学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Integrating Machine Learning and Optimization Techniques for Short-Term Management of Shared E-Scooters under Demand Uncertainty
(機械学習と最適化技術の統合による需要不確実性下での shared e-scooter の短期オペレーション)

Shared mobility has proliferated in global cities as an innovative transportation mode enhancing urban mobility and as a potential solution to address first- and last-mile problems. Recently, a new emerging shared transportation, dockless electric scooters (e-scooters), has gained popularity worldwide for their specific advantages, including environmentally friendly, time and cost-saving mode, congestion, parking constraint, and satisfied riding experience. Besides these advantages, this shared mode has several disadvantages, including volatile demand, excessive or starving stations, short service life, costly maintenance, battery recharging, and distribution regulations. As a new transportation mode, there are limited studies about shared e-scooters, especially related to daily operations. Therefore, this study aims to develop an efficient framework for better managing this dockless shared service by taking advantage of open-source historical ridership data, machine learning, and deep learning methods. This study thus is separated into three main sections as follows.

From the literature review, shared e-scooters are mainly used for recreational or tourism activities, which differs from shared bikes. This trip purpose with dockless policy led to high demand volatility while requiring a higher service level. To deal with the heteroscedasticity of the demand, both demand and variance prediction models are developed using deep learning (Recurrent Neural Networks) and Autoregressive Conditional Heteroskedasticity (ARCH), respectively. Moreover, Box Cox transformation was also employed to remove the heteroscedasticity. Based on numerical results from three real-world datasets (Austin TX, Minneapolis MN, and Thammasat TH), machine learning and deep learning achieved higher prediction accuracy than conventional regression models, SARIMAX. Box Cox transformation can improve the prediction accuracy, especially MAE by around 5.36

Even machine- and deep-learning models can outperform conventional statistical models; their performance strongly depends on the choice of hyperparameters, while optimizing these hyperparameters is usually computationally expensive. To deal with this problem (i.e., Hyperparameter Optimization or HPO), this study proposed a novel algorithm, Iterative Decision Tree (IDT), which employs a Decision Tree regressor based on the Classification and Regression Tree (CART) algorithm as the surrogate function. Our algorithm suggests several new candidates per iteration as random or extreme points from a few best-performed leaves. This characteristic allows IDT to be trained in parallel, which solves the main disadvantage of previous sequential model-based algorithms (ex., Bayesian Optimization). To evaluate the performance of IDT, it was employed to optimize several benchmark problems, including nonconvex functions and HPO of machine learning and deep learning models. As a result, IDT showed very effective performance for both computational time and objective value compared to benchmark algorithms.

Based on the above results, a new framework for short-term rebalancing planning was proposed for the unique characteristic of shared e-scooters, including volatile and heteroscedastic demand, recharging the battery, and faulty e-scooters. Monte Carlo simulation based on the predicted trip gaps and standard deviations was employed to generate the stochastic demand scenarios. The framework was examined based on e-scooter data from Minneapolis MN, while k-means clustering algorithm was employed to aggregate the trip generation and attraction for the total clusters of 15, 30, and 60. For this data-driven stochastic optimization problem, two separated formulations were constructed and solved by the Integer Linear Programming (ILP) and the Hybrid of Ant Colony Optimization with ILP (ACO-ILP). Under limited computational time, ILP solver is efficient for solving small-size problems (15 and 30-cluster problems), but the Hybrid approach is more efficient for large-size problems (60-cluster problems). Based on the numerical result of the most practical case (60-cluster problems), our data-driven framework for rebalancing planning for shared e-scooters could reduce the expected objective value by around 13.27

In summary, dockless shared e-scooters require proper operational planning to minimize their negative impacts, so that this shared mode can become a potential solution for compacted urban mobility. This objective can be achieved through the proposed data-driven framework, which integrates machine learning and optimization techniques to minimize the demand uncertainty and driving distance for the rebalancing vehicle. For instance, start-of-art prediction models with hyperparameter optimization can effectively handle the volatile demand of shared e-scooters, while rebalancing optimization planning can be addressed through the exact approach (ILP solver) or the heuristic algorithm (ACO-ILP).