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The generalized rollon-rolloff vehicle routing problem and savings-based algorithm

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ABSTRACT

Taking the waste collection management as the practical background, the rollon-rolloff vehicle routing problem (RRVRP) involves tractors pulling large containers between customer locations and the disposal facility. Each used-tractor begins and ends its route at the depot. Customer demand includes emptying a full container, ordering an empty container or changing a container. The objective is to find tractor routes that feature the minimum amount of total nonproductive time. In the literature the RRVRP is formulated as the node routing problem, and the "trip" definition that is the complete transport service of a container is used. To relax some assumptions of the RRVRP to cater to practical desires, we present a variant called the generalized RRVRP (G-RRVRP). The G-RRVRP generalizes the practical background, the objective function and the demand flow, and considers specially container loading and unloading time constraints. The G-RRVRP classifies demand into loaded-container demand and cargo demand with time windows. On condition of respecting container loading/unloading time and customer time windows, the G-RRVRP can design tractor routes for the synchronous scheduling of loaded and empty containers so as to ensure the timeliness of transport service. The G-RRVRP aims to minimize the total running cost of used tractors, instead of the total nonproductive time of tractors adopted by the RRVRP. A mixed integer linear programming model for the G-RRVRP is proposed. The Benders decomposition algorithm involving Pareto-optimal cuts and Benders decomposition-callback implementation, and a two-stage heuristic involving the savings algorithm followed by a local search phase are provided. The mathematical formulation and the two-stage heuristic are tested by solving 40 small-scale instances and 20 benchmark instances. Small-scale instances can be solved directly by CPLEX through the Benders decomposition strategies to find exact solutions. The case study indicates the applicability of the G-RRVRP model and the two-stage heuristic to realistic-size problems abstracted from intercity linehaul systems. The computational experiments and case study indicate that the heuristic can solve various instances of the G-RRVRP such that the solution quality and the computation time are acceptable.

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1. Introduction

So far researchers have put forward several kinds of vehicle routing problems (VRPs) catering to waste collection management, one of which is the rollon-rolloff vehicle routing problem (RRVRP). The basic form of the RRVRP was presented by Bodin et al. (2000). The RRVRP involves one depot for holding tractors and one disposal facility for emptying full-containers. Each used-tractor begins and ends its route at the depot. Customer demand includes emptying a full container, ordering an empty container or replacing a full container with an empty container. Tractors pull large containers between customer locations and the disposal facility. Tractors can only move one container to serve one customer at a time (Kim et al., 2006). The objective is to find tractor routes that feature the minimum of total nonproductive time. In nonproductive time tractors run alone on arcs.

The waste collection management is the practical background of the RRVRP. Formulating the RRVRP as the node routing problem, Bodin et al. (2000) presented the RRVRP on a directed complete graph $G=(V, A)$. A is the arc set. V is the vertex set that consists of one depot, one disposal facility which is also regarded as an unlimited inventory of empty containers, and an amount of customer locations. Customer demand is classified into several types of trips served by tractors. A “trip” is defined to be the complete service of a container for a customer. Four types of trips (i.e., Type 1, Type 2, Type 3, and Type 4) are defined in the RRVRP stated by Bodin et al. (2000). For the Type 1, a full container is transported by a tractor from a customer to the disposal facility for emptying, and the emptied container is returned to the customer by the same tractor. For the Type 2, an empty container is exchanged with a full container at a customer location. For the Type 3, an empty container is brought to a customer. For the Type 4, a full container from a customer is transferred to the disposal facility. The service time of a trip includes container loading/unloading time and traveling time. The loaded container leg and the empty container leg are integrated in the first or the second type of trips.

In the literature several variants of the RRVRP have been proposed, which are characterized by the involved service types, time windows, etc. De Meulemeester et al. (1997) solved a variant associated with the collection and delivery of skips. A tractor can carry only one skip at a time. In one skip a tractor departing from a depot transports a full container from a customer location to a disposal site. Bodin et al. (2000) solved the RRVRP through several heuristics, and twenty benchmark instances ranging from 50 to 199 trips and belonging to four classes (i.e., class A, B, C, or D) were used. In each class there are five test problems. The four classes differ in the mix of Type 1, Type 2, Type 3, and Type 4 trips. The number of trips in the five test problems in each class is 50, 75, 100, 150, and 199 trips, respectively. The class A problems have a preponderance of Type 1 trips, the class B problems have about the same number of Type 1 and Type 2 trips, and the class C problems have a preponderance of Type 2 trips. All class A, class B, and class C problems have only a few Type 3 and Type 4 trips. The class D problems have about the same number of Type 1, Type 2, Type 3, and Type 4 trips. Derigs et al. (2013) combined local search and large neighborhood search to solve the twenty benchmark instances provided by Bodin et al. (2000). Wy and Kim (2013) adopted a large neighborhood search and various improvement methods to solve the RRVRP. New best-known solutions are found for seventeen instances out of the twenty benchmark instances of Bodin et al. (2000). Baldacci et al. (2006) proposed the multiple disposal facilities and multiple inventory locations RRVRP (M-RRVRP). Five types of trips are considered. A bounding procedure combining three lower bounds derived from different relaxations of the M-RRVRP formulation is provided. Wy et al. (2013) presented the RRVRP with time windows (RRVRPTW) considering multiple disposal facilities and multiple inventory locations. Hauge et al. (2014) addressed another type of the RRVRP in which four types of trips, multiple depots, multiple disposal facilities and various container types are considered.

Despite the widely practical application of waste collection problems, many important realistic features are often ignored in the literature (Markov et al., 2016). Both practitioners and researchers are striving to find more suitable ways to tackle various practical situations, since the situations that waste collection enterprises may face vary. Most of the optimization techniques used for tactical and operational situations derive from methods for the RRVRP and some variants (e.g., the RRVRPTW). To make some assumptions of the RRVRP to be more practical and to generalize the situation of the RRVRP, we present in the paper a new variant called the generalized rollon-rolloff vehicle routing problem (G-RRVRP). Compared with the RRVRP, the G-RRVRP generalizes the practical background, the objective function and the demand flow, and considers specially container loading and unloading time constraints. On condition of respecting container loading/unloading time and customer time windows, the G-RRVRP provides tractor routes for the synchronous scheduling of loaded and empty containers so as to ensure the timeliness of transport service.

The G-RRVRP is based on the RRVRP defined by Bodin et al. (2000). The G-RRVRP caters to practical issues and is more general and complicated than the RRVRP models discussed in previous literature. The motivation for generalizing the RRVRP to the G-RRVRP is as follows.

(i) As shown by the computational results in Pradenas et al. (2013), the types of vehicles and the use rates of vehicles are of importance to the total cost of vehicle routes. Considering the constitution modes of the autonomous and non-autonomous parts, truck vehicles can be classified into two types (Drexl, 2013): single-unit trucks and combination trucks. The tractor-container combination is one type of combination trucks. The RRVRP employs the tractor-container combination for waste collection management. The tractor-container combination allows increased use rate of the tractor. Both the waste collection management and the intercity linehaul system are the practical backgrounds of the G-RRVRP. The tractor cannot directly load cargoes, and is only used for pulling containers. In practice a tractor can travel with a loaded-container, travel with an empty container, or travel alone. The combinations with various