Charging Time and Location Recommendation Strategy Considering Taxi User Satisfaction

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Abstract—**This paper considers the impact of money and time on the charging satisfaction of electric taxi users, considering the taxi passenger revenue and time-of-use price in different time, aiming at the highest user satisfaction of unit electricity, proposes a recommended strategy for the best charging time and charging location. Firstly, the unit time revenue of taxi users is calculated according to the passenger capacity. Secondly, the time cost and power cost are calculated according to the charging queue time, charging time, user time revenue, demand power and time-of-use price. The optimal charging time is calculated according to the minimum unit electricity cost. Then, when choosing the charging station, the driving time, queuing time, charging time and unit time revenue are taken into account to calculate the time cost, and the power demand and charging price are taken into account to calculate the power cost. In addition, the impact of charging time on user satisfaction is considered. Finally, the best charging location is recommended with the highest user satisfaction of unit electricity. The simulation results show that the proposed charging recommendation strategy can reduce the unit electricity cost of electric taxi users, improve the charging satisfaction of users, and verify the effectiveness of the proposed method.**

Keywords-electric vehicle; charging time recommendation; charging location recommendation; user satisfaction

I. INTRODUCTION

Environmental pollution, energy shortage and other problems are becoming more and more serious. As a low-carbon, environmental friendly means of transportation, electric vehicles (EVs) have developed rapidly [1]. Electric taxi has the characteristics of long running time, large power consumption and different revenue in different operating periods. The electric taxi users are faced with the problems of when is the most suitable charging time and which charging station has the best user satisfaction. Therefore, it is necessary to recommend a reasonable charging time and location to reduce the cost of taxi charging and improve the satisfaction of users.

In recent years, EV charging recommendation has been deeply studied at home and abroad. Literature [2] proposes a

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large-scale EV optimal charging path planning strategy based on traffic network and distribution network information to minimize the impact of EV charging on the distribution network and traffic network. Based on the real-time information interaction system, a method of large-scale EV charging path planning is proposed in reference [3], which comprehensively considers the information of traffic network, charging station and distribution network. Literature [4] considers the factors such as the operating income of electric taxi and the queuing of charging stations to select the charging slot for the driver, and chooses the appropriate charging station for the taxi based on the game theory. In reference [5], considering the convenience of the electric taxi to the next destination and the electric private car to the final destination after charging, a charging guidance strategy for the next destination is proposed. In reference [6], considering the path selection and the remaining battery capacity constraints, a charging path planning model for EVs is established to minimize the sum of the weights of total travel distance, total time and charging price. Literature [7] from the EV users, electric power companies, charging station operators, road traffic departments to carry out the research on the optimal charging navigation strategy of EVs, and put forward the multi-objective optimization ordered charging navigation system. In reference [8], based on TOU pricing, considering that the choice of charging path of EV is closely related to the driving behavior of the owner, a charging navigation strategy is proposed aiming at the optimal sum of time cost and economic cost. In reference [9], considering the GPS trajectory of taxis, a charging recommendation strategy with the least total time is proposed. In reference [10], a charging recommendation strategy based on the mobile edge computing framework is designed to improve the communication efficiency and user charging experience in the charging recommendation process. At present, most of the articles on charging recommendation study the best charging station, and rarely combine the hourly income of taxis to study the best charging time.

Considering the time cost, electricity cost and satisfaction of taxi, this paper proposes the best charging time and charging location recommendation strategy. First of all, considering the passenger carrying situation of taxi in different time, get the unit time revenue. Then, considering the factors of unit time revenue, queuing time, charging time and time-of-use (TOU) price, the most suitable charging time is obtained with the goal of minimizing the comprehensive cost of unit electricity. After the optimal charging time, considering driving time, queuing time, charging time and service charge of charging station, as well as the influence of total time on user satisfaction, the charging station is recommended with the maximum user satisfaction per unit electricity.

II. CHARGING RECOMMENDATION SYSTEM FRAMEWORK

The satisfaction of user charging is defined as the difference between the user cost of normal charging and this charging. The larger the value is, the more satisfied it will be. The money and time that taxi drivers need to pay for charging are two major factors that affect user cost and satisfaction, As shown in Fig.1. The money includes the cost of charging electricity and the reduction revenue during the charging period. Time refers to the influence of the total time of charging activities on people's psychology. When choosing the charging time, since there is no specific charging station involved, the charging time is only selected from the cost of unit electricity, regardless of the impact of time on human psychology. When choosing charging location, we should consider the influence of time on people, and recommend charging station with the highest user satisfaction.

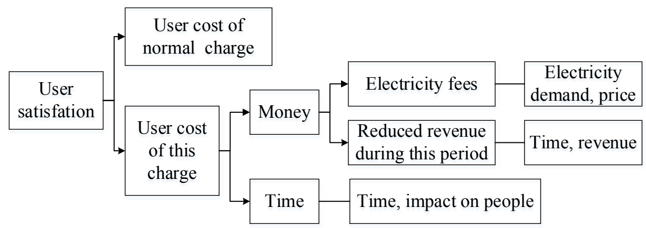

Figure 1. User satisfaction.

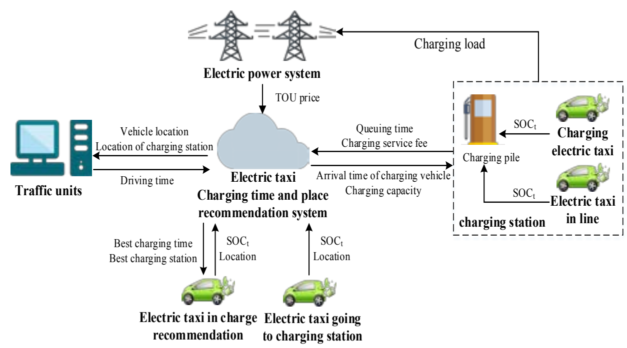

Figure 2. Charging recommendation system framework,

The charging recommendation system framework is shown in Fig.2. The charging recommendation system interacts with EV users, charging stations, power systems, and transportation departments through wireless networks to make optimal charging time and location decisions for users. When the electric taxi vehicle interacts with the charging recommendation system, the system obtains the TOU price, demand power and queuing time of the taxi, considers the time and price cost, and recommends the appropriate charging time for users. In the best charging time, the charging recommendation system obtains the driving time to the charging station through the transportation department according to the location of the taxi. Obtain the charging service charge, the number of cars being charged and queued and the required electricity from the charging station. According to the arrival time of the vehicles going to the charging station and the demand of electricity in the system, the queuing time is calculated. The time cost, electricity cost and user satisfaction are considered comprehensively, so as to recommend a suitable charging station for users.

III. RECOMMENDED CHARGING TIME MODEL OF TAXI

The charging station charges on the basis of TOU price, and the taxi needs to choose the period with low electricity price to reduce the cost. Vehicle charging takes time of queuing and charging, but the passenger income of taxis is different in different time periods. If taxis charge in the time period with large passenger capacity, the income will be reduced. Therefore, in order to reduce the charging cost, it is necessary to select the best charging time by considering the TOU price, charging capacity, consumption time and unit time revenue.

A. Unit Time Revenue of Taxi

The number of passengers carried by the taxi in the hour T is calculated as Z_T, the average driving mileage per time is H, the starting price of the taxi within m km is C_q, and the charge per km above m km is C_d. Then the revenue per unit time of the taxi in the hour T is K_T as shown in (1).

$$K_T = \begin{cases} Z_T C_q & H \le m \\ Z_T (C_q + (H-m)C_d) & H > m \end{cases} \tag{1}$$

B. Charging Capacity and Charging Time

t is the minute of zero crossing, T is the hour, for example, 1:40 is $t = 100$, $T = 1$. The electric power of the EV at time t is SOC_t. Assuming that the EV is charged in the period of T+p, p is taken as 0,1, N_t, then the electric power at that time is $SOC_{charging,T+p}$ as shown in (2), demand power Q_{T+p} as shown in (3), and the time required for the EV to be fully charged is $T_{c\_t,T+p}$ as shown in (4). The queuing time of the charging station in T+p time period is obtained from the historical queuing situation, which is expressed as $T_{q\_t,T+p}$. Since no specific charging station has been selected at the current stage, the driving time T_{d_t} is determined according to the average driving time to the charging station in the past.

$$SOC_{\text{charging},T+p} = SOC_t - \frac{V_{ave}\Delta Th}{C} \tag{2}$$

$$Q_{T+p} = (1 - SOC_{\text{charging},T+p})C \tag{3}$$

$$T_{c\_t,T+p} = \frac{Q_{T+p}}{P} \tag{4}$$

where, V_{ave} is the average speed of electric taxi, ΔT is the time interval between the time of t and the time of T+p, h is the power consumption per unit distance, C is the battery capacity, P is the charging power. N_t is the number of hours before $SOC_{charging,T+p}$ is less than the minimum charging threshold SOC_{min}, as shown in (5). N_t is rounded down. When the power is less than SOC_{min}, the vehicle finds the charging station for charging immediately.

$$N_t = t/60 - T + \frac{(SOC_t - SOC_{\min})C}{V_{ave}h} \tag{5}$$

C. Best Charging Time Selection Strategy

The electric taxi will go to the charging station in T+p hours. Considering that the total charging time may last for the next hour, the time cost $F_{1,T+p}$ of the vehicle due to charging is calculated as shown in (7), and the cost of electricity $F_{2,T+p}$ due to charging is shown in (8). The earlier the vehicle is charged, the less power the vehicle needs, the shorter the charge cost and charging time, and the lower the total cost of each charging. However, the more times it needs to be charged, so charging immediately is not necessarily the best strategy, but the lowest cost per unit electricity is the best. Since no specific charging station is selected, the impact of time on people is not considered. Consider the cost of time and electricity, the best charging time is recommended according to the comprehensive cost of unit electricity, the lowest comprehensive cost of unit electricity is calculated, such as (9), and then the corresponding charging time is recommended to the electric taxi users.

$$T_{all,T+p} = T_{d\_t} + T_{q\_t,T+p} + T_{c\_t,T+p} \tag{6}$$

$$F_{1,T+p} = \sum_{j=1}^{J} K_{T+p+j-1} T_{all,T+p,j} \tag{7}$$

$$F_{2,T+p} = \sum_{j=1}^{J} (S_{T+p+j-1} + S_{CS,ave}) Q_{T+p,j} \tag{8}$$

$$F = \min\left(\frac{F_{1,T+p} + F_{2,T+p}}{Q_{T+p}}\right) \tag{9}$$

where, $T_{all,T+p}$ is the total charging time when charging in T+p, J is the number of hours in which the total charging time is located, K_{T+p} is the unit time revenue in the T+p hour, $T_{all,T+p,j}$ is the charging time in the j-th hour, S_{T+p} is the TOU price in the T+p hour, $S_{CS,ave}$ is the average service charge of all charging stations, $Q_{T+p,j}$ is the charging energy in the j-th hour.

IV. RECOMMENDED MODEL OF TAXI CHARGING LOCATION

A. Driving Time

In this paper, graph theory is used to describe the topological structure of road network $G\{N,L\}$. Where N represents the set of nodes in the road network, L is used to describe the length of each road section and the connection relationship between nodes.

$$L(i,j) = \begin{cases} l_{ij}, & (i,j) \text{ is accessed} \\ 0, & i = j \\ \inf, & (i,j) \text{ is not accessed} \end{cases} \tag{10}$$

$$L = \begin{bmatrix} 0 & l_{12} & \inf & \cdots & \inf \\ l_{21} & 0 & l_{23} & \cdots & \inf \\ \inf & l_{32} & 0 & \cdots & \inf \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ \inf & \inf & \inf & \cdots & 0 \end{bmatrix} \tag{11}$$

where l_{ij} is the length between node i and node j.

The shortest driving distance $L_{min,i}$ from the taxi to the i-th charging station is obtained according to Dijkstra algorithm, and the shortest driving time $T_{d\_d,min,i}$ is shown in (12).

$$T_{d\_d,\min,i} = \frac{L_{\min,i}}{V_{ave}} \tag{12}$$

B. Queuing time

Through data interaction with the charging station, the charging recommendation system can obtain the total number k of vehicles in the charging station and the time set $T_{1,i}\{T_{1,i,1}, T_{1,i,2}, \cdots, T_{1,i,k}\}$ when they leave the charging station. The sets are arranged from small to large. It is assumed that no new vehicle requests the charging recommendation system in the process of taxi driving to the charging station, only the vehicle that has already sent the charging recommendation request is considered. The calculation of the shortest queuing time $T_{q\_d,min,i}$ is shown in Fig. 3, where $T_{qc,i,1}$ is the charging time of the first vehicle queuing at i-th charging station, which is calculated by the taxi driver reporting SOC to the charging station.

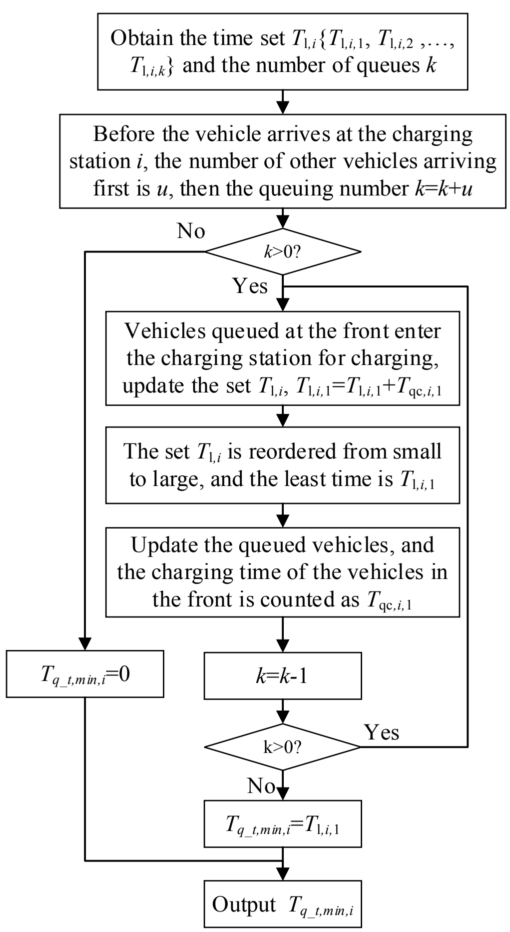

Figure 3. Queuing time.

C. Charging Capacity and Charging Time

The taxi needs to consume extra power when it goes to the charging station i. after arriving at the charging station, it needs to charge $Q_{t,i}$ as (13), and the charging time is $T_{c\_d,i}$ as (14).

$$Q_{t,i} = (1 - SOC_t)C + L_{\min,i}h \tag{13}$$

$$T_{c\_d,i} = \frac{Q_{t,i}}{P} \tag{14}$$

D. Best Charging Location Selection Strategy

First of all, considering the remaining power of electric taxi, the charging station is selected within the range of remaining mileage. Then, considering the driving time, queuing time and charging time, calculate the time cost $Y_{1,i}$ paid by the electric taxi to choose charging station i, as shown in (16). In the market environment, the service charge of each charging station may be different. Considering the different service charges, the electricity cost $Y_{2,i}$ is shown in (17). Considering the psychological impact of time, user cost W_i that affect the user's charging satisfaction are shown in (18), including the total money and total time per unit electricity. The satisfaction of user charging is defined as the difference between the user cost of normal charging and this charging. Finally, recommend the corresponding charging station for the user with the highest satisfaction, such as (19).

$$T_{all,i} = T_{d\_d,\min,i} + T_{q\_d,\min,i} + T_{c\_d,i} \tag{15}$$

$$Y_{1,i} = \sum_{j=1}^{J} K_{T+j-1} T_{all,i,j} \tag{16}$$

$$Y_{2,i} = \sum_{j=1}^{J} (S_{T+j-1} + S_{cs,i}) Q_{t,i,j} \tag{17}$$

$$W_i = \frac{\alpha(Y_{1,i} + Y_{2,i}) + (1-\alpha)T_{all,i}}{Q_{t,i}} \tag{18}$$

$$W = \max(W_{his} - W_i) \tag{19}$$

where, $T_{all,i}$ is the total charging time at i charging station, $T_{all,i,j}$ is the charging time at j-th hour, $Q_{t,i,j}$ is the charging power at j-th hour, $S_{CS,i}$ is the service charge at i charging station. α is the influence weight of money on satisfaction. W_{his} is the user cost per unit electricity during normal charging. The normal charging situation here refers to that the charging time is SOC less than the threshold value, and the charging location is the nearest charging station.

V. Simulation Process of Electric Taxi Charging Recommendation

Taxis find their destination in the road network, and plan the route with the shortest distance. The vehicle consumes electricity during driving. When the power is less than the user's psychological threshold, it starts to interact with the charging time recommendation system to get the best charging time. In the best charging period, the taxi interacts with the charging location recommendation system to get the best charging station. The vehicle goes to the charging station for charging and continues its journey after it is fully charged. The charging station collects the time when the EV is fully charged and the demand of the queuing vehicles, and provides data for the charging recommendation system. The simulation process is shown in Fig.4.

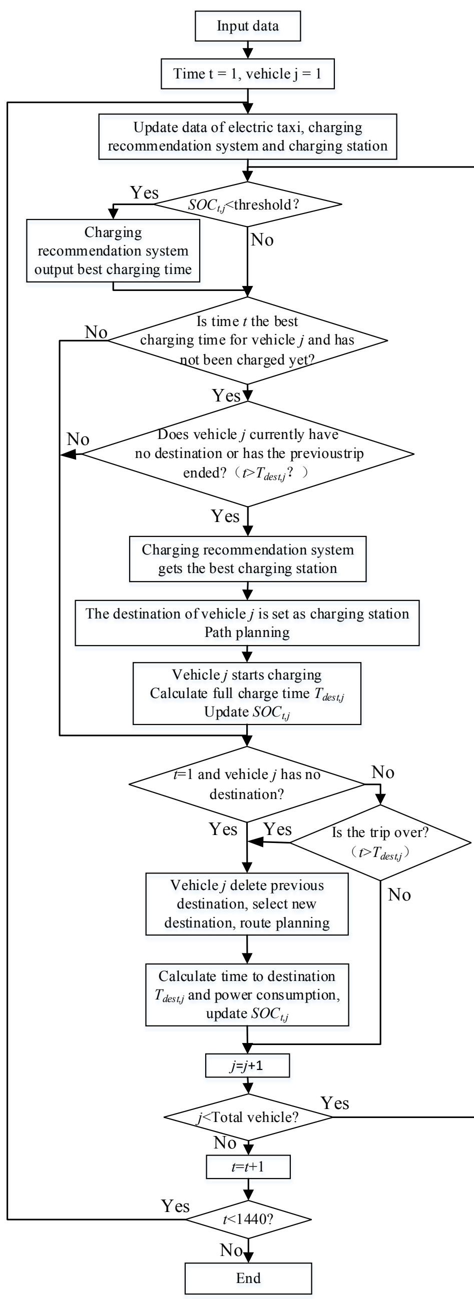

Figure 4. Simulation flow chart

VI. EXAMPLE ANALYSIS

A. Parameter Setting

Taking the Third Ring Road of Beijing as an example, as shown in Fig. 5, the road network covers an area of about 225km^2, including 245 road nodes and 424 roads, with a total length of 355km. Suppose that there are 3000 electric taxis in this area, and the vehicle model is BYD E6. The battery capacity is 60 kWh [11], the average driving speed is 30km/h, and the power consumption is 0.1-0.2 kWh per kilometer. The threshold of SOC of each user is randomly distributed between 0.1-0.3, and the minimum charging threshold SOC_{min} is 0.1. Taxis are open 24 hours a day, and the number of taxi passengers is shown in Fig. 6 [12]. The starting price of taxi in Beijing is 13 yuan, and then 2.3 yuan per kilometer. The average single trip distance of electric taxi is 4.66km[13]. There are 10 charging stations in this area, as shown in Fig. 5. Each charging station has 60 charging piles, the charging power of which is 60kW, the service charge of odd numbered charging station is 0.8 yuan/kWh, the service charge of even numbered charging station is 0.9 yuan/kWh, and the TOU price is shown in Table I. Suppose the influence weight of money on satisfaction is 0.5. The simulation is repeated many times to simulate the vehicle charging situation for several days. The SOC, average driving time and average queuing time at the end of each simulation are the initial quantities of the next simulation. Simulate the charging condition of electric taxi for 1440 minutes every day.

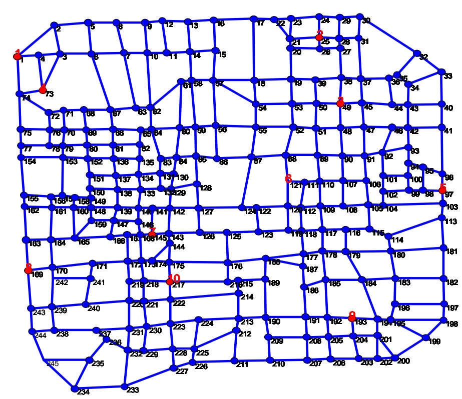

Figure 5. Beijing Third Ring road network.

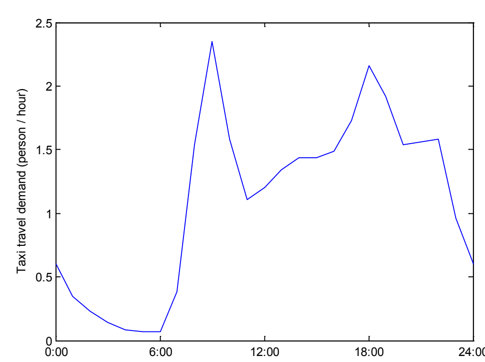

Figure 6. The time distribution of taxi demand.

TABLE I. TIME-OF-USE PRICE

	Price	Time
Peak price	1.0044 yuan/kWh	10:00-15:00,18:00-21:00
Flat price	0.6950 yuan/kWh	7:00-10:00,15:00-18:00,21:00-23:00
Valley price	0.3946yuan/kWh	23:00 of the day- 7:00 of the next day

B. Simulation Result

The charging load time distribution of the charging station is shown in Fig. 7. The charge price in the morning is the valley price, because the capacity of 4:00-6:00 is small and the charge load is high. From 8:00 to 9:00, the taxi has the largest passenger capacity and small charging load, so the load is small. 10:00-15:00, due to the peak electricity price, the charging load is not large. At 15:00, after the electricity price was reduced to flat price, the charging load increased rapidly. From 18:00 to 22:00, due to the large passenger capacity and high electricity price, the load is small. Late at night for valley price, charging load is large.

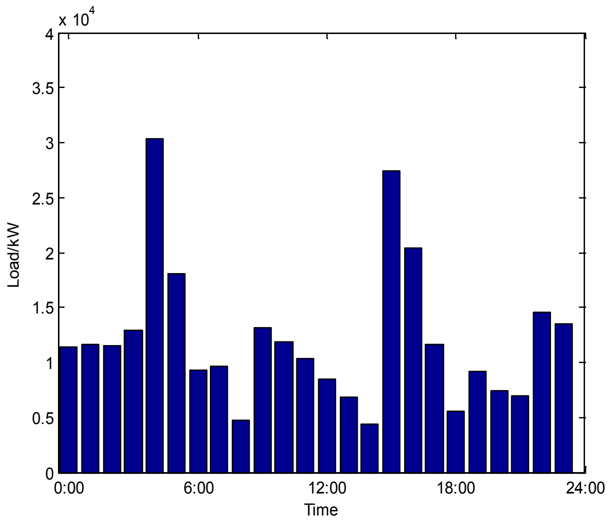

Figure 7. Time distribution of charging load.

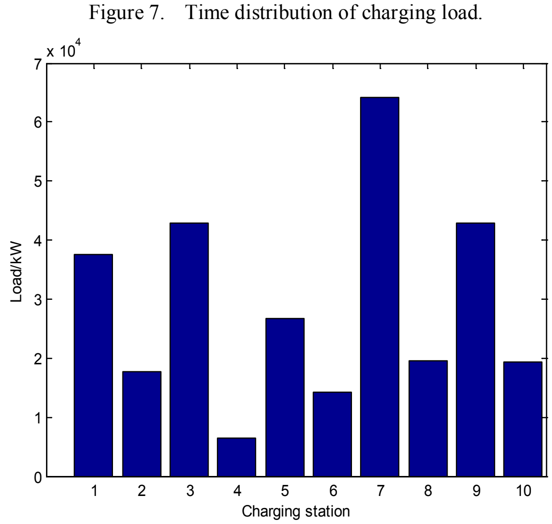

Figure 8. Space distribution of charging load.

The charging load of each charging station in one day is shown in Fig. 8. The service charge of odd number charging station is lower and the charging load is higher; the service charge of even number charging station is higher and the charging load is lower.

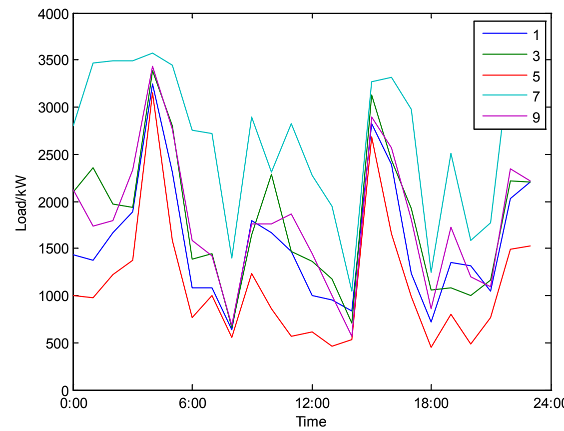

Figure 9. Time distribution of charging station load with service charge of 0.8 yuan

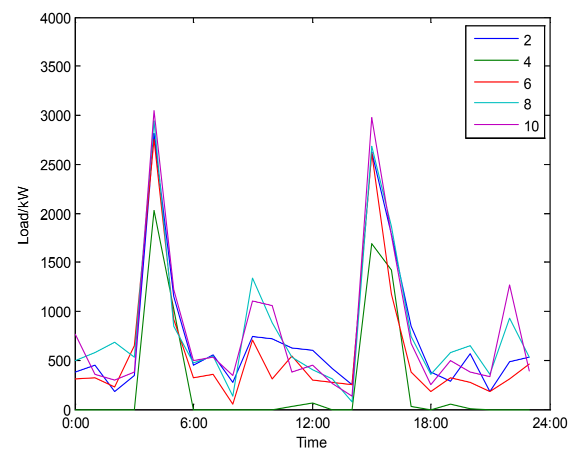

Figure 10. Time distribution of charging station load with service charge of 0.9 yuan

The load time distribution of charging stations with service charge of 0.8 yuan and 0.9 yuan is shown in Fig. 9 and Fig.10 respectively. All charging stations have large load in the early morning and afternoon, while those with high service charge at other times have low load.

Comparing the recommended charging strategy and other charging modes. Two modes are set when choosing charging time. Mode 1: select the charging time according to the charging time recommendation strategy proposed in the article; Mode 2: when the SOC of the vehicle is less than the SOC threshold, immediately recharge. Four modes are set when choosing charging location. Mode 1: the highest satisfaction strategy proposed in the article selects the charging station; Mode 2: select the nearest charging station; Mode 3: select the charging station with the least driving time, queuing time and charging time; Mode 4: select the charging station with the least charging cost. Combined with two modes of choosing charging time and four modes of choosing charging location, eight groups of simulation are done to compare with the charging recommendation strategy proposed in this paper. The cost and satisfaction of each charging of electric taxi are shown in Table II.

TABLE II. COST AND SATISFACTION PER CHARGE

Time	Location	Driving time/min	Queuing time/min	All time /min	Time cost /yuan	Electricity cost/yuan	Total cost /yuan	Comprehensive cost per unit electricity /yuan	Reduced cost/%	Satisfaction of unit electricity
Mode 1: Time and electricity costs	***Mode 1: satisfaction***	5.44	0.30	58.27	15.90	75.67	91.57	1.7825	0	0.11
	Mode 2: distance	4.46	0.75	58.38	16.06	76.88	92.94	1.8060	1.30	0.09
	Mode 3: time	4.88	0.16	57.75	15.46	76.90	92.35	1.7931	0.59	0.11
	Mode 4: electricity	7.11	18.68	81.49	20.65	75.41	96.06	1.8142	1.75	-225.15
Mode 2: SOC < threshold	***Mode 1: satisfaction***	5.00	0.14	53.78	16.79	73.57	90.36	1.8913	5.75	0.01
	Mode 2: distance	4.46	0	53.08	16.67	74.84	91.51	1.9185	7.09	0
	Mode 3: time	4.46	0	53.02	16.65	74.91	91.56	1.9138	6.86	0.01
	Mode 4: electricity	8.41	46.44	102.08	26.58	70.69	97.27	2.0644	13.66	-363.43

When the charging recommendation strategy proposed in this paper is adopted, the comprehensive cost of vehicle charging is the least and the user satisfaction is the highest. When the charging station is selected according to the minimum total time, the satisfaction is also the highest. Although the satisfaction is the same, the cost of the recommendation method proposed in this paper is lower and the relative total time is longer. The user satisfaction of choosing charging station according to charging cost is the lowest, because a large number of taxis are concentrated in several charging stations, which leads to a great increase of queuing time and a decrease of satisfaction. Compared with other charging recommendation strategies, the strategy proposed in this paper can reduce the cost of unit electricity by up to 13.66%, greatly reducing the charging cost of electric taxi, and also improving user satisfaction.

VII. CONCLUSION

In this paper, the time cost and electricity cost of charging are calculated by considering the passenger income and time-of-use price of taxi in each time. At the same time, the influence of charging time on customer satisfaction is considered. The charging time selection strategy is proposed with the lowest comprehensive cost of unit electricity, and the charging location selection strategy is proposed with the highest customer satisfaction. After adopting the proposed charging recommendation strategy, from the simulation of the charging load time-space distribution, it can be seen that the load is concentrated in the time period with less passenger capacity and lower TOU price, and in the space in the charging station with lower service charge. The charging recommendation strategy proposed in this paper reduces the comprehensive cost of electric taxi and improves the satisfaction of users.

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