Analysis on the Distribution of Automobile Charging Station

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Abstract. Electric vehicles are a new energy transportation vehicle in the future and are receiving more and more attention from all walks of life. Its development has become the key to the sustainable development of the automotive industry. Charging stations that provide services such as energy supply and maintenance for the operation of electric vehicles are an important supporting infrastructure necessary for the development of electric vehicles. It is of great significance to promote and promote the construction of electric vehicles and other supporting service facilities. On the basis of summarizing relevant research results at home and abroad, this paper takes the electric vehicle charging station as the research object, and establishes the charging station optimization planning distribution model and the optimal quantity and optimal allocation model. Taking the US Tesla automobile as the research object, studying the quantity, layout and growth planning of electric vehicle charging stations provides a rich theoretical basis for studying the diversification of electric vehicles.

1. Introduction

1.1. Background
At present, motor vehicle exhaust emissions have become one of the important sources of pollution affecting urban air quality, especially in large cities with high population and traffic concentration, which seriously restricts the sustainable development of cities. Therefore, controlling vehicle exhaust emissions and improving the atmospheric environment have become an unavoidable problem for large cities in China to ensure people's healthy lives and achieve sustainable development. With the future development of the automotive industry, electric vehicles are increasingly recognized by people. In this regard, the United States not only uses electric vehicles as a future vehicle promotion direction, but also has established a large number of electric vehicle charging stations worldwide, including destination charging and boosting modes, and more charging modes.

1.2. Major aspects of research

1.2.1. Analyze the current Tesla charging station network in the United States. Tesla currently offers two types of charging stations: (1) destination charging, designed to charge once or even overnight; (2) boost designed for longer road trips in just 30 minutes of charging time. We need to consider that if everyone turns to an all-electric personal passenger car in the United States, the number of charging stations is needed, as well as the distribution problem between urban, suburban and rural areas.
1.2.2. **Taking South Korea as an Example.** If our country can immediately move all individual passenger vehicles to an all-electric vehicle (without transition time), determining the optimal number, location and distribution of charging stations becomes a critical issue. It is also important to study the key factors that influence the development of the program. According to our growth plan, we need to consider how long it takes to have 10% of electric vehicles, 30% of electric vehicles, 50% of electric vehicles or 100% of electric vehicles on the roads of selected countries. Based on the calculated data, the timetable for the full development of electric vehicles in the country is derived.

2. **Assumptions**
   1. To simplify the problem, we have the following basic assumptions, which are properly justified.
   2. The corresponding supporting facilities of electric vehicles, such as charging and discharging substations, have been relatively perfect to meet the needs of the industrialization of electric vehicles.
   3. Each EV charging station is the same size.
   4. The driving performance of electric vehicles can also meet the requirements of consumers.
   5. The government subsidies for new energy vehicles. And preferential policies continue to be maintained, and the power system firmly supports the development of the electric vehicle industry.
   6. The new electric vehicle, after all, the high price, and there are traditional vehicles such as transport as a substitute, therefore, some consumers purchase decision free from other consumers.
   7. All EV charging ports can be docked with charging columns built around them.

3. **Variable Descriptions**

| L(X) | Membership degree corresponding to the value of X. | μ | The constant value corresponding to item i |
|------|--------------------------------------------------|---|----------------------------------------|
| C_l  | The characteristics of the comparison.            |   | Coefficient of association between item J and standard I |
| m    | Market maximum submersible.                       | C'_j | The annual average construction cost of the charging station. |
| p    | Innovation coefficient (external influence coefficient). | C'_j | Annual average operating cost of charging station. |
| q    | Imitating coefficient (internal influence coefficient). |   | Cumulative purchases at T time |
| r    | Electricity consumption per kilometer.            |   | The value of the I item of the j scheme |
| D    | Maximum mileage of electric vehicle.              |   | The optimal selection of the location of the charging station |

4. **Tesla charging station network in USA**

4.1. **Charging Station Optimal Planning Distribution Model**

Electric vehicle charging demand distribution. Firstly, the daily starting power consumption of electric vehicles is simulated by the daily residual power density function of electric vehicles. Then the Markov chain is used to simulate the state of electric vehicles at different moments to get the location of the electric vehicles at each moment and the destination at the next moment. Finally, based on the road network information, the shortest path method is used to simulate the running trajectory of electric vehicles on the road and the distribution of charging demand on the road is estimated.

The daily mileage of private cars satisfies the logarithmic normal distribution with the probability density Function is
\[ \Gamma_D(X) = \frac{1}{X \sigma_D \sqrt{2\pi}} e^{-\frac{(\ln x - \mu)^2}{2\sigma_D^2}} \] (1)

For a given type of vehicle, in the case of full charge, the maximum mileage \( D \) is fixed, get the remaining capacity of electric vehicles \( Q \) is:

\[ Q = r(D - X) \] (2)

4.2. Establishment of Optimal Quantity and Optimal Distribution Model

The distribution of charge demand in the previous section based on the space, according to the electric vehicle charging station to find the nearest user habits, Dijkstra method is first used to get each short charging demand points along a path of the road network toll station in each moment, in each of the charging demand point to obtain the latest charging station and the remaining power is reached after the toll station, each charging station power can be accurately calculated in every moment. From the planning point of view of the constraints of charging stations for electric vehicles, when the residual capacity in charging demand is not enough to get to the nearest car charging stations along the shortest path, which indicates that the charging demand is not reachable, should be reasonably distributed in the road network has enough charging station accessibility needs to reduce the charge. In addition, when the charging demand of charging station is greater than that of charging station, the demand of charging will not be met in time. In order to maintain a good user charging experience, the requirement that does not meet the charging requirement can not be higher than the ideal value. Based on the above idea, the purpose of this paragraph is to minimize the annual total cost of the charging station and to optimize the address of the charging station from the candidate site.

The objective function

\[ \min_{\text{cost}} F = \sum_i (C_i^e + C_i^f) \] (3)

Where, \( C_i^e \) is the average construction cost of the charging station; \( C_i^f \) is the average annual operating cost.

Average annual construction cost of charging station.

\[ C_i^e = \frac{r_0(1 + r_0)^m}{(1 + r_0)^m - 1} \left[ A_i^e(S)C_i^L + Z_i^C(S)C^C \right] \] (4)

Where \( i \in I \) is the candidate charging station index, \( I \) is the charging station candidate site set, \( r_0 \) is the investment recovery rate, \( m \) is the operating target lifetime, and \( A_i^e(S) \) and \( C_i^L \) are respectively the charging station area and its unit price \( S = \{0, 1, 2, ..., NS\} \). When \( S_i = 0 \), it means charging station \( i \) is not built. Otherwise, charging station \( i \) is built. Capacity for the capacity of \( S_i \) for the corresponding capacity level; \( N^S \) for the charging station can choose to invest in building capacity levels, different capacity levels of charging stations using different land areas.

Average annual operating cost of charging station.

\[ C_i^f = \sum_{h} \sum_{j-i} (P_i^h - P_i^j) d_i^{hj} V_i^{hj} + C_i^{HR} + C_i^{m}(S) \] (5)

Wherein, \( V_i^{th} \) is the total charge capacity at charging station \( i \) at time \( t \), where \( h \) is the typical date type index; \( d_i^{hj} \) is the number of days represented by typical day \( h \); \( P_i^h \) and \( P_i^j \) are the purchased power at
time \( t \) Price and charging price; \( C^I_{l} \) is the labor cost; \( C^m(S_i) \) is the maintenance cost of the charging station, which is a function of \( S_i \). The maintenance costs of charging stations with different capacity levels are different.

The total amount of charging at charging station \( i \) at time \( t \) is

\[
V^t_i = \sum_{n \in N^t_i} (W_E - Q_n + \frac{Y_{in}}{R_E} W_E)
\]  

(6)

Where \( N^t_i \) is the set of charging demand points at charging station \( i \) at time \( t \) in a day and is obtained from (7); \( R_E \) is the maximum driving range of electric vehicle; \( W_E \) is the rated capacity of electric vehicle; \( Q_n \) is the charging demand point \( n \), \( Q_n \in B^t \), where \( B^t \) is the set of remaining electric vehicles at time \( t \), which is obtained from the process of electric vehicle charging simulation. \( Y_{ni} \) is the shortest distance from charging demand point \( n \) to charging station \( i \), which is obtained by Dijkstra's method. When charging station \( i \) is not built, \( Y_{ni} = \infty \). The unreachable charging demand is excluded from the charging demand of the charging station, and the set of charging demand points satisfied at the charging station \( i \) at a time \( t \) in a day

\[
N^t_i = \left\{ n \left| \frac{Y_{in}}{R_E} W_E \leq Q_n, n \in N^t_i \right. \right\}
\]  

(7)

The electric vehicle that needs to be charged will be charged to the nearest charging station, and the set of charging demand points to be met at charging station \( i \) at time \( t \) is \( N^t_i \)

\[
\bar{N}^t_i = \left\{ n \left| Y_{in} = \min(Y_{in}), n \in G^t, j \in I \right. \right\}
\]  

(8)

In the formula, \( G^t \) is the set of demand points of the total EV charging in the city at time \( t \), which is obtained according to the simulation process of EV charging.

5. Taking South Korea as an Example

5.1. Determination of Evaluation Index System for Site Selection of Charging Stations

Charging station site selection decision evaluation index system should take into account the benefits and customer convenience. Considering the factors such as construction cost, traffic factor, charging method and charging station capacity of charging station, five indicators of charging station construction cost, design scale, traffic flow, service radius and maintenance cost are selected to determine the charging of EV Site selection decision evaluation index system.

(1) Construction costs. Construction costs refer to the total infrastructure costs, distribution facilities costs, natural factors and land costs of investment and construction of charging stations, as well as operating costs such as personnel training.

(2) Design scale. Design scale in accordance with the capacity of the charging station to determine, generally through the number of charging pile to reflect.

(3) Traffic flow. Traffic flow refers to the number of traffic entities passing through a certain point, section or lane of a road within a certain period of time, and its size can determine the traffic flow status.

(4) Service radius. Reference to "Urban Road Traffic Planning and Design Code" in the city gas station service radius of the relevant provisions, taking into account the characteristics of the operation of electric vehicles, service radius should be combined with the region within the electric vehicle ownership, average daily mileage and driving range Factors to be determined.
5. Maintenance costs. The maintenance cost refers to the maintenance cost of charging stations for electric vehicles consumed each year to protect the normal operation of the charging stations, the loss cost during the charging process, the annual loss expense and the charging cost of the grid.

In order to eliminate the influence of subjective factors, this paper uses AHP to calculate the weight value of five evaluation indexes of EV charging station location selection in Table 1, and the weights represent the status and function of different indexes in the site selection of charging station.

| Index | construction cost | design scale | traffic flow | service radius | maintenance cost |
|-------|-------------------|--------------|-------------|----------------|-----------------|
| Weight | 0.20              | 0.20         | 0.30        | 0.15           | 0.15            |

5.2. Charging Station Location Decision Model

According to the fuzzy incompatibility problem of charging station location decision, the location decision-making model of EV charging station is established and solved by fuzzy matter-element analysis theory.

The application of fuzzy matter-element analysis theory to the charging station site planning into compatibility issues, in order to achieve the optimal location of the electric vehicle charging station. Through the calculation and analysis of the examples, the optimal scheme of electric vehicle charging station location is obtained.

Fuzzy matter-element matrix construction things, features, fuzzy amount of fuzzy matter element analysis theory is used to describe the basic elements of things, can be expressed as:

$$R = \begin{bmatrix} M \\ C \\ L(X) \end{bmatrix}$$  \hspace{1cm} (9)

The establishment of j comparison of the i-dimensional compound fuzzy matter matrix, expressed as:

$$R_{ij} = \begin{bmatrix} M_1 & M_2 & \ldots & M_j \\ C_1 & L(X_{i1}) & L(X_{i2}) & \ldots & L(X_{ij}) \\ C_2 & L(X_{i1}) & L(X_{i2}) & \ldots & L(X_{ij}) \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ C_j & L(X_{i1}) & L(X_{i2}) & \ldots & L(X_{ij}) \end{bmatrix}$$  \hspace{1cm} (10)

Membership degree matrix transformation.

The introduction of the principle of subordination to achieve membership matrix transformation, including the following two modes.

Mode I:
1. The bigger the better. The transformation formula is:

$$L_{ij} = \frac{X_{ij}}{\max X_{ij}}, \quad j = 1,2,\ldots,m; \quad i = 1,2,\ldots,n$$  \hspace{1cm} (11)

2. The smaller the better. The transformation formula is:

$$L_{ij} = \frac{\min X_{ij}}{X_{ij}}, \quad j = 1,2,\ldots,m; \quad i = 1,2,\ldots,n$$  \hspace{1cm} (12)
3. The closer to a constant, the better. The transformation formula is:

\[ L_{ji} = \frac{\min(X_{ji}^\mu, \mu_0)}{\max(X_{ji}^\mu, \mu_0)}, \quad j = 1, 2, ..., m; \quad i = 1, 2, ..., n \] (13)

In equations (11) - (13), \( X_{ji} \) is the magnitude of the i-th indicator of item j, \( L_{ji} \) is the subordinate membership of the corresponding indicator, and \( u_0 \) is the constant corresponding to the i-th indicator.

Mode II:
1. The bigger the better. The transformation formula is:

\[ L_{ji} = \frac{X_{ji} - \min X_{ji}}{\max X_{ji} - \min X_{ji}}, \quad j = 1, 2, ..., m; \quad i = 1, 2, ..., n \] (14)

2. The smaller the better. The transformation formula is:

\[ L_{ji} = \frac{\max X_{ji} - X_{ji}}{\max X_{ji} - \min X_{ji}}, \quad j = 1, 2, ..., m; \quad i = 1, 2, ..., n \] (15)

3. The closer to a constant, the better. The transformation formula is:

\[ L_{ji} = \frac{\min(X_{ji}^\mu, \mu_0)}{\max(X_{ji}^\mu, \mu_0)}, \quad j = 1, 2, ..., m; \quad i = 1, 2, ..., n \] (16)

According to the implication of evaluation index of EV charging site selection, the three indicators of design size (C2), traffic flow (C3) and service radius (C4) are bigger and better, construction cost (C1) and maintenance cost (C5) The two indicators are smaller and more excellent type.

Solving the Correlation Function \( N(x) \) with x as the middle element is equivalent to the membership function \( L(x) \).

\[ N_{ji} = L_{ji}, \quad j = 1, 2, ..., m; \quad i = 1, 2, ..., n \] (17)

Where: \( N_{ji} \) is the correlation coefficient between the j-th program and the i-th index between the standard programs. As mentioned above, there are n correlation coefficients (n = 5) for each site selection scheme in the charging station site selection decision matrix. The degree of concentration of the n correlation coefficients of a charging station alternative is expressed by the degree of association \( K_i \); the weight of each evaluation indicator of each charging station alternative is denoted by \( R_W \); the compound fuzzy matter elements of each scheme are denoted by \( R_K \), then have:

\[ R_K = R_W \cdot R_N \] (18)

In this paper, we use M (#, +) operation, all the weights are involved in the operation, and the degree of relevance includes the interaction of all factors, that is
Correlation degree processing

The fuzzy matter-element analysis of charging station location decision-making needs comparative analysis of the obtained correlation degree to find the optimal solution, and the maximum correlation degree principle is used to find the maximum value from the correlation degree of each solution, that is:

\[ K^* = \max(K_1, K_2, \ldots, K_m) \]  

Among them: \( K^* \) corresponding to the site selection scheme is the optimal choice of charging station location.

Based on the location decision model given by the fourth module and the optimal programming model, the optimal location and distribution of the EV charging station can be obtained.

5.3. Electric Vehicle Comprehensive Development Schedule Based on Bass Model

The following mainly for market-oriented electric vehicles, research based on the Bass model to keep the amount of forecasting methods.

The Bass model is based on the assumption that there are no repeat buyers when considering the level of product design. Only the first purchase is considered, taking the purchase per customer as the base unit. According to the assumption that the number of product buyers can directly reflect the sales of goods. The Bass model argues that the decision of some customers whether to adopt a new product or not is irrelevant to other individuals in the social relationship. Although these customers and other members are objectively interacting with each other, the purchasing pressure on the new product will not be impacted As a result, there is a positive correlation between the purchasing pressure and other customers who choose to buy new products because of the influence of other members. According to this analysis, the customer does not buy a new product at a certain moment, and the probability of choosing to purchase at this moment is a linear function of the current number of buyers. Mathematical formula that the model is as follows:

\[ F_T = F_{T-1} + p(m - F_{T-1}) + q \frac{F_{T-1}}{m}(m - F_{T-1}) \]  

\( F_T \) is the cumulative purchase amount at time \( T \), \( F_{T-1} \) is the cumulative purchase amount at time \( T - 1 \); \( m \) is the market's maximum potential; \( p \) is the innovation coefficient (external influence coefficient), \( Q \) is the mimic coefficient (coefficient of internal influence), which reflects the number of users who choose to buy a new product due to network effects and other people's purchasing decisions.

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