Quantitative calculation and optimization of demand for electric vehicle charging stations

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Abstract. The rapid development of electric vehicles (EVs) requires a reasonable plan in building charging stations. The number of charging stations should meet the charge demand of all users at least. Firstly, based on the statistics of CAAM, the bass diffusion model and the logistic regression forecast are used to obtain the EVs ownership in China in 2020. Secondly, based on the analysis of user trip data (NHTS), the expectation of the average daily mileage of electric vehicles is obtained, and is calculated as the daily average mileage with high reliability. Finally, analogous to the construction of gas stations and taking into account the user’s travel habits to classify users, taking the charging stations of the State Grid and the BYD E6 model as an example, the number of charging stations that China needs to build in 2020 is calculated in detail. The calculation method is scientific and can provide a scientific theoretical basis for construction.

1. Introduction

The popularization of fuel vehicles has aggravated the shortage of petroleum resources and brought about environmental problems. The large-scale promotion of electric vehicles has become an inevitable trend[1].

Reasonable construction of electric vehicle charging stations is a prerequisite for the promotion of electric vehicles. At present, the construction of electric vehicle charging stations is carried out in an orderly manner, but the lack of reasonable and well-founded quantitative calculations is likely to cause waste of resources. How to quantitatively calculate the number of charging stations has gradually become the focus of scholars.

The literature [2]clarifies the factors that affect the demand and layout of electric vehicle charging stations. The literature [3]has studied the best area for installing charging stations through AHP. The literature [4]has conducted in-depth calculations on the daily charging power requirements of electric vehicles. The literature [5]calculated the distribution ratio of the decentralized charging equipment for electric vehicles based on SOC.

The above documents are less concerned with the quantitative calculation of the ratio of charging stations for electric vehicles. This article aims at satisfying the charging demand of light electric vehicles from the perspective of probability and statistics, and considering the classification of users, uses the analogy to the idea of gas station construction to calculate charging stations by analyzing the demand for total electricity consumption. The demand can provide a scientific theoretical basis for the construction of electric vehicle charging stations.
2. Forecast of electric vehicle ownership

2.1. Two calculation methods for predicting the ownership of electric vehicles

In order to obtain the total electricity demand on a daily basis, the inventory of electric vehicles needs to be calculated. However, there is less research on the prediction of electric vehicle ownership.

The methods for predicting the quantity of fuel vehicles are extrapolation, causality, and multiple linear regression analysis. In this article uses multiple regression prediction and Bass model to predict the EV ownership.

2.2. Multiple regression prediction of EV ownership

The amount of electric vehicle ownership is affected by many factors, such as economic level (GDP), urban population (P), city size (S), and Gini coefficient (GN). Based on the existing historical data, multiple linear regression methods are used to predict the amount of electric vehicle ownership in a future period. The main idea of multiple linear regression is to treat the dependent variable as a linear combination of multiple independent variables. Its mathematical expression is

\[ C_i = \alpha k_i = \delta(a_i \cdot GDP + b_i \cdot P + c_i \cdot S) + d_i \cdot GN \] (1)

When considering more practical factors, the more conventional multiple regression expression is

\[ y_i = \beta_0 + \beta_1 x_{i1} + \beta_2 x_{i2} \cdots + \beta_k x_{ik} + u \] (2)

For the prediction of electric vehicle ownership, \( y_i \) in formula (1) represents sales data of electric vehicles over the years, \( x_{ij} \) represents GDP, city size, urban population, etc., and can be obtained from historical data. The solution of matrix \( \beta \) is

\[
\begin{bmatrix}
\beta_0 \\
\beta_1 \\
\beta_2 \\
\vdots \\
\beta_k
\end{bmatrix} = \begin{bmatrix}
1 & x_{11} & x_{12} & \cdots & x_{1k} \\
1 & x_{21} & x_{22} & \cdots & x_{2k} \\
1 & x_{31} & x_{32} & \cdots & x_{3k} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
1 & x_{r1} & x_{r2} & \cdots & x_{rk}
\end{bmatrix}^{-1} \begin{bmatrix}
E(y_{r1}) \\
E(y_{r2}) \\
E(y_{r3}) \\
\vdots \\
E(y_{rn})
\end{bmatrix}
\] (3)

Furthermore, based on the data of GDP, urban population, city size and other parameters, the electric vehicle ownership can be predicted.

3. Bass model prediction of EV ownership

3.1. Bass model

The Bass model is a nonparametric conditional likelihood model that uses three variables to predict the sales of electric vehicles, namely the maximum market potential \( m \), the innovation coefficient (external influence coefficient) \( p \), and the imitation coefficient (internal influence coefficient) \( q \). The formula for the time-discrete Bass model is

\[ N(t + 1) = p(1 - N(t)) + q \cdot N(t) \cdot [1 - N(t)] \] (4)

The specific meaning of the parameters in the formula can be referred to literature [8].

3.2. Bass model parameter setting
Some consumers are not affected by other consumers when it comes to purchasing decisions on this new type of electric vehicle. Usually this part of the consumer can quickly adapt to the new traffic mode of electric cars.

The innovation coefficient $p$ can reflect the number of consumers of this part of the electric vehicle, $p$ is between 0.00 and 1.00. The closer the value is to 1, the faster the innovator can accept electric vehicles.

There is not enough historical data in China. According to former studies[9], $p = 0.01$ is a reasonable assumption.

The purchase decision of word-of-mouth consumers is mainly influenced by other consumers' satisfaction to electric vehicles. The coefficient of imitation $q$ can reflect the number of consumers of electric cars. The closer $q$ is between 0.00~1.00, the closer the value is to 1, the faster the electric vehicle will spread in the potential user group. Research has shown that $q = 0.3$ is an appropriate value. This article sets the parameters $p$, $q$ as follows

| YEAR | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|------|------|------|------|------|------|------|------|------|------|
| P    | 0.02 | 0.021| 0.022| 0.0228| 0.0236| 0.0244| 0.0249| 0.0254| 0.0258|
| Q    | 0.4  | 0.42 | 0.44 | 0.47  | 0.51  | 0.54  | 0.58  | 0.62  | 0.67  |

Combining formula (5) with historical data, it is possible to predict the amount of EV ownership in the future.

4. Establishment and calculation of EV charging station demand model

4.1. Electric vehicle charging mode
For the choice of energy supply mode, there are two modes including the entire vehicle charging system (including conventional charging and fast charging) and ground charging system. Since private cars account for the largest proportion of travel modes and are of the most research significance, this article examines the entire car charging system and only considers the situation of private cars.

4.2. Classification of electric vehicle users
Because there are obvious differences in the travel behaviour of electric vehicles, in order to make the calculation of demand more in line with the actual situation, this difference needs to be taken into account. According to the law of the electric vehicle's activity, the electric cars in the area can be divided into regular users, regular users, and random users[11].

This kind of classification is significant because users of different categories have obvious differences in the requirements for charging options and charging capacity. When they are specifically executed, accurate statistics of classification can greatly increase the accuracy of calculations.

4.3. Calculation model of electric vehicle charging station
The demand for electric vehicle charging stations is closely related to the total daily demand for electric vehicle charging power. After analysis, the total daily demand for electric vehicle charging power[6] is

$$W = \sum_{i=1}^{3} C_i p_i L_i \quad (5)$$

In the formula: $W$ is the total daily demand for electric vehicle charging power; $i$ is the user classification of three different types of trip laws; $C_i$ is the amount of possession of three types of electric vehicles. $p_i$ is the average hundred kilometers of electric vehicle. $L_i$ is the average daily mileage of electric vehicles.
According to the total daily demand for electric vehicle charging power $W_\Sigma$ and the charging station's daily rated charging capacity $P_{N_j}$, the required number of chargers $N_j$ is deduced, and the total amount of required charging stations $N$ is calculated. The formula is

$$\begin{align*}
N &= \sum_{j=1}^{n} N_j \\
W_\Sigma &\geq \sum_{j=1}^{n} P_{N_j} N_j \\
&j = 1, 2, 3 \ldots, n
\end{align*}$$

(6)

For the quantitative calculation of $N$, three parameters of $C, p, L$ need to be calculated scientifically, among which the amount of $C_i$ has been given in the above prediction method, $p_i$ is given in the parameters of all kinds of electric vehicles, only $L_i$ needs to be calculated scientifically.

4.3.1. Calculation of the average daily mileage $L_i$ of electric vehicles.
We use the single-mileage mileage data from the National Household Travel Survey (NHTS 2009)\cite{10} to calculate the average daily mileage of electric vehicles.

The statistical data is normalized and the daily mileage of the electric vehicle is approximated as a normal distribution by the method of maximum likelihood estimation. The results are shown in the figure below.

![Figure 1. Driving distance during one day](image)

Daily mileage meets the lognormal distribution and its probability density function is

$$f_D(x) = \frac{1}{x \sigma_D \sqrt{2\pi}} \exp \left[ - \frac{(\ln x - \mu_D)^2}{2\sigma_D^2} \right]$$

(7)

Where $\mu_D = 3.20; \sigma_D = 0.88$. Therefore, the average daily mileage of electric vehicles is expected to be 24.5 miles, approximately 39.2 kilometers.

In addition, studies\cite{12} have shown that the average annual mileage of China's light-duty vehicles is $2.691 \times 10^4$km, with an average daily rate of 73.7km. In this paper, a conservative estimate is used, which is an average of 39.2km per day.

5. Analysis of examples

5.1. Prediction of EV’s ownership
In this paper, according to the situation of electric vehicle ownership in 2011\cite{13}, logistic regression models and the diffusion model of bass are used to predict the EV's inventory in 2020. Electric vehicle ownership is shown in Table 2.
Table 2. Historical EV ownership

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 |
|------|------|------|------|------|------|------|------|
| Value | 8368 | 12522 | 17533 | 74763 | 331092 | 517000 | 777000 |

5.1.1. Logistic regression fitting prediction

After the existing data is centralized and normalized, the curve is fitted with a block growth curve. The fitting results are shown in Figure 2.

![Logistic regression curve fitting for EV ownership](image)

Its growth function is:

\[ N = \frac{1}{(a + b \cdot c^t)} \] (8)

In the formula: \( a = 10^{-7} \), \( b = 7.9 \times 10^{-6} \), \( c = 0.13 \).

According to calculations, it is expected that the number of cars in China will reach 7.91 million by 2020.

6. Bass model prediction

According to the existing data in 2011, the bass model prediction results are shown in the figure, and the ordinates are shown in logarithm for comparison.
The prediction of the bass model is not accurate. This is mainly due to the favorable policies in recent years, and the explosive growth of electric vehicles. The parameters are difficult to set in advance. Improvements in this point can be found in the literature [14].

6.1. Charging station demand calculation example

In the above, the predicted value of EV population in 2020 has been calculated, and the average daily mileage of electric vehicles has been calculated based on NHTS data. This article uses the BYD electric vehicle with the largest market share in China as an example to calculate the number of charging stations needed in 2020.

This article assumes that BYD E6 has a large market share in 2020 and can be considered as having full possession. The basic parameters of this vehicle are shown in Table 3.

| EV model | Power consumption per kilo d/(kW·h) | Battery capacity/s/(kW·h) | Charging power p/kW |
|----------|------------------------------------|---------------------------|---------------------|
| BYD E6   | 0.195                              | 58.5                      | 8                   |

The charging station parameters are shown in Table 4.

|                          | Voltage(V) | Current(A) | Power(KW) |
|--------------------------|------------|------------|-----------|
| National grid fast filling pile | 375       | 115        | 43        |
| Tesla fast charging pile | 380        | 220        | 84        |
7. Conclusion

Based on the analysis of historical sales data and user trip law data, this paper presents a method to analyze the modeling and quantitative calculation of charging station requirements:

First, based on the statistics of the China Automobile Association, after centralized and normalized processing, the diffusion model of China's electric vehicles in 2020 was obtained by using the diffusion model and the exponential fitting. The results show that the bass model predicts the annual increase of electric vehicles. There is a large amount of error in the quantity, because the sales volume of the electric vehicle is closely related to the formulation of the national policy, it is difficult to determine the bass model parameters, and using the fitting to predict can achieve better results. Secondly, based on the analysis of users' travel data, the average daily mileage of electric vehicles is expected, and this is calculated as the daily average mileage, which is highly reliable. Finally, taking the BYD electric vehicle, which is currently the best-selling vehicle in China, as an example, it analyzes the total daily electricity demand and calculates the demand for charging stations.

According to the quantitative calculation method in this paper, it can be determined that the approximate number of charging stations should be built to provide reference for scientific and reasonable charging station planning.

In the planning of charging stations, the market share of different electric vehicles should be fully considered, and the travel data of different regions should be thoroughly investigated to make the plans more reasonable and applicable.

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