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Research on the Best Economic Way for Electric Vehicle Users to Choose the Charging Station in the Area

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Abstract. The electric car transforms the electric energy into the kinetic energy of driving the car, which is green and environmentally friendly.The government is actively promoting the development of electric vehicles, and the number of electric vehicles has been developed. This paper puts forward an economic selection method for the electric vehicle users in the region to choose the charging station.By building the information interaction platform between the electric vehicle users and the charging stations, the queuing mathematical model is introduced to calculate the time cost of the electric vehicle arriving at the charging station.Then the cost of mileage is calculated further.Finally, the single target letter is determined to find the charging station to determine the most economical way.

1. Introduction

Limited oil resources have been reduced, and environmental pollution is increasingly serious [1]. Traditional cars are one of the main factors of environmental pollution. **EV** (**Electric vehicle**) has the advantages of high efficiency, energy saving, zero emission and so on, which has been developed rapidly.

Document [2] studies the queuing system of **EV** through queuing theory and calculates the relevant operating indexes of the system. In document [3], the modeling and simulation of queuing system is mainly studied, and the connection of charging time between **EV** and the charging pile in the station can be deeply analyzed, which can effectively guarantee high quality service efficiency. After the innovation of technology in document [4], the charging of electric vehicle will show obvious advantages. Literature [5, 6] applies the queuing theory to the study of site selection and capacity of urban areas. With the aid of the expectation model in statistical mathematics, the point demand model aims at the maximum **EV** quantity of the charging station in the appropriate response time range. The charging behavior of **EV** has great uncertainty. According to document [7] analysis, the charging behavior of **EV** users is based on queuing theory, and the total cost of charging facilities service system investment is minimum, and the charging station facilities and service system is established. Document [8] takes into account the **M/M/C/N** queuing model of users' non weary and stop behavior. The service facilities of the charging place are studied to obtain the dynamic equilibrium equation under the steady state of the system. Document [9] puts forward that considering the related factors of network state structure, **EV** traffic information and the capacity of distribution network, we further optimize the planning strategy of **EV** charging station. In document [10], a simulated annealing algorithm is used to simulate the migration of **EV** charging load on the grid node voltage. In many literatures, queuing theory is applied to the location planning model of **EV**.

In this paper, some evaluation indexes in mathematical models of queuing theory are applied to the selection of charging stations by electric vehicles. **EV** chooses charging stations to choose according to different economic costs. In this paper, the time cost and mileage cost of **EV** charging stations are determined through information from **EV** users and electric vehicle charging stations interaction platform. Finally, the most economical way is obtained by comparing the total cost value.

2. Current development of electric vehicles

In 2013, global **EV** sales were 225 thousand and 500. The global **EV** sales of more than 37000 vehicles in May 2015 increased by 37% compared with 2014. According to the relevant domestic authoritative data, the domestic new energy EV production reached 65 thousand in September 2016. According to the statistics of the China Auto Industry Association, in the first half of 2017, new energy EV produced and sold 346 thousand and 320 thousand vehicles, up 33.5% and 30.2% over the same period. In February 9, 2018, the official charging Committee of China charged a total of 225071 charging piles, including 355038 piles and 580 thousand charging piles. The rapid development of EV has benefited from the support of national policies and the progress of electric vehicle technology. A growing number of electric car users are considering how to minimize the cost of charging. In this paper, the problem of the cost of charging is converted to the problem of choosing the best economic route for the user.

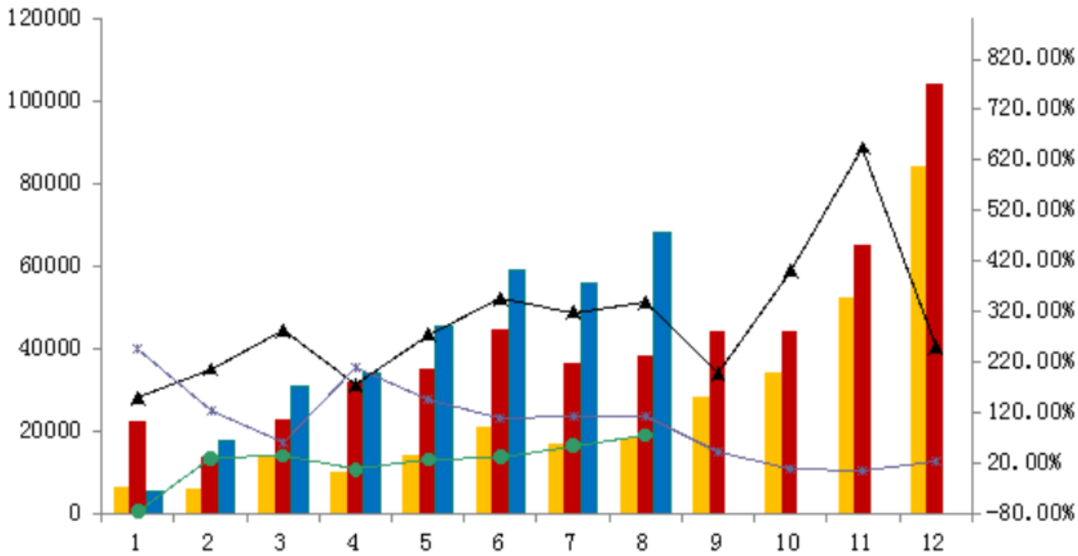

Figure 1. 2015-2017 changes in sales of electric cars per month

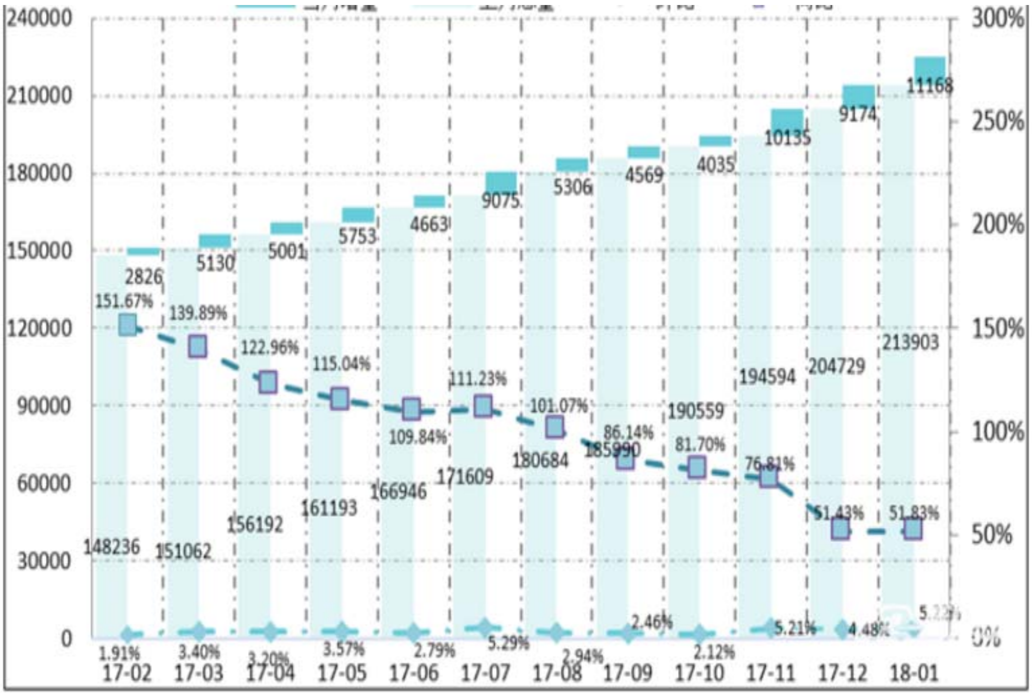

Figure 2. Changes in the number of charging piles per month in 2017

3. Model condition hypothesis and parameter setting

3.1. Condition hypothesis

1) The number of **EV** users entering and leaving are infinite, and the time of **EV** users to the charging station has more obvious random characteristics.

2) The time of the **EV** user to choose the charging station is short enough. The **EV** user has and can only choose one charging station and make an early appointment to arrive on time.

3) The service capacity of the **EV** charging station is limited, all of the electric vehicles that are close to the charging station. When all the charging piles are put into use, the **EV** users can choose to queue and choose to leave.

4) The system capacity of each charging station is $\mathbf{N}_j$, and when the number of vehicles waiting to be charged exceeds the position of the charging pile in the station, the **EV** user needs to wait in line.

5) The mileage $\boldsymbol{i}$ of **EV** is linearly related to the charge state ***Soc*** of **EV**.

3.2. Parameter setting

1) Set a range, the number of $\boldsymbol{N}$ charging stations operating and the number of $\boldsymbol{M}$ vehicles for electric vehicles are limited. The number of charging stations corresponding to the charging station is $\boldsymbol{P_j}$, and the number of system capacity is $\boldsymbol{N_j}$ (j=1, 2 ...N).

2) For the determined charging station, the number of the charging piles are fixed $\boldsymbol{P_j}$, and the efficiency of each charger is the same and the number of charging piles is more than 1.

3) The system capacity of each charging station is greater than the number of **EV** charging piles.

4) The charging state of the electric vehicle is expressed in $\boldsymbol{X_{ij}}$, and the value of 1 means that the $\boldsymbol{i}$ electric vehicle is charged at the j charging station. The value of $\boldsymbol{0}$ means that the electric vehicle $\boldsymbol{i}$ is not charged at the $\boldsymbol{j}$ charging station.

5) According to the information feedback from the ***GPS*** navigation system, it is assumed that the average speed between the last two schedulers is the speed of ***EV*** moving from the current location to the charging station location $\boldsymbol{V_{ij}}$.

4. Electric vehicle users choose the mathematical model of the charging station

4.1. Construction of information interactive platform

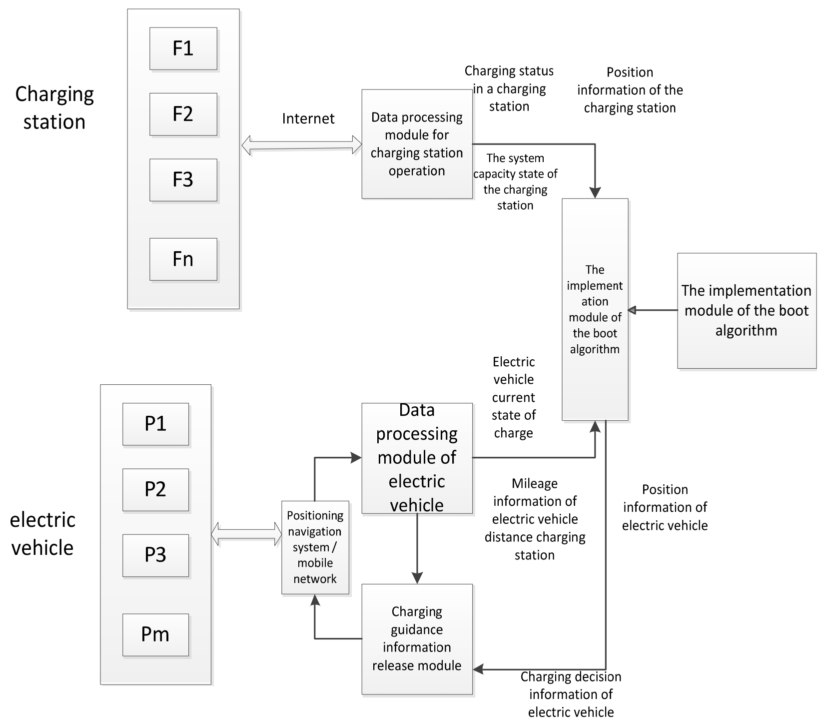

Figure 3. EV user and charging station information platform

(1) State information of recharging station reaction
1) State information of the charging pile in n different charging stations

$$\begin{Bmatrix} F_{1-1} & F_{1-2} & \cdots & F_{1-p_1} \\ F_{2-1} & F_{2-2} & \cdots & F_{2-p_2} \\ F_{3-1} & F_{3-2} & \cdots & F_{3-p_3} \\ \vdots & \vdots & & \\ F_{n-1} & F_{n-2} & \cdots & F_{n-p_n} \end{Bmatrix} \quad (1)$$

The number of the charging stations in the area is n, and the number of charge piles corresponding to each charging station are $\mathbf{P_1, P_2, ... P_j ... P_n}$, and the number is different ($\mathbf{P_j>1}$).
2) The corresponding system capacity state information of the charging station

$$\left(N_1,\ N_2,\ N_3 \cdots N_j \cdots N_n\right)^T \quad (2)$$

3) Position information of the charging station

$$\left(L_1, L_2, L_3, \cdots L_j \cdots L_n\right)^T \quad (3)$$

(2) The state information of the electric vehicle reaction:
1) The state of charge status of the current position of ***M*** electric vehicle

$$\left(S_{oc1}, S_{oc2}, S_{oc3} \cdots S_{oci} \cdots S_{ocm}\right)^T \quad (4)$$

2) The state information of the mileage matrix of $\boldsymbol{i_{EV}}$ users from different stations at different stations $\boldsymbol{j}$

$$\begin{pmatrix} l_{11} & l_{12} & \cdots & l_{1n} \\ l_{21} & l_{22} & \cdots & l_{2n} \\ l_{31} & l_{32} & \cdots & l_{3n} \\ \vdots & \vdots & \ddots & \vdots \\ l_{m1} & l_{m2} & \cdots & l_{mn} \end{pmatrix} \tag{5}$$

Among them: $\mathrm{i} = (1,2,\cdots m)$; $\mathrm{j} = (1,2,\cdots n)$

3) Position status information of electric vehicle

$$(L_1, L_2, L_3, \cdots L_{\mathrm{i}} \cdots L_m)^T \tag{6}$$

The $\boldsymbol{i}$ electric vehicle interacts with the information between the different charging stations.The reservation is made in advance by the target function according to the actual situation, and the charging station takes a certain specific scheme according to the feedback information of the electric vehicle.

4.2. Determining the time cost and mileage cost of the electric vehicle users

Determining the time cost of an electric vehicle user, the time of number $\boldsymbol{i_{EV}}$ user reaches number $\boldsymbol{j}$ charging station

$$\mathrm{t}_{ij} = \delta_j \sum_{i=1}^{m} x_{ij} + \frac{\mathrm{l}_{ij}}{v_i} + t_j^f + t_j^p \tag{7}$$

In the formula: $\boldsymbol{\delta_j}$ is priority coefficient of a charging station; $\boldsymbol{l_{ij}}$ is the mileage of electric vehicles arriving at the charging station; Vi is the average speed between the last **2** scheduling times; $\boldsymbol{t_j^f}$ is queuing time for electric vehicles; $\boldsymbol{t_j^p}$ is The battery power that the electric vehicle consumes at the destination is converted into the charging time.

When calculation queuing time of the number $\boldsymbol{i_{EV}}$ reaches number $\boldsymbol{j}$ charging station, in this paper, the knowledge of $\boldsymbol{M/G/P_j/N_j}$ queuing theory is adopted. ***M*** is **EV** users charging time interval to satisfy the exponential distribution. Suppose that the number of electric cars arriving at a unit time is $\boldsymbol{\lambda}$, the $\boldsymbol{1/\lambda}$ represents the average time interval between the EV user arriving at the charging station; G is the service time of the charging station meets the normal distribution; Assuming that $\boldsymbol{u}$ is the **EV** charging time, **1/u** indicates the average service charge time; the number of charging piles in the charging station corresponds to $\boldsymbol{P_j}$, and the system capacity of the charging station is $\boldsymbol{N_j}$. $\boldsymbol{P_j}$ is number of charging piles in a charging station; $\boldsymbol{N_j}$ is System capacity of a charging station.

The basic principle of queuing theory: Stationary distribution of **EV** queuing system.

$$P_{\mathrm{n}} = P\{N = n\}$$

n=0, 1, 2, ... is the probability distribution of the system to reach the stationary captain ***N***.

The equilibrium equation of the **EV** charging station service system can be obtained

$$\begin{cases} \mathrm{u}_1 p_1 = \lambda_0 p_0 \\ \lambda_{n-1} p_{n-1} + u_{n+1} p_{n+1} = (\lambda_0 + u_n) p_0 \end{cases} \tag{8}$$

In the formula: The number of charging piles is $\boldsymbol{P_j}$. $\boldsymbol{\lambda_n}$ is the rate of arrival for a system with a state of ***n*** to the next ***EV*** arrival time; $\boldsymbol{U_n}$ is The average service rate for a system with a state of ***n*** to the next ***EV*** departure.

$$\lambda_{\mathrm{n}} = \lambda_{\mathrm{j}} = \lambda \tag{9}$$

$$U_n = \begin{cases} nu, n = 0,1,2,\cdots \mathrm{p}_j. \\ pu, n = p_j, p_j + 1,\ldots \end{cases} \tag{10}$$

$$\begin{cases} \mathrm{p}_1 = \dfrac{\lambda_0}{u_1} p_0 \\ p_{n+1} = \dfrac{\lambda_n}{u_{n+1}} p_n = \dfrac{\lambda_n \lambda_{n-1} \cdots \lambda_0}{u_{n+1} u_n \cdots u_1} p_0 \end{cases} \tag{11}$$

ρ is the average amount of ***EV*** that is receiving charging services in the ***EV*** charging station system. $\rho = \frac{\lambda}{\mathrm{u}}$ indicates that the service intensity of the charging station reflects the busy degree of the charging station. ***u*** is the amount of ***EV*** can be completed at a unit time. For the charging service system with P_j charging piles, $\rho_{P_j} = \frac{\rho}{P_j} = \frac{\lambda}{P_j u}$ is the use of charging facilities rate. In ***EV*** waiting for the queuing model, the system achieve balance charging station when requirements to meet the conditions of $\rho_{pj}<1$. P_0 is the probability of an idle state of a service desk:

$$\mathrm{p}_0 = \frac{1}{\sum_{n=0}^{P_{\mathrm{j}}-1} \dfrac{\rho^n}{n!} + \dfrac{\rho_{P_{\mathrm{j}}}(1-\rho_{P_{\mathrm{j}}}^{N_j - P_{\mathrm{j}}+1})}{P_{\mathrm{j}}!(1-\rho_{P_{\mathrm{j}}})}} \tag{12}$$

L_q is the average queue length of the **EV** charging station service system:

$$L_{\mathrm{q}} = \frac{p_0 \rho^{P_j} \rho_{P_j}}{P_j!(1-\rho_{P_j})^2}\left[1-\rho_{P_j}^{N_j-P_j+1} - (1-\rho_{P_j})(N_j - P_j + 1)\rho_{P_j}^{N_j - P_j}\right] \tag{13}$$

Average queuing time:

$$\mathrm{t}_j^f = \frac{L_q}{\lambda_e} \tag{14}$$

Due to the limited space of the charging station system, the effective rate of arrival of electric vehicles λe must be taken into account:

$$\lambda_{\mathrm{e}} = \lambda(1 - p_{N_{\mathrm{j}}}) \tag{15}$$

$$\mathrm{p}_{N_{\mathrm{j}}} = \frac{\lambda^{N_{\mathrm{j}}}}{N_{\mathrm{j}}!\ \mathrm{u}^{N_{\mathrm{j}}}} p_0 \tag{16}$$

When number ***i*** electric vehicle arrive at the N_j charging station from the current position, the consumption of electric energy requires a conversion of the charging time

$$\mathrm{t}_j^p = \frac{l_{ij}}{l_s} * \frac{S_{total}}{P_N} \quad \mathrm{j} \in (1,2,\cdots n) \tag{17}$$

P_N is the rated power of EV charging; l_s is total range of endurance; $S_{\mathbf{total}}$ is the rated power;
Time matrix of number ***i*** vehicle reaches number ***j*** charging station.

$$\begin{pmatrix} t_{11} & t_{12} & \cdots & t_{1n} \\ t_{21} & t_{22} & \cdots & t_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ t_{m1} & t_{m2} & \cdots & t_{mn} \end{pmatrix} \tag{18}$$

$i = (1,2,\cdots m)$; $j = (1,2,\cdots n)$

For the number ***i*** vehicle:

$$t_{ij}^{max} = \max(t_{i1}, t_{i2}, t_{i3}, \cdots t_{in}) \tag{19}$$

$$\alpha_{ij} = \frac{t_{ij}}{t_{ij}^{max}} \tag{20}$$

The greater the corresponding value, the smaller the opportunity for the charging user to choose the charging station.

4.3. Determining the mileage cost of EV users

For the number i vehicle reaches number j charging station,

Selecting the $\boldsymbol{l}_{ij}$ as the basic target for the charging station, the mileage matrix of ***m*n*** is

$$\begin{pmatrix} l_{11} & l_{12} & \cdots & l_{1n} \\ l_{21} & l_{22} & \cdots & l_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ l_{m1} & l_{m2} & \cdots & l_{mn} \end{pmatrix} \tag{21}$$

$$l_{ij}^{max} = \max(l_{i1}, l_{i2}, \cdots l_{in}) \tag{22}$$

$$\beta_{ij} = \frac{l_{ij}}{l_{ij}^{max}} \tag{23}$$

The greater the corresponding value, the smaller the opportunity for the charging station to be chosen.

5. Constraint conditions and objective functions

5.1. Constraint condition

(1)The area to be charged in the area can only be charged by a charging station. $\sum_{j=1}^{n} x_{ij} = 1$.

(2)The maximum distance from the I electric vehicle to the j charging station should be less than the maximum distance that the I vehicle can exercise $l_{ij}^{max} \le l_i^{max}$.

(3) Charging pile of electric vehicle in charging $\boldsymbol{P_j > 1}$.

(4) The system capacity of the charging station is larger than the number of charging piles in the charging station $\boldsymbol{N_j > P}_j$.

(5) The charging service system $\boldsymbol{P_j}$ charging pile, with**ρ**pjsaid the use of charging facilities rate: $\rho_{P_j} = \frac{\rho}{P_j} = \frac{\lambda}{P_j u} < 1$

5.2. Objective function

The I electric vehicle selects the cost objective function of different paths:

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$$F = \min\left(\sum_{j=1}^{n}\left[x_{ij}(\alpha_{ij}+\beta_{ij})\right]\right) \tag{24}$$

$$x_{ij} = \begin{cases} 1, & j = n, \text{Choice}; \\ 0, & j \neq n, \text{No choice}. \end{cases} \tag{25}$$

The I electric vehicle arrives at the cost of the j at different charging stations.For a specific ***i*** electric vehicle to choose the charging station around it, the different time cost and mileage cost will be obtained for the different charging stations ***j***.It is determined that the sum of the time cost and mileage cost of the ***i*** electric vehicle to the ***j*** of different charging stations is the smallest, and the best charging station is selected according to the magnitude of the numerical value.

6. Summary

This paper introduces the mathematical model of queuing theory into the selection of charging stations for electric vehicles, which has practical significance, and can help electric vehicles choose the best charging route.First of all, the information interaction platform of electric vehicle users and electric vehicle charging stations is set up to determine the time cost and mileage cost of electric vehicles arriving at the charging station respectively.Determine the single objective function to find the determined charging station to determine the most economical way.

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