Advancing Operational Algorithms for Electric Mobility Systems Modeling

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Abstract

The transportation industry is undergoing a significant transformation with the widespread adoption of electric vehicles (EVs). This transition has spurred the development of innovative methodologies aimed at addressing operational challenges and optimizing infrastructure planning for EV mobility. However, the availability of comprehensive EV trajectory datasets remains limited, leading to potentially biased solutions. Moreover, persistent consumer concerns such as range anxiety and inadequate charging infrastructure hinder widespread EV adoption. Therefore, to accelerate the adoption of EVs and improve the efficiency of electrified mobility operations, there is a pressing need for a comprehensive framework that encompasses dataset preparation, system performance evaluation, and the development of EV operational strategies.

This dissertation endeavors to advance the field of energy-efficient EV mobility systems through a comprehensive approach integrating data analysis, machine learning & reinforcement learning techniques, and optimization methodologies. Initially, a framework is proposed to overcome the challenge of limited and unreliable EV trajectory datasets by accurately detecting and generating EV trips from mixed vehicle trajectory datasets. Subsequently, the study investigates the impact of EVs on existing mobility systems, particularly within the ride-hailing systems where EVs play a significant role. The analysis includes consideration of taxi drivers' charging costs in queueing models to reveal the influence of electricity rates on system performance, such as driver supply and passenger demand. Additionally, practical algorithms are developed to optimize EV efficiency operations, including energy consumption estimation, energy-efficient routing, and charging control strategies. Specifically, this dissertation analyzes correlations between EV energy consumption and various factors to devise prediction intervals that accommodate uncertainties in road-level energy consumption estimation. Besides, a novel model for EV online energy-efficient routing is proposed, facilitating the identification of minimal expected energy consumption paths for multiple origin-destination pairs simultaneously. These algorithms, augmented with a path elimination mechanism and variance-covariance information, exhibit superior performance compared to traditional methods, significantly reducing energy consumption and enhancing overall operational efficiency. Finally, a framework for EV charging control recommendation is designed under a power-sharing strategy, considering multiple objectives, such as charging time & costs and the pressure on the power grid.

The methodologies and insights presented in this dissertation advance the understanding and implementation of energy-efficient EV operations and lay the scientific foundations of a more sustainable and efficient EV mobility system. Furthermore, this dissertation offers valuable guidance for policymakers, urban planners, and industry stakeholders in developing more efficient and environmentally friendly transportation networks.