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Exact and meta-heuristic approach for a general heterogeneous dial-a-ride problem with multiple depots

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ABSTRACT

Dial-a-ride problems are concerned with the design of efficient vehicle routes for transporting individual persons from specific origin to specific destination locations. In real-life this operational planning problem is often complicated by several factors. Users may have special requirements (e.g. to be transported in a wheelchair) while service providers operate a heterogeneous fleet of vehicles from multiple depots in their service area. In this paper, a general dial-a-ride problem in which these three real-life aspects may simultaneously be taken into account is introduced: the Multi-Depot Heterogeneous Dial-A-Ride Problem (MD-H-DARP). Both a three- and two-index formulation are discussed. A branch-and-cut algorithm for the standard dial-a-ride problem is adapted to exactly solve small problem instances of the MD-H-DARP. To be able to solve larger problem instances, a new deterministic annealing meta-heuristic is proposed. Extensive numerical experiments are presented on different sets of benchmark instances for the homogeneous and the heterogeneous single depot dial-a-ride problem. Instances for the MD-H-DARP are introduced as well. The branch-and-cut algorithm provides considerably better results than an existing algorithm which uses a less compact formulation. All seven previously unsolved benchmark instances for the heterogeneous dial-a-ride problem could be solved to optimality within a matter of seconds. While computation times of the exact algorithm increase drastically with problem size, the proposed meta-heuristic algorithm provides near-optimal solutions within limited computation time for all instances. Several best known solutions for unsolved instances are improved and the algorithm clearly outperforms current state-of-the-art heuristics for the homogeneous and heterogeneous dial-a-ride problem, both in terms of solution quality and computation time.

1. Introduction

In dial-a-ride problems, users specify transportation requests from a specific origin location to a specific destination location. Often two related requests are formulated by a user, an outbound request (e.g. from home to a destination) and an inbound request (e.g. return trip to home). These requests are subject to desired pickup or drop off times. To ensure service quality, a maximum user ride time may be imposed as well. The aim is to design a set of efficient routes to perform these transportation requests using a fleet of vehicles with limited capacity.

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Dial-a-ride problems arise in the context of demand responsive transportation. A common application is the door-to-door transportation of elderly and disabled people. These people often cannot make use of general public transportation services because these are not adapted to their needs. Other applications of dial-a-ride problems may be found in patient transportation and transportation in rural areas with a lack of general public transportation services. Dial-a-ride services differ from costly taxi services by the fact that users may be grouped together in a vehicle in order to reduce operating costs (Chevrier et al., 2012). Although dial-a-ride services are currently provided in many large cities, these services are expected to become even more widely spread in the future due to the aging population and the trend towards the development of ambulatory health care services (Cordeau and Laporte, 2007; Paquette et al., 2013). Hence, a need for efficient planning tools exists.

In the majority of papers on dial-a-ride problems, a single user type and a homogeneous fleet of vehicles located at a single depot are assumed. In reality, the problem is often more complex due to the presence of users with special requirements and a heterogeneous fleet of vehicles (Mitrović-Minić, 1998; Parragh, 2011; Wong and Bell, 2006). In the context of transporting elderly and disabled people, some users may request to be transported in a wheelchair while others may take a regular vehicle seat. In the context of patient transportation, some users may need to be transported on a stretcher. Moreover, users may often request an accompanying person to join them (Parragh, 2011). To accommodate these varying transportation needs, service providers usually operate a heterogeneous fleet of vehicles. In addition, these vehicles may be stationed at different vehicle depots in their service area (Cordeau and Laporte, 2007; Mitrović-Minić, 1998). Each vehicle should return to its original depot at the end of its route in order to allow the driver to go home by its own means of transport. In some cases, drivers might even be allowed to take the vehicles home at the end of their shift, resulting in the same number of depots as vehicles. Such a situation arises for example when service providers rely on volunteers which use their own passenger car to transport disabled people, a common practice in Belgium (Neven et al., 2014). It is important to take this inherent heterogeneity into account when studying dial-a-ride problems. While heterogeneous users and heterogeneous vehicles have been considered by some authors, the multi-depot aspect has rarely been studied. Furthermore, although these three aspects jointly arise in many real-life applications, to the authors' knowledge only Carnes et al. (2013) study a dial-a-ride problem involving all three aspects (in the context of air-ambulance services).

The contribution of this paper is fourfold. First, a general static dial-a-ride problem is introduced in which heterogeneous users, heterogeneous vehicles and multiple vehicle depots may be taken into account. We will denote this problem the Multi-Depot Heterogeneous Dial-A-Ride Problem (MD-H-DARP). Second, an existing branch-and-cut algorithm for the single depot homogeneous Dial-A-Ride Problem (DARP) is adapted to be applicable to problems with heterogeneous users, heterogeneous vehicles and multiple depots. This branch-and-cut algorithm provides considerably better results for the Heterogeneous DARP (H-DARP) than an existing branch-and-cut algorithm which uses a less compact problem formulation. All previously unsolved benchmark instances for the H-DARP can be solved to optimality within a matter of seconds. Third, a new deterministic annealing meta-heuristic is proposed to solve the DARP, H-DARP and MD-H-DARP. Extensive numerical experiments are presented on benchmark data sets for the single depot DARP and H-DARP. The algorithm clearly outperforms current state-of-the-art meta-heuristics, both in terms of solution quality and computation time. Several best known solutions for unsolved benchmark instances are improved. Finally, benchmark instances are proposed for the multi-depot version of the heterogeneous dial-a-ride problem. These instances are larger and hence more challenging than current benchmark instances for the H-DARP. High quality solutions for these new instances are obtained by both the exact and the meta-heuristic algorithm.

The structure of the paper is as follows. In Section 2, an overview of literature on dial-a-ride problems is presented. Section 3 provides a problem description of the MD-H-DARP, together with a discussion of a three-index and a two-index formulation. The branch-and-cut algorithm and the meta-heuristic algorithms are described in Sections 4 and 5. In Section 6, computational experiments on different sets of benchmark instances are reported. Finally, conclusions are drawn and opportunities for future research are identified in Section 7.

2. Literature review

Detailed overviews of literature on dial-a-ride problems are available in Cordeau and Laporte (2003a, 2007) and Parragh et al. (2008). In the following paragraphs, for the greater part only more recent contributions to the literature are discussed. For a discussion of earlier work we refer to the aforementioned papers. Readers interested in dynamic dial-a-ride problems are referred to Berbeglia et al. (2010) as well.

Due to the application oriented character of dial-a-ride problems, a large variety of objective functions and constraints may be observed in the literature. Together with a lack of benchmark instances in the past, this has complicated the evaluation and comparison of different models and solutions methods. However, Cordeau and Laporte (2003b) provide a rather general problem description, together with a set of benchmark instances (Parragh et al., 2010). Time windows on either the pickup or delivery, maximum ride times and a maximum route duration limit are assumed. The objective is to minimize routing costs. This problem definition has been adopted by several other authors (Cordeau, 2006; Cordeau and Laporte, 2007; Jain and Van Hentenryck, 2011; Paquette et al., 2013; Parragh et al., 2010; Parragh, 2011; Parragh and Schmid,