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Project Title:
Strategic Planning and Design for Electric Bus Systems

University:
University of Utah

Principle Investigators:
Xiaoyue Cathy Liu, Ph.D.
Assistant Professor
Department of Civil and Environmental Engineering
University of Utah
110 Central Campus Dr., Suite 2000
Salt Lake City, UT 84112
Phone: (801) 587-8858
Email: cathy.liu@utah.edu

Ran Wei, Ph.D.
Assistant Professor
School of Public Policy
University of California at Riverside
900 University Ave
Riverside, CA 92521
Phone: (951) 827-1012
Email: ran.wei@ucr.edu

Research Needs:
Electric bus with zero-emission has been recognized as a promising alternative to diesel and compressed natural gas (CNG) bus to advance air quality and save fuel costs (Tzeng et al. 2005). The adoption of electric buses requires significant investment and needs strategic and comprehensive planning on how to deploy electric buses and associated infrastructure (e.g., charging stations). Important decisions in deploying electric buses and charging stations will include, among others, identifying appropriate driving range (battery specification) for electric buses, allocating electric buses to appropriate transit routes, and determining locations of charging stations and their corresponding capacities that can charge the electric buses in a cost and time-effective way.

While previous research has investigated the system design of public infrastructure for private electric vehicles, no research currently exists investigating the system design for electric buses and associated infrastructure. This research fills this gap by developing and using a combination of geographic information system (GIS) and optimization methods to identify optimal deployment strategies for electric bus systems to achieve specified planning goals. As many transit agencies are testing electric buses and considering the integration of electric buses into

future fleet, this research will help the transit agency evaluate the capital and operational cost, greenhouse-gas emission reduction and fuel cost saving associated with the integration of electric buses, and make informed decisions regarding strategic planning and design for electric bus systems.

Research Objectives:

The strategic planning and design for electric bus systems is essential for transit agencies to implement the electrification of the public transportation. This research will help transit agencies make informed decisions regarding strategic planning and design for electric bus systems by achieving the following specific objectives:

1. Develop a systematic approach to identify optimal deployment strategies for electric bus systems to achieve specified planning goals.
2. Evaluate the cost (capital and operations) and benefits (emission reduction and fuel cost saving) of electric bus fleets in comparison with the diesel or CNG fleets.

Research Methods:

In order to support the strategic planning and design of electric bus systems, this research will investigate the characteristics of electric bus and its associated infrastructure, conduct a comprehensive feasibility analysis for deploying electric bus system, develop and use a combination of GIS methods and optimization models to identify the optimal deployment strategies for electric bus system, and evaluate the cost and benefits associated with the adoption of electric buses.

The specifications of electric bus and its associated infrastructure (e.g., charging stations) will be collected from two leading electric bus companies: the BYD and Proterra. The driving ranges, charging requirements and associated costs will be summarized for each type of electric bus. The feasibility analysis will be performed by comparing the existing bus routes with the possible driving ranges, and examining the potential capacity of bus terminals for deploying on-route charging stations. After the feasibility analysis, we will develop and use a combination of GIS methods and optimization models to identify the optimal deployment strategies for electric buses and charging stations to achieve the specified planning goals (e.g., one third of the bus fleet will be electric buses). The optimization models will be used to determine the following specific items:

1. What is the driving range of electric bus for each route?
2. How many electric buses should be introduced into each bus route?
3. Where and how many charging stations should be deployed to serve all electric buses?

The optimization model will be able to minimize the capital and operational cost of deploying the electric bus system while ensuring the expected emission reduction. The identified optimal scenarios to deploy the electric bus system will be visualized in a standalone or Web GIS application, allowing the transit planners to modify the input parameters or output scenarios.

Finally, the costs and benefits associated with the identified optimal scenarios will be compared with the diesel bus fleet and CNG bus fleet and recommendations based on data analysis will be created for transit agencies.

Expected Outcomes:
This result will provide a systematic approach to identify the optimal deployment strategies for electric bus systems to achieve specified planning goals. A comprehensive summary on existing electric buses and associated infrastructure will be provided and a report documenting the feasibility analysis on the implementation of electric buses for each bus route will be generated. In addition, a new optimization model will be developed to support the strategic planning and design of the electric bus system. This model will be incorporated into a standalone GIS software or Web GIS application to allow transit planners to modify input parameters and output scenarios. A cost-and-benefit analysis comparing electric bus with the diesel and CNG bus fleet will also be provided to the transit agencies.

Relevance to Strategic Goals:
The proposed project falls squarely within the purview of USDOT strategic goals of "Environmental Sustainability" and "Livable Communities".

Environmental Sustainability: Battery electric bus can help metropolitan areas reduce the need for fossil fuel and improve air quality by diminishing emissions and the pollutants that create smog. A systematic approach to facilitate the implementation of electric bus systems will directly contribute to the goal of environmental sustainability.

Livable Communities: Improving air quality and reducing noise due to public transportation are crucial for fostering livable communities. This research will help transit agencies develop optimal deployment strategies for electric bus systems, allowing planners and decision makers to create transportation systems that better serve livable and sustainable communities.

Educational Benefits:
Two graduate students will be heavily involved in this research. The graduate research assistants will lead the preparation of journal publications resulting from the work, and in most cases, deliver conference presentations. The undergraduate/graduate seminar GEOG 5960/6960: Location and Transportation Modeling, is the ideal platform to introduce the concept of electric bus and the challenges and benefits associated with it. The procedures for collecting electric bus and transit data, performing feasibility analysis and evaluating the cost-and-benefits will lead to new material and possibly group project to teach the students practical skills on transportation planning.

Work Plan:
The above objectives will be accomplished through a tasked approach. The following major tasks are anticipated along with the timeline:

The potential audiences for this research are individuals involved in the transit operations and planning and transportation asset management, including transit planners, and senior leaders at FHWA, FTA, and at individual transit agencies. The following agencies, offices, and committees are those most likely to take a leadership role in implementing the research results:

- Utah Transit Authority
- Federal Transit Administration

- TRB Transit Capacity and Quality of Service Committee
- TRB Managed Lane Committee
- TRB Highway Capacity and Quality of Service Committee

The proposed PI and Co-PI routinely interact with UTA, FHWA/FTA, SHRP 2 Implementation Program, and the listed TRB Committees (also serve as committee member of the listed committees). The 2017 TRB Annual Meeting will be an opportunity to share early results and future directions of the research project. The proposed PI and Co-PI will work with the committee chairs to possibly give a presentation on the project added to the committee meetings' agenda as well. At least one TRB paper on this work will be submitted for presentation and publication.

	2016			2016			2017			2017		
	7	8	9	10	11	12	1	2	3	4	5	6
Electric Bus and Transit Route Feasibility Analysis												
On-route Charging Station and Bus Terminal Feasibility Analysis												
Optimization Model Development												
GIS Application Development												
Research Dissemination												
Final Project Report												

Project Cost:
Total Project Costs: $60,000
MPC Funds Requested: $30,000
Matching Funds: $30,000
Source of Matching Funds: Utah Transit Authority

TRB Keywords:
Public transit; electric bus; charging stations

References:
Tzeng, G.H., Lin, C.W. and Opricovic, S., 2005. Multi-criteria analysis of alternative-fuel buses for public transportation. *Energy Policy*, *33*(11), pp.1373-1383.