Abstract: Battery Electric Vehicles (BEVs) have the potential to reduce the emission of air pollution and greenhouse gas. One difficulty in promoting the usage of BEVs is the availability of charging infrastructures. A new recharging method called dynamic wireless charging lanes is promising to solve this problem because it can charge the electric vehicles while driving on the road. This paper first analyzes the features attracting drivers to use charging lanes. Since the charging lane technology is still under experiment, we design a stated preference (SP) survey and distribute to 161 BEV drivers in China. The results show that income and travel distance significantly affect the charging method choice of drivers: with the distance and income increase, people are more likely to use charging lanes. We also compared three classification models to explore the method with the highest prediction accuracy. Second, given the locations of public charging stations and charging lanes, this paper developed a network equilibrium model to describe the effect of charging infrastructures on the route choice of drivers. At last, a numerical analysis is conducted on a simple road network. The results show that the location of charging lanes and charging stations has a significant influence on the route choice of drivers. When the income increases, or the investment of charging lanes decreases, charging lanes can be an economical effective charging method for drivers.
Extended Abstract

Network Equilibrium Model of Electric Vehicles with Stationary and Dynamic Charging Infrastructure on the Road Network

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INTRODUCTION
The availability of charging infrastructure is an important difficulty in promoting battery electric vehicle (BEVs) (1). The types of charging infrastructure for BEVs include stationary charging stations and dynamic charging lanes. Direct current fast charging (DCFC) is the quickest stationary charging method and promises to expand BEVs' useful range, because it can charge the BEVs to 80% state-of-charge (SOC) within 30 minutes (2). An emerging charging method is dynamic charging lanes, which can charge the vehicle while driving.

The objects of this paper are firstly to analyze the attributes that affect BEV drivers’ choices between the two charging methods. Secondly, given the locations of these charging methods, this paper builds a traffic assignment model on the road network to analyze the route choices of the drivers.

To address these research questions, first, this paper designs a stated preference survey and dispatches it to 161 BEV drivers in China. Then, given the location of charging stations and charging lanes, we build a network equilibrium model to assign traffic on the road network, so each driver makes his/her charging plan between origin and destination to minimize the private cost.

Because charging stations and charging lanes have appeared recently, there is relatively little research to analyze the choice behavior of drivers and their impacts on traffic networks. For charging stations, some research has examined optimal deployment plans. The methods include travel-data based approach (3), Flow-Capturing Location Model (4), Flow Refueling Location Model (5), and Clustering Method (6). Since charging lanes are still experimental, the literature is sparser. Lukic and Pantic reviewed the development of Wireless Power Transfer (WPT) technology (7). Jang et al. analyzed the initial investment cost of dynamic charging lanes systems (8). Utah State University first implemented the system to public transportation on their campus (9).

The main findings of this paper include: (a) the cost difference of the two charging methods, income of drivers and the electricity remaining when arriving the destination significantly affect the charging method choice in our survey; as income and remaining energy increase, people would like to choose dynamic charging lanes, but when the charging lane cost is high, people prefer to use charging stations; (b) the position of charging facilities has a significant impact on the traffic assignment and the route choice of BEV drivers.

This paper, to our best knowledge, is the first study to build a traffic equilibrium model to consider both charging lanes and charging stations on the road network. The model could help infrastructure developers with deployment planning of charging lanes and charging stations in the future.

METHODOLOGY
In this paper, we first investigate the features affecting drivers’ charging behavior. A Stated Preference (SP) survey was designed and distributed to 161 BEV drivers in China. The survey included two parts: (a) a questionnaire of socio-demographic information, including BEV ownership, gender, age, education level, monthly income, the year of buying a BEV, days of driving per week; and (b) a travel scenario that includes charging time at charging station, charging costs of charging station and charging lanes, total driving time, SOC remaining upon arrival, and travel purpose. The respondents were asked to choose one charging method.
In our experimental design, we use six designed attributes shown in Table 1. Three designed attributes (travel purpose, travel distance, and SOC left) are directly given to the respondents; the rest of the designed attributes (charging power of DC fast charging station, unit electricity cost of charging station and charging lane) were not given directly. Instead, we computed the total charging time, total cost of charging lanes and charging stations to make the scenario more intuitive. In this paper, we use D-optimal to reduce the total combinations of factor designs from 5400 to 200.

**TABLE 1 Attributes and Their Levels of the Experiments**

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Description</th>
<th>Attributes Levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>Travel Purpose</td>
<td>The travel purpose of a one-way trip</td>
<td>Tourism, Shopping, Appointment</td>
</tr>
<tr>
<td>Travel Distance (km)</td>
<td>The total travel distance of the one-way trip</td>
<td>150 km, 180 km, 210 km, 250 km, 300 km</td>
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<tr>
<td>SOC left</td>
<td>The state-of-charge left when arriving the destination</td>
<td>10%, 25%, 50%, 75%, 100%</td>
</tr>
<tr>
<td>DC Charging Power (kW)</td>
<td>The charging power of DC fast charging stations</td>
<td>50kW, 100kW, 120kW</td>
</tr>
<tr>
<td>DC Charging Price (¥/kWh)</td>
<td>The unit electricity cost of DC fast charging stations</td>
<td>0.9, 1.2, 1.5, 1.8, 2, 2.4</td>
</tr>
<tr>
<td>Charging Lane Price (¥/kWh)</td>
<td>The unit electricity cost of DC charging lanes</td>
<td>2, 2.5, 3, 3.5</td>
</tr>
</tbody>
</table>

The scenario given to the respondents are shown in Figure 1.

**FIGURE 1** Screenshot of the survey tool: charging decision of a one-way trip
With the survey results, this paper uses three classification models to do predictions: mixed logit model, support vector machine and random forest. The mixed logit model has the highest prediction accuracy.

Next, after using the mixed logit model to decide the proportion of drivers to use the two charging methods, this paper builds a traffic assignment model on the road network. We make some assumptions to simplify the question: (a) the energy consumption only depends on the travel distance; (b) the proportion could be predetermined before the traffic assignment. Because the drivers choose the path with minimum cost, which follows the character of user equilibrium, a non-linear complementary problem (NCP) is formulated to solve the traffic assignment problem.

At last, a numerical analysis is conducted on a simple road network. We first determine the demand for using charging lanes and charging stations for each O-D pair by the mixed logit model. Then we solve the NCP to assign the traffic on the road network.

FINDINGS
First, the survey results show that the income of drivers, energy left when arriving, and the cost difference between the two charging methods significantly influence the stated charging behavior of BEV drivers. When the income and remaining energy increase, people are more likely to use charging lanes, and when the cost for charging lanes is expensive, drivers prefer to use the charging station. Moreover, people are more likely to use charging lanes in all scenarios (58%).

Second, the traffic assignment model suggests that on some charging-lane links, the proportion of charging lane flow over charging station flow is very high. Moreover, if the link’s origin or destination is a charging station, the proportion is relatively lower. Therefore, we could conclude that the position of charging facilities has a significant impact on the traffic assignment and the route choice of BEV drivers. In addition, the cost of charging lanes is higher than that of charging stations, but when income increases (the value of time could reflect the income in our model), the costs two charging methods are closer and closer. If the value of time turns to be 112 Yuan per hour the costs are equal. It indicates that although the charging lane technology may
not be an economical charging method at present, it is promising in the future when the technology is fully developed, and the investment is reduced.

CONCLUSION
The results of this paper suggest that dynamic charging lanes, although still under development, are an excellent choice for people with high income going on a long-distance trip. Furthermore, the locations of charging lanes and charging stations has a significant influence on the route choices of drivers. Hence, the government could rebalance the traffic by making a reasonable deployment plan for the charging facilities in the future. When income increases or the investment of charging lanes decreases, charging lanes can be a more economical charging method for drivers.

An issue with the cost analysis process is that the unit cost of charging lanes we use. It is retrieved from the initial investment estimation of Jang, Y et al.’s work (8) and may not be accurate. The value will significantly affect our exact number in the value of time and cost analysis but will not influence the overall trend and our conclusion.

REFERENCES