Research on the Location Selecting Problem of Electric Vehicle Charging Station

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Abstract: - Firstly the location selecting principle of electric vehicle charging station are analyzed; and then the problem of electric vehicle charging station location selecting and its evaluation are described in detail. In order to determine the charging station location, a spatial clustering algorithm is put forwarded. The process of the spatial clustering algorithm is analyzed in detail. The example analysis of the charging station location shows the effectiveness of this algorithm. In order to evaluate the charging station location, the location factors of electric vehicle charging station are analyzed. Based on the location factors of electric vehicle charging station, the hierarchical evaluation structure of electric vehicle charging station location is constructed, divided into three levels, including 4 first-class factors of evaluation and 14 second-class factors of evaluation. A multi hierarchy fuzzy method to evaluate electric vehicle charging station based on the hierarchical evaluation structure is proposed. The fuzzy multi-level evaluation model and algorithm and given, analysis results show that the multi-level fuzzy method can reasonably, to complete the electric vehicle charging station location evaluation.

Key-Words: - electric vehicle; charging station; location selecting; spatial clustering; fuzzy analytic hierarchy process

1 Introduction

The industrialization process of electric vehicles depends largely on a reasonable solution of battery charging [1][2][3][4]. In addition to the electric vehicle charging technology, the construction of related facilities must be considered in advance. For the charging stations' construction, location problem should be solved firstly. Only appropriate station location can bring user convenience and attract more users to buy electric vehicles, at the same time improve benefit of the charging station. It is also important for the investment in infrastructure, charging station's quality, safety and economy.

At present, the electric vehicle industry is developing rapidly, but is still in the early stages of development. Research in the layout and location of charging station is still in the exploratory stage. Although there are a lot of studies on the theory of networking facility location, there is little study on the location of quantitative modeling location, especially for the location of this new service facility of electric vehicle charging station.

Two classical issues in the study of location, proposed by Hakimi (1964) for the first time were P-median and P-center [5]. The purpose of P-median was to make the total weighted distance from all the demand point to the facility shortest, while the purpose of P-center was to site the limited number of service facilities, to make the maximum distance from each demand point to its nearest facility minimum. Toregas (1971) etc. were the first one to put forward the concept of SCLM (Set Covering Location Model) [6], whose aim was to minimum the cost and the quantity of the service facilities, meeting the constraint of all the requirements. Church (1974) etc. proposed MCLM (Maximum Covering Location Model) [7] firstly, aiming to maximize the demands covering, with a limited number of facilities. In order to solve the multi-objective location of the service facility location problem, Current (1985) etc. proposed MCSPP (Maximum Covering and Shortest Path Problem) [8] firstly, aiming at maximum covering of the demanding point and shortest path. In the study of gas charging station location, Bapna(2001) etc. expanded MCSPP into MC3SP(Maximum Covering/Shortest Spanning Subgraph Problem) [9], in order to satisfy the filling service in short-range within the cities and the long distance running in big cities. The objective was to minimize the initial cost of construction and vehicle users filling cost, and to maximize the covering of demand point.

In the real word, the requirement of the service facility (such as oil charging station ,gas charging station and electric vehicle charging station) , includes not only the demand points(group), which can be converged to one point, also including the demand (demand flow) passing in the daily line. Goodchild(1987) etc. first bonded the two demands(fixed demand point and passing demand flow) [10], maximized the market share of the enterprise in the building of the oil station site, and established the model considering two kinds of demand accordingly. Hodgson(1990) etc. first proposed the throttling problems FCLM (Flow Capturing Location Models) [11], studied how to locate in network, in order to maximize the total quantity of the demand passing by the service facility, in the certain requirement route and traffic and under the restriction of quantity of the service facility. Hodgson and Rosing (1992) extended FCLM to a mixed goal programming model [12], which combines the throttling problems and P-median. In considering of the vehicle range, Kuby and Lim (2005) extended FCLM to FRLM (Flow Refueling Location Model) [13], which considers that the demand flow in the network can be served by multiple service stations (station assembly) in the shortest path.

Kou L.F. etc. [14] established an optimal cost model of the location and capacity of the electric charging stations. This model simulates the amount of the electrical car with the distribution of resident, and give the candidate site weight coefficient with analytic hierarchy process. Under the constraint of the candidate site and the distance of the substation, the installation cost of the electric vehicle charging station, the quantity of electric cars and other conditions, the objective function also joined the charging station running costs and network loss costs and charging station distribution transformer investment.

Zhou H.C. [15] brought in game theory to evaluate electric vehicle charging station layout scheme, and showed the optimization model and algorithm, in order to achieve the optimal planning, finally carried on the instance analysis. The conclusion was that this model can improve the level of quantification of charging station’s location. The idea of dynamic traffic network was applied in paper [16], for the establishment of charging station layout based on hard time window constraints and the optimal size of multi-objective optimization model. This model put minimization of recharging cost and charging station cost as optimization target, and put forward the two-phase heuristic algorithm to solve the model.

Morrow(2008) etc. in the paper [17], analyzed the demands of charging facility in three different areas, and made evaluation and compare between the different charging stations construction cost.

Wang H.S.(2010) etc. in the paper [18], established a multi-objective programming mode, considering the factors of charging station, charging user characteristics, grid layout, urban planning and so on.

2 The problem description of charging station location selecting and its evaluation

2.1 Charging station location selecting problem description

There is a district of one city existing n users who have purchased the electric vehicle, and need to construct m charging stations (Note: m<n). For the charging station, the location of the goal is that the residence of every user of electric vehicles to the nearest charging station distance is the minimum. The location problem can be defined as "the smallest distance" problem.

The problem is described as follows with math language:

$$\begin{cases} d = \sum_{i=1}^{m} d_i \\ d_i = \sum_{j=1}^{k} d(a_j, s_i) \end{cases} \quad (1)$$

Where, d is the summed distance from all users residence who have purchased electric vehicle to the nearest charging station. d_j is the summed distance from the ith charging station to all k users who are the nearest users to this charging station. a_j is the location of the jth user residence, $j = 1,2,\cdots n$. s_i is the location of the ith charging station, $i = 1,2,\cdots m$.

The charging station location problem is finding s_i ($i = 1,2,\cdots m$) to get $\text{Min}(d)$. An improved spatial clustering algorithm is used to solve this problem. Spatial clustering is one of the main method in spatial data mining, and a method to find larger clusters or dense region in a big multidimensional data set based on measuring distance [19][20][21].

2.2 Charging station location evaluation problem description

A city of a region needs to build a charging station, the charging station address is obtained through some optimization methods advance, but the optimized address may be due to constraints not comprehensive result can not be used, such as can not be removed the old block, well planned city green space etc..

How to choose the charging station location involves too many factors, such as government planning, distribution of electric vehicles around, land use situation, traffic condition, weather condition, fire and explosion prevention condition, station harmonic pollution problem, electricity grid situation, total investment cost, annual operating cost. There are huge search spaces and multiple objectives, meanwhile many factors are difficult to be quantified. Traditional modeling methods can not effectively solve the optimization problem of charging station location. A fuzzy AHP decision method is put forward to solve this problem.

3 spatial clustering algorithm of electric vehicle charging station location selecting

3.1 The spatial clustering algorithm

Based on the above describe of charging station location selecting problem, the problem can be solved by clustering algorithm. The specific algorithm is as follows:

1) Input

$$A = \{a_1, a_2, \cdots\cdots, a_n\} \tag{2}$$

Where, A represents the user settlements; n is the number of user settlements;

t is the number of cycles.

2) Output

$$S = \{s_1, s_2, \cdots\cdots, s_m\} \tag{3}$$

Where, S represents the charging station address; m is the number of charging station would be constructed (m<n).

3) Objective function

$$\begin{cases} \mathrm{Min}(d) \\ d = \sum_{i=1}^{m} d_i \\ d_i = \sum_{j=1}^{k} d_{ij} \\ d_{ij} = d(a_j, s_i) \end{cases} \tag{4}$$

Where, $d_{ij} = d(a_j, s_i)$ is the distance from the ith charging sattion to the jth user's settlement.

4) The algorithm flow

① Selecting m user settlements $(a_1', a_2', \cdots\cdots, a_m')$ from A as clustering center at random.

②Calculating the distance d_{ij} from every a_i of A to every clustering center a_j' in turn, $d_{ij} = \sqrt{(a_{ix} - a_{jx}')^2 + (a_{iy} - a_{jy}')^2}$. The a_i which get Min(d_{ij}) should be divided to the clustering center.

③Calculating the coordinate mean of all a_i of every clustering center, and the distance all a_i to the coordinate mean. Then selecting the coordinate mean as a new clustering center a_j'.

④ Calculating the $d = \sum_{i=1}^{m} d_i$, $d_i = \sum_{j=1}^{k} d_{ij}$, $d_{ij} = d(a_j, s_i)$; and executing ②、③ in loop until the cycle num t is arrived.

3.2 Example analysis

Taking a city as an example, the city has 15 settlements, each resident has same number electric car users, now need to construct 3 electric vehicle charging stations in the city. The coordinate 15 settlements are shown in table 1.

Table 1 coordinates of settlement area

residential area	north latitude	east longitude
1	31.446721	117.165523
2	31.437235	117.178956
3	31.429221	117.184563
4	31.421397	117.195240
5	31.423456	117.184521
6	31.428526	117.174563
7	31.435645	117.175230
8	31.434567	117.165231
9	31.443569	117.189654
10	31.428546	117.198965
11	31.435632	117.174563
12	31.434562	117.200456
13	31.441235	117.167895
14	31.425631	117.192546
15	31.432230	117.174589

The spatial clustering result of the electric vehicle charging station location is shown in Figure 1, the circle points represent city 15 settlements, the fork points represent the electric vehicle charging station address meeting the clustering condition, three coordinate electric vehicle charging stations address as given in table 2.

Table 2 coordinates of address of charging station for electric vehicle

residential area	North latitude	East longitude
1	31.4267	117.1943
2	31.4346	117.1789
3	31.4408	117.1662

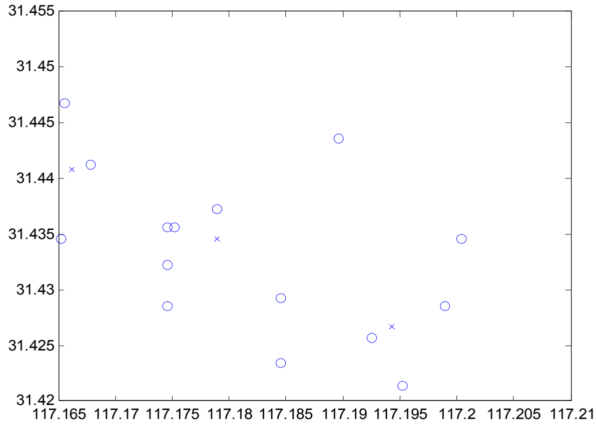

Figure 1 location result of charging station for electric vehicle

4 Evaluation of Electric Vehicle Charging Station Location

AHP was developed by American scholar Thomas L. Saaty, which is a multi-criteria decision-making method in system analysis. It arranges the different indexes involved in a problem according to their types to form a hierarchical structure model, and finally turns into the relative weight determine of the lowest level to the highest level in the model [22]. The concrete steps on decision of charging station location with fuzzy AHP decision are as follows:

①Building the fuzzy AHP decision model that describes the charging station location;

②Constructing the weight judgment matrix;

③Solving the weight judgment matrix, verifying the consistency of each matrix, and calculating the combinational weight of the bottom indexes.

④Establishing the membership function of the bottom evaluation indexes and calculating the degree of membership;

⑤ According to the degree of membership, evaluating the comprehensive evaluation value of charging station location decision.

4.1 Construction of the hierarchy for charging station location and judgment of experts

As mentioned above, it is judged by four aspects, natural factors, management environment, public facilities and economic factors. Natural factors are evaluated by four aspects including the weather conditions, geological conditions, hydrological conditions and topographic conditions. The management environment factors are evaluated by five aspects including government planning, policy environment, distribution of electric vehicles around, traffic conditions and land use conditions. The public facilities factors are evaluated by three aspects including electricity grid situation, station harmonic pollution problem and fire and explosion prevention. The economic factors are evaluated by two aspects including total investment cost and annual operating cost. The judgment hierarchy is constructed as Figure 1, divided into three levels, including 4 first-class factors of evaluation and 14 second-class factors of evaluation.

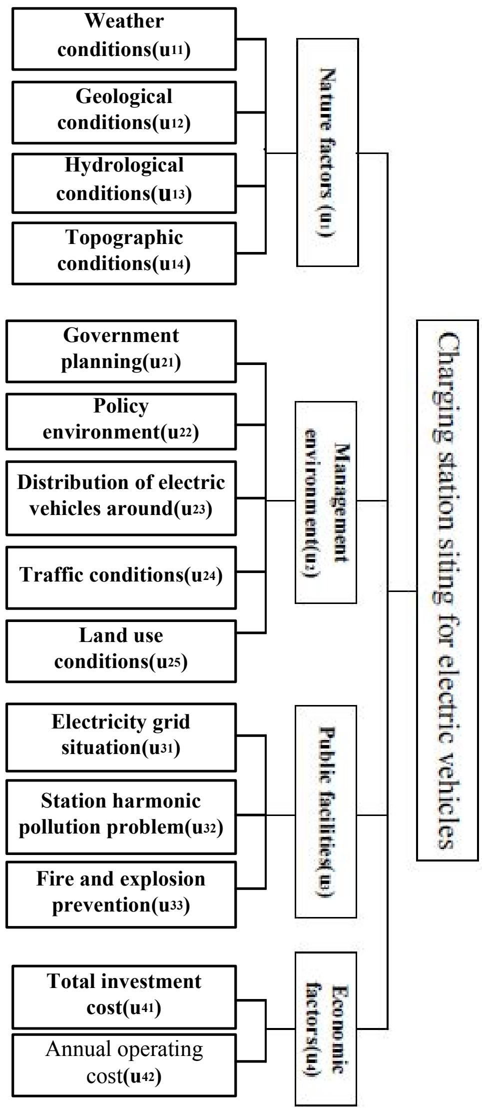

Figure 2 evaluation model with fuzzy AHP for charging station location

Table 3 average of expert score for electric vehicle charging station location

Factors		Average of expert score
Nature Factors	Weather conditions	7.6
	Geological conditions	6.1
	Hydrologic conditions	7.2
	Hydrologic condition	6.5
Management Factors	Government planning	8.0
	Policy environment	8.0
	Distribution of electric vehicles around	3.3
	Traffic conditions	6.0
	Land use conditions	4.8
Public Facilities Factors	Electricity grid situation	6.5
	Station harmonic pollution problem	5.5
	Fire and explosion prevention	7.1
Economics Factors	Total investment cost	6.8
	Annual operating cost	8.7

Suppose that a city needs to build a charging station for electric vehicles and three candidate sites are determined after preliminary investigation. Now nine experts are organized to grade the three sites. For personal subjective factors caused by expert judgment make it hard for the study, by fixing the evaluation measure, the difference of expert judgment can be reduced. The expert judgment uses a 10-point scale, in which 10 is the highest level, meaning the best, 1 is the lowest level, meaning it does not meet the performance requirement at all, and 5 is the dividing line. The results of expert judgment are as Table 3.

4.2 Charging station location with fuzzy AHP

1) Establishment of evaluation factors set

The calculation process of AHP is expanded around the hierarchy diagram. The purpose is to work out the relative importance score of various sub factors to the overall target, namely comprehensive weight. But the local weight in the hierarchy need to be solved first, namely the relative importance of this level to the upper level.

Make the indexes set in evaluation model:

$$U = \{u_1, u_2, \cdots, u_n\}$$

(5)

According to the four evaluation content, the set is divided into four indexes, including nature, management environment, public facilities and economic factors. The corresponding sub sets are:

$$u_1 = \{u_{11}, u_{12}, u_{13}, u_{14}\}$$

(6)

$$u_2 = \{u_{21}, u_{22}, u_{23}, u_{24}, u_{25}\}$$

(7)

$$u_3 = \{u_{31}, u_{32}, u_{33}\}$$

(8)

$$u_4 = \{u_{41}, u_{42}\}$$

(9)

To reduce the influence of large individual difference caused by subjective evaluation, the evaluation value is treated with discrete analysis first. When check an expert judgment, it is on the basis of the difference between the value given by the expert and the average value to judge if the expert judgment is far away from the average evaluation value. Two expert evaluation data are excluded at most.

2) Determine the weight of each index

Each U_i is a part of U, standing for one characteristic of U. In accordance with their importance, the weight distribution is given.

$$W = \{w_1, w_2, \cdots w_N\}$$

(10)

So the weight distribution of Ui is

$$W_i = \{w_{i1}, w_{i2}, \cdots w_{ik}\}$$

(11)

Where, $0 \le w_{ij} \le 1$, $\sum_{j=1}^{k_i} w_{ij} = 1$.

On the basis of the 1-9 proportion quotient proposed in reference [23], the judgment matrix is established to make the evaluation quantitative as follows:

$$P_1 = \begin{bmatrix} 1 & 1/2 & 1/2 & 1 \\ 2 & 1 & 1 & 2 \\ 2 & 1 & 1 & 2 \\ 1 & 1/2 & 1/2 & 1 \end{bmatrix}$$

$$P_2 = \begin{bmatrix} 1 & 1/5 & 1 & 1 & 1/2 \\ 5 & 1 & 5 & 1 & 1/2 \\ 1 & 1/5 & 1 & 1 & 1/2 \\ 1 & 1 & 1 & 1 & 1/2 \\ 2 & 2 & 2 & 2 & 1 \end{bmatrix}$$

$$P_3 = \begin{bmatrix} 1 & 1/2 & 1/2 \\ 2 & 1 & 1/2 \\ 2 & 2 & 1 \end{bmatrix}$$

$$P_4 = \begin{bmatrix} 1 & 1/2 \\ 2 & 1 \end{bmatrix}$$

$$P = \begin{bmatrix} 1 & 2 & 2 & 1 \\ 1/2 & 1 & 1 & 1/2 \\ 1/2 & 1 & 1 & 1/2 \\ 1 & 2 & 2 & 1 \end{bmatrix}$$

After establishing the judgment matrixes, consistency should be checked [24]. If the consistency is poor, it is necessary to adjust the matrixes to make sure a satisfactory consistency. The consistency index of the judgment matrixes (P_1, P_2, P_3, P_4, P) are respectively:

$$CI_{P1} = \frac{\hat{\lambda}_m - n}{n-1} = \frac{4-4}{4-1} = 0 \le 0.1 \times 0.9$$

$$CI_{P2} = \frac{\hat{\lambda}_m - n}{n-1} = \frac{5.078-5}{5-1} = 0.019 \le 0.1 \times 1.12$$

$$CI_{P3} = \frac{\hat{\lambda}_m - n}{n-1} = \frac{3.0536-3}{3-1} = 0.0268 \le 0.1 \times 0.58$$

$$CI_{P4} = \frac{\hat{\lambda}_m - n}{n-1} = \frac{2-2}{2-1} = 0 \le 0.1 \times 0$$

$$CI_{P} = \frac{\hat{\lambda}_m - n}{n-1} = \frac{4-4}{4-1} = 0 \le 0.1 \times 0.9$$

So *CIP*1, *CIP*2, *CIP*3, *CIP*4, *CIP* all satisfy the standard, and the inconsistency is acceptable.

For each type indexes *i*, the weight of each index is determined with AHP, according to the degree of importance for each index in the specific program, seen in Table 4.

Table 4 the weight of evaluation index

weight	Value
W_1	[0.167,0.333,0.333,0.167]
W_2	[0.143,0.221,0.143,0.165,0.329]
W_3	[0.196,0.311,0.493]
W_4	[0.333,0.667]
W	[0.333,0.167,0.167,0.333]

According to the requirements of the comprehensive evaluation objectives and reviews as well as characteristics of the evaluation indexes, the membership functions of all indexes can be divided into two types: large and moderate type. For example, the precision of steering, difficulty level of corner correction, performance of steering wheel return ability and driver fatigue all belong to the large membership function. While steering effort, sensibility, roll feeling and steering response belong to the moderate type. For large type index ui, whose scope of variable is xi, when the reviews of worst, worse, medium, better, best respectively have the membership functions $u_{i1}, u_{i2}, u_{i3}, u_{i4}, u_{i5}$, triangle membership function form are used, as is shown in Figure 3. The center values of variable x to each membership function are $x_{i1} \sim u_{i5}$.

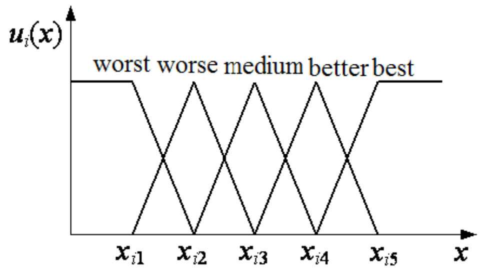

Figure 3 Triangle membership function

Then the evaluation matrix of single index R_i (*i*=1, 2, 3, 4) is achieved, which includes:

$$R_1 = \begin{bmatrix} 0 & 0 & 0 & 0.7 & 0.3 \\ 0 & 0 & 0.45 & 0.55 & 0 \\ 0 & 0 & 0 & 0.9 & 0.1 \\ 0 & 0 & 0.25 & 0.75 & 0 \end{bmatrix}$$

$$R_2 = \begin{bmatrix} 0 & 0 & 0 & 0.5 & 0.5 \\ 0 & 0 & 0 & 0.5 & 0.5 \\ 0 & 0.85 & 0.15 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 \\ 0 & 0.1 & 0.9 & 0 & 0 \end{bmatrix}$$

$$R_3 = \begin{bmatrix} 0 & 0 & 0.25 & 0.75 & 0 \\ 0 & 0 & 0.75 & 0.25 & 0 \\ 0 & 0 & 0 & 0.95 & 0.05 \end{bmatrix}$$

$$R_4 = \begin{bmatrix} 0 & 0 & 0.1 & 0.9 & 0 \\ 0 & 0 & 0 & 0.15 & 0.85 \end{bmatrix}。$$

3) Comprehensive evaluation with fuzzy AHP

①First level comprehensive evaluation

With fuzzy synthetic $W_i \circ R_i$, the first comprehensive matrix $B_i(b_{i1}, b_{i2}, b_{i3}, b_{i4})$ is achieved, with which the total evaluation matrix R is constructed:

$$R = \begin{bmatrix} B_1 \\ B_2 \\ B_3 \\ B_4 \end{bmatrix} = \begin{bmatrix} W_1 \circ R_1 \\ W_2 \circ R_2 \\ W_3 \circ R_3 \\ W_4 \circ R_4 \end{bmatrix} =$$

$$\begin{bmatrix} 0 & 0 & 0.1920 & 0.7250 & 0.0833 \\ 0 & 0.1545 & 0.4001 & 0.2645 & 0.1820 \\ 0 & 0 & 0.2248 & 0.7506 & 0.0247 \\ 0 & 0 & 0.0333 & 0.8667 & 0.1001 \end{bmatrix}$$

②The second level comprehensive evaluation

After synthesizing, the $W \circ R$, the second comprehensive evaluation matrix is achieved:

$$B = W \circ R = \begin{bmatrix} 0 & 0.0258 & 0.1794 & 0.6996 & 0.0956 \end{bmatrix}$$

According to the principle of maximal membership, the evaluation grade of this electric vehicle charging station would be selected is “better”.

5 Conclusions

For the charging station, the location of the goal is that the residence of every user of electric vehicles to the nearest charging station distance is the minimum. The location problem can be defined as "the smallest distance" problem. The spatial clustering algorithm can resolve this charging station location selecting problem effectively.

Charging station location selecting for electric vehicle involves many factors, which brings some difficulty for location evaluation. With fuzzy AHP, the fuzzy evaluation model for charging station location is established, which includes all indexes affecting the total performance. The evaluation result is achieved that makes it easy to compare the different sits for electric vehicle charging station.

Fuzzy AHP not only considers the influence of all factors, but also keep all information of every evaluation level. By assigning different weight coefficient to each index, important evaluation programs are enhanced, and the result can be easily converted into specific score when it is needed. So it is easy to compare different programs and has good value in use.

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