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Route design for last-in, first-out deliveries with backhauling

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ABSTRACT

The retail route design problem extends the capacitated vehicle routing problem with time windows by introducing several operational constraints, including order loading and delivery restrictions (last-in, first-out), order-dependent vehicle capacity, material handling limits at the warehouse, backhauling, and driving time bounds. In this paper, the problem is modeled on a directed network for an application associated with a major grocery chain. Because the corresponding mixed-integer program proved too difficult to solve with commercial software for real instances, we developed a greedy randomized adaptive search procedure (GRASP) augmented with tabu search to provide solutions. Testing was done using data sets provided Kroger, the largest grocery chain in the US, and benchmarked against a previously developed column generation algorithm. The results showed that cost reductions of $4887 per day or 5.58% per day on average, compared to Kroger's corresponding solutions.

1. Introduction

Major grocery chains and retail outlets require daily deliveries from one or more warehouses to restock their inventory and replenish perishable items. On the return trip, it is common for a subset of the vehicles to pick up salvage items (or "returns") from the stores and bring them back to the warehouse. The resulting problem, which we call the retail route design problem (RRDP) with backhauls extends the capacitated pickup and delivery vehicle routing problem with time windows (VRPTW) by incorporating context-specific considerations. As is in the traditional VRPTW, a vehicle corresponds to a truck-trailer combination that is assigned to a route for delivery of replenishment orders and pickup of salvage orders. In our context, it is assumed that there are a sufficient number of drivers, trucks and trailers available on any given day to meet the demand within the given time windows. The costs associated with a vehicle route consist of two components: (1) the travel cost incurred by each route on a per mile basis and (2) the driver idle time cost incurred when arriving too early at a store and having to wait for the start of the delivery and pick up windows.

In addition to the requirements in the traditional VRPTW, the RRDP investigated here has a number of practical and unique constraints. First, there are three types of delivery orders and one type of pickup order. The delivery orders are required to be loaded onto the truck in a particular sequence that ensures compliance with a last-in-first-out (LIFO) rule for the route (e.g. see Cherkesly et al., 2015); pickups can only begin after all deliveries are made. Second, the truck has pre-specified weight and volume limits. Separation curtains must be placed between different delivery order types for tem-

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perature control. The weight of the curtains can be ignored but not the volume, which reduces the capacity of a truck on that dimension. Third, the loading capacity at the warehouse must be taken into account on a 30-min basis, so only a limited number of vehicles can be loaded in each time slot. Lastly, the total time of a route and the actual time a driver is behind the wheel must adhere to certain legal restrictions and union regulations.

To model the RRDP, we first construct a route diagram in the form of a directed network in which each order is represented as a node and where the arcs capture possible transitions between the nodes. Based on this diagram, we developed a mixed-integer program (MIP) for the problem. However, because it was not possible to obtain solutions for realistic instances with a commercial code, we developed a column generation algorithm (Novoa et al., 2016) which produced good solutions when compared to current practice. Runtimes were on the order of hours, though, which proved impractical for daily planning. As an alternative, we then developed a greedy randomized adaptive search procedure (GRASP) grounded in the work Kontoravdis and Bard (1995) and Solomon (1987), which is the focus of this paper. In the construction phase, GRASP exploits the unsurprising observation that orders for the same store are usually served by the same route in high-quality solutions. In the improvement phase, we initially relied on tabu search to find local optima; however, we discovered that every solution is likely to have many degenerate neighbors, i.e., neighbors with the same cost as the current solution. This limits the extent to which the feasible region can be locally explored. To overcome this difficulty, we implemented a randomized variable neighborhood search as well as several augmented versions of tabu search.

Extensive testing was done to determine the best combination of procedures. The results showed that GRASP with tabu search in phase II edged out pure tabu search with random variable neighborhood search when both procedures were run for 30 min. In the second set of tests, we compared the GRASP solutions with our column generation approach as well as those provided by Kroger, the sponsoring company, and found that cost reductions averaging $6429 or more than 6.72% per day can be obtained with our heuristic.

Accordingly, the contributions of the paper are fourfold: (1) we investigate a new version of a pickup and delivery VRPTW in which vehicle capacity is order dependent; (2) we develop several solution algorithms that integrate a number a metaheuristic ideas; (3) we perform extensive comparisons of the considered approaches; and (4) we compare the solutions obtained with our best algorithm with a column generation heuristic and those obtained with an experimental set-partitioning code.

The rest of the paper is organized as follows. Section 2 presents the literature review, and Section 3 gives a formal description of the RDDP. This is followed by our MIP formulation in Section 4 and the development of alternative solution algorithms in Section 5 including a GRASP. In phase I of the GRASP, feasible solutions are constructed by sequentially inserting orders into existing routes, and in phase II we propose a variety of local improvement methods. Test results are included in Section 6 using seven days of data provided by Kroger, one of the largest grocery chains in the U.S. We close in Section 7 with some insights and suggestions for future research.

2. Related literature

The past two decades have witnessed an outsized interest in the VRPTW and its variants. Both branch and cut (e.g., see Lysgaard et al., 2004) and branch and price (e.g., see Bard et al., 2014; Azi et al., 2010) have been applied successfully to find exact solutions to instances with a 100 or more nodes. Cherkesly et al. (2015) investigated a problem similar to ours in which LIFO loading is a major consideration. To find solutions, they developed several branch-and-price-and-cut algorithms whose effectiveness was shown on instances ranging from 30 to 75 customers. As a variation, Prescott-Gagnon et al. (2009) developed a large neighborhood search algorithm that takes advantage of the power of branch-and-price. For more information on exact solution methods, see the surveys by Baldacci et al. (2012).

Various heuristics have also been proposed for the VRPTW. Bräysy and Gendreau (2005a, 2005b) present an extensive survey of related research that covers route construction algorithms, local search algorithms, and metaheuristics. Solomon (1987) discusses and compares several solution-construction approaches including saving heuristics, a nearest-neighbor heuristic, and insertion heuristics. He found that an insertion-type heuristic consistently gave good results. Various local search methods have also been developed to improve phase I solutions. Rochat and Semet (1994) present an insertion procedure to construct an initial solution followed by tabu search to improve the incumbent. Taillard (1993) developed two partition methods to speed up the tabu search for VRPs. Other variants of local search applied to these problems include granular tabu search (Toth and Vigo, 2003), variable neighborhood search (Kytöjoki et al., 2007), and large neighborhood search (Ergun et al., 2006). Also, see Kontoravdis and Bard (1995) for a GRASP to solve the VRPTW and Nagata et al. (2010) for a memetic algorithm.

An expansion of reverse logistics activities has led to a renewed interest in the study of the VRP with pickup and deliveries (PDP), that is, a VRP with demand for two types of services. Berbeglia et al. (2007) and Parragh et al. (2008) present extensive surveys. Depending on the problem context, some studies only allow vehicles to perform pickups after all the deliveries are made while others allow simultaneous pickups and deliveries (e.g., Bianchessi and Righini, 2007; Tasan and Gen, 2012). Various heuristics have been proposed to solve the PDP. Bent and Hentenryck (2006) present a two-stage hybrid approach in which a single simulated annealing algorithm is used in the first stage to decrease the number of routes while large neighborhood search is used in the second stage to reduce total travel cost. Bianchessi and Righini (2007) present and compare construction algorithms, local search algorithms, and tabu search. Their computational results give experimental evidence