Pickup and delivery problems with autonomous vehicles on a ring

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1 Introduction

It is a matter of a fact that urban mobility (by means of public transport or personal cars) has become a key factor in people's everyday life, making it easier. But urban mobility is also the source of some issues, some of which are traffic congestion, air pollution and noise. Some of these problems may be solved by replacing normal vehicles with autonomous cars, minibuses, and shuttles. However, the use of autonomous vehicles raises legal, ethical, economic and safety issues. Due to these problems it is not likely that autonomous vehicles will totally replace normal vehicles very soon. However, they will probably first be authorized for collective transportation.

There already exist few cases where fully autonomous vehicles are used in public transportation. A collective transportation service is active in the Saclay Plateau neighborhoods. An autonomous Transdev-Lohr i-Cristal shuttle serves four stops, providing users with transportation between the Massy station and the Saclay Plateau to supplement the existing train, regional express, coach and bus services.

On 17 December 2018, Keolis and the European Metropole of Lille launched an electric autonomous shuttle service at the university of Lille in Villeneuve d'Ascq. The service employed two NAVYA electric autonomous shuttles for one year serving four dedicated stops on a 1.4 km route and providing connections to two metro stations. For a recent benchmark study on experimentations with Autonomous Shuttles for Collective Transport, the reader is referred to Antonialli [1].

In these situations there is often a need to schedule the transportation requests that the autonomous vehicles must serve while moving on circular routes (we will call them rings). Pickup and Delivery and Dial-a-Ride problems on circular tracks have already been studied in a certain number of papers, such as [2, 4, 5, 6].

The problems we want to study in this paper have the following structure. There are m stations arranged in a circle and served by some capacitated vehicles that can travel in either one or both directions. The vehicles must serve some transportation requests. A *transportation request* (i, j) $(i, j = 1, ..., m,\ i \neq j)$ requires a vehicle to reach station i (if it is not already there), pick up a certain number of people or objects and then move them to station j. The number of requests they can serve at the same time depends on their capacity. An additional station (0) is added, that can be thought of as the depot, i.e. a station where the vehicles stay before starting the service and after serving all the requests. Due to the circular layout, to go from station i to station j the vehicles must pass through all intermediate stations between i and j. There can be identical requests. From this common structure, several different problems can be defined.

The objective of all problems is to minimize either the maximum completion time or the total completion time subject to different constraints, such as the the vehicle capacity, release dates or due dates.

2 Our contributions

We propose a classification scheme for these problems, insipired by the three-field notation for scheduling problems introduced by Graham et al. [3]. It is made up of three fields separated by a vertical bar. Each field may be a comma separated list of symbols that describe one or more features of the problem.

We investigate the complexity of different variants, presenting some complexity results. We prove the complexity of some them by showing reductions from known problems, while for some others we describe new complexity proofs.

We show the equivalence of some variants, in the sense that each can be polynomially reduced to the other and thus solved with the same algorithm. We also show the relations between some problem variants and arc routing, graph coloring and scheduling problems.

For polynomially solvable problems we present some efficient exact algorithms, while for some NP-hards problems we propose mathematical formulations and greedy heuristics. We also compare these heuristics with integer programming models solved with CPLEX and we show the experimental results.

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