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Influence of Charging Behaviour given Charging Station Placement at Existing Petrol Stations and Residential Car Park Locations in Singapore

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Abstract
Electric Vehicles (EVs) are set to play a crucial role in making transportation systems more sustainable. However, charging infrastructure needs to be built up before EV adoption can increase. A crucial factor that is ignored in most existing studies of optimal charging station (CS) deployment is the role played by the charging behaviour of drivers. In this study, through an agent-based traffic simulation, we analyse the impact of different driver charging behaviour under the assumption that CSs are placed at existing petrol stations and residential car park locations in Singapore. Three models are implemented: a simple model with a charging threshold and two more sophisticated models where the driver takes the current trip distance and existing CS locations into account. We analyse the performance of these three charging behaviours with respect to a number of different measures. Results suggest that charging behaviours do indeed have a significant impact on the simulation outcome. We also discover that the sensitivity of model parameters in each charging behaviour is an important factor to consider as variations in model parameter can lead to significant different results.

Keywords: Charging Station, Charging Behavior, Traffic Simulation, Electric Mobility

1 Introduction

A wide adoption of Electric Vehicles (EVs) is important in moving towards a sustainable transportation system. An EV offers the advantage of zero local emissions; this is especially useful in mega-cities where dense vehicle population can cause significant health concerns. In order to prevent range related anxiety, two approaches exist. On the one hand, there is significant

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research being done in advancement of battery technology for increased range and decreasing battery cost [25]; on the other hand, there is a recognition that an efficient charging infrastructure is also crucial.

In the last few years, much research has focused on the charging station (CS) placement problem. Different optimisation objectives are chosen to address the problem, such as cost, travel time and waiting time at CS. However, most of these charging infrastructure optimisation work either neglects the charging behaviour of the EV driver, or at best, considers very simple charging behaviours. A fixed threshold of the battery state-of-charge (SOC) is defined at which the EV driver decides to go charging [19].

In this paper, we analyse the impact that different charging behaviours can have on the effectiveness of CS placement. In particular, we consider three charging behaviour with different level of complexity. The least complex one makes charging decision based on a battery SOC threshold as in [19]. The next charging behaviour makes estimation on the trip energy consumption. The most complex one takes the CS locations at the trip destination into account, additionally to the energy consumption estimation in the previous behaviour. For our analysis, we investigate a Singapore based scenario.

The major contribution of this paper is the analysis of the effect that different charging behaviours can have on a realistic electric mobility scenario in the case study of Singapore. We discuss our findings with respect to real world traffic data and a realistic vehicle energy consumption model. Results show that different charging behaviours do have an influence on the electric mobility system as a whole. Performance differences are also observed within one charging behaviour but using different model parameters. These results suggest that the charging behaviour plays an important role when optimising for CS locations.

The remainder of the paper is organized as follows: Section 2 describes related work regarding the CS placement problem using analytical and simulation-based approaches. This section also highlights work addressing charging behaviour modelling from a psychological perspective. Section 3 explains the three charging behaviours in more detail. Section 4 provides an overview of the simulation setup. Section 5 presents the experimental results. Section 6 discusses the work and gives an outlook for future work.

2 Related Work

Different optimisation objectives are used to solve the CS placement problem. Operation costs, maintenance and network loss costs of the CSs [34], CS coverage and convenience for EV drivers to reach CSs [23] as well as energy cost for vehicles to travel to CSs [8] are objectives for minimization in addition to investment costs. [6] estimated the optimal density of EV CSs accounting for the delay time cost of charging and access cost to the CS besides the investment and operation costs. The cost for EV drivers to go charging is modelled as the travel time to [32] and queuing time at the CS [26]. [16] and [21] maximises the CS coverage. [31] has the objective to optimise the amount of energy recharged with a focus on different type of chargers.

Real world data can support the work towards CS placement optimisation. Household travel survey data is used to generate traffic pattern and break down vehicles are used as an input for the optimisation [7]. The objective is to minimise the total travelled distance to access CSs. Similarly, those vehicles where a full charge of battery is not sufficient to cover their daily commute and require intermediate charging are taken into account for charging cost optimisation in [17]. Household travel survey data is also used in [10] to select CS locations with an objective function that minimises the total walking distances from the CS to the destination. As an alternative to household travel survey, [29] describes the usage of pervasive cell-phone