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Scaling Up Electric Vehicle Battery Swapping Services in Cities

Abstract: Battery swapping for electric vehicle refueling is reviving and thriving in our cities. Despite a captivating future where swapping batteries will be as convenient as refueling gas today, tensions are currently mounting: On one hand, it is desirable to maximize battery proximity and availability to customers. On the other hand, it is undesirable to incur too many batteries which are environmentally detrimental. Additionally, power grids for battery charging are not accessible everywhere. To reconcile these tensions, some cities are embracing an emerging infrastructure network in which decentralized swapping stations replenish their inventory of charged batteries from centralized charging stations that are colocated with grids of sufficient capacity.

In this paper, we model this new infrastructure network to understand its cost and environmental implications. This task is complicated by a non-Poisson behavior of swap demand arrivals, which we observe from a large data set, and by the intertwined operations of swapping, charging, stocking and circulating batteries among swapping and charging stations. We show that these operational complexities can be captured by analytical models. We next propose a model for citywide deployment of hub charging stations. This new location-inventory problem is high-dimensional, non-convex and piecewise. We show that an algorithm that exploits submodularity and combines constraint-generation and parameter-search techniques can solve the problem exactly and efficiently. Our major finding is that, compared with the status-quo on-site charging at swapping stations, centralizing battery charging is significantly less scalable in terms of both cost-efficiency and battery asset-lightness. However, this finding is reversed if foreseeing that on-site charging will be limited in access to grids that permit large-volume fast charging. In addition, centralized charging allows remarkable flexibilities in reducing the battery stock level and adjusting charging station locations, without much compromising the cost-effectiveness. In a broader sense, this work deepens our understanding about how mobility and energy are coupled in future smart cities.

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