Location of Electric Vehicle Charging Station Based on Spatial Clustering and Multi-hierarchical Fuzzy Evaluation

Wang Meng, *Liu Kai* *

School of Traffic and Transportation, Beijing Jiaotong University, Beijing 100044, P. R. China

(Received 12 June 2016; revised 26 October 2016; accepted 28 October 2016)

Abstract: For the charging station construction of electric vehicle, location selecting is a key issue. There are two problems in location selection of the electric vehicle charging station. One is determining the location of charging station; the other is evaluating the location of charging station. To determine the charging station location, an spatial clustering algorithm is proposed and programmed. The example simulation shows the effectiveness of the spatial clustering algorithm. To evaluate the charging station location, a multi-hierarchical fuzzy method is proposed. Based on the location factors of electric vehicle charging station, the hierarchical evaluation structure of electric vehicle charging station location is constructed, including three levels, 4 first-class factors and 14 second-class factors. The fuzzy multi-hierarchical evaluation model and algorithm are built. The analysis results show that the multi-hierarchical fuzzy method can reasonably complete the electric vehicle charging station location evaluation.

Key words: electric vehicle charging station; spatial clustering; multi-hierarchical fuzzy evaluation

CLC number: TM263 **Document code**: A **Article ID**: 1005-1120(2017)01-0089-08

0 Introduction

The industrialization process of electric vehicles depends largely on a reasonable solution of battery charging [1-4]. In addition to the battery charging technology of electric vehicle, the construction of related facilities must be considered in advance. For the construction of charging stations, location problem should be solved firstly. Only appropriate station location can facilitate the use of charging station and promote the sales of electric vehicles, thus improving theutilization rate of charging station. It is also important for the investment in infrastructure, charging station's quality, safety and economy.

Despite its early stages of development the electric vehicle industry is developing rapidly. 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, few studies have been reported on the location of quantitative modeling location, especially for the location of new service facility of electric vehicle charging station.

Two classical issues about location selecting proposed by Hakimi for the first time were P-median and P-center [5]. The purpose of P-median was to minimize 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 minimize the maximum distance from each demand point to its nearest facility. Toregas was the first one to put forward the concept of set covering location model (SCLM)[6], whose aim was to minimize the cost and the quantity of the service facilities, for meeting the constraint of all the requirements. Church et al. proposed the maximum covering location model (MCLM)[7] firstly, aiming to maximize the demands covering, with a limited number of facilities. In order to solve the multi-objective lo-

* Corresponding author: E-mail: liukai@bjtu. edu. cn.

How to cite this article: Wang Meng, Liu Kai. Location of electric vehicle charging station based on spatial clustering and multi-hierarchical fuzzy evaluation[J]. Trans. Nanjing Univ. Aero. Astro., 2017,34(1):89-96.
http://dx. doi. org/10. 16356/j. 1005-1120. 2017. 089

cation of the service facility location problem, Current et al. proposed the maximum covering and shortest path problem (MCSPP)[8] firstly, aiming at maximum covering of the demanding point and shortest path. In the study of gas charging station location, Bapna et al. expanded MCSPP into the maximum covering/shortest spanning subgraph problem (MC3SP)[9], 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.

Actually, 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 et al. first integrated 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 proposed the throttling problems based on flow capturing location models (FCLMS)[11], and 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 under the restriction of quantity of the service facility. Hodgson and Rosing extended FCLM to a mixed goal programming model[12], which combines the throttling problems and P-median. Taking the vehicle range into account, Kuby and Lim extended FCLM to flow refueling location model (FRLM)[13], which considers that the demand flow in the network can be served by multiple service stations (station assembly) in the shortest path.

Kou et al. [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[15] proposed the game theory to evaluate electric vehicle charging station layout scheme, and showed the optimization model and algorithm. To find the optimal planning, some exmples were finally analyzed. The conclusion was that this model can improve the level of quantification of charging station′s location.

The idea of dynamic traffic network was introduced in Ref. [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 aimed to minimize recharging cost and charging station cost, and presented the two-phase heuristic algorithm to solve the model.

Morrow et al. [17] analyzed the demands of charging facility in three different areas, and evaluated and compared the different charging stations construction cost.

Wang et al. [18] established a multi-objective programming mode, considering the factors of charging station, charging user characteristics, grid layout, urban planning and so on.

1 Model for selecting charging station location

1.1 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 ($m < n$). For the location of the charging stations, the goal is to minimize the distance from the residence of every user of electric vehicles to the nearest charging station. The location problem can be defined as "the smallest distance" problem.

The problem is described as

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

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

The charging station location selecting problem is to find $s_i (i = 1, 2, \cdots, m)$ for obtaining Min(d). A spatial clustering algorithm is used to solve the problem. Spatial clustering is one of the main methods for spatial data mining, and for searching the larger clusters or dense region in a big multidimensional data set based on measuring distance[19-21].

1.2 Charging station location evaluation

When a region in a city needs to build a charging station, the charging station location can be obtained by some optimization methods available. The optimized location may be subjected to constraints with comprehensive restrictions, such as the immovable old block, the well-planned city green space etc.

Many factors influence the choice of the charging station location, 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 and so on. Among them, several factors are difficult to be mathematically defined. Traditional modeling methods cannot effectively solve the optimization problem of charging station location. A multi-hierarchical fuzzy method is presented to tackle the problem.

2 Spatial Clustering Algorithm for Selecting Electric Vehicle Charging Station

2.1 Traditional spatial clustering algorithm

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

(1) Input

$$A = \{a_1, a_2, \cdots, a_n\} \quad (2)$$

where A is the user settlements, n the number of user settlements, and t the number of cycles.

(2) Output

$$S = \{s_1, s_2, \cdots, s_m\} \quad (3)$$

where S is the charging station address and m the number of charging station to be constructed ($m < n$).

(3) Objective function

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

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

(4) The algorithm flow

① Selecting m user settlements $(a'_1, a'_2, \cdots, a'_m)$ from A as the clustering center at random.

② Calculating 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 with which Min(d_{ij}) is obtained should be divided into the clustering center.

③ Calculating 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 $d = \sum_{i=1}^{m} d_i, d_i = \sum_{j=1}^{k} d_{ij}$, $d_{ij} = d(a_j, s_i)$; and repeating steps ②, ③ in the loop until the iteration number t is obtained.

2.2 Example analysis

Taking a city as an example, the city has 15 districts, and each district has the same number of electric car users. It is supposed that three charging stations for electric vehicles are to be built in the city. The geographical coordinates of 15 districts are shown in Table 1.

Table 1 Coordinates of 15 districts

District	North latitude	East longitude
1	40.477	115.965
2	40.467	115.979
3	40.459	115.985
4	40.451	115.995
5	40.453	115.985
6	40.459	115.975
7	40.466	115.975
8	40.465	115.965
9	40.474	115.986
10	40.459	115.999
11	40.466	115.975
12	40.465	116.000
13	40.471	115.968
14	40.456	115.993
15	40.462	115.975

The spatial clustering result of the location of electric vehicle charging stations is shown in Fig. 1, where dark triangles represent the 15 districts, and the circles mark the location of charging stations meeting the clustering requirments. Moreover, three coordinates locating the electric vehicle charging stations are listed in Table 2.

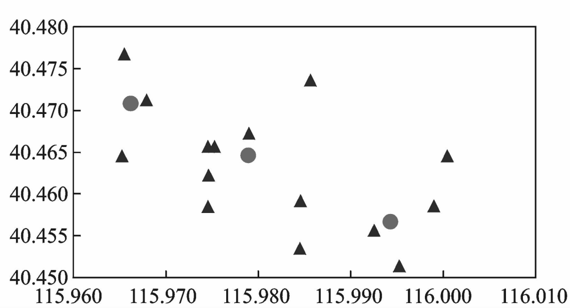

Fig. 1 Location of charging stations for electric vehicle

Table 2 Geographical coordinates of 3 charging station for electric vehicles

Residential area	North latitude	East longitude
1	40.456 7	115.994 3
2	40.464 6	115.978 9
3	40.470 8	115.966 2

3 Evaluation of Electric Vehicle Charging Station Location

Analytic hierarchy process (AHP) was developed by the 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:

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

(2) Constructing the weight judgment matrix;

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

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

(5) Evaluating the comprehensive evaluation value of charging station location decision according to the degree of membership.

3.1 Construction of hierarchy for charging station location and rating experts

As mentioned above, it is judged by four aspects, i.e., natural factors, management environment, public facilities and economic factors. Natural factors are evaluated by four aspects including the weather, geological, hydrological, 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-using conditions. The public facilities factors involve three aspects, including electricity grid situation, station harmonic pollution problem, and fire and explosion prevention. The economic factors are evaluated by two aspects, that is, total investment cost and annual operating cost. The rating hierarchy is constructed, as shown in Fig. 2, and divided into three levels, including four first-class factors of evaluation and 14 second-class factors of evaluation.

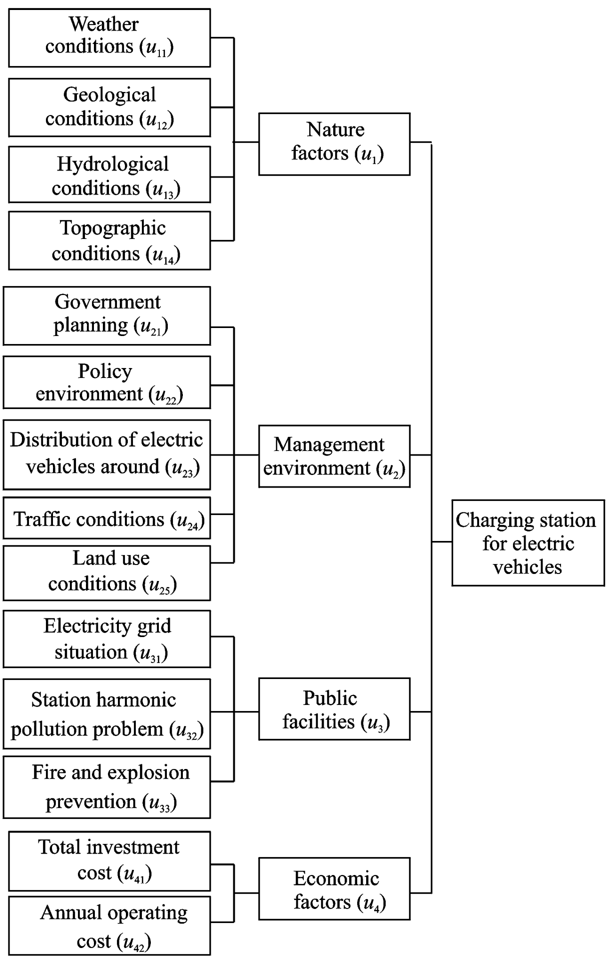

Fig. 2 Evaluation model with fuzzy AHP for charging station location

Suppose that a city needs to build a charging station for electric vehicles and three candidate sites are determined after the preliminary investigation. Now nine experts are invited to organize a board for grading the three sites. Since expert rating is subjective, fixing the evaluation measure can reduce the difference of expert rating. The expert rating uses a 10-point scale, in which 10 represents the highest level, while 1 the lowest level, which means it does not meet the performance requirement at all. Here, 5 is the dividing line. The results of expert rating are listed in Table 3.

Table 3 Average of expert scores for electric vehicle charging station location

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

3.2 Charging station location with fuzzy AHP

3.2.1 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.

Given the indexes set in the evaluation model

$$U = \{u_1, u_2, \cdots, u_n\} \tag{5}$$

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

$$u_1 = \{u_{11}, u_{12}, u_{13}, u_{14}\} \tag{6}$$

$$u_2 = \{u_{21}, u_{22}, u_{23}, u_{24}, u_{25}\} \tag{7}$$

$$u_3 = \{u_{31}, u_{32}, u_{33}\} \tag{8}$$

$$u_4 = \{u_{41}, u_{42}\} \tag{9}$$

To reduce the influence of large individual difference introduced by subjective evaluation, the evaluation value is treated with discrete analysis first. When check an expert rating, 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 rating data are excluded at most.

3.2.2 Determination of 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.

$$W=\{w_1, w_2, \cdots, w_N\} \tag{10}$$

So the weight distribution of U_i is

$$W_i=\{w_{i1}, w_{i2}, \cdots, w_{ik}\} \tag{11}$$

where $0 \leqslant w_{ij} \leqslant 1$, $\sum_{j=1}^{k_i} w_{ij}=1$.

On the basis of the 1—9 proportion quotient proposed in Ref. [23], the judgment matrix is established to quantify the evaluation as follows

$$\boldsymbol{P}_1=\begin{bmatrix}1 & 1/2 & 1/2 & 1\\ 2 & 1 & 1 & 2\\ 2 & 1 & 1 & 2\\ 1 & 1/2 & 1/2 & 1\end{bmatrix}$$

$$\boldsymbol{P}_2=\begin{bmatrix}1 & 1/5 & 1 & 1 & 1/2\\ 5 & 1 & 5 & 1 & 1/2\\ 1 & 1/5 & 1 & 1 & 1/2\\ 1 & 1 & 1 & 1 & 1/2\\ 2 & 2 & 2 & 2 & 1\end{bmatrix}$$

$$\boldsymbol{P}_3=\begin{bmatrix}1 & 1/2 & 1/2\\ 2 & 1 & 1/2\\ 2 & 2 & 1\end{bmatrix}$$

$$\boldsymbol{P}_4=\begin{bmatrix}1 & 1/2\\ 2 & 1\end{bmatrix}$$

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

After establishing the judgment matrixes, consistency should be checked[24]. If the consistency is poor, it is necessary to adjust the matrixes to attain a satisfactory consistency. The consistency index of the judgment matrixes ($\boldsymbol{P}_1, \boldsymbol{P}_2, \boldsymbol{P}_3, \boldsymbol{P}_4, \boldsymbol{P}$) are

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

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

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

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

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

As CI_{P1}, CI_{P2}, CI_{P3}, CI_{P4}, CI_P all satisfy the standard, 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, as shown in Table 4.

Table 4 Weight of evaluation index

Weight	Value
$\boldsymbol{W}_1$	[0.167, 0.333, 0.333, 0.167]
$\boldsymbol{W}_2$	[0.143, 0.221, 0.143, 0.165, 0.329]
$\boldsymbol{W}_3$	[0.196, 0.311, 0.493]
$\boldsymbol{W}_4$	[0.333, 0.667]
$\boldsymbol{W}$	[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 type 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 u_i, with scope of variable x_i, when the reviews of worst, worse, medium, better, best have the membership functions $u_{i1}, u_{i2}, u_{i3}, u_{i4}, u_{i5}$, respectively, triangle membership function is used, as shown in Fig. 3. The center values of variable x to each membership function are x_{i1}—x_{i5}.

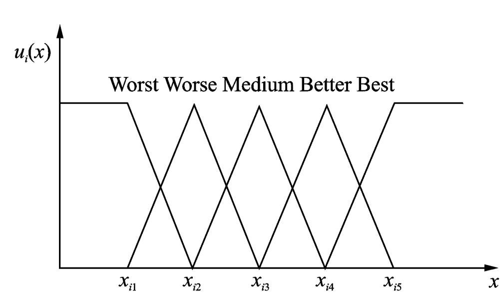

Fig. 3 Triangle membership function

Then the evaluation matrixes of single index $\boldsymbol{R}_i$ (i=1, 2, 3, 4) are obtained.

$$\boldsymbol{R}_1=\begin{bmatrix}0&0&0&0.7&0.3\\0&0&0.45&0.55&0\\0&0&0&0.9&0.1\\0&0&0.25&0.75&0\end{bmatrix}$$

$$\boldsymbol{R}_2=\begin{bmatrix}0&0&0&0.5&0.5\\0&0&0&0.5&0.5\\0&0.85&0.15&0&0\\0&0&0.5&0.5&0\\0&0.1&0.9&0&0\end{bmatrix}$$

$$\boldsymbol{R}_3=\begin{bmatrix}0&0&0.25&0.75&0\\0&0&0.75&0.25&0\\0&0&0&0.95&0.05\end{bmatrix}$$

$$\boldsymbol{R}_4=\begin{bmatrix}0&0&0.1&0.9&0\\0&0&0&0.15&0.85\end{bmatrix}$$

3.2.3 Comprehensive evaluation with fuzzy AHP

With fuzzy synthetic $\boldsymbol{W}_i \circ \boldsymbol{R}_i$, the first comprehensive matrix $\boldsymbol{B}_i(b_{i1}, b_{i2}, b_{i3}, b_{i4})$ is obtained, with which the total evaluation matrix $\boldsymbol{R}$ is constructed.

$$\boldsymbol{R}=\begin{bmatrix}\boldsymbol{B}_1\\\boldsymbol{B}_2\\\boldsymbol{B}_3\\\boldsymbol{B}_4\end{bmatrix}=\begin{bmatrix}\boldsymbol{W}_1\circ\boldsymbol{R}_1\\\boldsymbol{W}_2\circ\boldsymbol{R}_2\\\boldsymbol{W}_3\circ\boldsymbol{R}_3\\\boldsymbol{W}_4\circ\boldsymbol{R}_4\end{bmatrix}=$$

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

After synthesizing, the $\boldsymbol{W}\circ\boldsymbol{R}$, the second comprehensive evaluation matrix can be expressed as $\boldsymbol{B}=\boldsymbol{W}\circ\boldsymbol{R}=[0\ \ 0.0258\ \ 0.1794\ \ 0.6996\ \ 0.0956]$.

According to the principle of maximal membership, the rating grade of the electric vehicle charging station would be regarded as "better".

4 Conclusions

For the charging station, the location should serve the goal of keeping the distance from the residence of every user of electric vehicles to the nearest charging station distance minimum. The location problem can be defined as ″the smallest distance″ problem. The spatial clustering algorithm can resolve the charging station location problem effectively.

Charging station location for electric vehicle involves many factors, which brings forth some difficulty in 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 results are obtained and compared with each other when different spots are chosen for electric vehicle charging station.

Fuzzy AHP takes the influence of all factor into account and keeps 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 a specific score when needed. So the proposed method provides a convenient approach to comparing different programs.

Acknowledgement

This work was supported by the National Natural Science Foundation of China (No. 51575047).

References:

[1] OUYANG M G. Chinese strategies and countermeasures for energy saving and vehicles with new types energy[J]. Automotive Engineering, 2006, 28 (4):317-321.

[2] XIN F Y, WANG H B. The developmental stage and commercial prospects of electric vehicles[J]. International Petroleum Economics Monthly, 2010,18(7): 20-24.

[3] WEN X. Environmental benefit analysis of electric vehicles[J]. Environment Herald, 2003,24:23.

[4] ZHANG W L, WU B, LI W F, et al. Discussion on development trend of battery electric vehicles in China and its energy supply mode[J]. Power System Technology, 2009,33(4):1-5.

[5] HAKIMI G. Optimum locations of switching centres and the absolute centers and medians of a graph[J]. Operations Research, 1964,12:450-459.

[6] TOREGAS C, SWAIN R, REVELLE C, et al. The location of emergency service facilities[J]. Operational Research, 1971,19(6):1363-1375.

[7] CHURCH R L, REVELLE C. The maximal covering location problem[J]. Regional Science Association, 1974,32(1): 101-118.

[8] CURRENT J R, REVELLE C S, COHON J L. The

maximum covering/shortest path problem: A multiobjective network design and routing formulation [J]. European Journal of Operational Research, 1985,21(2):189-199.

[9] BAPNA R, THAKUR L S, NAIR S K. Infrastructure development for conversion to environmentally friendly fuel[J]. European Journal Operation Research,2002,142: 480-496.

[10] GOODCHILD M F, NORONHA V T. Location-allocation and impulsive shopping the case of gasoline retailing[J]. Spatial Analysis and Location-Allocation Models, 1987:121-136.

[11] HODGSON M J. A flow-capturing location-allocation model[J]. Geographical Analysis,1990,22(3): 270-279.

[12] HODGSON M J, ROSING K E. A network location-allocation model trading off flow capturing and p-median objectives[J]. Annals of Operations Research, 1992,40(2):247-260.

[13] KUBY M J, LIM S. The flow-refueling location problem for alternative-fuel vehicles[J]. Socio-Economic Planning Sciences, 2005,39(2):125-145.

[14] KOU L F, LIU B F, ZHOU H. Regional electric vehicle charging station planning model and algorithm [J]. Modern Electric, 2010,27(4):44-48.

[15] ZHOU H C, LI H F. Electric vehicle charging station location optimization model research based on game theory[J]. Science Technology and Industry, 2011,11(2): 51-54.

[16] REN Y L, SHI L F, ZHANG Q, et al. The optimal distribution and scale of electric vehicle charging stations research[J]. Elecric System Automatic, 2011, 35(14): 53-57.

[17] MORROW K, KARNER D, FRANCFORT J. Plug-in hybrid electric vehicle charging infrastructure review[R]. Idaho Falls, Idaho National Laboratory, Office of Energy Efficiency and Renewable Energy, U. S. Department of Energy, 2008.

[18] WANG H S, HUANG Q, ZHANG C H, et al. A novel approach for the layout of electric vehicle charging station[C]// International Conference on Apperceiving Computing and Intelligence Analysis (ICACIA). [S. l.]:[s. n.], 2010:64-67.

[19] NG R, HAN J. Efficient and effective clustering methods for spatial data mining[C]// Proceedings of the 20th VLDB Conference. Chile, Santiago:[s. n.], 1994:144-155.

[20] ESTER M, KRIEGEL H P, XU X. A database interface for clustering in large spatial database[C]// Proceedings of 1st International Conference on Knowledge Discovery and Data Mining (KDD-95). Montreal, Canada:[s. n.], 1995:94-99.

[21] ESTER M. A density-based algorithm for discovering clusters in large spatial database with noise[C]// Proceedings of 2nd International Conference on Knowledge Discovery and Data Mining (KDD-96). Portland, USA:[s. n.], 1996: 226-231.

[22] SUN J G, GE P Q, LIU Z C, et al. Two-grade fuzzy synthetic decision-making system with use of an analytic hierarchy process for performance evaluation of grinding fluids[J]. Tribology International, 2001,34 (10):683-688.

[23] SAATY A L. Modeling unstructured decision problems the theory analytical hierarchies[J]. Math Compute simulation,1978,20(2):147-158.

[24] SATTLY T L. The analytic hierarchy process[M]. New York: McGraw Hill, 1996.

Ms. **Wang Meng** received her M. S. degree in Material Engineering from Huazhong University of Science and Technology, Wuhan, China, in 2003. She is currently a Ph. D. candidate working in School of Traffic and Transportation, Beijing Jiaotong University. Her current research interests include location and planning of electric vehicle charging station, planning method and theory of modern logistics.

Prof. **Liu Kai** is a professor and Ph. D. supervisor in School of Traffic and Transportation, Beijing Jiaotong University, Beijing, China. His research interests include transportation planning and management, modern logistics and supply chain management.

(Executive Editor: Zhang Tong)