Transportation Research Part B 91 (2016) 34–51

Contents lists available at ScienceDirect

Transportation Research Part B

journal homepage: www.elsevier.com/locate/trb

A scenario-based planning for the pickup and delivery problem with time windows, scheduled lines and stochastic demands

Veaceslav Ghilas*, Emrah Demir, Tom Van Woensel

School of Industrial Engineering, Operations, Planning, Accounting and Control (OPAC), Eindhoven University of Technology, Eindhoven, 5600 MB, The Netherlands

ARTICLE INFO

Article history:
Received 9 September 2015
Revised 22 April 2016
Accepted 23 April 2016
Available online 13 May 2016

Keywords:
Freight transportation
Pickup and delivery problem
Scheduled lines
Stochastic demands
Heuristic algorithm

ABSTRACT

The Pickup and Delivery Problem with Time Windows, Scheduled Lines and Stochastic Demands (PDPTW-SLSD) concerns scheduling a set of vehicles to serve a set of requests, whose expected demands are known in distribution when planning, but are only revealed with certainty upon the vehicles' arrival. In addition, a part of the transportation plan can be carried out on limited-capacity scheduled public transportation line services. This paper proposes a scenario-based sample average approximation approach for the PDPTW-SLSD. An adaptive large neighborhood search heuristic embedded into sample average approximation method is used to generate good-quality solutions. Computational results on instances with up to 40 requests (i.e., 80 locations) reveal that the integrated transportation networks can lead to operational cost savings of up to 16% compared with classical pickup and delivery systems.

1. Introduction

Integrated public and freight transportation flows have been successfully achieved in long-haul transportation. Apart from the passengers, cruise ships carry freight between ports (Hurtigruten, 2013). Passenger aircraft are used to transport freight without affecting the service level for passengers (Levin et al., 2012). On the other hand, freight and passenger transportation are rarely integrated in short-haul transportation operations. There are only a few initiatives to investigate the potential benefits of integrated system. MULI was a demonstration project in the west of Germany between 1996 and 1999 (Trentini and Malhene, 2010). Special-design buses were used for both passengers and small-sized packages to reduce emissions. City Cargo Amsterdam was set up as a pilot experiment in 2007 (CargoTram, 2007). Two cargo trams were redesigned to transport packages in the city center of Amsterdam. In 2009, the project was abandoned due to lack of public funds. Later, Masson et al. (2015) investigated a freight distribution system in the French city La Rochelle. The results demonstrated that integrated short-haul transportation systems could lead to improved vehicle utilization and reduced operational costs. In our view, aforementioned projects did not succeed due to a number of practical challenges, such as decision support, information sharing between involved parties and insufficient funding for (re-)designing existing transportation systems.

As a result of economic development and increased populations, urban areas are densely covered by public transportation lines (i.e., bus, metro, tram), which typically operate according to predefined routes and schedules. In this paper, such public

* Corresponding author. Tel.: +31 40 247 4984.
E-mail addresses: V.Ghilas@tue.nl (V. Ghilas), E.Demir@tue.nl (E. Demir), T.v.Woensel@tue.nl (T.V. Woensel).

http://dx.doi.org/10.1016/j.trb.2016.04.015

transportation services are referred as *scheduled line services* (SLs). A possible integration of freight transportation with SLs might provide efficiency gains for all transport stakeholders. The integrated system can potentially reduce operational costs of logistic service providers (LSPs) and can lead to extra revenue for public transport companies. As a side effect, fewer emissions can be achieved with shorter vehicle routes (Demir et al., 2014; 2015b, see, e.g.,). Integrated transport systems may also be beneficial to low-density areas, where vehicles usually make fewer stops over longer distances (Santos et al., 2010).

This paper investigates the *Pickup and Delivery Problem with Time Windows, Scheduled Lines and Stochastic Demands* (PDPTW-SLSD), in which a set of geographically-spread freight requests need to be transported to their destinations using a fleet of heterogeneous pickup and delivery (PD) vehicles (i.e., a priori optimization). Moreover, capacitated SL services can be used as a part of requests' journey without affecting passenger service level. This characteristic of the PDPTW-SLSD implies that a request can be served in two ways, direct delivery or transferred through SLs. Furthermore, the exact quantities demanded by each customer are only learned upon vehicles' arrival at the corresponding pickup locations. Depending on the demand realizations, there are two possible violation outcomes: *(i)* PD vehicle may arrive at a pickup location without enough carrying capacity, and *(ii)* SL service capacity might not be sufficient for the realized demand. In such cases, called *route failures*, corrective (or recourse) actions need to be applied in order to recover feasibility. These actions obviously lead to extra costs which can be charged by LSPs or freight carriers.

In order to consider demand uncertainty, a *Sample Average Approximation* (SAA) method along with an adaptive large neighborhood search (ALNS) algorithm is proposed. The SAA is a scenario-based framework to deal with stochastic discrete optimization problems (Kleywegt et al., 2001). The basic steps of the SAA are as follows: *(i)* solving the SAA problem for a given restricted set of scenarios (i.e., a subset of a larger set of scenarios), *(ii)* evaluating the found solution on a larger set of scenarios and approximating the expected value function by the sample average function, and *(iii)* iterating (*step (i)–(ii)*) until the defined stopping criterion is reached. We note that exact as well as heuristic algorithms (i.e., ALNS) can be used to solve the SAA problem in *step (i)*.

The scientific contribution of this study is two-fold: (*i*) we propose a solution approach for the integrated short-haul transportation problem in a stochastic environment, and (*ii*) we quantify the benefits of the integrated system in stochastic setting. The remainder of this paper is organized as follows. Section 2 provides a brief literature review on related topics. The problem description and the mathematical formulation are discussed in Section 3. The solution approach is given in Section 4. Section 5 presents the results of extensive computational experiments. Conclusions are stated in Section 6.

2. Literature review

In this section, we present a brief review on the existing literature related to the PDPs with transfers, as these are the most closely related to the PDPTW-SLSD. We then present recent works on stochastic PDPs.

2.1. PDPs with transfers

To the best of our knowledge, there are only a few studies on PDPs with transfers to public transportation services. One of the first attempts to combine the deterministic dial-a-ride problem (DARP) with SLs was done by Liaw et al. (1996). The authors proposed heuristic algorithms to tackle static and dynamic aspects of the problem and solved instances with up to 120 requests. In another study, Aldaihani and Dessouky (2003) investigated an integrated DARP with public transportation. A two-stage heuristic algorithm was proposed to solve instances with up to 155 requests. They concluded that shifting some requests to available SLs reduces the overall trip times of the requests and total traveled distance by all PD vehicles. Häll et al. (2009) formalized the integrated DARP as an arc-based mixed-integer program (MIP) and used an all-purpose solver to tackle instances with up to four requests. The authors disregarded the schedules of the public transportation services.

In another study, Ghilas et al. (2016c) provided an arc-based MIP formulation for the deterministic PDPTW-SL. The authors optimally solved instances with up to 11 requests and showed that significant operating-cost savings of up to 20% can be achieved due to the use of available SLs. As a follow-up study, Ghilas et al. (2016b) proposed an ALNS to solve large-size PDPTW-SL instances. The authors concluded that the benefits of the integrated system remain significant for large instances as well. Later, Ghilas et al. (2016a) developed an exact branch-and-price algorithm to solve small- to medium-size instances of the PDPTW-SL. The authors reformulated the problem in terms of paths (routes), and the latter were generated by solving a variant of the elementary shortest path with resource constraints using a tailored labeling algorithm. Instances with up to 50 requests were optimally solved.

The interested readers are referred to Drexl (2012) for an extensive literature review on Vehicle Routing Problems (VRPs) with synchronization constraints. In addition, a related survey on planning semi-flexible transit systems can be found in Errico et al. (2013).

2.2. Stochastic PDPs

Over the years, there has been an increasing interest for the VRP with stochastic demands (VRPSD) (see, e.g., Laporte et al., 2002; Verweij et al., 2003; Secomandi and Margot, 2009). The most advanced solution approaches can be categorized into two groups according to the use of stochastic techniques. The most commonly used approach is *stochastic programming*