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# Energy Consumption Estimation in Last-mile Electric Vehicle Routing with Multi-factor Modeling

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## Abstract

This research aims to evaluate the impact of vehicle components, driving conditions, and environmental factors on the energy consumption calculations along route segments in solutions for the Capacitated Electric Vehicle Routing Problem (EVRPC) in last-mile deliveries. A mathematical model was proposed for the problem, and solutions were obtained using the Gurobi solver. The energy consumption estimation model accounts for driver behavior (including speed, acceleration, and braking), topography, vehicle load, auxiliary system usage, and the operation of the regenerative braking system. To enhance the accuracy of predictions, the energy consumption calculation was further refined using a machine learning model trained with real-world consumption data. This study seeks to address the gap in integrated methodologies for estimating energy consumption within routing models for Battery Electric Vehicles (BEVs) in last-mile deliveries. The results demonstrate that the proposed mathematical model significantly optimizes the average utilization of BEVs compared to a baseline scenario, reducing the fleet size required to meet demand. The optimized routes result in lower total distance traveled and reduced overall energy consumption, with less variability in consumption. These findings suggest that more sophisticated methodologies can enhance the reliability of predictions and improve delivery operations. Furthermore, incorporating vehicle dynamics and using a nonlinear energy consumption estimate greatly influences the routing problem's results. Replacing a single linear parameter with a variable consumption model — considering factors such as speed, acceleration, braking, topography, load, auxiliary system usage, and temperature — enables more efficient delivery strategies, better battery conservation, and reduced State of Health (SOH) loss.

## Keywords
Electric vehicles, Logistics, Machine learning, Mathematical optimization, Vehicle routing.