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Vehicle routing with private fleet, multiple common carriers offering volume discounts, and rental options

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ABSTRACT

The problem addressed in this paper extends the vehicle routing problem with private fleet and common carriers by three aspects: two types of rental options, a cost function considering volumes and distances, and volume discounts offered by the common carriers. For its solution, we present a mixed integer program and three heuristics based on Variable Neighborhood Search. The computational analysis demonstrates the suitability of these heuristics and the positive effects of two newly introduced mechanisms. Analyzing the interdependencies between available outsourcing options and economic benefits, it shows that a subset of options is sufficient to reduce costs remarkable.

1. Introduction

In this article, a comprehensive extension to the (capacitated) vehicle routing problem with private fleet and common carriers (VRPPC) is presented. The VRPPC, as discussed over the last ten years, tackles the problem of delivering products from a single central depot (e.g., shipping company) to customer locations. This task is accomplished either by the company's privately owned homogeneous or heterogeneous vehicle fleet (self-fulfillment) or by employing external common carriers (subcontracting), i.e., less than truckload (LTL) carriers. This standard VRPPC consists of a selection decision combined with a clustering decision and a routing decision. The first decision is to select one of the two delivery modes for each customer to be served; the second decision comprises the standard vehicle routing problem for the private fleet serving the assigned customers. Concerning the VRPPC, each customer must be served by exactly one vehicle of the limited private fleet or by exactly one external carrier (no split-delivery), every route of the private vehicles start and end at the depot, and vehicles of the private fleet have a specific capacity and perform at most one route per day. The objective is to minimize total delivery costs to serve all customers. Regarding the two delivery modes self-fulfillment and subcontracting, it is assumed that full truckload (FTL) deliveries executed by own vehicles are always cheaper than other delivery modes. Nevertheless, great saving opportunities are in subcontracting LTL deliveries to external carriers.

In this paper, we extend the VRPPC by three aspects. First, we consider two exclusive rental options as additional options for subcontracting: one with a rental fee charged on a route basis (mileage) and the second with a rental fee charged on a daily basis (see e.g., Krajewska and Kopfer, 2009). Both rental options provide the opportunity to reduce total delivery costs

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by increasing the FTL delivery volume. The latter rental option is identical to the consideration of (full) truckload carriers that account for fixed cost per load up to a given capacity (see e.g., Rieksts and Ventura, 2008 or Toptal and Bingöl, 2011). Second, a more realistic concave freight function based on volumes and distances is integrated to determine the costs of LTL carriers (see e.g., Krajewska and Kopfer, 2009). The third aspect is the consideration of volume discounts offered by (some) LTL carriers. Generally, volume discounts are a financial incentive used to foster demand and can be characterized as all-unit quantity discounts or incremental quantity discounts (Wilcox et al., 1987; Weng, 1995). From the view of a common carrier, these discounts provide potential to realize scale effects by freight consolidation in the short term (especially on the inbound route to a distribution center - see Nguyen et al., 2014; Campbell, 1990, on the effects of freight consolidation). In this context, Nguyen et al. (2014) discuss the increase of a customer's order size fostered by volume discounts offered to consolidate delivery orders. Discounts could also be used by LTL carriers to achieve a higher customer density, which leads to decrease in total delivery costs (see, Sun et al., 2015 on this relation). Therefore, the external carrier's operational costs per unit are likely to decrease and these savings could partially be passed to the shipper (to achieve a competitive advantage). Consequently, the shipper's delivery costs will also decrease. This and the previous aspect leads to a heterogeneous set of common carriers defining individually parametrized cost functions. Therefore, the new freight function for common carriers needs to be concave to represent decreasing freight rates depending on volumes and distances and needs to enable carrier-dependent discounts.

Altogether, these aspects lead to a new delivery planning approach for shipping companies addressed in this manner for the first time. We name this new approach the vehicle routing problem with private fleet, multiple common carriers offering volume discounts, and rental options (VRPPCdR). In order to solve problem instances of virtually any size, new and enhanced solution methods based on the principles of Variable Neighborhood Search (VNS) are proposed herein. First enhancement is an explicit shaking mechanism for solution perturbation to support the exploration of the solution space. Second, a distance proportionate selection mechanism is introduced in order to increase the efficiency of the local search procedures.

The structure of the paper is as follows. The literature review in Section 2 examines similar problems in detail and shows the relevance of the new planning approach. The VRPPCdR is formally described in Section 3 and a mixed integer program (MIP) is presented there. The different solution methods and the introduced enhancements are described in Section 4. The computational analysis in Section 5 shows that the solution methods are suitable to solve the VRPPC and particularly the VRPPCdR. The analysis also shows that the new planning approach is able to reduce delivery costs remarkable and provides managerial insights on the effects of different subcontracting scenarios. Finally, conclusions and potential further research topics are described in Section 6.

2. Literature review

Basically, two main research streams address operational transportation planning problems with subcontracting: one investigates the planning problem from the perspective of a freight forwarding company; the other one investigates the perspective of a shipping company. The main difference between both streams lies in the basic planning problem: freight forwarding companies have to solve a pickup and delivery problem (PDP), whereas shipping companies owning a private fleet have to solve a capacitated vehicle routing problem (VRP). Of course, several variants of each of these basic problems are addressed in the literature. Another difference between a shipper and a forwarder is in the objective: While shippers aim to lower their total delivery costs, freight forwarders aim to acquire high volumes in order to generate revenues and lower costs per unit by consolidated full truck loads.

Since this paper takes the shipper's perspective, only a brief review of the relevant literature concerning the freight forwarding perspective is given by selected papers. The paper of Krajewska and Kopfer (2009) is one of the first that combines several subcontracting options in an integrated manner. The authors enhance the underlying pickup and delivery problem with time windows (PDPTW) by external carriers and the two exclusive rental options, described above. The authors called this problem the Integrated Transportation Planning Problem (ITPP; later also called Integrated Operational Transportation Planning - IOTP) and propose a tabu search heuristic extended by special types of moves for the different subcontracting options. In a similar context, Liu et al. (2010) address a task selection and routing problem in collaborative truckload transportation and solve the problem by a memetic algorithm. In contrast to the VRPPC, the authors include external delivery task during the shippers' distribution planning and the private fleet is of unlimited size. Based on the ITPP, Wang and Kopfer (2014) and Wang et al. (2014) formulate the Collaborative Transportation Planning (CTP) problem. Generally, collaborative planning can be seen as a joint decision making process and CTP aims at the reallocation of requests among the partners in a horizontal cooperation. Accordingly, the main difference between the CTP and the ITPP is that CTP bases on an equal partnership, while in ITPP (and also the VRPPC) the players have a hierarchical relationship. Ziebuhr and Kopfer (2014) consider the IOTP from a forwarders perspective extended by compulsory requests, which are only permitted for self-fulfillment or premium subcontracting mode. Therefore, they use a formulation with common carriers and self-fulfillment and apply a large neighborhood search. Defryn et al. (2016) for example also address a vehicle routing problem in a collaborative environment: Based on the selective vehicle routing problem (SVRP), which can be interpreted as a VRPPC, different cost allocation methods for the SVRP in a collaborative environment are analyzed.

The first article that considers external carriers in the perspective of a shipping company originates from Ball et al. (1983). The authors investigate a fleet-size optimization problem, covering the option to outsource destinations to one external car-