MPC-513
July 12, 2016

Project Title:
Optimal Deployment of Wireless Charging Facilities for an Electric Bus System

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Utah State University

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Research Needs:
Greenhouse gas (GHG) emissions from the transportation sector account for about 27% of the total GHG emissions in the United States. Due to increased travel demand and limited improvement in fuel efficiency, the GHG emissions from transportation have increased by 16% since 1990 (USEPA, 2015). About 80% of transit buses are currently powered by diesel engines, which are a primary source of the particulate matter (PM) and nitrogen oxides (NOx) emitted by motor vehicles. Furthermore, most transit buses are operated in densely populated urban areas, and they are generally in-use for large portions of the day. Electric buses, which produce zero tailpipe emissions, offer huge potential in improving environmental sustainability and livability of urban areas. However, the range problem associated with on-board batteries has substantially limited the popularity of electric buses.

Wireless charging technology, also called inductive charging, an application of wireless power transfer (WPT), offers the promise of eliminating the range problem of electric vehicles (EVs). Dynamic wireless charging provides bus operators with the ability to charge buses while in motion, using wireless inductive power transfer pads embedded underneath the roadway. The technology potentially makes pure electric buses as capable as their diesel counterparts. The dynamic wireless charging technology has been implemented in a bus line in Gumi City, South Korea (Jang et al., 2015). The United Kingdom recently conducted a feasibility study of implementing this technology on its strategic road network (Highways England, 2015). Another benefit of wireless charging technology is that it could reduce the on-board battery size substantially. Battery packs on electric buses can account for about a quarter of the weight of the vehicle and cost as much as 39% of the cost of a pure electric bus (Bi et al., 2015). Bi et al. (2015) demonstrated the potential of downsizing the battery to about one-third the weight of a plug-in charged battery, assuming stationery wireless charging is employed. The battery downsizing not only makes electric buses more affordable, but also offers additional energy saving benefits, due to reduced curb vehicle weight.

To enable dynamic wireless charging for an electric bus system, wireless charging facilities must be built strategically in the road network. The charging facility deployment problem is twofold. First, it is necessary to locate the optimal location for building wireless charging facilities. Existing studies on this topic (e.g., Jeong et al., 2014; Jang et al., 2015a; Jang et al., 2015b; Ko et al., 2015; Ko and Jang, 2013) only consider electric bus systems with a single bus line. However, a real-world bus system almost always contains more than one bus line. Moreover, multiple transit lines may have significant portions of overlap, especially for areas with high transit demand, e.g., downtown, or shopping malls. For overlapping transit lines, they could share wireless charging pads. The synergistic effect among different transit lines could substantially bring down the average cost of constructing a charging facility for individual bus lines and make wireless charging more economically attractive for real-world implementation. Second, one must consider the trade-off between on-board battery size and the number (length) of wireless charging facilities. These two problems should be treated simultaneously, in a network setting.

Research Objectives:
This project is to propose a modeling framework to deploy wireless charging facilities for an electric bus system. The proposed project will accomplish the following two objectives:

1. Develop an optimization problem that determines the location for building wireless charging facilities in a road network and explicitly considers the trade-off between on-board battery size and the number (length) of wireless charging facilities simultaneously.
2. Conduct a case study to demonstrate the viability of applying dynamic wireless charging technology to an electric bus system with multiple overlapping bus lines.

Research Methods:
In the proposed research, we will formulate wireless charging facility deployment problem in a mathematical programming framework. The objective of the optimization problem is to find the optimal combination of battery size and location for building wireless charging facilities to minimize the total system implementation cost subjective to energy consumption constraints and operational requirements of electric buses.

The system implementation cost includes the costs of on-board battery pack, power inverter, charging pad, and construction cost. The battery cost approximately holds a linear relationship with the battery capacity. However, the cost of wireless charging facility is generally not in a linear relationship with its distance because a segment of wireless charging lane may contains multiple wireless charging pads but only needs one inverter. Two sets of binary decision variables will be used to denote whether a wireless charging pad and a power inverter are needed on a road link. All electric buses are assumed to depart from their base station with full state of charge (SOC). After utilizing the wireless charging pads along the service route, a bus should be able to return to the base station with a predefined minimum SOC. An empirical energy consumption model will be used to calculate the electricity consumption of electric buses. When a bus drives over a road segment equipped with wireless charging pads, the bus can get recharged. Proper solution algorithms will be explored depending on the properties of the formulated model.

A case study will be conducted using a campus shuttle bus system to demonstrate the proposed methodology. The results will also be used to illustrate the potential of employing dynamic wireless charging technology in public transportation. The impact of transit demand variation and travel time uncertainty on the deployment of wireless charging facilities will also be accessed.

Expected Outcomes:
The project is expected to produce an optimization framework to deploy wireless charging facilities for an electric bus system. The research findings will not only have theoretical significance, but also have a wide range of applications in implementing more sustainable public transportation systems. The end product will be useful to the Utah Transit Agency (UTA), Utah Department of Transportation (UDOT), and other transportation agencies in planning new electric bus systems. The results of this study will be presented at conferences, published in professional journals.

Relevance to Strategic Goals:
The proposed project contributes to three goals of MPC, i.e., environmental sustainability, livable communities, and economic competitiveness. Although electric bus has been promoted as a green transportation mode, the range problem has greatly limited its application and popularity. The proposed dynamic wireless charging facility could be transformative in terms of electric bus operations and system planning. The research results potentially will lead to a faster adoption of electric buses in urban areas and subsequently improve the environmental sustainability and livability of urban communities. Furthermore, making public transportation more sustainable may also increase its mode share, which will help reduce traffic congestion and support economic competitiveness of a region.

Educational Benefits:
One graduate student will be involved in the research and receive training in transportation network modeling, optimization, and public transportation. The research results will provide fresh materials and case studies to expand the transportation curricula at USU.

Work Plan:
The proposed research will be carried out in a period of 18 months with the following schedule:

Literature Review-We will conduct a thorough literature review on wireless charging technology and its applications in the transportation industry.

Formulating the Optimal Deployment Problem-We will formulate the optimal deployment of wireless charging facilities for an electric bus system as a mathematical programming problem.

Solving the Optimal Deployment Problem-We plan to explore and compare solution algorithms identified in the literature review.

Case Study-We will conduct a case study using a campus shuttle bus system. Sensitivity analysis will be conducted to access the impact of transit demand variation and travel time uncertainty on the deployment of wireless charging facilities.

Report Writing

Project Cost:
Total Project Costs: $ 111,932
MPC Funds Requested: $55,965
Matching Funds: $55,967 Source of Matching Funds: LTAP

TRB Keywords:
Public transportation, electric bus, wireless charging, wireless power transfer, charging facility deployment, greenhouse gas emission, and emission reduction.

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