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A Biased-Randomised Large Neighbourhood Search for the two-dimensional Vehicle Routing Problem with Backhauls

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ABSTRACT

The two-dimensional loading vehicle routing problem with clustered backhauls (2L-VRPB) is a realistic extension of the classical vehicle routing problem where both delivery and pickup demands are composed of non-stackable items. Despite the fact that the 2L-VRPB can be frequently found in real-life transportation activities, it has not been analysed so far in the literature. This paper presents a hybrid algorithm that integrates biased-randomised versions of vehicle routing and packing heuristics within a Large Neighbourhood Search metaheuristic framework. The use of biased randomisation techniques allows to better guide the local search process. The proposed approach for solving the 2L-VRPB is tested on an extensive set of instances, which have been adapted from existing benchmarks for the two-dimensional loading vehicle routing problem (2L-VRP). Additionally, when no backhauls are considered our algorithm is able to find new best solutions for several 2L-VRP benchmark instances with sequential oriented loading, both with and without items rotation.

1. Introduction

The Vehicle Routing Problem (VRP) is a well-known combinatorial optimisation problem in which a fleet of vehicles has to service a set of customers at the lowest possible cost (Golden, Raghavan, & Wasil, 2008; Toth & Vigo, 2014). The most basic variant of the VRP is the Capacitated Vehicle Routing Problem (CVRP), and more complex versions are built upon it. In the CVRP, it is assumed that there is a homogeneous fleet of vehicles with restricted capacity, based at a central depot, which is used to satisfy customers' demands by visiting them only once. Additional restrictions, such as distance or time-based constraints, are often considered in richer variants of the problem. The CVRP and richer versions have been extensively studied due to their potential applicability on real-life transportation activities (Cáceres-Cruz, Arias, Guimarans, Riera, & Juan, 2014; Lahyani, Khemakhem, & Semet, 2015). Moreover, the CVRP is regarded as a NP-Hard problem, and so are its extensions. Hence, it constitutes a challenging problem and a rich environment to develop new methods, either exact or approximate (Cordeau, Gendreau, Hertz, Laporte, & Sormany, 2005; Laporte, 1992).

In this paper, we consider a realistic variant of the CVRP that combines vehicle routing and loading (packing) aspects as well as backhauls. This variant is an extension of the Two-dimensional Capacitated Vehicle Routing Problem (2L-VRP) (Iori, Salazar, & Vigo, 2007), where customers' demands consist of a set of rectangular items that cannot be stacked due to their weight, dimensions, or fragility. Our work was originally motivated by real-life transportation activities at Opein (www.opein.com), a medium-sized company which provides industrial equipment to its customers, mostly in the building-construction field. Opein has to periodically deliver and pickup a large variety of industrial machinery, namely aerial-work platforms, energy-generation sets, compressors, dumpers, forklifts and professional cleaning equipment. Similar issues arise in other industries where large-sized items pickup and delivery is also required, e.g. furniture or appliances. These items must be efficiently packed on the truck surface to attain a high vehicle's utilisation. Thus, one needs to consider not only the items weight, but also their length and width. For the purposes of this paper, we consider these items to be of rectangular shape, and we assume they cannot be piled up or overlap.

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Several variants of the 2L-VRP have been defined, depending on constraints on the loading configuration: *(i)* oriented loading (OL), where items cannot be rotated; *(ii)* non-oriented or rotated loading (RL), allowing items to be rotated 90° when loaded on the vehicle; *(iii)* sequential loading (SL), where items should be loaded in reverse order to the customers' visits, as they cannot be rearranged inside the vehicle once the route has started; and *(iv)* unrestricted loading (UL), allowing items rearrangement during the distribution process. The different combinations of the aforementioned constraints yield a classification into four 2L-VRP variants: *(i)* two-dimensional sequential oriented loading (2|*SO*|*L*); *(ii)* two-dimensional sequential non-oriented (rotated) loading (2|*SR*|*L*); *(iii)* two-dimensional unrestricted oriented loading (2|*UO*|*L*); and *(iv)* two-dimensional unrestricted non-oriented (rotated) loading (2|*UR*|*L*). So far, only Fuellerer, Doerner, Hartl, and Iori (2009) have solved all four problem variants. In fact, only Fuellerer et al. (2009) and Dominguez, Juan, and Faulin (2014b) have addressed the non-oriented loading configurations (see Section 3). In this work, we consider both oriented and non-oriented cases combined with sequential loading (2|*SO*|*L* and 2|*SR*|*L*, respectively). Sequential loading might be a frequent requirement in real-life distribution practices, since unloading and re-loading heavy machinery might represent a significant cost in terms of both time and resources. In our opinion, allowing items rotation is also a realistic assumption that has shown to attain significant savings when compared to oriented configurations (Dominguez et al., 2014b).

As an industrial machinery hire company, Opein also needs to fetch their equipment at the end of the hiring lease. These add a considerable burden to their logistics and yields separate problems for delivery and pickups, dealing with spatial and capacity constraints in both cases. Backhauling has been proven to be an efficient way to achieving significant savings (Golden, Baker, Alfaro, & Schaffer, 1985). In the Vehicle Routing Problem with Backhauls (VRPB), the set of customers is divided into delivery locations (*linehaul*) or pickup points (*backhaul*). The critical assumption is that all deliveries must be made on each route before any pickups can be made (i.e. clustered backhauls). This arises from the fact that the vehicles are rear-loaded, and rearrangement of the loads on the trucks at the delivery points is not deemed economical or feasible (Goetschalckx & Jacobs-Blecha, 1989). This is also coherent with our selection of sequential loading variants of the 2L-VRP. In addition, no route can contain only backhaul customers, although linehaul-only routes are allowed. Fig. 1 shows an example of a route containing linehaul and backhaul customers and its corresponding packing plans. Notice that items have been loaded on the vehicle in inverse order to the visits for linehaul customers, while items picked up at backhaul locations are loaded in sequential order.

This article proposes a hybrid algorithm for solving the Two-dimensional Capacitated Vehicle Routing Problem with clustered Backhauls (2L-VRPB), considering sequential loading and items rotation. To the best of our knowledge, this is the first time this problem is tackled in the literature. Only Malapert, Guéret, Jussien, Langevin, and Rousseau (2008) have previously studied the combination of both problems, but without considering items rotation. Our proposed method combines a Large Neighbourhood Search (LNS) metaheuristic framework (Pisinger & Røpke, 2010) with biased-randomised versions of classical routing and packing heuristics. Biased randomisation of heuristics refers to the use of skewed probability distributions to induce an oriented (i.e. biased) random behaviour of the heuristic, transforming a deterministic method into a probabilistic algorithm often suitable for multi-start and parallel approaches (Juan et al., 2009). In our case, we use a biased-randomised version of the well-known Clarke and Wright savings heuristic for the CVRP (Clarke & Wright, 1964), enhanced with memory-based techniques (Juan et al., 2011). In order to deal

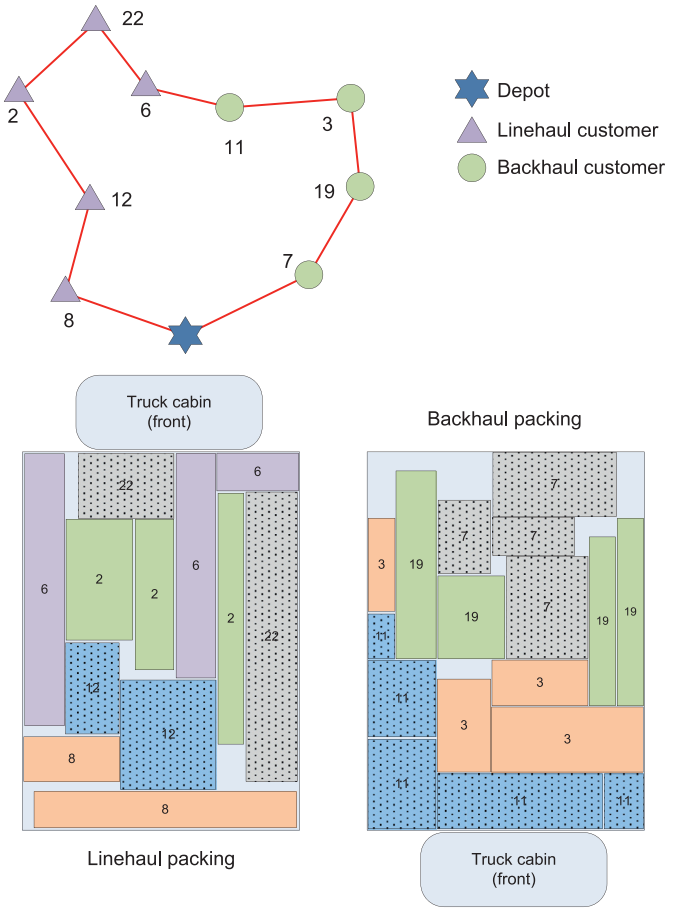

Fig. 1. Example of a combined linehaul–backhaul route with two packing plans.

with backhauls, we omit all edges connecting backhaul locations to linehaul customers, so a vehicle is not allowed to perform any delivery once it visits the first backhaul customer in its route. We integrate the packing process within our randomised savings-based heuristic. To compute packing plans, we use biased-randomised versions of the Best-Fit heuristic (Burke, Kendall, & Whitwell, 2004) and the Touching Perimeter algorithm (Lodi, Martello, & Vigo, 1999). This process is used to check feasibility before merging any two routes in our routing heuristic. Our results show that the proposed approach is an efficient way of solving the 2L-VRPB with oriented and non-oriented loading, as we show in Section 5. In addition, our method has been able to generate new best-known solutions for benchmark instances of the 2L-VRP with sequential loading, both with and without rotation (2|*SR*|*L* and 2|*SO*|*L*, respectively).

The remaining of this paper is structured as follows. We first formally introduce the 2L-VRPB problem in detail in Section 2 and provide an overview on related work in Section 3. A detailed description of our Large Neighbourhood Search with biased randomisation approach is given in Section 4. Section 5 describes some numerical experiments that contribute to illustrate and validate our approach. Finally, Section 6 summarises the main contributions and results of this work.

2. Problem definition

In the 2L-VRPB a complete undirected graph $G = (V, E)$ is given, where $V = \{0\} \cup L \cup B$ is a set of $1 + n + m$ vertices: the vertex 0 corresponds to the depot, while disjoint subsets $L = \{1, \ldots, n\}$ and $B = \{n + 1, \ldots, n + m\}$ represent linehaul and backhaul customers,