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A hybrid column generation approach for an industrial waste collection routing problem

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ABSTRACT

This paper presents a practical roll-on/roll-off routing (ROROR) problem arising in the collection of industrial waste. Skip containers, which are used for the waste collection, need to be distributed between, and collected from, a set of customers. Full containers must be driven to dump sites, while empty containers must be returned to the depot to await further assignments. Unlike, the traditional ROROR problem, where vehicles may transport one skip container at a time regardless of whether it is full or not, we consider cases in which a vehicle can transport up to eight containers, at most two of which can be full. We propose a generalized set partitioning formulation of the problem and describe a hybrid column generation procedure to solve it. A fast Tabu Search heuristic is used to generate new columns. The proposed methodology is tested on nine data sets, four of which are actual, real-world problem instances. Results indicate that the hybrid column generation outperforms a purely heuristic approach in terms of both running time and solution quality. High quality solutions to problems containing up to 100 orders can be solved in approximately 15 min.

1. Introduction

This paper focuses on a routing problem that arises in connection with the disposal of bulky waste using large containers. In a complex world where environmentally friendly solutions and recycling are on the top of the agenda, waste management systems become even more complicated. This has forced municipalities to prioritize and implement cost-effective solutions to deal with all kinds of waste. Here, we consider waste that comes from industry and which must be transported to dump sites using containers.

This particular problem belongs to the roll-on/roll-off routing (ROROR) class of problems that already exist in the literature. The ROROR problem is a variant of the very general framework of the Rich Vehicle Routing Problem (RVRP) – see e.g. Drexl (2012) and Schmid and Doerner (2010). As we will see, the ROROR problem can be specialized further depending on the different characteristics and constraints of the problem.

We will in this paper look at a specific variant of the ROROR problem in order to demonstrate how optimization-based methods and metaheuristics together can result in efficient problem solving and a flexible framework. Pratical ROROR problems are today solved using very simple heuristics approaches because the constraints and characteristics make an exact approach challenging to implement and the solution time potentially intractable. In addition, all ROROR problems are subtly different and therefore a framework that can be modified is necessary, and this flexibility is difficult to get with an exact approach. Companies that build software for the waste management industry therefore rely on a range of flexible heuristic framework. Finally, we also see this paper as a vehicle to push the use of optimization-based methods and metaheuristics to a wider range of vehicle routing problems than just the ROROR. Many of the problems within the general definition of Rich Vehicle Routing Problems would be interesting to study using framework developed in this paper.

Simple extensions include a maximum number of trucks, many types of goods (different types of containers), capacity constraints and multiple depots. The more complex features of the problem include the introduction of disposal facilities as well as four different order types, each requiring several visits at depots, customers and/or dump sites.

Golden, Assad, and Wasil (2002) gives an introduction to waste collection as a vehicle routing problem component of the overall waste management process. A classification of ROROR problems into residential, commercial and industrial is also provided. Whereas residential problems are mainly viewed as arc routing

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problems, the ROROR problem is in general seen as a vehicle routing problem where nodes are used to represent depots, dump sites and customers. The ROROR problem is often characterized by a number of different *trip types*, which together comprise a complete tour for a vehicle. As an example, the following sequence of trip types would describe a complete tour for a truck starting and ending at the same depot: the truck leaves depot, it drives empty to a customer, here it picks up a container, the truck then empties the container at a dump site and transports the empty container back to customer before returning to its depot.

To the best of the authors' knowledge, the first paper defining the ROROR problem is Bodin, Mingozzi, Baldacci, and Ball (2000). Here, a problem set up with a single depot and a single dump site is presented, and four different heuristics are devised based on seeing the problem as a combined vehicle routing and bin packing problem.

The ROROR problem we consider closely resembles the problem studied by Baldacci, Bodin, and Mingozzi (2006); the order types are practically the same, there are different sizes and shapes of containers, and the available dump sites and depots vary depending on which order is considered. However, one major difference exists. Namely, the capacity. In the problem presented by Baldacci et al. (2006), each vehicle can transport at most one container. It is therefore not possible to mix the visits related to different orders. As soon as a vehicle has picked up a container for one order, it cannot attend another order before it has delivered the container in question, at which point the first order is completed. The problem presented by Blanc, Krieken, Krikke, and Fleuren (2006) considers using vehicles with a capacity of two containers and is concerned with the collection of containers that are being scraped. The authors describe an enumeration approach for generating a large set of routes.

Archetti and Speranza (2004) refer to the problem as the *skip collection* problem and study several interesting features such as different waste types, multiple dump sites, priorities and time windows. Again the solution approach is based on a heuristic algorithm. In addition, De Meulemeester, Laporte, Louveaux, and Semet (1997) consider a skip collection problem with industrial as well as domestic customers and four different trip types. As in most papers within the area, the capacity of a vehicle is assume to be one container.

More recent papers within the area are Wy and Kim (2013) and Wy, Kim, and Kim (2013). The authors propose metaheuristic solution approaches and add more realistic constraints like time windows, changing service types and heterogeneous vehicle fleet to the ROROR problem. The problem instances contain between 50 and 200 orders for their instances.

Our main contribution is to describe and implement a solution approach for a variant of the ROROR where multiple containers can be stacked on top of each other, and, in addition, we focus on an approach that combines the exact approach of column generation with advanced metaheuristics. This gives a solution approach that exploits the benefits of state-of-the-art exact approaches for RVRP's with the flexibility of metaheuristics.

The rest of the article is structured as follows. In Section 2, we define the problem considered in more detail and include a review of existing literature on related problems. Section 3 presents the model we propose and discusses the devised solution approach. The algorithm is tested extensively in Section 4, where comparisons are made between the developed algorithm and the purely heuristic approach currently being used by our industrial partner. Finally, conclusions and directions for future work are summarized in Section 5. The main contributions of this paper is twofold; first we describe a solution approach to a real-life routing problem and secondly we describe a hybrid approach between exact methods and heuristic approaches.

2. Problem description

As mentioned previously, the problem under consideration deals with transportation of bulky waste containers. A problem instance is defined by a set of *orders*, a set of *locations*, and a set of *trucks* that can be used for handling the orders. An order consists of *picking up* and/or *delivering* and/or *emptying* a container at a specific location, which can be one of the three following types. A *customer* location refers to the order of a certain customer, whose location is the geographical location of the customer. A *dump site* refers to the place where containers must be taken for emptying. Full containers must be taken to a site before they can be taken anywhere else. Note that it is not permitted to leave an empty container at a dump site. Finally, a *depot* denotes the location where empty containers are stored and collected from.

There are four types of orders in the problem, all of which involve visiting some or all of the location types defined above. The first type is termed the *pickup* order. This entails picking up a full container of waste from one of the customers and transporting it to a dump site. The empty container is then returned to a depot.

A *delivery* order is defined similarly. It simply entails delivering an empty container to a particular customer.

A combination of a pickup order and a delivery order is termed a *swap*. Here, an empty container is picked up at a depot and transported to the customer. At the customer the empty container is put down to replace a full container. The full container is picked up during the same visit and taken to a dump site to be emptied. It is then returned to a depot.

A so-called *change* order resembles the pickup order; however, instead of taking the empty container back to a depot, it must be returned to the customer from whom it was picked up earlier. Fig. 1 gives an example of this. Such an order is used if there is not enough free space at the customer for performing a swap, or if the company does not have ownership over the container.

Despite the fact that bulky waste containers are large, some trucks can carry more than one at a time. Orders that involve visiting the same locations can be handled simultaneously to save time and money. An example of this is illustrated in Fig. 2, where two customers are located close to each other, but far from the dump site. Here it is advantageous to visit both customers prior to visiting the dump site.

We now briefly describe several features, and extensions, that concern dump sites, depots, the capacity of the trucks, and the order structure. In many vehicle routing problems (VRPs), each order corresponds to a single visit, namely a visit to the customer who placed the order. In this problem, any order consists of several *sequenced* visits. For example, the swap order consists of picking up an empty container at a depot (visit 1), delivering the empty container and picking up a full container at the customer (visit 2), emptying the full container at a dump site (visit 3), and returning the now empty container to a depot (visit 4). As is shown in Fig. 2, visits belonging to the same customer do not necessarily have to be scheduled immediately after each other; the vehicle is allowed to visit customer B between two visits that are related to order A (the visit at customer A and the visit at the dump site). Furthermore, the visit at the dump site in Fig. 2 is actually the dump site visit for both orders A and B since the containers of both these orders are emptied during the visit. Even though visits of the same order are not required to be performed immediately after each other, they must be performed by the same vehicle and in the correct order. This means that if the first visit of a swap order is assigned to some vehicle, then that vehicle will also have to perform visits 2, 3 and 4 of that order later on its route. For customer visits, we assume that we can pick up (and/or deliver) the container at any time during the working hours of a typical day. That is,