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WIRELESS ELECTRICAL VEHICLE CHARGING ROADS

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Abstract : With the development of wireless charging technology, charging-while-driving now becomes possible. In this paper we propose a model to optimize the location of the wireless charging lanes (WCL) by taking into account their effects on road capacity and traveler's route choice. The model is formulated as a nonlinear programming problem. A new method is developed to reduce the maximum error in the linearization process. The model and solution method are tested on MATLAB. The numerical results show that relatively high charging power and reasonable budget are necessary to recover the investment when charging lanes are deployed on road network. It is also demonstrated that the impacts of WCL on road capacity drop and travelers' route choice are not negligible, and should be considered in the determination of WCL location.

***Index Terms* – Wireless Charging.**

I. INTRODUCTION

As an environmentally friendly means of transportation, adoption of electric vehicles (EVs) have been prompted by governments through various policies, such as green-car subsidy program, license plate bias, public charging station overlap plan. However, the relative low driving range and frequent long-time charging have hampered wide application of EVs. To overcome these shortcomings, charging-while-driving (CWD) technology is being developed and tested all over the world. For example, the wireless charging lanes (WCL) deployed on a network was tested in South Korea (Bansal, 2015), which means that the CWD would come true in reality and private vehicles can charge electricity like trolleys.

II. LITERATURE REVIEW

To make CWD possible, charging infrastructure should be constructed near the roads. So far, a limited number of studies are conducted to discuss the optimal location of WCL. Riemann et al. (2015) proposed a flow-capturing location model with the consideration of driver's route choice behavior to deploy the wireless charging infrastructure, the routes with WCL are assumed to have an additional utility in their model. Chen et al. (2016) explicitly analyzed the route choice behavior and battery recharging plans to deploy the WCL more reasonably. Fuller (2016) developed a dynamic charging infrastructure location model, and showed that dynamic charging is an economically viable charging method. Chen et al. (2017) investigated the competition between dynamic charging and charging at stations, and concluded that dynamic charging lanes are competitive for attracting drivers under some circumstances. Liu et al. (2017) developed a mixed integer linear program to deploy the optimal locations of wireless charging and design the battery size for an electric bus system with multiple overlapping bus lines. To deal with the uncertainty of energy consumption and travel time of electric bus in the dynamic wireless power transfer location problem, Liu and Song (2017) adopted a robust optimization methodology to provide robust locations. Jang (2018) provided an overview of researches on the operational and systematic issues related to both dynamic and quasi-dynamic types of wireless charging EVs. To minimize the life cycle costs of dynamic wireless power transfer infrastructure, Bi et al. (2019) applied a genetic algorithm to select the road segments and determine the year of deployment of the infrastructures. With the development of wireless power transfer technology, Abdolmaleki et al. (2019) introduced a new concept of vehicle-to-vehicle wireless power transfer between EVs. Charging station (especially fast charging station) has become a potential charging mode for EVs and attracted researchers to propose various charging station location models. Some studies used a wide variety of data to estimate the charging demand, e.g., the vehicle's trajectory data, especially the taxi or the bus fleet's GPS data (Tu et al., 2016, Yang et al., 2017, Xu et al., 2017, Xylia et al., 2017), the questionnaire data (Yang et al., 2016), the national average data (Huang and Zhou, 2015), the municipal statistical yearbooks and the national census data (He et al., 2016), etc. Other researchers used origin–destination (OD) travel demand as the basic charging demand and proposed mathematical models to study the impacts of some factors on optimal locations and equilibrium flow pattern, e.g., the trip chain paths' influences on optimal locations (He et al., 2015), and the influences of distance constraints on equilibrium network flow (Wang et al., 2016b).

III. ORGANIZATION OF THE PAPER

The above location models can deploy WCL and/or charging station to some extent, but they seldom consider the WCL's adverse effects on traffic. The charging vehicles on WCL would move slowly, which undoubtedly reduces the road capacity. When a road has only one lane in each direction, the wireless charging facilities have to be located on the lane, which results in all the vehicles behind a charging vehicle being delayed. When a road has two or more lanes, the charging facilities can be placed on one lane, as a result, all the vehicles behind a charging vehicle will be delayed. When a road has two or more lanes, the charging facilities can be placed on one lane, i.e., the lanes can be divided into WCL and usual lanes (UL), then the charging vehicles can move on WCL, and un-charging vehicles can use the UL. However, when the slow charging vehicle replenishes energy, other vehicles would perform lane-changing maneuvers to travel on UL, which may cause speed fluctuation and capacity drop. As a result, deployment of WCL may reduce road capacity, which in turn affects traveler's route choice and probably decrease network traffic efficiency (i.e., increase total network travel time).

This paper focuses on studying the adverse impacts of WCL on road capacity and the traveler's route choice behavior in the WCL location model. The remainder of the paper is organized as follows. In Section 2, we first formulate a location model in the absence of WCL's adverse effect, and then present a location model taking account of WCL's adverse impact. In Section 3, the location model is linearized, and a new method is developed to reduce the maximum error of the linearization. Section 4 conducts some numerical tests to validate the proposed model and Section 5 concludes the paper.

IV. PROPOSED MODEL AND ITS WORKING

Charging lane location model without the change of driving behavior

The location model aims to place charging lanes on those roads which can serve the most vehicles or realize the maximal recharged electricity. If we assume that the drivers' behavior does not change when wireless charging lanes are constructed, the charging lane location model can be formulated as follows maxyaR=∑aRaya,
subject toγ∑alaya⩽B,where ya equals 1 if a charging lane is deployed on link a and 0 otherwise, γ is the construction cost per lane per kilometer, la is the length of link a, B is

Linearization of the proposed model

The charging lane location model without consideration of the change of traveler's driving behavior (i.e., the model (1)) is a mixed integer linear program. When the charging vehicle's adverse effect on drivers' route choice is considered (i.e., the model (26)), nonlinearity occurs. The nonlinearity comes from the mean route travel time function.

The piecewise linearization method has been employed to solve the nonlinear problem (Wang and Lo, 2010, Riemann et al., 2015, Wang et al., 2016a).

V. RESULTS AND DISCUSSION

A few location models have been proposed to deploy WCL, but they seldom considered the adverse effect of WCL on traffic. This paper proposed two charging lane location models to explicitly investigate this adverse effect on traveler's route choice behavior and optimal WCL location. We then further linearize the location model and design a new method to partition the domain of the nonlinear function for minimizing the maximum error. The effectiveness of the proposed models is verified

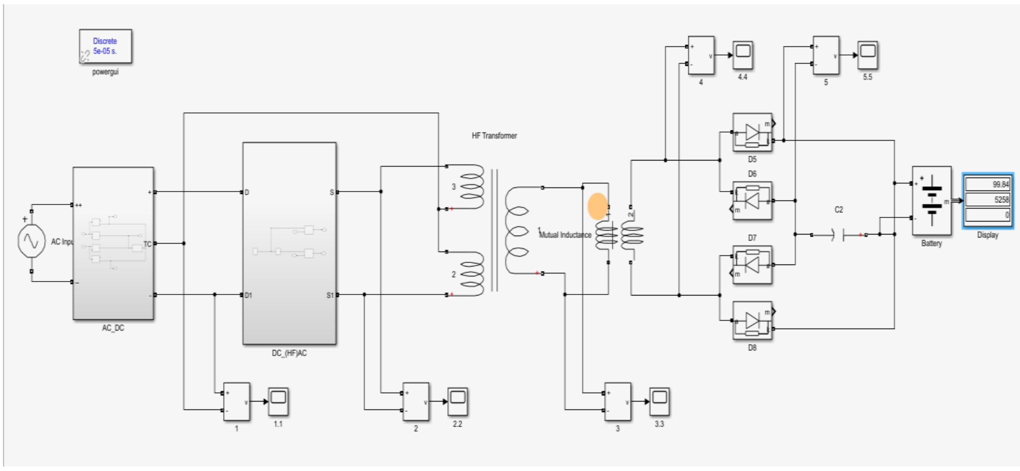

Figure 1: Circuit Diagram of the proposed model.

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