Transportation Research Part C 67 (2016) 131–148

Contents lists available at ScienceDirect

Transportation Research Part C

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

Incorporating institutional and spatial factors in the selection of the optimal locations of public electric vehicle charging facilities: A case study of Beijing, China

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ARTICLE INFO

Article history:
Received 10 June 2015
Received in revised form 2 February 2016
Accepted 8 February 2016

Keywords:
Electric vehicle
Facility location model
p-median model
Maximal covering location model
Optimisation
Set covering model

ABSTRACT

In this paper, we present a case study on planning the locations of public electric vehicle (EV) charging stations in Beijing, China. Our objectives are to incorporate the local constraints of supply and demand on public EV charging stations into facility location models and to compare the optimal locations from three different location models. On the supply side, we analyse the institutional and spatial constraints in public charging infrastructure construction to select the potential sites. On the demand side, interviews with stakeholders are conducted and the ranking-type Delphi method is used when estimating the EV demand with aggregate data from municipal statistical yearbooks and the national census. With the estimated EV demand, we compare three classic facility location models – the set covering model, the maximal covering location model, and the *p*-median model – and we aim to provide policy-makers with a comprehensive analysis to better understand the effectiveness of these traditional models for locating EV charging facilities. Our results show that the *p*-median solutions are more effective than the other two models in the sense that the charging stations are closer to the communities with higher EV demand, and, therefore, the majority of EV users have more convenient access to the charging facilities. From the experiments of comparing only the *p*-median and the maximal covering location models, our results suggest that (1) the *p*-median model outperforms the maximal covering location model in terms of satisfying the other's objective, and (2) when the number of charging stations to be built is large, or when minor change is required, the solutions to both models are more stable as *p* increases.

1. Introduction

Promoting the usage of EVs is a long-term solution designed to maintain a healthy balance of urban mobility and energy consumption. As the largest carbon-emitting country in the world, China is putting a great deal of effort into EV marketisation. Central and local governments have both launched many strategies to promote the construction of public charging

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http://dx.doi.org/10.1016/j.trc.2016.02.003
0968-090X/

infrastructure. However, because the EV market is still in its infancy and lacks sophisticated planning methods, more research work is needed regarding an appropriate deployment plan for public charging infrastructure (Budde et al., 2012).

Optimal locations for public charging facilities are an important issue in transport planning. EVs are promoted worldwide as an effective mobility alternative to address peak oil and air pollution problems (Liu et al., 2013). However, along with this new technology come challenges (Romm, 2006). Among these factors, limited accessibility to charging facilities has been highlighted as a very pressing problem that largely constrains the popularisation and market acceptance of EVs (Melaina and Bremson, 2008; Wang et al., 2013). For many European and Asia-Pacific regions, where many people live in high-rise apartments, people have to rely more on public charging infrastructure due to limited access to off-street home charging (Giménez et al., 2014). It is estimated that 45% of the charging demand would have to be satisfied by fast public charging stations (Liu, 2012).

The driving factors for charging facility development are highly dependent on the local settings (Mikler, 2009; Wells, 2010). The multiple stakeholders involved and their motivations will affect the constraints and objectives of the facility location models (Kley et al., 2011). Many other studies have suggested that the potential main locations for charging facilities should be the workplace, public shopping malls, and university parking lots (Chen and Liao, 2013; Xi et al., 2013), but these locations may not be the investment foci in many Chinese cities. The present deployment of public charging stations in Beijing is largely a top-down planning process. The government has indicated a number of potential location sites for public charging stations. The unique planning system in Beijing provides an opportunity to improve the facility location decisions by considering contextual factors such as local settings, spatial settings, and government policies. Such local settings can be the driving factors for charging facility development (Mikler, 2009; Wells, 2010).

Unlike many other facility location problems, such as in the application domains of medical services (Dökmeci, 1977; Marianov and ReVelle, 1996; Jia et al., 2007), fire facilities (Badri et al., 1998), humanitarian logistics (Balcik and Beamon, 2008), postal services (Bouliane and Laporte, 1992), school locations (Pizzolato, 1994) and waste management (Barros et al., 1998), in our application, the convenience of access to locations has a direct impact on the consumption (*i.e.*, the adoption of EVs). The more conveniently accessible are the charging stations for potential EV users, the higher is the expected adoption level of EVs. Particularly at the present time, when the government is strongly promoting the use of environmentally sustainable vehicles and planning the supporting infrastructure, the ease of access to EV charging facilities should be a major consideration when determining their locations. This also motivates us to consider the socio-demographic factors, which may impact upon the EV adoption level, in different areas of Beijing, when determining the optimal locations.

This paper has two objectives. The first objective is to study the potential of incorporating institutional and spatial factors into facility location models, such as the local government requirements on charging facility deployment and the spatial distribution of the potential sites across the city. The second objective is to compare the optimal facility locations based on three classic location models and to provide transport planning implications. Regarding the first objective, we will first derive potential demand and supply based on the local institutional and spatial constraints summarised from interviews, policy studies and spatial analysis. Then, regarding the second objective, we will incorporate the supply and demand information into models of three popular facility location problems – the set covering problem (SCP), the maximal covering location problem (MCLP), and the *p*-median problem (PMP) – to conduct a case study of public EV charging stations' planning in Beijing, China. By assessing the effectiveness of these models and examining the characteristics of the solutions, we aim to identify the optimal locations of public EV charging stations.

The rest of the paper is organised as follows. In Section 2, we will review general facility location models and related studies on public EV charging stations. In Section 3, we will describe the study area of Beijing, the methods that we used to estimate the demand and supply of the EV charging stations, and the three models. The socio-economic and demographic indicators of each census tract will be considered in order to estimate the charging demand while the institutional and spatial constraints will influence the supply of public charging stations. We will then present the mathematical formulations of SCP, MCLP and PMP. In Section 4, we will present and compare the results from these three models. In Section 5, we conclude the paper with policy recommendations for the deployment of public EV charging stations in Beijing.

2. Literature review

This research is grounded on classic location science (Church, 1999; Yeh and Chow, 1996; Murray, 2010; Ritsema van Eck and De Jong, 1999). In this section, we will first review the literature on general facility location models and then other recent relevant papers that develop models more specifically for EV charging infrastructure.

2.1. Facility location models

Facility location problems have been studied for more than half a century (for example, Cooper, 1963). As the literature on location problems is vast, here we review only the papers on the fundamental models; for detailed surveys on facility location problems, we refer the reader to Hale and Moberg (2003), ReVelle and Eiselt (2005), ReVelle et al. (2008) and Farahani et al. (2012). SCP is one of the most popular problems for facility location planning. The objective of SCP is to minimise the number of facilities, whereas all the demands of communities have to be covered by an established facility within a specified distance; in the rest of this paper we call this the critical coverage distance or radius. Toregas et al. (1971) considered SCP for