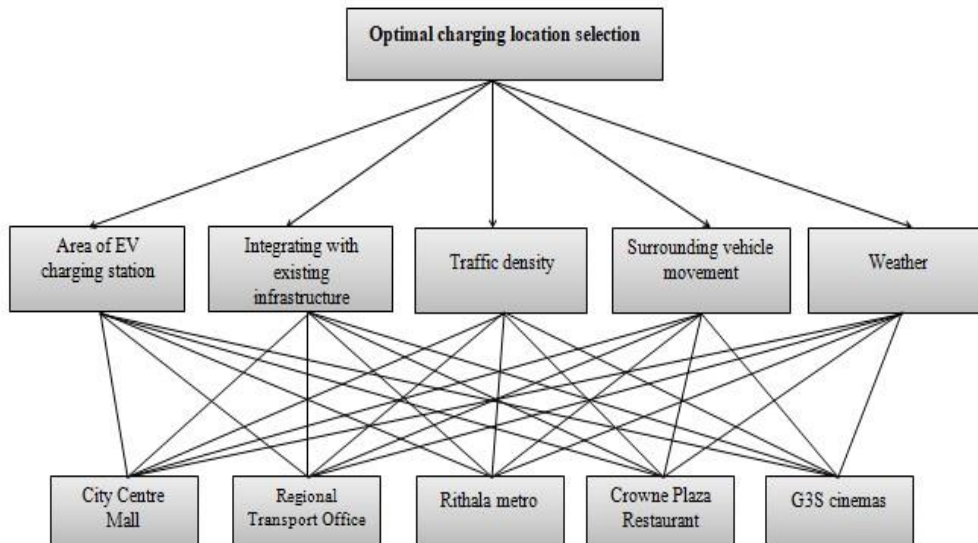


Figure 1. Levels of hierarchy

The criteria that we identified were the area of electric vehicle charging station (CR1), integrity with existing infrastructure (CR2), traffic density (CR3), surrounding vehicle movement (CR4), and weather (CR5). After this, the AHP approach followed, and the pairwise criteria matrix constructed, and the criteria weights determined are presented in Table 4. Now the values of λ_{\max} , CI, RI, and CR calculated, as shown in equation (11). The consistency ratio is less than 0.1, which is acceptable. We can now proceed with the TOPSIS method. Here we have chosen Rohini, New Delhi, India, as the area where we wish to put up the electric vehicle charging station. We selected five potential locations. The locations are City Centre Mall, Rohini sector-10 (L1), Regional Transport Office, Rohini sector-16 (L2), Rithala Metro Station, Rohini (L3), Crowne Plaza Restaurant, Rohini sector-10 (L4) and G3S Cinemas, Rohini sector-11 (L5). The fuzzy evaluation matrix, as illustrated in Table 5, drawn then the fuzzy weighted matrix, as shown in Table 6 and subsequent TOPSIS steps followed. The overall values represented in Table 7.

Table 4. Pairwise comparison of all criteria

Criteria	CR1	CR2	CR3	CR4	CR5	Weight
CR1	1	1/5	1/3	3	3	0.144
CR2	5	1	5	6	6	0.537
CR3	3	1/5	1	2	2	0.173
CR4	1/3	1/6	1/2	1	2	0.084
CR5	1/3	1/6	1/2	1/2	1	0.062

$$\lambda_{\max} = 5.40, CI = 0.10, RI = 1.12, CR = 0.089 . \quad (11)$$

Table 5. Evaluation matrix

	CR1	CR2	CR3	CR4	CR5
L1	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.7,0.9,1.0)	(0.3,0.5,0.7)
L2	(0.5,0.7,0.9)	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.5,0.7,0.9)
L3	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
L4	(0.5,0.7,0.9)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.5,0.7)	(0.3,0.5,0.7)
L5	(0.7,0.9,1.0)	(0.5,0.7,0.9)	(0.7,0.9,1.0)	(0.7,0.9,1.0)	(0.7,0.9,1.0)
Weight	0.144	0.537	0.173	0.084	0.062

Table 6. Fuzzy weighted matrix

	CR1	CR2	CR3	CR4	CR5
L1	(0.072,0.101,0.130)	(0.269,0.376,0.483)	(0.052,0.087,0.121)	(0.059,0.076,0.084)	(0.019,0.031,0.043)
L2	(0.072,0.101,0.130)	(0.269,0.376,0.483)	(0.052,0.087,0.121)	(0.025,0.042,0.059)	(0.031,0.043,0.056)
L3	(0.101,0.130,0.144)	(0.376,0.483,0.537)	(0.121,0.156,0.173)	(0.025,0.042,0.059)	(0.019,0.031,0.043)
L4	(0.072,0.101,0.130)	(0.161,0.269,0.376)	(0.052,0.087,0.121)	(0.025,0.042,0.059)	(0.019,0.031,0.043)
L5	(0.101,0.130,0.144)	(0.269,0.376,0.483)	(0.121,0.156,0.173)	(0.059,0.076,0.084)	(0.043,0.056,0.062)

Table 7. Overall values

	D_j^+	D_j^-	CC_j	Ranking
L1	4.339	0.686	0.136	3
L2	4.358	0.669	0.133	4
L3	4.191	0.824	0.164	1
L4	4.477	0.553	0.110	5
L5	4.229	0.791	0.157	2

8 Conclusion

The selection of a suitable site for the charging system is an essential activity for promoting electric vehicles and examination of multiple factors need to be satisfied for developing a commercially viable charging station. In this paper, we examined the various factors, which are suitable for selecting the electric vehicle charging station. For the selection of the most appropriate location, this paper proposed an integrated AHP and fuzzy TOPSIS method. AHP determines the weights of the criteria, while fuzzy TOPSIS determines the priorities of alternatives. The ranking of the locations in descending order is L3, L5, L1, L2, and L4. The proposed model results indicate that L3 is the best location among the five selected locations in the given area. Since we are pushing for electric vehicles, we need charging stations too, and to choose the proper location is a big challenge, which, if achieved, would be of utmost use. Our approach gets applicable to any given area or region and helps solve this problem by providing the optimum site for an electric vehicle charging station.

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