Spatio-temporal modeling of fast-charging along highway networks for stress-testing planned charging infrastructure capacity

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Overview

With the ongoing growth of the battery electric vehicle (BEV) fleet, the fast-charging infrastructure needs to be continuously expanded to meet increased charging demand and promote the diffusion of electro-mobility in passenger transport. Many studies have proposed models for the planning of fast-charging infrastructure which determine optimal placement and sizing based on the minimization of infrastructure investment costs. Within such models, charging infrastructure is often designed to meet a certain peak charging demand (e.g., daily, seasonal), focusing on high spatial resolution rather than temporal, and thereby neglecting hourly, daily and seasonal dynamics in charging demand. In this work, we present a modelling framework which considers these temporal fluctuations in charging demand and, further, also uncertainties in technological parameters of vehicles driving along the highway network.

Methods

Within the presented modeling framework, we model the traffic flow movement at high temporal resolution ($\Delta t = 15min$) and determine the occupancy of charging points and queuing processes at charging stations. In order to stress-test a given fast-charging infrastructure, different case studies representing extremes in charging demand are considered. These include peak charging demand resulting from increased traffic load as well as from low temperatures. The modeling framework encompasses two important parts: Traffic flow is determined under the consideration of uncertainties in departure time and battery capacity using the Monte-Carlo simulation. This serves as an input for an optimization model with which queuing times and load curves are obtained under the minimization of the number of waiting vehicles, n^{wait}:

$$\min_x \sum n^{wait}$$

Results

Preliminary results have been generated using a simple case study which is illustrated in Figure 1: A car fleet of 40 cars departure from an origin node with a state of charge (SOC) of 50%. Along the route, one charging station is installed. Figure 2 displays the optimized recharging activity of the vehicle fleet: The left sub-figure illustrates the reacharged energy at the charging station, while in the right one, the change in the fleet's state of charge along its route is presented, indicating a rising SOC at the charging station in highway section 3. The vehicle arrives at its destination, located at the end of highway section 5, with a minimum required state of charge which corresponds to a SOC of 10%. Figure 3 displays waiting and charging activity at the charging station in time (at 15min timesteps). In the given set-up, vehicles wait up to an hour in the queue.

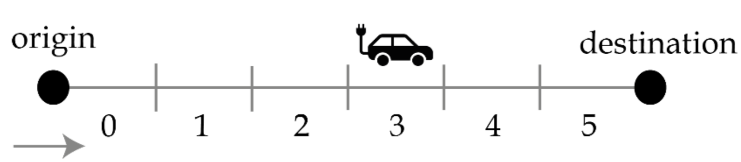
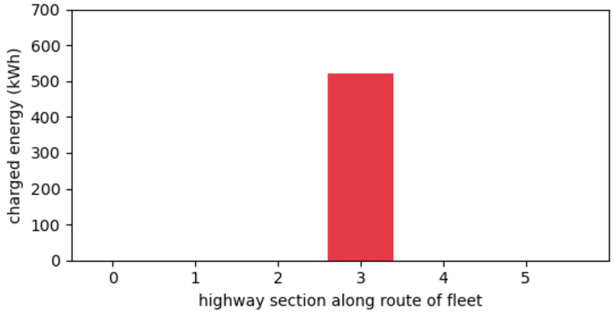


Fig. 1: Illustration of case study for the demonstration of the optimization model. Numbers 0-5 indicate the enumeration of highway sections along the displayed route. A charging station is installed in highway section 3.



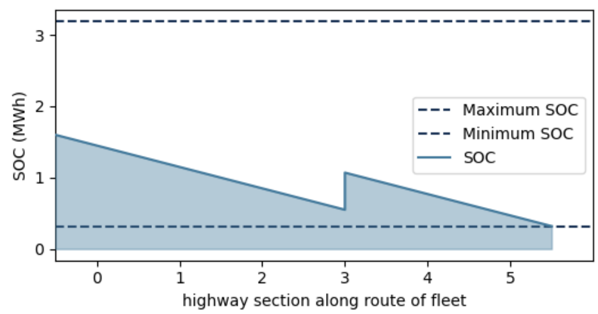


Fig. 2: *Right sub-figure:* Charged energy along the car fleet's route. *Left sub-figure:* Development of state of charge (SOC) of car fleet.

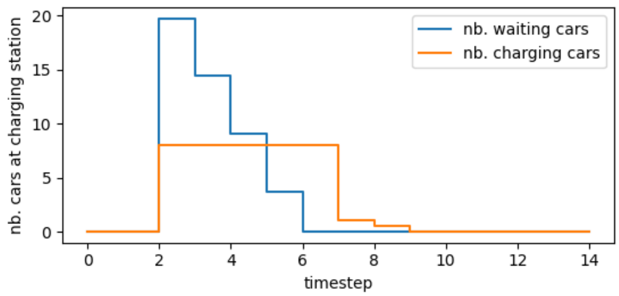


Fig. 3: Building on these preliminary results, the modeling framework is applied to planned fast-charging infrastructure along the Austrian highway network which was determined during the work described in the study Golab et al., 2022 [1].

Conclusions

The goal is (a) to evaluate whether the considered fast-charging infrastructure is sufficient to enable recharging of vehicles in time, without significantly extending travel time, and (b) to give insight into what temporal effects are important to be further implemented in placement and sizing models to ensure cost-efficient planning of charging infrastructure that sufficiently covers fast-charging demand along high-level road networks.

References

[1] Golab, Antonia, Sebastian Zwickl-Bernhard, and Hans Auer. "Minimum-Cost Fast-Charging Infrastructure Planning for Electric Vehicles along the Austrian High-Level Road Network." Energies 15.6 (2022): 2147.