A Continuum Approximation Model for One-Way Electric Vehicle Sharing

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Abstract

This paper proposes a Continuum Approximation (CA) model for design of an one-way Electrical Vehicle (EV) sharing system that serves a metropolitan area. This model determines the optimal EV sharing station locations and the corresponding EV fleet sizes to minimize the comprehensive system cost (including station construction investment, vehicle maintenance, transportation, and vehicle balancing) under stochastic and dynamic trip demands. This is a very complex problem due to the NP-hard nature of location design, the large size of trip numbers, and the stochasticity and dynamics of generated trips. Further, the considerable charging time required by EVs distinguishes this problem from traditional car sharing problems where a vehicle is immediately available for pickup after being dropped at a station. We show that the CA approach can overcome this modeling challenge by decomposing the studied area with a number of small neighborhoods that each can be approximated by an Infinite Homogeneous Plane (IHP). We find that the system cost of an IHP is a unimodal function of the station service area size and can be efficiently solved in a sub-linear time by the bisecting algorithm. Then integrating the solutions of all IHPs yields an approximated solution to the original heterogeneous area. With numerical experiments, we show that the CA solution is able estimate the total system cost of the discrete counterpart solution very efficiently with reasonable accuracy, even for relatively heterogeneous problems. This implies that the proposed CA approach is capable of solving an near-optimum solution to the comprehensive design of a practical large-scale EV sharing system. With this model, we also conduct sensitivity analysis to reveal insights into how cost components and system design vary with the key parameter values. As far as the author's knowledge, this study is the first work that addresses design of an EV sharing system considering both longer-term location and fleet size planning and daily vehicle operations. The proposed CA model also extends the CA methodology literature from traditional location problems with stationary demand, single-facility based service to EV sharing problems considering dynamic demands, OD trips, and nonlinear vehicle charging times.