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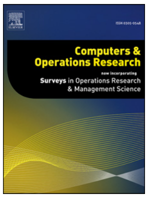

Stochastic local search with learning automaton for the swap-body vehicle routing problem

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ABSTRACT

This work presents the stochastic local search method for the Swap-Body Vehicle Routing Problem (SB-VRP) that won the First VeRoLog Solver Challenge. The SB-VRP, proposed on the occasion of the challenge, is a generalization of the classical Vehicle Routing Problem (VRP) in which customers are served by vehicles whose sizes may be enlarged via the addition of a swap body (trailer). The inclusion of a swap body doubles vehicle capacity while also increasing its operational cost. However, not all customers may be served by vehicles consisting of two bodies. Therefore swap locations are present where one of the bodies may be temporarily parked, enabling double body vehicles to serve customers requiring a single body. Both total travel time and distance incur costs that should be minimized, while the number of customers visited by a single vehicle is limited both by its capacity and by a maximum travel time. State of the art VRP approaches do not accommodate SB-VRP generalizations well. Thus, dedicated approaches taking advantage of the swap body characteristic are desired. The present paper proposes a stochastic local search algorithm with both general and dedicated heuristic components, a subproblem optimization scheme and a learning automaton. The algorithm improves the best known solution for the majority of the instances proposed during the challenge. Results are also presented for a new set of instances with the aim of stimulating further research concerning the SB-VRP.

1. Introduction

The Swap-Body Vehicle Routing Problem (SB-VRP) was proposed by the EURO Working Group on Vehicle Routing and Logistics Optimization (VeRoLog) and the PTV Group at the First VeRoLog Solver Challenge (Heid et al., 2014). It is a generalization of the classical Vehicle Routing Problem (VRP) based on real problems faced by industry.

The classical VRP is one of the most studied problems in combinatorial optimization and is defined under capacity and route length constraints (Cordeau et al., 2007). The SB-VRP primarily differs from the VRP insofar as vehicles consist of either one or two bodies (trailers). The lengthened vehicles are called trains and have exactly twice the capacity of the regular vehicles (trucks). Fig. 1 shows an example of a truck, a swap body (with a trailer) and a train, respectively.

Customers have individual demands and must be served by exactly one vehicle. Three types of customers are considered: those who can only be reached by trucks, those who can be served by both trains and trucks, and those whose demands exceed the capacity of a truck and must be attended to by trains. Customers are geographically dispersed. Travel times and distances between all locations are given.

In addition to the depot and customers' locations, swap locations are present, where one of the bodies of a train may be temporarily left, enabling the vehicle to serve customers with a single body (truck).

The SB-VRP considers both total time and distance to derive costs that should be minimized. These costs vary depending on whether the considered vehicle is a train or truck. Furthermore, additional costs for operations at swap locations are also considered. Vehicles routes are limited by both their capacity and a maximum travel duration.

The present paper proposes a stochastic local search heuristic approach to the problem. Initially, a naive solution is quickly built. Different intensification and diversification strategies are subsequently applied to improve the solution. These strategies include a subproblem optimization scheme and different neighborhood structures, both of which are embedded in a metaheuristic

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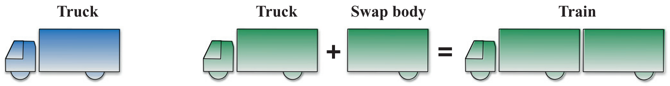

Fig. 1. Vehicle type examples.

framework. A preprocessing procedure reduces the solution space and thus dramatically increases the heuristic's efficiency. The stochastic local search won the First VeRoLog Solver Challenge and continues to outperform all other proposed approaches for the problem.

The approach has significant practical relevance for a range of business activities including production, distribution and also the transportation sector more generally. The delivery of both perishable and urgently-required goods (fuel, for example), which almost always necessitates transportation by road, becomes greatly optimized. Indeed, very often the transportation costs associated with such products are disproportionate when compared against the cost of the products themselves. Furthermore, the approach ensures efficiency with regard to a number of important economic and ecological factors such as: the number of vehicles, number of drivers, travel distance and time, and the environmental impact.

The present work is organized as follows. Section 2 details the problem. Section 3 presents a literature overview about the SB-VRP and related work. The proposed algorithm is introduced and described within Section 4. The neighborhood structures considered for the local search are discussed in Section 5. Section 6 presents computational experiments and, finally, Section 7 summarizes the conclusions and indicates future research directions.

2. Problem description

The SB-VRP is a generalization of the classical VRP and, by consequence, is an NP-Hard problem. It can be defined on a graph $G = (V, A)$, where the vertices V are the locations and the arcs A are the connections between these locations. Three vertex categories are considered: depot, customers and swap locations. A single depot vertex is defined.

The customers, represented by the subset $C \subset V$, are divided into three groups: truck-only ($C_1 \subseteq C$), flexible ($C_2 \subseteq C$) and train-only ($C_3 \subseteq C$). These groups are defined according to the types of vehicle that can be employed to visit the customers. Truck-only customers can only be attended to by trucks, flexible customers can have their demands satisfied by both trucks and trains, and train-only customers require trains.

All customers $i \in C$ have an associated demand q_i and service time s_i. These demands must be satisfied with exactly one visit. Since the capacity of a swap body is given by constant Q, truck-only and flexible customers' demands must be bounded by Q, such that $q_i \leq Q \ \forall i \in C_1 \cup C_2$. Contrastingly, train-only customers have demands that trucks cannot satisfy, therefore implying $Q < q_i \leq 2Q$ $\forall i \in C_3$.

Swap locations, represented by the subset $S \subset V$, are associated with neither demand nor service time. Nevertheless, depending on the operation executed at a swap location, a certain amount of time is consumed. In total, four operations are possible at a swap location, each consuming varying amounts of time:

park : leaves the back swap body of the train at the swap location;

exchange : leaves the front swap body of the train at the swap location;

pickup : picks up the swap body that was left at a swap location;

swap : leaves the currently attached swap body and picks up the swap body that was left at the swap location.

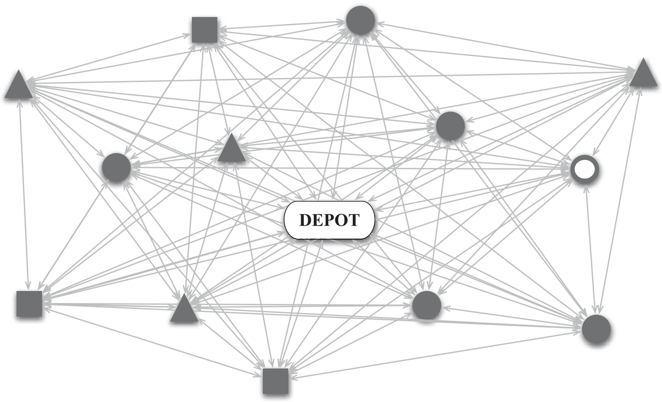

Fig. 2. Graph representation of a small SB-VRP instance.

As Miranda-Bront et al. (2017) have highlighted, the consumed capacity of the bodies may be distributed across routes such that the first action on a swap location is always *park*. *Exchange* generally requires more time than *park*, and thus employing *park* rather than *exchange* results in less time spent in a swap location.

Each arc $(i, j) \in A$ connects location i to location j, has a distance d_{ij} and a travel time t_{ij}. Note that the distances and travel times are asymmetric, meaning d_{ij} and t_{ij} are not guaranteed to be equal to d_{ji} and t_{ji} respectively.

Fig. 2 shows a graph representation of a small SB-VRP instance. Triangles represent swap locations, squares indicate truck-only customers, filled circles denote flexible customers and, finally, open circles identify train-only customers.

Vehicles must leave and return to the depot with the same swap bodies. Crucially, routes must begin and end in the depot and swap bodies may not be exchanged between vehicles. Therefore, if a vehicle leaves a swap body in a swap location, the body must be retrieved later by the same vehicle. Henceforth, the part of the route that comprises of the customers between the two swap location visits will be referred to as a sub-route.

All routes must respect capacity constraints and a maximum route duration T. Each route's duration is given by the sum of its travel times, service times and swap operation times.

In the SB-VRP considered the objective is to minimize the total operation cost, given by the sum of two components:

vehicle/driver costs : consisting of a fixed cost for using a vehicle, a cost per kilometer traveled and a cost per hour (driver's cost);

swap body costs : consisting of a fixed cost per additional swap body and a cost per kilometer traveled with it.

A sample solution for the problem depicted by Fig. 2 is shown in Fig. 3. This example employs three vehicles: one truck and two trains. Note that one of the routes (route 3) contains a sub-route, therefore indicating it utilizes a swap location. The swap location temporarily stores one of the vehicle's swap bodies, while it visits two truck-only customers. After visiting these two customers (or directly before finishing the sub-route), the vehicle reattaches the parked body and continues towards the next customers.

3. Literature review

The SB-VRP considered by this work was introduced recently in the literature. Huber and Geiger (2014) addressed the SB-VRP with an iterative variable neighborhood search (VNS) procedure. They employed a cluster-first route-second approach to produce initial solutions. Both sequential and parallel versions of the algorithm were evaluated. Lum et al. (2015) applied a VRP-Reduce