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An adaptive large neighborhood search heuristic for the share-a-ride problem

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ABSTRACT

The Share-a-Ride Problem (SARP) aims at maximizing the profit of serving a set of passengers and parcels using a set of homogeneous vehicles. We propose an adaptive large neighborhood search (ALNS) heuristic to address the SARP. Furthermore, we study the problem of determining the time slack in a SARP schedule. Our proposed solution approach is tested on three sets of realistic instances. The performance of our heuristic is benchmarked against a mixed integer programming (MIP) solver and the Dial-a-Ride Problem (DARP) test instances. Compared to the MIP solver, our heuristic is superior in both the solution times and the quality of the obtained solutions if the CPU time is limited. We also report new best results for two out of twenty benchmark DARP instances.

1. Introduction

In most real-life situations, especially in urban areas, people and freight transportation operations are managed separately. New city logistics approaches are needed to ensure an efficient urban mobility for both people and goods.

For a real-world application, online shopping becomes increasingly popular, and the delivery time is the key to success of online shopping business. To attract customers, many companies offer same-day delivery service (for instance, Amazon, 360Buy). Currently, the parcels are mainly delivered by vans. However, road congestion becomes a serious obstacle for a timely delivery. The main reason for road congestion is the significantly large number of vehicles on the road. Basically, there are two kinds of vehicles on the road: vehicles for passengers (e.g. bus, taxi, private car) and vehicles for freight (e.g. truck, van). Ensuring an efficient urban mobility for both people and goods becomes more and more critical. Furthermore, the accessibility of some districts is limited for trucks (e.g. no trucks or limited hours for trucks to enter a city center), while taxis are allowed almost everywhere at anytime. We propose a potential collaboration between people transportation companies and online shopping companies in Li et al. [7]. For example, Connexxion (a transportation company in the Netherlands) can deliver both passengers and parcels, and the parcels can be provided by bol.com (an online shopping website in the Netherlands). The parcels can be put in the trunk or under the seat. Thus, the use of a people-and-parcel ridesharing system reduces costs, alleviates urban congestion, and reduces environmental pollution. People-and-parcels sharing can be modeled as the Share-a-Ride Problem (SARP, see Li et al. [7]). The authors give an introduction to the SARP, which is mainly used in mixed commodity services where people and parcels are simultaneously handled by the same transportation network. An application for this problem is the taxi sharing system.

The problem under consideration can be described as follows. A number of taxis drive in a city to serve transportation requests coming from people. At the same time, they deliver some parcels in case it does not affect their passengers significantly. In Fig. 1, an example is given of a combined route of the taxi for parcels and people service.

This involves planning the taxi routes capable of accommodating people and freight as much as possible, under a given set of constraints (related to pickup and delivery times, and capacity of a taxi). This application can be extended to other transportation modes, such as bus, train, or tram.

From the modeling perspective, the SARP can be considered as an extension of the Dial-a-Ride Problem (DARP), which is known to be NP-hard [14]. What makes the SARP even more difficult is that it adds passenger priority constraints to the classic DARP. The differences between the SARP and the DARP can be summarized as follows:

(i) The SARP ensures that any passenger request must be processed within a given time period, and parcels have no such constraints.

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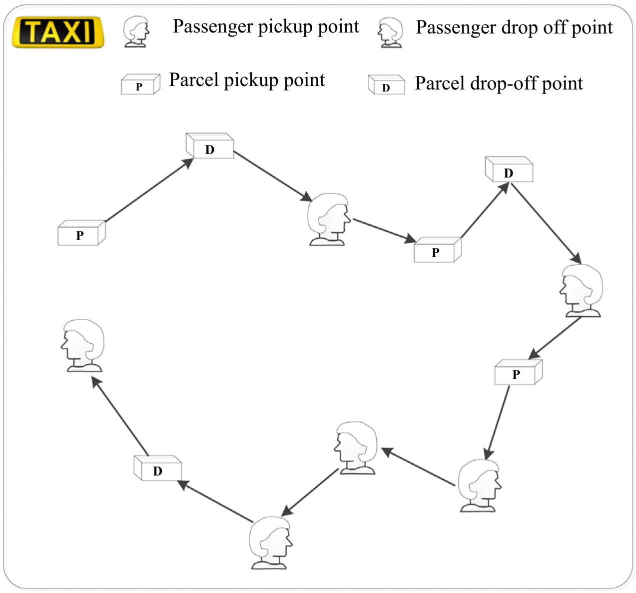

Fig. 1. The SARP—taxis serve both passengers and parcels.

(ii) Two passengers cannot be in the same taxi at same time but two parcels can, and a passenger service has a higher priority: we can insert at most η requests between the pickup and the drop off point of a passenger ($\eta \in \{0, 1, 2, \dots\}$).

(iii) In the DARP and the SARP, the time window and travel time constraints lead to time slacks. Most DARP models in the literature do not consider the time slacks. Even if some DARP model has the constraints related to the time slacks, the time slacks can always be put forward to the previous requests or postponed to the following requests. But for the SARP, the discount for passengers in the objective function is related to extra ride time as compared to the direct trip. Thus, when the taxi is serving a passenger, it is better not to assign any time slacks within the passenger trips.

Furthermore, the SARP is a generalization of the Pickup and Delivery problem (PDP). The main difference between the SARP and the PDP is that the SARP considers transportation of both passengers and parcels, it includes extra constraints for passengers, and constraints that describe the relationship between passengers and parcels.

The straightforward exact approach can only solve relatively small problems [7]. An efficient tool, however, is critical for the practical application of the SARP, which motivates us to develop a metaheuristic algorithm to solve it.

In this paper, we describe our heuristic that is based on an adaptive large neighborhood search (ALNS). Three main contributions of this paper are as follows:

- We propose a time slack strategy for the route scheduling.
- We describe an entropy-based diversity measurement. The measurement method can be used: (i) to monitor the performance of subroutines. (ii) adjust the heuristic during its execution.
- We show that medium-sized real life instances can be solved within a relatively short CPU time.

The remainder of this paper is organized as follows. The literature is reviewed in Section 2. Section 3 briefly introduces the problem and model formulations used in this paper. In Section 4, we describe our ALNS. The evaluation of the ALNS and computational results are presented in Section 5. Finally, Section 6 concludes the paper.

2. Literature review

The description of the SARP was proposed recently. Li et al. [7] explained the conceptual and mathematical models in which people and parcels are handled in an integrated way by the same taxi network. To our knowledge, there is no specific solution algorithm available for the SARP. However, the SARP can be considered as an extension to the DARP, and most of the heuristics used for the DARP can be adjusted for solving the SARP. Several versions of the DARP were studied over the past four decades. We refer to three surveys on the DARP by Cordeau and Laporte [4,5,2]. In this section, we mainly review the class that was solved by tabu search, insertion-based, and cluster-based heuristics. The reason is that these approaches can easily accommodate a large variety of constraints, and allow solving instances with hundreds of requests, according to [5].

Tabu search is a classical method to solve the DARP. Cordeau and Laporte [12] described a tabu search heuristic for the DARP that has time windows. The results presented in that paper were used as a benchmark in subsequent papers that attempted to solve the DARP by heuristics. The instances generated in that paper together with instances provided by Li and Lim [3] are mainly used in the literature related to the pickup and delivery problem with time windows (PDPTW) and the DARP problems.

Since large neighborhood search heuristics have shown excellent results in solving transportation and scheduling problems in recent years, researchers applied them to the Pickup and Delivery problem. Ropke and Pisinger [8] proposed an adaptive large neighborhood search heuristic for the PDP with time windows. The heuristic was tested on more than 350 instances. The instances were modifications of those first proposed by Li and Lim [3]. The regret insertion heuristic they used in this paper performs well: it decreases at least 10% of the gap from the best known solution as compared to the basic greedy operator (based on 16 tested problems).

Parragh et al. [16] proposed a variable neighborhood search-based heuristic, using three classes of neighborhoods: (1) the first class uses simple swap operations; (2) the second class is based on the so-called ejection chain idea (moving sequences of requests); (3) the third neighborhood class exploits the existence of trips where the vehicle load is zero. Regarding the test instances proposed by Cordeau and Laporte [12], they reported 16 new best solutions.

Good insertion heuristics are critically important to the performance of a neighborhood search. Lu and Dessouky [9] presented an insertion-based construction heuristic to solve the multi-vehicle pickup and delivery problem with time windows, which considered both incremental distance measures and the cost of reducing the time window slack due to the insertion. The proposed heuristic was tested on the instances provided by Li and Lim [3]. Diana and Dessouky [10] presented a new regret insertion-based construction heuristic to solve the large-scale DARP with time windows. In their paper, time window control was used to quickly check the feasibility of an insertion. The algorithm was tested on data sets of 100 and 500 requests generated from a para-transit service data. Häme [11] addressed an adaptive insertion algorithm for the single-vehicle DARP. The performance of the heuristic with different objective functions (related to route duration and time slack) was evaluated.

Other heuristics, such as 2-opt or 3-opt route construction methods and multi-phase construction heuristics, are described in the literature. Savelsbergh [13] investigated the implementation of edge-exchange improvement methods for the vehicle routing problem. According to this paper, the computing time for 2-exchange and OR-exchange can be linear in the number of requests. Hernàndez-Pèrez and Salazar-Gonzàlez [15] proposed