Simulation-optimization of Charging Infrastructure and Scheduling for Heavy-Duty Electric Trucks

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1 Introduction

Freight transport electrification is mandatory for reducing greenhouse gas emissions, improving air quality, and reducing dependence on fossil fuels. The Netherlands has put forward an ambitious plan to foment the electrification of freight transport with the placement of Zero Emission Zones (ZEZs) in major cities of the country, where only zero-emission commercial vehicles will be permitted to operate [3]. Providing explainable and robust models to logistic distribution operators would be an important step to help transition faster to electric truck usage. We focus on dimensioning the infrastructure and vehicle specifications that would help implement a smooth and robust transition from an existing ICE vehicle operation to electric-powered freight.

2 Methods

The approach taken in this research is two-pronged: given an initial itinerary (VRP solution) of an existing logistic operator we first solve for the optimal number of chargers at each distribution center (DC) and charging schedule (CS) of each vehicle. Secondly, the different components of the system are modeled as individual objects in an agent-based model (ABM) to test the robustness of the solution and identify bottlenecks in specific situations [1].

2.1 Preliminary Optimization

This paper deals with a special instance of a facility location problem. We are provided with an itinerary for each truck k of pickup and deliveries that must be completed with an electric truck fleet. The daily itinerary of a truck k is given by the set $\mathscr{L}^k$ composed of individual trip legs l between origins i and destinations j. By discretizing our problem time into steps of size T, we can have a binary decision variable $Y^{t,r}_{l,k}$ that identifies whether a truck k charges at a certain trip leg l at a charger of type r at time interval t. Thus, we guarantee that state of charge $E^{k,l}_j$ at the destination j is sufficient to perform the trips from i to j:

$$E^{k,l}_j \geq E^{k,l}_i + d_{ij} \cdot c^k_{\text{cons}} + T \cdot \sum_{t,r} Y^{k,l}_{t,r} \cdot P^r_{\text{ch}} \quad \forall l \in \mathscr{L}^k, \forall r \in \mathscr{R}, \forall k \in \mathscr{K}. \quad (1)$$

To fulfill this charging schedule, the optimal locations i, quantity X, and types r of chargers are denoted by the integer decision variable X^r_i. The number of chargers must be enough to satisfy the energy needs of the fleet (i.e, satisfy the constraints given by equation (1)) whilst minimizing the delays produced by vehicle queuing (in case of having to wait for a charge) and total cost of infrastructure.

$$X^r_i \geq \sum_{k,l} Y^{t,r}_{l,k} \quad \forall t \in \mathscr{T}, \forall r \in \mathscr{R}, \forall l \in \mathscr{L}^k. \quad (2)$$

2.2 Agent Based Simulation

To test for the robustness of the solution an ABM is developed, where the trucks, distribution centres and chargers are modeled as objects that interact according to an existing fleet plan. Three types of trucks endowed with respective physics-based power consumption model [2] and internal decision logic. The distribution centers considered have fast chargers fast chargers compliant with Megawatt Charging Systems (MCS) of level 1 and 2. Monte Carlo simulations are leveraged to obtain critical metrics of logistic performance and power requirements with probabilistic bounds.

3 Findings

A tradeoff between the number of vehicles, chargers and flexibility of the schedules becomes patent in terms of waiting times and peak energy requirements. Increased charger power rates provide more time flexibility for charging, but create considerable stress on local power grids. The complementary nature of ABM with global optimization is highlighted in this context of varying operational conditions coupled with infrastructure decision-making. Explainable models that incorporate uncertainty will be key to ensure a smooth transition to electric logistics.

References

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