Optimal scheduling of an on-demand passenger transport service through electric autonomous vehicles

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1 Introduction

In this work, we are interested in the real-world application of using electric autonomous vehicles for transporting customers. More specifically, we study an upon-request customer transport service, which will be the modus operandi of the considered line in off-peak hours (peak hours being served by a classical fixed timetable). The line is fixed in the sense that customers can be picked up and dropped off only on the considered infrastructure, at the place of their choice. Customers also have either a preferred departure or arrival time. Our problem consists in maximizing the level of service for the customers (minimum travel times, minimum gaps with preferred dates) while minimizing the fleet use (and therefore operating costs). We have to manage the assignment of customers to shuttles, as well as the shuttle's operation. Since the shuttles travel on a dedicated infrastructure, we model the problem at the microscopic level, handling the occupation of the infrastructure by each individual shuttle, even handling the take over between shuttles. We also take care of the possible recharge of the shuttles at depots. This microscopic modeling hence brings some new features specific for this type of problem which do not usually appear in guided transport traffic management (e.g. railways) or road transportation problems.

2 Two solving approaches: description and preliminary numerical assessments

2.1 Mixed-integer linear formulation

We model the whole problem as a MILP, which includes six types of constraints:

- Assignment of customers to shuttles with respect to time and location demands
- Shuttles state: position, capacity, time
- Ordering and overtaking constraints
- Recharging constraints
- Maintenance constraints
- System state at the start (boarded clients, shuttles position and charge, etc...)

We assess these different methods on real-size instances on a real line of around 7 kilometers long. We test the scalability sensitivity of the different methods in number of shuttles (5,7,10), trips (each trip corresponding to a turn back of a shuttle) and customers. The results obtained by giving the mixed integer linear formulation to CPLEX 12.9 enlighten the scalability difficulty of such an approach for solving real-life instances provided by the French company SNCF. The linear relaxation has been considerably improved (by a factor 10) thanks to the addition of valid inequalities specific to the problem. These valid inequalities enable in particular to link the transport of a customer with the effective use of the shuttle. However, if such improvements enable to reduce the gaps (from 80 % to 20 % on average for instances of 10 customers, 2 trips), they remain at about 90 % for 3 trips. Operationally, as we want to optimize for the whole off-peak hours, the number of trips by shuttles is expected to be higher than 2, and the number of customers would be in the hundreds. For these reasons, the MILP can not be used for solving real-life instances, and therefore we designed a matheuristic algorithm described in the next section.

2.2 Design of a matheuristic algorithm

The main idea of the proposed algorithm is to decompose the problem in two phases, taking first the decision of assigning customers (which customer assigned to which shuttle at which (approximated) time and locations) and second the other decisions (priority between shuttles for overtaking, recharge, ..). The interest of such an approach is that the assignment problem can be greedily tackled shuttle by shuttle, selecting for each customer the shuttle most appropriate to serve him, based on the information of the customers already assigned to this shuttle. We hence propose a greedy constructive algorithm for the assignment problem. We consider the customers in a randomly generated order, generating 100 such orders, and keep the best solution. In the second phase, we impose the solutions found by the assignment algorithm and use the MILP to solve it. We improve the MILP by using all the information provided by assignments (we know the occupations of the shuttles in the infrastructure, and approximately the interactions between shuttles, e.g. the ones which will never overlap). However, the number of constraints on real-life instances is still important in this reduced MILP, which leads us to work on a constraint programming approach for solving the second phase and hence being able to have an efficient matheuristic for solving real life instances with a large number of customers.