Transportation Research Part D 33 (2014) 39–46

Contents lists available at ScienceDirect

Transportation Research Part D

journal homepage: www.elsevier.com/locate/trd

Siting public electric vehicle charging stations in Beijing using big-data informed travel patterns of the taxi fleet

Hua Cai [a,b], Xiaoping Jia [c], Anthony S.F. Chiu [d], Xiaojun Hu [e], Ming Xu [a,b,*]

[a] School of Natural Resources and Environment, University of Michigan, Ann Arbor, MI 48109-1041, United States
[b] Department of Civil and Environmental Engineering, University of Michigan, Ann Arbor, MI 48109-2125, United States
[c] School of Environmental and Safety Engineering, Qingdao University of Science & Technology, Qingdao, China
[d] Department of Industrial Engineering, De La Salle University, Manila, Philippines
[e] Energy Research Institute, Shanghai Jiao Tong University, Shanghai, China

ARTICLE INFO

Keywords:
Electric vehicle
Charging stations
Travel pattern
GPS data
Transportation emission
Grid impact

ABSTRACT

Charging infrastructure is critical to the development of electric vehicle (EV) system. While many countries have implemented great policy efforts to promote EVs, how to build charging infrastructure to maximize overall travel electrification given how people travel has not been well studied. Mismatch of demand and infrastructure can lead to under-utilized charging stations, wasting public resources. Estimating charging demand has been challenging due to lack of realistic vehicle travel data. Public charging is different from refueling from two aspects: required time and home-charging possibility. As a result, traditional approaches for refueling demand estimation (e.g. traffic flow and vehicle ownership density) do not necessarily represent public charging demand. This research uses large-scale trajectory data of 11,880 taxis in Beijing as a case study to evaluate how travel patterns mined from big-data can inform public charging infrastructure development. Although this study assumes charging stations to be dedicated to a fleet of PHEV taxis which may not fully represent the real-world situation, the methodological framework can be used to analyze private vehicle trajectory data as well to improve our understanding of charging demand for electrified private fleet. Our results show that (1) collective vehicle parking "hotspots" are good indicators for charging demand; (2) charging stations sited using travel patterns can improve electrification rate and reduce gasoline consumption; (3) with current grid mix, emissions of CO_2, PM, SO_2, and NO_x will increase with taxi electrification; and (4) power demand for public taxi charging has peak load around noon, overlapping with Beijing's summer peak power.

Introduction

Greenhouse gas (GHG) emissions and air pollutions generated from fossil fuel-based road transportation have received ever greater attention in recent years, especially in large, dense cities. Electric vehicles (EVs), which include plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), are considered promising alternatives to replace internal combustion engine (ICE) vehicles to reduce energy dependence, mitigate GHG emissions, and improve air quality in urban areas. As part of the efforts to increase urban sustainability, many countries have set goals for electric vehicle adoption (Skerlos and

* Corresponding author at: 440 Church Street, Ann Arbor, MI 48109-1041, United States. Tel.: +1 734 763 8644; fax: +1 734 936 2195.
E-mail address: mingxu@umich.edu (M. Xu).

http://dx.doi.org/10.1016/j.trd.2014.09.003
1361-9209/

Winebrake, 2010). China hopes to have 500,000 hybrid and electric vehicles on the road by 2015 and five million by 2020 (Murphy and Chiu, 2014). To promote the adoption of electric vehicles, governments in many countries have made significant investment to subsidize EV manufacturers and buyers, build charging stations and posts, and offer tax breaks and other non-monetary incentives (e.g., access to HOV lanes) (Ministry of Finance, 2013; Nilsson et al., 2012; Zheng et al., 2012).

Charging infrastructure is critical to the development of the electric vehicle system (Egbue and Long, 2012). Low availability of charging infrastructure could hinder EV adoption, which could then in turn reduce incentives to invest in charging infrastructure development. Although construction of charging stations has been moving forward in many cities, few research has been done to study where should charging infrastructure be built to maximize overall travel electrification given how people travel. Mismatch of charging demand and charging infrastructure can lead to under-utilized charging stations which is a waste of public resources (CRIENGLISH, 2014).

However, estimating charging demand, especially public charging demand, is a difficult task due to lack of realistic travel pattern data (Zhang et al., 2013). Previous studies use road traffic density (Ip et al., 2010), distribution of gas stations (Liu, 2012), and vehicle ownership data (Frade et al., 2011; Li et al., 2011; Sadeghi-Barzani et al., 2014) as proxy for charging demand. Unlike gasoline or hydrogen fueling which only takes a few minutes, the charging process is normally much longer and could take up to hours. As a result, charging is more likely to happen at the end of a trip rather than in the middle of a trip. Furthermore, in addition of charging vehicles at public charging stations, EV owners can also have the option to charge at home. Therefore, traffic flow volume or vehicle ownership density does not necessarily represent demand for public charging infrastructure. Realizing the importance of charging opportunity at the trip destinations, trips simulated with origin–destination pairs are also used to study charging demand (He et al., 2013; Namdeo et al., in press; Sweda and Klabjan, 2011; Xi et al., 2013) but simulated travel patterns might be different from the real ones. Household travel surveys can provide detailed trip and parking information for surveyed individuals (Chen et al., 2013), but each individual is only surveyed for a limited duration (e.g., a day or two) which may not be representative. Recent attempts to use real world travel data to study charging infrastructure planning is yet constrained by the limited data sample size of private vehicles (Dong et al., 2014). Due to sampling cost and privacy concerns, sample size of private vehicles is usually in the hundreds. Because public charging demand is an emergent property of heterogeneous individual travel patterns, it is hard to draw conclusions at the fleet or city level with data whose sample size is several magnitudes lower than the fleet population. Fortunately, increasing amount of large-scale travel trajectory data of public fleets have been made available by the recent development of information and communication technologies, which brings unprecedented opportunity to better understand how charging infrastructures can be better planned to match real world charging needs. Although results concluded based on the public fleet analysis may not be directly applied to private vehicles, methods developed for public fleets can be directly applied to private vehicles with similar travel trajectory data.

Using Beijing as a case study, this research examines a large-scale data set containing 11,880 taxis in Beijing for a month to study the impact of travel patterns on public charging infrastructure needs. Public fleets (i.e., taxis and buses) are likely early adopters for electric vehicles (Krieger et al., 2012). Beijing aims to put 100,000 electric vehicles on roads by 2015 and build 466 charging stations to support these vehicles (Qi, 2011). Results of this research can provide policy guidance for early stage charging infrastructure development in Beijing. In addition, this study demonstrates the benefit of using large-scale individual-based trajectory data (a type of big data) to inform charging infrastructure development. Although this study only includes data from one type of fleet in a specific city, the method and framework developed are readily applicable to other cities when similar data become available.

Data and method

There are two major views regarding to the integration of public charging infrastructure into a city: gas-station-based and parking-lot-based, each with its own merits and disadvantages. Gas-station-based charging stations fit existing consumer habit of vehicle refueling and can help reduce "range anxiety". In addition, in long term, while EVs gradually replace ICE vehicles, the increasing charging service can balance the decreasing refueling service at the gas stations and maintain efficient utilization of public infrastructure resources (Wang et al., 2010). However, it is unrealistic to expect drivers to wait around gas stations if the charging takes hours. Parking-lot-based charging stations are more ideal for long duration public charging because it makes charging an add-on activity of a trip (e.g. work, shopping, etc.) and does not require extra time. However, in order to charge at the parking-lot-based charging stations, EV drivers often have to pay for parking fees which could be more expensive than the electricity cost of the charging itself. Because taxis do not normally park for an extensive amount of time during the day (drivers will lose income) and drivers will avoid paying unnecessary parking fees, this research focuses on the gas-station-based public charging stations.

Fig. 1 outlines the model framework used in this research. We first extract taxi stop events from the trajectory data to evaluate public charging opportunities. Collective charging opportunity exists in locations where many taxis choose to stop for a long duration. We then score each existing gas station based on how well it aligns with identified charging opportunity. A non-overlapping set of existing gas stations are then selected based on different criteria (e.g. maximum number of parking events, maximum daily parking time, or average parking time per vehicle) as charging stations. It is notable that the identified charging opportunity is not the same as charging demand. True charging demand depends not only on the parking time and location, but also the state-of-charge (SOC, represents the remaining capacity of the battery relative to the all-electric