PROPOSAL ON REASEARCH PLANS

BIO539

ELECTRIC VEHICLE CHARGING BEHAVIOR IN EXISTING INFRASTRUCTURES

BY

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Over 300,000 battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs) were registered in the United States (U.S.) as of 2015. EV sales significantly increased in 2016 to just under 160,000 vehicles with 2017 half-year trends around 90,000 vehicles [1-5]. In 2015, the number of registered BEV and PHEVs in Rhode Island (RI) was 421, however, with the initiation of the RI DRIVE rebate program (circa 2016) by the Office of Energy Resources (OER) the sales and leases increased by 32 percent; ranking one RI dealership fourth nationally in electric vehicle (EV) sales behind three in California [6, 7]. In RI the change is noticeable, from 2013 to 2017, there was an approximately linear growth of charging events ($p = 0.918$, R-squared = 0.9813), see Figure 1.

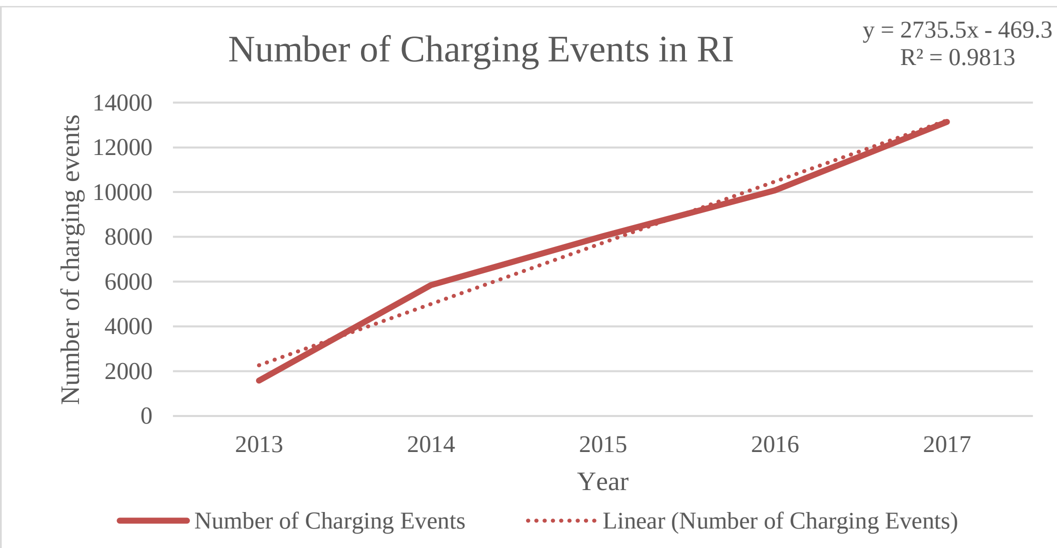

Figure 1: Number of charging events from 2013 to 2017 in RI

New technology implemented in EVs has made transitioning for consumers more feasible by increasing driving range and battery capacity while decreasing charging time [1]. With the RI DRIVE program funded through 2018 and the RI Zero Emission Vehicles (ZEV) Actions (i.e., 5.2, 6.1 and 6.3) [7, 8], a prudently designed infrastructure of charging stations is required to effectively serve this growth. EV charging stations are installed based on interest or algorithms (i.e., simulations, optimizations) with very little to no user behavior or user expectations, which can lead to increased infrastructure costs further down the road [9-12]. To accurately develop a customer-oriented charging station infrastructure requires knowledge of how users utilize the current EV stations and how that corresponds to their charging expectations. This research explores the patterns of relationships between how EV charging stations are being utilized in Rhode Island.

EV are expected to be the vehicle of the future [13], as a bridge to autonomous vehicles (AVs) for private, single users. To make EVs available for the mass market, vehicle and insurance costs have to be reduced, which can happen by improving the transportation system overall instead of simply investing in larger batteries [14]. Additionally, lithium-ion battery prices are projected to decrease, reducing production costs thus making EVs even more attractive [15]. To serve this EV market growth the charging station location selection problem is an important new field of interest [12]. To examine this problem there are different approaches.

Primarily, researchers create numerical models to simulate the problem in order to solve for potential solutions. There are multi-objective (e.g., gas-station demands, power grid infrastructure) planning models to layout charging station distributions, in some studies they also determine scheduling charging and operation costs [10, 16, 17]. Simulation-optimization models determine where to locate EV charging stations in order to maximize the use for privately owned EVs [9]. There are also studies which utilize multi-objective planning models to improve the transport system efficiency, as well as improve the grid system operations [18]. Other studies use linear programming to include electricity price variation, the capability of EVs to charge and discharge when desired, called vehicle-to-grid technology [19, 20]. Further research on vehicle-to-grid technology provided evidence that this approach was not viable due to high infrastructural costs and significantly shortened lifespan of EV batteries by the higher number of charge/ discharge cycles [21, 22]. Certain station location selection models are based on existing optimization routines/heuristics that can find charging locations based on reducing queuing times via prediction of existing data from non-EV vehicles [12, 23, 24]. Yet, these algorithms or models still do not consider EV users preferences and behavioral patterns. Another approach to the problem is by analyzing driving behavior from the EV driver: analyzing their driving, parking, and charging patterns. This level of research has been attempted by making test drives or tracking fleet vehicles [25, 26] and a few only insert charging data but for commercial, medium duty EVs or fleet vehicles [25-27]. Therefore, personal use EVs are not considered with respect to charging behavioral patterns even with current growth, use, and installations throughout the country.

The research outcomes provide a better understanding of the charging behavior of customers based on real data from all the charging stations in Rhode Island and will assist the RI Department of Transportation (RIDOT), RI OER, and RI Department of Environmental Management (DEM) to make customer-centered charging infrastructure decisions. Results will establish a database and a process for future analysis of the charging infrastructure use and demand at locations types. This information can determine the need for non-residential charging and promote charging infrastructure installation at various parking facilities.

Ultimately, a future-oriented infrastructure of charging stations could be generated, and their distribution optimized based on customer-oriented design, where EV drivers can use these charging stations according to their own requirements of needs and travel. Overall, conclusions of state trends in charging behavior can be established and considered within the national trends. Additionally, the information would be valuable to improve the transportation infrastructure for each user and integrate future parties, such as autonomous vehicles.

This research seeks to understand the data of existing Rhode Island charging stations for EVs through statistical methods to provide empirical models of charging behavior. The study will observe Level-2 charging station locations throughout RI and analyze them under specific conditions. Charging patterns will be analyzed, with a summary utilization of the entire RI charging infrastructure and pattern recognition based on the different location types of charging stations.

All Rhode Island charging stations will be divided into certain areas of interest (e.g., institutional, commercial, industrial, residential) and analyzed under specific conditions. The research objectives of this study are to execute an algorithm for analyzing charging station data for the RIDOT and OER which allows for better infrastructure forecasting. The 2013-2017 RI Charging Station database obtained from OER will be established for future infrastructure decision making.

To gain sufficient knowledge about the topic a literature review about infrastructural development of EV charging stations in the U.S., EV charging in general and related studies has been started and will be continued the entire time.

First, the charging station infrastructure in Rhode Island will be analyzed: how they are distributed, which different kinds of areas are they in and how they can be divided. A consistent way of clustering them will be determined.

There are three different types of charging stations: Level-1 (110V) approximately 16 hours charging time, mostly used residentially; Level-2 (240V) approximately 4 to 8 hours, primarily commercial charging most common in RI; DC Fast charger, charges 80% in 20-30 minutes, not all EVs are equipped with this port and charging costs are higher [11, 29-32]. Most of the charging stations which will be observed, provide two 7.2 kW (208/240V at 30A) Level-2 charging ports [29, 30].

The data for this study is provided by OER with locations verified by ChargePoint. The data was stripped of user identifying information prior to dissemination; the only personal data was through an encoded user identification number (User-ID) and postal zip code. Assumptions are that the user is also the driver and always drives the same EV. The energy used for these charging stations is provided by National Grid, partly generated from conventional energy plants and partly from renewable energy (i.e., solar and wind) [33]; cost to charge is mostly free. A "frequent user" is assumed to be a user who used the station greater than ten times.

To analyze this data different methods will be used. The data will be analyzed with different tools and software packages, such as Excel, MiniTab, R, and Python via statistical analyses. Methods like forecasting models, hypothesis testing, comparison tests, and mapping will be applied. An R script will be generated where updated data can be implemented and analyzed the same way as older versions of the dataset. Within this R script first, descriptive statistics about the data will be provided, like means, standard deviation, and descriptive charts to understand the data. After that, a map from the United States will be generated where, to visualize the distribution of RI charging stations users, this will be achieved by mapping the postal zip codes of the drivers on the map. This zip code is assumed to be the home zip code of the driver. Furthermore, comparison or hypothesis testing can be applied to answer specific questions which come up while analyzing the data. Finally, seasonal forecasting will be applied to explore the further evolution of charging events at certain areas.

After that conclusions about the use of the charging stations can be drawn and a future perspective can be identified and disseminated back to OER with the means and ability to repeat this analysis.

The following research questions will be explored throughout this thesis:

- How are charging stations being utilized and how frequently?
- Show charging stations certain types of areas similar or different behavioral patterns?
- What pattern distributions exist, such as seasonality, calendar dependent (i.e., weekly, daily, or hourly), and can they predict future usage trends?
- Since parking is a valuable commodity, are people using charging stations as parking spots or simply for charging?

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