European Journal of Operational Research 000 (2016) 1–14

Contents lists available at ScienceDirect

European Journal of Operational Research

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

Production, Manufacturing and Logistics

Making the most of fleets: A profit-maximizing multi-vehicle pickup and delivery selection problem

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ARTICLE INFO

Article history:
Received 24 June 2015
Accepted 5 October 2016
Available online xxx

Keywords:
Decision support systems
Transportation
Logistics
Branch and bound
Heuristics

ABSTRACT

Road freight transportation is a pillar of the modern economy. Despite the increasing competition, over 20% of all vehicles run empty on European roads. As a remedy, freight exchanges have been established to bridge such supply-demand imbalances, with the largest markets trading over 200,000 daily offers. Carriers searching for profit-maximizing freights on such markets face a Profit-Maximizing Pickup and Delivery Selection Problem (PPDSP) that has not yet been addressed in previous research. In this paper, we develop a novel graph search that branches on feasible routes for an exact solution and, based on this, we develop a randomized search heuristic for the single vehicle case, a greedy heuristic for the multi-vehicle case, and a Maximum Set Packing formulation for the case of homogeneous and heterogeneous fleets. Computational experiments show that most instances of the various setups can be solved optimally and much faster than the solution offered by the Gurobi optimizer. Both heuristics are highly efficient and the problem of fleets can be solved almost as quickly as the single vehicle case.

1. Introduction

Road freight transportation has become an integral element of the globalized world: more cargo is shipped on roads than rail, water and air shipment combined. Yet over 20% of all vehicles are traveling empty.[1] This creates unnecessary carbon emissions footprints by wasting huge residual capacities. Instead, excess capacity can be traded by logistics carriers on freight exchanges as a remedy. As such, freight exchanges represent a lever to address the increasing competition in almost every industry, especially in the transportation sector, as well as the demand for more agile and adaptable supply chains (Lee, 2004).

The concept of freight exchanges is not now; there are over 100 exchanges online in Europe, ranging from simple bulletin boards to international exchanges that trade 1.2 million tons of freight daily.[2] Carriers trading on such markets face a new challenge: identifying the most profitable route from among the 200,000 daily offers.

Traditional operations research has addressed this problem for truckload carriers, which ship only one request at a time. This can be modeled as a mixed graph with requests as directed arcs and inter-request routes as undirected edges. The aim is to find the minimal cost route that traverses all arcs as in the Stacker Crane Problem (Coja-Oghlan, Krumke, & Nierhoff, 2006), or the most profitable route that traverses a selective subset of the arcs, i. e., the Orienteering Problem (Vansteenwegen, Souffriau, & van Oudheusden, 2011). Truckload problems are relatively simple since each delivery must be made right after its pickup and, hence, each request can be treated as a node, making the problem similar to the classic Vehicle Routing Problem (Toth & Vigo, 2002).

In contrast, the *less-than-truckload* (LTL) version has been considered only rarely. LTL carriers consolidate multiple requests in one vehicle and transport them together, as into parcel delivery, for example. Consequently, they must consider not only request-specific attributes, but also whether multiple requests fit together into the delivery plan. The cost minimizing case is often modeled as the *Pickup and Delivery Problem* (PDP), while the profit maximizing case with selective pickup has not been studied thus far. Solving this problem optimally and quickly helps to improve the operational efficiency of the carriers, and contributes to greener transportation.

In this paper, we propose a novel *Profit-Maximizing Pickup and Delivery Selection Problem* (PPDSP) with time windows and selective pickups. The contributions are threefold:

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[2] Teleroute: *Teleroute freight exchange*. URL: http://www.teleroute.com/. Accessed on June 10, 2014.

http://dx.doi.org/10.1016/j.ejor.2016.10.010
0377-2217/

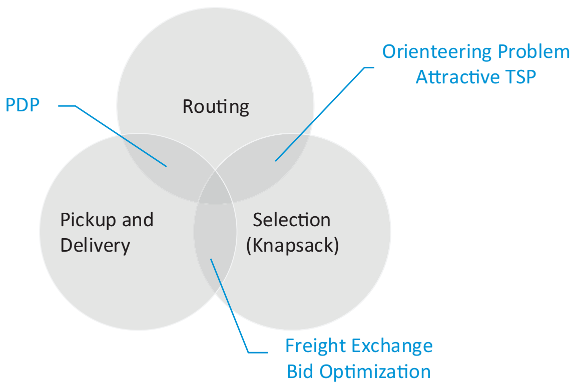

Fig. 1. Classification of related problems with the Profit-Maximizing Pickup and Delivery Selection Problem located in the central intersection.

1. We develop a simple graph search that enumerates feasible routes under pickup and delivery constraints, which solves the multi-vehicle PPDSP optimally and reaches the solution much faster than the state-of-the-art Gurobi optimizer (Gurobi, 2014).
2. We develop two heuristics: (i) a randomized search for the single vehicle case and (ii) a greedy heuristic for the multi-vehicle case. Both of these are fast and highly efficient.
3. For the case of fleets, we show that the problem can be modeled as a Maximum Set Packing problem upon the feasible routes, and that an optimal solution may be found to optimum in approximately the same time as in the single vehicle case.

The remainder of the paper is structured as follows: Section 2 surveys related works on the Pickup and Delivery Problem, as well as routing problems with selective pickup. Section 3 defines the model and its assumptions, while Section 4 presents the optimization algorithms. This is followed by computational experiments in Section 5. Section 6 concludes and presents an outlook for future research.

2. Related work

Our *Profit-Maximizing Pickup and Delivery Selection Problem* (PPDSP) is a transportation optimization problem characterized by three aspects: (i) profit-maximizing routing, (ii) pickup and delivery and (iii) selective pickup. Our following literature review shows that each of these aspects has been studied on its own but that their combination has been neglected in prior research. Altogether, the corresponding classification is illustrated in Fig. 1.

Each of the three previously mentioned problem characteristics has been covered extensively in operations research (Toth & Vigo, 2002): routing is solved in the naïve *Traveling Salesman Problem* (TSP) and *Vehicle Routing Problem* (VRP). These are then augmented with request pickups and deliveries in the *Pickup and Delivery Problem* (PDP). The PDP is a large family of vehicle routing problems that transport objects or people between origins and destinations (Berbeglia, Cordeau, Gribkovskaia, & Laporte, 2007). Most PDPs aim to find the route with minimal cost under side constraints. A comprehensive survey of PDPs can be found in Parragh, Doerner, and Hartl (2008).

PDPs are frequently classified into three groups according to the number of origins and destinations (Berbeglia et al., 2007) – *many-to-many*, *one-to-many-to-one* and *one-to-one* – as follows (see Table 1): the many-to-many case considers only one or a few objects, which can be transported between any locations. Examples are refueling petrol stations or redistributing rental bikes (Ting & Liao, 2013). The exact solutions usually utilize branch-and-cut approaches (Hernández-Pérez & Salazar-González, 2007, 2014) and necessitate (meta-)heuristics for large instances (Mladenović, Urošević, Hanafi, & Ilić, 2012). The one-to-many-to-one case introduces two depots; then, objects are transported from the depot to customers in order to satisfy demand or from the customers back to the depot. Examples include supplying beverages to supermarkets and collecting the empty bottles (Gribkovskaia, Laporte, & Shyshou, 2008). Here, Gutiérrez-Jarpa, Desaulniers, Laporte, and Marianov (2010) investigate a variant with selective pickups, while Masson, Ropke, Lehuédé, and Péton (2014) study an application to shuttle routes. Our PPDSP falls into the one-to-one case where each object or request is unique and associated with one origin and a corresponding destination.

Several approaches to one-to-one PDPs are known. As this problem does not allow for trans-shipment, it often occurs as a Pickup and Delivery Traveling Salesman Problem (Dumitrescu, Ropke, Cordeau, & Laporte, 2010; Hernández-Pérez & Salazar-González, 2009; Rodríguez-Martín & Salazar-González, 2011), or PDP with time windows (Cherkesly, Desaulniers, & Laporte, 2015; Ropke & Cordeau, 2009). The largest problem size that can currently be solved optimally contains around 500 requests with tight time windows using a branch-cut-price algorithm. A highly effective variant of the latter algorithm has been proposed, for instance, in Baldacci, Bartolini, and Mingozzi (2011). When transporting people, e. g., when routing ambulances, the one-to-one PDP is referred to as the Dial-a-Ride Problem, DARP for short (Cordeau & Laporte, 2007). The instances which are solved optimally are usually relatively small, with the largest containing 58 requests (Parragh, Cordeau, Doerner, & Hartl, 2012).

The *General Vehicle Routing Problem* (GVRP) resembles our definition, but without a total trip time (Goel & Gruhn, 2008). In addition, it generalizes our problem by allowing each request to entail a sequence of delivery locations, instead of having only a single delivery location. Therefore, column generation is a viable approach to ordering the multiple tasks associated with each request (Goel, 2010). Furthermore, the GVRP is approached by an improvement heuristic for reduced neighborhoods, which optimizes a tour using operations, such as insertions, swaps and relocations (Goel & Gruhn, 2008). However, the operators harness the fact that a request entails more than one delivery location, while being inept with only one drop-off. Accordingly, our work is closely linked to viable starting heuristics of the GVRP.

Table 1 summarizes recent studies on the Pickup and Delivery Problem. The problem size is measured by the number of objects or requests. Since one object is here associated with one pickup node and one delivery node, we report figures for which we divided the number of nodes by two for reasons of consistency.

The third characteristic of our problem, i. e., selective pickup, resembles the Knapsack problem in which the goal is to choose a profit-maximizing combination of requests that fits the vehicle's capacity and fulfills the delivery plan (e. g., constraints of time windows). Combined with routing, selective pickup appears as the *Orienteering Problem* (OP), whose aim is to find a route that visits as many *"checkpoints"* as possible in order to maximize rewards (Vansteenwegen et al., 2011). A similar problem is given by the *Attractive Traveling Salesman Problem*. The latter can, for instance, be optimally solved for instances of up to 400 vertices using branch-and-cut (Erdoğan, Cordeau, & Laporte, 2010).

In practice, carriers face a bid optimization on freight markets, which can be approach by finding an optimal combination of selective pickup and transportation requests. Accordingly, the exchange exploits complementary properties of different offers to find a suitable allocation, for instance, via combinatorial auctions (Caplice & Sheffi, 2006). Within the domain of trading on freight exchanges, several studies have investigated similar problems that incorporate routing: Song and Regan (2003) propose an approximation algorithm that searches feasible routes for forming optimal bids. A similar problem with up to 100 requests is solved by Schönberger and Kopfer (2005) using a memetic algorithm.