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A branch-and-cut algorithm for a realistic dial-a-ride problem

Mengyang Liu [b], Zhixing Luo [a,*], Andrew Lim [c,a,b,1]

[a] International Center of Management Science and Engineering, School of Management and Engineering, Nanjing University, Nanjing 210093, PR China
[b] Department of Management Sciences, City University of Hong Kong, Tat Chee Ave, Kowloon Tong, Hong Kong
[c] School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore 637371, Singapore

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ABSTRACT

In this paper we study a realistic dial-a-ride problem which simultaneously considers multiple trips, heterogeneous vehicles, multiple request types, configurable vehicle capacity and manpower planning. All of these features originate from practical applications in recent years. To formulate the problem, we propose two mathematical models that use different methods to deal with requests associated with the depot. To further strengthen the models, we propose eight families of valid inequalities, and based on them, we propose a branch-and-cut algorithm to solve the problem. The branch-and-cut algorithm was extensively tested on a set of instances generated according to the data of a real world application. The computational results showed that seven families of inequalities can improve the lower bounds substantially and the branch-and-cut algorithm can solve instances with up to 22 requests within 4 h.

1. Introduction

The classic dial-a-ride problem (DARP) mainly arises in door-to-door transportation services for elderly or disabled people (Madsen et al., 1995; Toth and Vigo, 1996, 1997; Melachrinoudis et al., 2007). Given a set of transportation requests, each of which involves transporting a client from an origin to a destination, the DARP consists of determining a set of trips for a fleet of vehicles to satisfy the requests, subject to a series of side constraints, like time window constraints and maximum riding time constraints of clients, and capacity constraints and maximum trip duration constraints of vehicles. The time window constraints of a client require the pickup and drop-off of the client to be within given time intervals, while the maximum riding time constraints restrict the riding time of the client. The capacity constraints and the maximum duration constraints of a vehicle ensure that the load and the trip duration of the vehicle cannot exceed its capacity and a given limit, respectively. The objective of the DARP can be maximizing the number of requests satisfied, minimizing the number of vehicles used, or minimizing the total travel distance of the vehicles.

In recent years, a trend of research on the DARP is to take more realistic constraints into consideration to make the problem more practical. Parragh (2011) and Parragh et al. (2012), motivated by observations made at Austrian Red Cross in the field of patient transportation, considered heterogeneous vehicles and clients in the DARP. In their problem, clients have requests for multiple types of facilities like seats, wheelchairs, and stretchers and the vehicles have different capacities for each type of facility. Qu and Bard (2013, 2014) studied a pickup and delivery problem (PDP) derived from a real application associated with daily route planning for the All-Inclusive Care Program for the Elderly organization. It considers not

* Corresponding author.
E-mail addresses: mengyliu2-c@my.cityu.edu.hk (M. Liu), luozx@nju.edu.cn (Z. Luo), lim.andrew@cityu.edu.hk (A. Lim).
[1] Currently on no pay leave from City University of Hong Kong.

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only heterogeneous vehicles and clients but also the configurability of the vehicles' capacities. In their problem, the vehicles have multiple configurations for seats and wheelchairs, which can be adjusted according to the destined clients before leaving the depot. Lim et al. (in press) studied another realistic DARP variant originating from the Non-Emergency Ambulance Transfer Service (NEATS) in Hong Kong. In this new variant, some clients may require several assistants to help her/him to get on/off a vehicle. These clients are mainly patients or the disabled who live in old buildings without elevators. Therefore, before a vehicle departs from the depot, there must be sufficient assistants on board the vehicle for the destined requests. An assistant on the vehicle occupies one seat. In addition, due to a strict limit on the trip duration, each vehicle performs several trips per day. The assistants can move freely from a trip of a vehicle to a trip of another vehicle given that the two trips do not cause time conflicts for the assistants. Therefore, the problem faced in the NEATS involves a complicated manpower planning problem (see Fig. 1). To deal with this problem, Lim et al. (in press) proposed an efficient heuristic with an ad-hoc component to handle the manpower planning problem. Zhang et al. (2015) proposed a memetic algorithm to solve a simplified version of the problem proposed by Lim et al. (in press) without manpower planning.

In this paper, we study a realistic variant of the DARP, referred to as the *R-DARP*, which simultaneously considers multiple trips, heterogeneous vehicles, multiple request types, configurable vehicle capacity and manpower planning. The R-DARP differs from the one studied by Lim et al. (in press) in the following major aspects. First, Lim et al. (in press) treats the demands of the requests in term of seats, instead of different types of facilities. For example, a client demanding a wheelchair (or stretcher) will be treated as demanding 1.5 (or 3) seats. This is unrealistic, because a vehicle cannot convert 1.5 (or 3) seats into a wheelchair (or stretcher) during the routing process. The configuration of vehicle capacity should be done before a vehicle departs from the depot. Second, the objective of the problem studied by Lim et al. (in press) is a linear combination of three parts: the number of requests satisfied, the total travel distance of vehicles and the workload balance of the staff, while in the R-DARP we follow the most common objective in the literature, namely minimizing the total travel distance of vehicles. Third, in the R-DARP we consider the maximum riding time constraints of the clients, because we think it is important to maintain a consistent and high service level in the public service sector, while Lim et al. (in press) ignore the maximum riding time constraints.

The contributions of the paper are summarized as follows. First, we introduce a realistic and practical variant of the DARP which simultaneously considers several new constraints appearing in recent years. Second, we formulate the problem into two mixed integer programming (MIP) models that use different methods to handle requests whose pickup or delivery points correspond to the depot. Third, we introduce eight families of valid inequalities to tighten the proposed models, and devise a branch-and-cut algorithm to optimally solve the proposed models. Last, we test the branch-and-cut algorithm on a set of instances generated from the NEATS data. Our computational results show that the eight families of valid inequalities can substantially improve the quality of lower bounds, and the proposed branch-and-cut algorithm can solve instances with up to 22 requests to optimality within 4 h. The proposed algorithm and computational results can serve as reference for future research on this problem.

The remainder of this paper is organized as follows. In Section 2, we conduct a literature review on the solution approaches for the DARP as well as the pickup and delivery problem with time windows (PDPTW), a problem similar to the DARP. In Section 3, we describe the two MIP models in detail. The eight families of inequalities and the details of the branch-and-cut algorithm are presented in Sections 4 and 5, respectively. Section 6 is devoted to the computational experiments, followed by Section 7, which concludes this paper with some closing remarks.

2. Literature review

In the past decades, many variants of the DARP have been proposed, like the dynamic DARP (Colorni and Righini, 2001; Attanasio et al., 2004; Coslovich et al., 2006), the single vehicle DARP (Psaraftis, 1980, 1983; Desrosiers et al., 1986), and the multi-vehicle DARP (Jaw et al., 1986; Cordeau and Laporte, 2003b). For a detail survey of the DARP, please see Cordeau and Laporte (2003a, 2007) and Parragh et al. (2008). Among all of these variants, the multi-vehicle DARP is the most relevant to the R-DARP, so we mainly review the literature on the multi-vehicle DARP. Solution approaches for the multi-vehicle DARP

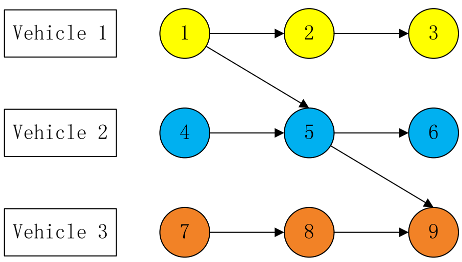

Fig. 1. An example of manpower planning. Vehicle 1 performs trip 1–3; vehicle 2 performs trip 4–6; and vehicle 3 performs trip 7–9. When an assistant is assigned to trip 1, 5, and 9, vehicle 1–3 must collaborate to avoid time conflicts for this assistant.