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Project Title

A Microscopic Approach for Electric Vehicle Demand Estimation

University

University of Utah

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Research Needs

The electric vehicle (EV) market has been progressively growing in the past decade with promising sales records in many countries (Paoli and Gül, 2022). In the United States, for example, the sales of EVs and plug-in hybrid electric vehicles (PHEVs) nearly doubled from 308,000 in 2020 to 608,000 in 2021. In China, EV sales grew by 85% over the prior year in 2019, significantly above the industry average (McKinsey, 2019). Such significant rise in EV adoption rate is attributable to policy incentives, technological advancement, promotion of carbon neutral and net-zero emissions economy, etc. The ever-increasing EV adoption is beneficial to reducing greenhouse gas (GHG) emissions, supporting the sustainable transport system, and decreasing the reliance on fossil fuels (Borén et al., 2017). As the booming of EVs creates positive impacts in multiple areas, it brings challenges to the entire society as well.

Among those challenges, the surge of EV charging demand in response to the fast EV adoption could potentially overload the power grid and affect infrastructure planning. EV charging can be divided into home charging and public charging depending on charging locations. In the United States, home charging is still the dominant charging mode, accounting for approximately 80% of all charging events (Smart and Schey, 2012). However, public charging plays an indispensable role under several circumstances. First, drivers that often perform long-distance trips would heavily rely on public charging due to the limited mileage range of EVs. Second, home charging requires the charging facilities to be installed at home garage. Yet many existing EV drivers or potential EV buyers may live in housing units that have no access to a garage or carport. For instance, Ou et al. (2018) evaluated that the home parking availability in Shanghai, China was merely 5.3% in 2005. Therefore, augmenting the network coverage of public charging infrastructures can effectively eliminate the resistance to EV purchase. Last but not least, the concept of taxi electrification has been widely expanded in recent years as electric taxi pilots have already been launched in several cities such as New York City in the U.S. , and Shenzhen, China (Yang et al., 2018). Considering the much longer daily mileage of taxis, public charging infrastructures appear to be crucial to support such service.

Research Objectives

With the aforementioned urgent needs, effectively EV charging management, more specifically, the efficient allocation of electrical vehicle supply equipment (EVSE) is much required. Addressing EVSE allocation problem can help alleviate range anxiety, which is ranked as the top concern for EV purchase. Besides, improving the operational efficiency of public charging facilities could significantly increase revenues for EVSE providers and benefit government agencies' infrastructure planning in both short- and long-terms.

This study aims to produce a realistic and high-resolution public charging simulation environment and provide practical guidance for future charging station deployment. There are three specific objectives to achieve this goal:

1. We will build an agent-based model to model the daily activities of all drivers within a study region;
2. We will estimate EV user distributions and charging demand based on socioeconomic attributes and public charging decision rules; and
3. We will develop an optimization framework based on the estimated public charging demand to efficient solve the EVSE allocation problem, in an effort to maximize the coverage of total charging demands under investment costs and load capacity constraints.

Research Methods

To simulate EV mobility and associated energy consumption in a high spatiotemporal resolution, the modeling framework is divided into four major components: populations and trips generation, travel activity simulation, public charging modeling, and charging station locations optimization. Figure 1 shows the flow chart of the methodology. We will begin by creating synthetic population using sociodemographic information at the traffic analysis zone (TAZ) level. In the meantime, a time-inhomogeneous Markov chain will be trained using American Time Use Survey (ATUS) data to produce stochastic daily activities. Following that, a location mapping technique is proposed to project those daily activities onto specific geographical locations based on historical travel patterns, point of interest (POI), and population information. These aforementioned pieces of information are then fed into Multi-agent Transport Simulation (MATSim), an open-source framework for implementing large-scale agent-based transport simulation, together with road network, to return the optimal travel plans for all drivers. For the post-simulation analysis, we will apply EV adoption probability model and EV energy consumption model to determine EV distribution and potential public charging demands. This is validated against real-world public charging observations. An optimization model is then employed to maximize the coverage of public charging demand under various constraints.

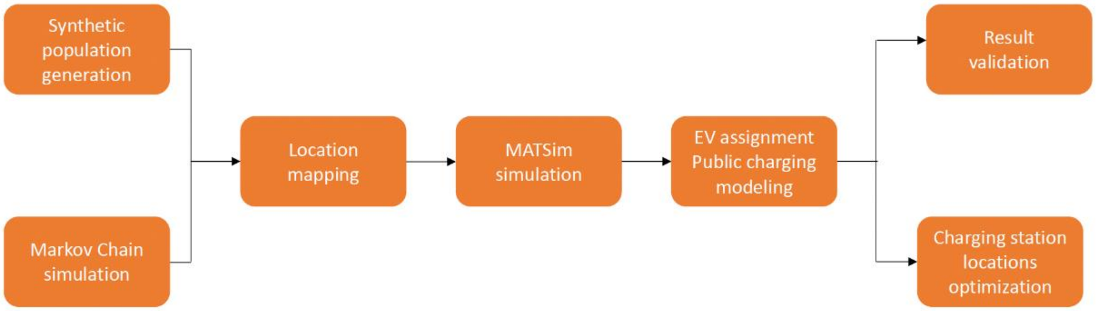

Figure 1. Model Development Framework.

Expected Outcomes

There are three expected outcomes as a result of this project:

- A city-scale agent-based simulation will be developed to produce daily travel profiles using time-inhomogeneous Markov chain, and location mapping technique in combination with American time use survey (ATUS). EV assignment and public charging decision modeling will be subsequently specified in post-simulation analyses using socioeconomic and demographic information to produce high-resolution public charging demand;
- The spatiotemporal distribution of synthetic charging demand will be validated against real-world public charging records. To overcome data availability issues, we will build a dynamic crawling pipeline using Amazon Web Services (AWS). The proposed pipeline will generate high-resolution usage information for existing public charging stations, and it can readily migrate to other regions for future studies; and
- Capacitated maximal coverage location problem (CMCLP) model will be applied to optimize the deployment of public charging stations taking into consideration both standard and fast charging demands. The capacity constraint will be formulated at different hours-of-the-day to ensure charging demands are satisfied during peak hours. The results can provide practical guidance for future public EVSE installation.

Relevance to Strategic Goals

This project primarily addresses USDOT strategic goals of "Environmental Sustainability" and "Livable Communities".

Achieving sustainable transportation to address future energy requirements is a critical mission. EVs play a crucial role in improving fuel economy and reducing greenhouse gas emission. Public charging demand is expected to grow in response to the aggressive EV adoption in the near future. Therefore, a robust prediction of the future charging demand is necessary for appropriately managing and planning public charging infrastructures. Moreover, effectively designing charging station locations can prevent power grid system overload and reduce range anxiety for EV drivers.

Educational Benefits

One graduate student will be heavily involved in this research. He/she will lead the preparation of journal publications resulting from the work, and in most cases, deliver conference presentations. The project will serve as a basis for his/her dissertation work. The PI is currently offering a graduate level course "Traffic Operations Analysis" every Fall semester, and an undergraduate/graduate level course "Transportation Planning" every Spring semester. The agent-based modeling technique developed in this research will lead to new material included in the courses to teach the students practical skills on simulation for modeling EVs' impact on transportation network.

Technology Transfer

Describe the process you will use for transferring your findings to other researchers, professionals and practitioners. The goal should be further development, commercialization and practical applications from the results of your research. Ultimately, technology transfer should sustain economic growth and improve efficiency, safety, and/or cost effectiveness through the development and commercialization of new technologies and practices. Technology transfer may occur through (but is not limited to) conferences, workshops, web pages, social media, and seminars. Please list how you intend to fulfill this requirement and remember to report your technology transfer activities in the SAPR (Semi-Annual Progress Report) – formerly the PPPR – for this project.

The research will inform the Long Range Transportation Plans of UDOT and WFRC. It is clear that there has been a significant acceleration of efforts by the auto industry, coupled with initiatives at federal and state levels to promote EV adoption. This research will result in greater certainty surrounding infrastructure planning for such aggressive EV adoption, and may be used to understand future capacity needs, as well as point to operational needs during the transition period when disruptive technologies get absorbed into the overall vehicle fleet.

The potential audiences for this research are individuals involved in the infrastructure and transportation planning, including traffic engineers, planners, and senior leaders at FHWA, state DOTs, and MPOs. The following agencies, offices, and committees are those most likely to take a leadership role in implementing the research results:

- Utah Department of Transportation
- Salt Lake City
- Rocky Mountain Power
- FHWA Office of Planning
- TRB Highway Capacity and Quality of Service Committee

The proposed principal investigator routinely interacts with UDOT, WFRC, UTA, FHWA, and the listed TRB Committee. Principal investigator will work with the TRB committee chairs to possibly get a presentation on the project added to the agenda. The principal investigator and her graduate students routinely attend TRB's annual meeting as well. At least one TRB paper on this work will be submitted for presentation and publication.

Work Plan

A total of seven major tasks are required to complete the project. The expected completion duration is listed below:

1. Synthetic population generation (2-month)
2. Time-inhomogeneous Markov chain (2-month)
3. Location mapping (1-month)
4. MATSIM simulation model build-up (3-month)
5. EV assignment and energy consumption model (2-month)
6. CMCLP optimization model (1-month)
7. Final Report (2-month)

Project Cost

Total Project Costs:	$135,000
MPC Funds Requested:	$ 60,000
Matching Funds:	$ 75,000
Source of Matching Funds:	GEIRINA (Global Energy Interconnection Research Institute North America)

References

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