Transportation Research Part A 85 (2016) 233–246

Contents lists available at ScienceDirect

Transportation Research Part A

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

Optimizing charging station locations for urban taxi providers

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ARTICLE INFO

Article history:
Received 24 February 2015
Received in revised form 15 January 2016
Accepted 19 January 2016
Available online 12 February 2016

Keywords:
Taxi
Electric vehicles
Charging infrastructure
Optimization
Maximal covering location problem

ABSTRACT

Recently, electric vehicles are gaining importance which helps to reduce dependency on oil, increases energy efficiency of transportation, reduces carbon emissions and noise, and avoids tail pipe emissions. Because of short daily driving distances, high mileage, and intermediate waiting time, fossil-fuelled taxi vehicles are ideal candidates for being replaced by battery electric vehicles (BEVs). Moreover, taxi BEVs would increase visibility of electric mobility and therefore encourage others to purchase an electric vehicle. Prior to replacing conventional taxis with BEVs, a suitable charging infrastructure has to be established. This infrastructure consists of a sufficiently dense network of charging stations taking into account the lower driving ranges of BEVs.

In this case study we propose a decision support system for placing charging stations in order to satisfy the charging demand of electric taxi vehicles. Operational taxi data from about 800 vehicles is used to identify and estimate the charging demand for electric taxis based on frequent origins and destinations of trips. Next, a variant of the maximal covering location problem is formulated and solved to satisfy as much charging demand as possible with a limited number of charging stations. Already existing fast charging locations are considered in the optimization problem. In this work, we focus on finding regions in which charging stations should be placed rather than exact locations. The exact location within an area is identified in a post-optimization phase (e.g., by authorities), where environmental conditions are considered, e.g., the capacity of the power network, availability of space, and legal issues.

Our approach is implemented in the city of Vienna, Austria, in the course of an applied research project that has been conducted in 2014. Local authorities, power network operators, representatives of taxi driver guilds as well as a radio taxi provider participated in the project and identified exact locations for charging stations based on our decision support system.

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http://dx.doi.org/10.1016/j.tra.2016.01.014
0965-8564/

1. Introduction

Electrification of vehicles can help to achieve clean and efficient transportation. It helps to reduce dependency on oil, to avoid tail pipe emissions, to reduce carbon emissions and noise, and to increase energy efficiency of transportation. Different types of (hybrid) electric vehicles are already available on the market and charging infrastructure is going to be established or extended. Among electric vehicles, battery electric vehicles (BEVs) have the highest potential for achieving clean transportation, since there are no tailpipe emissions or additional weight due to an auxiliary combustion engine. Major drawbacks of pure electric vehicles are higher acquisition costs and reduced driving ranges due to limited energy storage capabilities.

Although BEVs have much lower driving ranges compared to ICEVs, this does not pose a problem as long as trips are shorter than the maximum driving range. Therefore, taxi vehicles are considered as relevant candidates for being replaced by BEVs: A high annual mileage accelerates the amortization of the BEV and almost all trips are far below the maximum driving range. Apart from economic and ecological advantages, taxi BEVs will increase visibility of electric mobility and thus encourage people in utilizing BEVs instead of ICEVs.

In order to emphasize the suitability of BEVs as taxis, we analyzed operational data obtained from a taxi dispatch center. Positioning data of approximately 800 taxi vehicles (currently ICEVs) from one radio taxi provider are used for analyzing driving patterns and determining a virtual charging demand. According to Egbue and Long (2012) a proper charging infrastructure is critical for the development of an electric vehicle system. In this study we present a method for placing a predefined limited number of charging stations (CSs) while maximizing the coverage of the estimated charging demand of taxi BEVs.

To convince drivers and taxi enterprises to use BEVs any negative impact on daily taxi business has to be avoided. This might occur when the vehicle has to be charged and cannot be used for accepting a customer trip. Therefore, the waiting time between consecutive customer trips should be used for charging. As in many other cities, taxis in Vienna are allowed to use taxi stands when waiting for a customer. In this study we define the time difference between arriving and leaving the taxi stand as the time waiting for a customer. The number of charging operations should be kept as low as possible, because each time the driver has to search for a CS and frequently plugging into and unplugging from a CS is inconvenient. Moreover, to minimize down-time of taxi BEVs the usage of fast charging stations is favoured.

We aim to find locations for new fast CSs while also considering already existing fast CSs. Charging demand is determined based on a large amount of operational data and intermediate waiting time at taxi stands are used for charging. When searching for optimal locations, we select regions instead of exact locations. It is then up to an expert (or authority) to determine the exact location of a CS within the region. Therefore, the result of the optimization process is rather a support for human decision makers instead of making an obligatory choice. Based on the recommended region an expert can choose specific locations for CSs based on different criteria (power supply, open space, etc.).

The key contribution of this study is the description of a decision support system for placing fast CSs. The system is designed to meet requirements of taxi vehicles and is implemented on the basis of real operational data. Already existing fast CSs are considered in the algorithm which allows a step-by-step improvement of the charging infrastructure. This study is intended to support authorities to enable a taxi service with BEVs and promote an environmental friendly transportation mode. In cooperation with an electricity provider, a predefined number of CS is installed. The number of CS is a trade-off between budget constraints on the one hand and coverage of charging demand and road network on the other hand. In this sense, the study at hand provides a method for finding this trade-off based on requirements of authorities (promote electric mobility), electricity provider (cover charging demand) and taxi drivers (reliable and seamless charging infrastructure).

All research efforts described in this paper have been implemented during a cooperative research project: Project W-ETaxi aims at introducing taxi electric vehicles in Vienna, Austria, involving different stakeholders in order to achieve an optimal and widely accepted result. In a possible follow up of this project, several CSs will be installed and BEVs purchased. Our investigations are based on the Nissan e-NV200 electric vehicle. This BEV has a maximum driving range of 170 km, is already used as taxi in other cities (e.g., London, New York City).

The paper is organized as follows: We discuss the state of the art regarding placing and sizing CSs in Section 2. In Section 3 first we give a description of the data used in this study and how charging demand is derived. Second, the method for finding locations for CSs embedded in a decision support system is described. In Section 4 we present corresponding experimental results. A summary of all findings and recommendations for future research activities are given in Section 5.

2. Literature review

In order to enable a seamless operation of electric vehicles, a charging infrastructure has to be established. In this context research activities regarding the optimal implementation of charging infrastructure gain in importance.

A general overview on related facility location problems and the corresponding state-of-the-art solution approaches can be found in Owen and Daskin (1998) and Daskin (2011). The location problem considered in this article is based on the so-called maximal covering location problem (Church and ReVelle, 1974) maximizing the covered demand subject to a limited number of facilities.

Wang et al. (2013) formulates the problem of optimally planning CSs as a classical facility location and sizing problem. This involves the location of CSs as well as the number of charging points per CS to meet the charging demand of existing and