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Synchronized dial-a-ride transportation of disabled passengers at airports

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ABSTRACT

The largest airports have a daily average throughput of more than 500 passengers with reduced mobility. The problem of transporting these passengers is in some cases a multi-modal transportation problem with synchronization constraints. A description of the problem together with a mathematical model is presented. The objective is to schedule as many of the passengers as possible, while ensuring a smooth transport with short waiting times. A simulated annealing based heuristic for solving the problem is presented. The algorithm makes use of an abstract representation of a candidate solution which in each step is transformed to an actual schedule by use of a greedy heuristic. Local search is performed on the abstract representation using advanced neighborhoods which modify large parts of the candidate solution. Computational results show that the algorithm is able to find good solutions within a couple of minutes, making the algorithm applicable for dynamic scheduling. Moreover high-quality solutions can be obtained by running the algorithm for 10 minutes.

1. Introduction

Around 1% of all passengers arriving at an airport need special assistance. Such passengers may be passengers returning from vacation with an injury, elderly or weak passengers, blind and deaf passengers, and passengers with other disabilities. We will refer to passengers needing assistance as passengers with reduced mobility (PRM). At the 31st biggest airport London Gatwick there was a throughput of 32 million passengers in 2009, of which around 900 each day needed assistance [10].

The support provided for the PRMs can be dedicated transport through the airport, and assistance at boarding. When assisting PRMs through an airport the PRM is picked up at the arriving location, e.g. check-in or gate of arrival, and delivered at the destination location, e.g. arrival hall or gate of departure.

Airports often have several terminals. At the studied airport the transport between the terminals is done in special buses solely for PRMs. Such buses will have a specific location for picking up PRMs at each terminal. Moreover, for aircrafts not located at a gate, the PRM will be transported in a special bus between the gate and the aircraft. Therefore, the pickup and delivery of a PRM is represented as a number of pickup and delivery segments. The airport and airlines require that the PRMs are not left alone at any point during their journey through the airport, and the PRMs are required to be in their assigned flight seat at a fixed pre-specified time before departure. However, the PRM may be left alone for a while before boarding at the departing terminal in a supervised area. It may be possible to assist more than one PRM at a time depending on whether they are able to walk and orient themselves or the PRM is in a wheelchair. Each PRM is assigned a weight depending on their disability and the personnel and vehicles are assigned a capacity depending on their type.

Given a fixed set of transporters, the objective is to minimize the number of PRMs not delivered and to minimize the total unnecessary travel time used on the journeys. PRMs which cannot be delivered on time must be scheduled for a later flight.

The studied airport requires to receive a solution within 2 minutes. One reason is that at airports the schedule often changes due to weather, breakdowns and other issues, therefore a new solution is needed several times during the day of operation. Small changes can be updated manually, while changes affecting many flights and passengers often require a complete reschedule.

We view the problem of assisting PRMs as a dial-a-ride problem (DARP), which is a generalization of the pickup and delivery problem (PDP).

The DARP is NP-hard by reduction from the Hamiltonian cycle problem see Baugh et al. [1].

Between each delivery and pickup of a PRM the transporter delivering the PRM must meet the transporter picking up the PRM. This vehicle synchronization is called a temporal dependency, therefore the problem is a dial-a-ride problem with temporal dependencies (DARPTD). The concept of synchronization in

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routing was used by Ioachim et al. [11] for the fleet assignment problem and later extended to the more general temporal dependencies by Dohn et al. [9]. In pickup and delivery problems the similar problem of cross docking has been considered. In cross docking there is a transfer of goods between vehicles at the synchronized points. The pickup and delivery with cross docking is used in supply chain and planning city logistics systems [2,7]. Pickup and delivery with cross docking was studied by Wen et al. [18] and Chen et al. [2]. In the cross docking problems the cross docking is optional for the vehicles. This is not the case in the problem of assisting PRMs at an airport, as the cross-docking points for each PRM are known and fixed. Moreover, even though cross docking problems often include a cost for the time the transshipped items spend at the cross docking facility, there is no requirement of synchronization. In the cross docking example considered by Chen et al. in [2] the demand is not a single pickup and delivery location pair. Instead, the demand is represented by a source and a sink for a given product and therefore the demand can be picked up at several different locations or delivered to several different locations. In the cross docking problems considered in [2,18] there will be at most one cross docking between the pickup and delivery of a resource. This also differs from the problem discussed in this paper as up to four synchronization points can be included in a transit journey through the airport. Other closely related problems are the pickup and delivery problem with transfers solved by Cortes et al. [6] in 2010 and the pickup and delivery with transfers and split delivery solved for liner shipping by Reinhardt and Pisinger [16] in 2011. The PDP with transfers described in [6] contains a limited number of transfer points where the vehicles are synchronized. A model is presented and instances with up to 6 requests, 2 vehicles and 1 transfer point are solved to optimality using a combinatorial Benders decomposition method. The problem considered by Reinhardt and Pisinger in [16] does not consider synchronization at transfer points and is solved by branch and cut for instances a little larger than those of Cortes et al. [6].

The synchronization constraints and the objective also separate the transportation of PRMs in airports from the rich pickup and delivery problem described in [15]. In the survey by Cordeau and Laporte [3] from 2007 a list of some of the methods used for the dial-a-ride problem with multiple vehicles is provided. In this list the only exact methods are, a branch and cut method optimizing on vehicle travel cost by Cordeau [5], and an improvement on this method by Ropke et al. [17]. The exact method has been tested on a maximum 96 requests and 8 vehicles, which was solved in 71 minutes.

The dial-a-ride problems are usually solved by heuristics, as the studied problems often are real-life cases. Real life problems generally contain some additional constraints, which can be complicating and the objective varies. Moreover, in real-life, there can be constraints or desires not defined in the problem, and the size of the problems is often large. Due to this an optimal solution may actually not be the best solution for the users.

Since the problem covered here is a dial-a-ride problem with complicating synchronization constraints and contains a large number of requests, vehicles and transfer locations, it is natural to consider heuristic solution methods. Moreover, there is a solution time requirement of 2 minutes given by the studied service provider. When solving instances with between 900 and 1500 requests within 2 minutes a heuristic method seems to be the only option.

For more details on the definition of DARP see Cordeau and Laporte [3] from 2007 and the more recent paper by Parragh et al. [14] where the variable neighborhood search heuristic is applied to a standard formulation of the dial-a-ride problem. Parragh et al. [14] report competitive solution for problems with up to 144 request based on the test sets delivered by Cordeau and Laporte [4]. Jaw et al. [12] in 1986 report finding good solutions to their dial-a-ride problem on an instance with 2617 requests and 28 vehicles using an insertion sort method. When run on present computers the method would satisfy the solution time requirement. Other heuristic methods, which are able to find good solutions for dial-a-ride problems with a large number of requests, are the regret insertion method by Diana and Dessouky [8] solving problems with 1000 requests, and a local search heuristic by Xiang et al. [19] solving problems with 2000 requests.

In this paper we present a local search heuristic for the specific problem based on simulated annealing. The algorithm makes use of an abstract representation, which is transformed to an actual schedule by use of a greedy heuristic. Local search is performed on the abstract representation using large neighborhoods. In each iteration, the resulting candidate solution is evaluated and accepted according to the standard criteria in simulated annealing. Computational results are reported showing that the algorithm is able to construct high-quality solutions in 10 minutes.

The model and algorithm can be used for other dial-a-ride problems with synchronization. An example of such a problem is the transport of patients for surgery at hospitals. Here, several steps occurs such as transport to the anesthesia area and then the transport to the surgery room, and from there to the “wake-up” room. During this procedure the patient is not to be left alone at any time. Other examples could be transports involving liner vessels and freight trains. Here, synchronization is needed at the port or station in order to avoid excessive costs due to crane rentals and space limitations in the unload-area.

The main contribution of the paper is to present a highly relevant multi-modal transportation problem. With still more passengers traveling by air, we may expect increasing need for transport planning of passengers with reduced mobility. The problem is a true multi-modal transportation problem with synchronization, which may be used to model several other coupled pickup-and-delivery problems appearing in real-life problems. Finally, the proposed local search based on an abstract representation is generally applicable for other tightly constrained problems, and it shows promising results for the considered instances.

This paper is organized as follows. Section 2 contains a detailed problem description to ensure a thorough understanding of the operational process. In Section 3 a mathematical model of the problem is presented. Section 4 presents the solution method used. Section 5 contains the specifications of the data instances received. In Section 6 the tuning of the parameters for simulated annealing is described. Section 7 contains the results of the solution method applied to the real-life instances received. Finally in Section 8 the results and future work are discussed.

2. Problem description

We will denote the considered problem the *Airport passenger with reduced mobility transport problem* (APRMTP). The APRMTP has been defined in cooperation with a service company providing the assistance for PRMs at a major transit airport. The company has 120 employees assisting between 300 and 500 PRMs through the airport each day. Each employee has a pre-specified working area such as a specific terminal, driving between the terminals bus stop locations or driving between aircrafts and gates. An employee assigned to one area may not move into another area. Therefore, the journey of the PRM is split into a pickup and delivery for each of these areas. We call the pick up and delivery in a specific area for a *segment* and the ordered set of segments of a given PRM for a *journey*. The path of a bus or a foot personnel is referred to as *route*. On average there are three segments per PRM, and hence with 300–500 PRMs each shift we get a total of between 900 and 1500 pick up and delivery segments. This also includes assistance