A Large Neighborhood Search for Battery Swapping Station Location Planning for Electric Scooters*

Thomas Jatschka[1], Matthias Rauscher[1], Bernhard Kreutzer[1], Tobias Rodemann[2], and Günther R. Raidl[1]

[1] Institute of Logic and Computation, TU Wien, Austria
{tjatschk,raidl}@ac.tuwien.ac.at, e1527543@student.tuwien.ac.at, e0927086@student.tuwien.ac.at
[2] Honda Research Institute Europe, Germany
tobias.rodemann@honda-ri.de

A major hindrance for the large-scale adoption of electric vehicles (EVs) are the long battery recharging times. An attractive alternative to directly recharging batteries of EVs is to replace them. Especially batteries of electric scooters are small enough that they can be exchanged directly by the customers at designated battery swapping stations in a short amount of time. Once a depleted battery is returned to the station, the battery gets recharged and can then be made accessible to customers again when fully charged.

In this work, we introduce the Multi Objective Battery Swapping Station Location Problem (MOBSSLP) and propose a large neighborhood search (LNS) [5] for solving the problem. In the MOBSSLP the task is to plan the setup of new stations for exchanging batteries of electric scooters or to extend existing stations with the aim of minimizing three different objectives while satisfying an expected demand. The three objectives are the setup cost for additional stations and extension modules, the cost for charging batteries, and the total duration of detours for users to exchange batteries. The amount of batteries a station can handle is decided by the number of battery modules assigned to the station. Each battery module can hold and charge a certain number of batteries. We specifically distinguish between the initial module and subsequent modules at a station, as the initial module generally tends to have a different capacity as well as higher setup costs than the subsequent modules. Due to production limitations only a certain total amount of battery modules is available for extending the stations.

Battery swapping stations can be set up at dedicated locations. Each station is associated with a maximum number of modules that can be added, opening times at which customers can exchange batteries, as well as setup and charging costs. A feasible solution to the MOBSSLP indicates at which locations battery swapping stations shall be built with how many battery modules. When planning the size of the stations, the charging time of batteries is taken into account in the sense that batteries are not available for exchange until fully charged. Moreover,

* This project was partially funded by Honda Research Institute Europe and Honda R&D Co., Ltd.

we consider that different types of vehicles exist requiring different numbers of batteries, although all batteries are of the same type.

The MOBSSLP can be classified as location-allocation problem [1] and is closely related to the capacitated multiple allocation fixed-charge facility location problem [2]. Moreover, MOBSSLP is an adaption of the Multi-Period Battery Swapping Station Location Problem (MBSSLP) [3]. Instead of tracking customers individually, in the MBSSLP as well as the MOBSSLP customers are considered in an aggregated fashion, allowing better scalability to large numbers of customers and potential locations for stations. The MOBSSLP, however, extends the MBSSLP by considering finer grained station configurations with modules, costs for charging batteries, costs for detours, and a constraint on the number of modules and stations to be newly opened.

In this work we first formalize the MOBSSLP as a mixed integer linear program (MILP) and then propose an LNS for solving larger instances heuristically. For each of the three objectives of the MOBSSLP individual destroy and repair operators exist. Additionally, a further operator is proposed which conceptually combines the other three destroy/repair operators. The LNS is implemented as a matheuristic [4] as the repair operators are based on solving a relaxation of the MOBSSLP's MILP for smaller subinstances. Note that deriving a feasible solution from such a relaxation is not trivial due to different opening times of the stations as well as different capacities of the battery modules.

We experimentally evaluate the proposed LNS on instances generated by adapted approaches from literature. The LNS with its developed repair and destroy operators is compared to the MILP model as well as a random LNS. Results show that the LNS can outperform the MILP w.r.t. larger instances, achieving solutions up to thirty percent smaller than the MILP. Further, our proposed LNS operators can also achieve solutions up to two percent better than the random LNS.

References

1. Boloori Arabani, A., Farahani, R.Z.: Facility location dynamics: An overview of classifications and applications. Computers & Industrial Engineering **62**(1), 408–420 (2012)
2. Farahani, R.Z., Hekmatfar, M.: Facility location: concepts, models, algorithms and case studies. Contributions to Management Science, Springer (2009)
3. Jatschka, T., Oberweger, F.F., Rodemann, T., Raidl, G.R.: Distributing battery swapping stations for electric scooters in an urban area. In: Olenev, N., Evtushenko, Y., Khachay, M., Malkova, V. (eds.) Optimization and Applications, Proceedings of OPTIMA 2020 – XI International Conference Optimization and Applications. LNCS, vol. 12422, pp. 150–165. Springer (2020)
4. Maniezzo, V., Stützle, T., Voß, S.: Matheuristics. Annals of Information Systems, Springer Nature, 1 edn. (2010)
5. Pisinger, D., Ropke, S.: Large neighborhood search. In: Gendreau, M., Potvin, J.Y. (eds.) Handbook of Metaheuristics, pp. 399–419. Springer (2010)