Using a Route-based and Vehicle Type specific Range Constraint for Improving Vehicle Routing Problems with Electric Vehicles

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Abstract

In this research project, we implement a vehicle type dependent range constraint into a Vehicle Routing Problem (VRP) to consider the limited range of electric-driven vehicles in urban freight transport planning due to its restricted battery capacity and energy consumption. We apply this VRP in the route optimization jsprit which is linked to the microscopic agent-based simulation MATSim. In the framework of a case study focusing on food retail distribution in Berlin, Germany, we operationalize the range constraint and demonstrate the functionality and the effectiveness of this constraint using the distance from routing in a transport simulation network. Based on the simulation results, we analyze and discuss the impacts of the limitations of battery electric vehicles (BEVs) on freight transport demand, road mileage performed and the resulting transport costs and GHG-emissions.

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Motivation and research objectives. The European Commission aims to reduce the transport emissions by 90% until 2050 (United Nations, 2015). To achieve this goal, electrifying the transportation sector could be a suitable solution. Hence, the current internal combustion engine vehicles (ICEVs) have to be replaced by battery electric vehicles (BEVs). The range of BEVs is currently restricted and recharging is still much more time consuming in comparison to refueling of ICEVs. For this reason, our research objective is to integrate the limited range of BEVs in existing Vehicle Routing Problem (VRP) to generate more realistic routes carried by BEVs. In this publication, we will investigate and show the impacts of the limitations of BEVs on freight transport demand, road mileage performed and the resulting transport costs and GHG-emissions. Due to the limitations of these vehicles we expect that more BEVs are necessary in comparison to ICEVs to fulfill the orders of the clients.

Methodology. In our study, VRPs have to be solved to generate tours in urban freight transport. Therefore, we use jsprit, an open source VRP-solver (jsprit, 2018), which could be linked to the open source transport simulation software MATSim (Horni et al., 2016). To generate realistic tours for BEVs in urban freight transport, we have to consider a range restriction of these vehicles. For this reason, we implement this constraint as an extension of the VRP. The

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aim is to generate only routes which consider the maximum range of the respective vehicle type. The program code of the range constraint is online available (see https://github.com/matsim-org/matsim-libs repository). The tour range of each vehicle type depends on the modification of the battery and the specific consumption. Based on this, it is not possible to generate a route with a longer than the maximum range of each vehicle type. Using the range constraint for a VRP, the constraint is checked at each part of changing the route. These changes could be the usage of a different vehicle type or adding a new job to the tour. The range restriction applies vehicles with a certain energy capacity. If a fuel capacity is also set for an ICEV, the constraint also works for the conventional vehicle. We assume that when a new pickup element should be added to the tour, the related delivery element is also included. In this context, the algorithm searches the minimal additional distance of each possible position of the delivery in the tour. Therefore, when accepting a pickup, this minimum distance is taken into account. In conclusion, we can include several vehicle types with different ranges in one scenario. Besides BEVs, vehicles without range limitations, can also be integrated to make the VRP solvable, if some of the locations are out of the range of BEVs.

Case study: Urban food distribution. In the framework of this case study, we investigate the food retail distribution in Berlin, Germany. This study was already developed with by Schröder and Liedtke (2014) and is modified for the present study. In the baseline scenario, deliveries to the food retail branches are carried out by diesel-driven trucks (ICEVs). In further scenarios, the baseline scenario is extended by including electric-driven trucks (BEVs). We assume that the battery size is designed in a way that both BEVs and ICEVs have the same payload capacity. We determine that only 70% of the theoretical (gross) battery capacity is used as (net) capacity for the tour planning to ensure an adequate battery lifetime and to maintain a reserve unexpected energy consumption. In this scenario, the newly implemented range constraint is applied for the BEVs. The ICEVs are not restricted in their range for tour planning. As a consequence, each carrier gets its own fleet composition with BEVs and/or ICEVs as a result of the tour planning algorithm. Since the algorithm is cost-orientated, the fleet composition depends on the different costs structure of the vehicle types provided. We parametrize this scenario with different variable costs per distance for the ICEVs to investigate the effects of the GHG-emissions tax.

Discussion of results. We showed that the algorithm works as expected. A small number of observed tours in the traffic simulation are exceeding the plan-able range. But even the tour with the largest divergence needs less than the half of the included tolerance. We increased the (variable) costs for the ICEVs by introducing taxes on GHG-emissions in the framework of the BEV scenarios. Thereby, we observed an increasing switch from the usage of ICEVs to BEVs. In addition, due to the limited range of the BEVs, a slight increase of the total number of vehicles used and kilometers driven can be determined in comparison to the baseline scenario with only ICEVs. For the corresponding Well-to-Wheel GHG-emissions we assumed different electricity mixes. We can state that GHG-emissions decrease by more than 50% from approx. 9 600 to 4 600 tons/year when using renewable electricity. Assuming the emissions based on the energy production in Germany in 2018 the decrease in the same scenario would be 15% (~ 1 500 tons). In contrast to ICEVs, the BEVs have the potential to become more environmentally friendly, without additional investments into the vehicle fleet, just by using an energy mix with increasing the proportion of renewable energy. Furthermore, there is either a need for a strong regulation toward the usage of BEVs or for promoting the change by market reactions and making the usage of BEVs cheaper than the usage of ICEVs. Besides e.g. subsidizing the purchase costs of BEVs, this could be easily implemented by introducing a significant GHG-emissions tax on ICEVs.

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References