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Heuristic methods for the fleet size and mix vehicle routing problem with time windows and split deliveries

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ABSTRACT

This paper proposes a scatter-search (SS) approach to solve the Fleet Size and Mixed Vehicle Routing Problem with Time Windows and Split Deliveries (FSMVRPTWSD). In the Vehicle Routing Problem with Split Deliveries (VRPSD), each customer can be served by more than one vehicle, as opposed to the classical VRP in which each customer is served only once. In the FSMVRPTW, the customers must be serviced within their time windows with minimal costs using a heterogeneous fleet. Experimental testing and benchmark examples are used to assess the merit of our proposed procedure. The results show that the proposed heuristics are competitive with the best results found in the literature.

1. Introduction

The classical vehicle routing problem (VRP) aims to find a set of routes with minimal cost (by finding the shortest path, minimizing the number of vehicles, etc.) and beginning and ending the route at the depot such that the known demand of all nodes is fulfilled. Each node is visited only once by only one vehicle, and each vehicle has a limited capacity. Selected formulations also include constraints on the maximum travel time.

The VRPSD is a variation of the classical VRP in which each customer can be served by more than one vehicle. Thus, for the VRPSD, in addition to the delivery routes, the quantity to be delivered to each customer by each vehicle must also be determined. The option of splitting a given demand makes it possible to service a customer whose demand exceeds the vehicle capacity. Splitting may also result in decreased costs. The vehicle routing problem with time windows and split deliveries (VRPTWSD) presents an extension of the VRPSD in which the time window restraints are added.

In the literature, three variants of a VRP with a heterogeneous fleet have been studied. The first was introduced by Golden, Assad, Levy, and Gheysens (1984) in which the variable costs were uniformly spread over all vehicle types with the number of available vehicles assumed as unlimited for each type. This version is addressed in this paper and is known as the fleet size and mixed vehicle routing problem (FSMVRP), the vehicle fleet mix (VFM) or the fleet size and composition VRP. The second version considers the variable costs that depend on vehicle type, a component that is neglected in the first version. The third version, referred to as the heterogeneous fixed fleet vehicle routing problem (HFFVRP), generalizes the second version by limiting the number of available vehicles of each type.

Lenstra and Rinnoy Kan (1981) have analyzed the complexity of the vehicle routing problem and have concluded that practically all vehicle routing problems are NP-hard (including the classical vehicle routing problem) because they are not solved in polynomial time. Because the FSMVRPTWSD is a combination of the FSMVRP, VRPTW and VRPSD, it remains NP-hard (Archetti, Savelsbergh, & Speranza, 2006; Dror & Trudeau, 1990; Dullaert, Janssens, Sorensen, & Vernimmen, 2002; Gendreau, Laporte, Musaraganyi, & Taillard, 1999; Solomon & Desrosiers, 1988; Taillard, 1999). Therefore, this observation makes a strong case for the application of heuristics and meta-heuristics to solve the problem.

This paper develops a scatter-search (SS) algorithm to solve the fleet size and mixed vehicle routing problem with time windows and split deliveries (FSMVRPTWSD). The algorithm proposed was adapted to solve three varieties of benchmark examples available in the literature: benchmark problems by Liu and Shen (1999) for the FSMVRP, benchmark problems by Ho and Haugland (2004) for the VRPSD, and benchmark problems by Solomon (1987) for the VRPTW.

The organization of this article is as follows. Section 2 reviews the literature on VRPSD and its extensions as well as FSMVRP and its extensions. Section 3 presents the problem definition, including the mathematical formulation, and Section 4 covers the scatter-search overview. Section 5 describes the constructive heuristics and the scatter-search approach proposed for solving the

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model. Section 6 presents the computational results, and conclusions are stated in the Section 7.

2. Literature review

2.1. Literature review for the VRPSD and its extensions

The vehicle routing problem with split deliveries (VRPSD) was introduced in the literature by Dror and Trudeau (1989, 1990), who presented the mathematical formulation of the problem and analyzed the savings that result when a customer is served by more than one vehicle; this situation creates economy with respect to both to the number of vehicles and the total distance traveled.

Dror, Laporte, and Trudeau (1994) have presented an integer programming formulation of the VRPSD, developed several families of valid inequalities, and established a hierarchy between these types. A constraint relaxation branch-and-bound algorithm for the problem was also described.

Frizzell and Giffin (1992, 1995) have developed construction and improvement heuristics for the VRPSD with grid network distances. In their second publication, they also considered the time window constraints.

Mullaseril, Dror, and Leung (1997) have described a feed distribution problem encountered on a cattle ranch in Arizona. The problem is cast as a collection of capacitated rural postman problems with time windows and split deliveries. They presented an adaptation of the heuristics proposed by Dror and Trudeau (1990).

Belenguer, Martinez, and Mota (2000) have proposed a lower bound for the VRPSD based on a polyhedral study of the problem that includes new valid inequalities. The authors developed a cutting-plane algorithm to solve small instances, and for larger instances, the integer values are obtained via a branch-and-bound approaches.

Archetti, Savelsbergh, et al. (2006) have performed a worst-case performance analysis for the vehicle routing problem with split deliveries. The authors have shown that the cost savings realized by allowing split deliveries is at most 50%. They also studied the variant of the VRPSD in which the customer demand may be larger than the vehicle capacity but each customer must be visited a minimum number of times. Archetti, Speranza, and Hertz (2006) have described a tabu search algorithm for the VRPSD. With each iteration, a neighboring solution is obtained by removing a customer from a set of routes in which it is currently visited and subsequently inserting it either into a new route or into an existing route with sufficient residual capacity. The algorithm also considers the possibility of inserting a customer into a new route without removing it from the old route.

Ho and Haugland (2004) have developed a tabu search algorithm for the VRPTWSD. The first stage constructs a VRP solution using node interchanges, and the second stage improves the VRP solution by introducing and eliminating splits. A pool of solutions is defined by different move operators, and the best solution in the current pool is always chosen.

Belfiore and Yoshizaki (2009) have proposed a scatter-search algorithm to solve a real-life heterogeneous fleet vehicle routing problem with time windows and split deliveries that occurred in a major Brazilian retail group. The results show that the total distribution cost can be reduced significantly when such methods are used.

2.2. Literature review for the VRP with a heterogeneous fleet and its extensions

Golden et al. (1984) developed a savings heuristic to solve the fleet size and mixed vehicle routing problem in addition to techniques for generating a lower bound and an underestimate of the optimal solutions. A new savings heuristic for the FSMVRP based on successive route fusion was presented by Desrochers and Verhoog (1991). In each iteration, the best fusion is selected by solving a weighted matching problem.

A mathematical programming formulation for the FSMVRP was presented by Gheysens, Golden, and Assad (1984). Gheysens, Golden, and Assad (1986) developed a two-stage general assignment-based heuristic that uses Golden et al.'s lower bound procedure to determine the fleet composition for use in the second phase of a generalized assignment heuristic.

A seven-phase improvement heuristic for the fleet size and mixed vehicle routing problem was developed by Salhi and Rand (1993). The aims were to match the total demand of a given route to an appropriate vehicle capacity, to eliminate an entire route by dropping its customers and inserting them into other routes, to reallocate customers from a given route to other routes such that a route could be served by a smaller vehicle (if profitable) and to either combine routes with a small total demand into fewer routes with a larger total demand or split larger routes into smaller ones.

Rochat and Semet (1994) proposed a tabu search approach for delivering pet food and flour in Switzerland. The company serves its customers out of one depot using a heterogeneous fixed fleet, and the customers are characterized by time windows and accessibility constraints. The last constraint refers to selected customers that cannot be served by the same vehicle.

A tabu search procedure for the multi-trip vehicle routing and scheduling problem (MTVRSP) was proposed by Brandão and Mercer (1997) in which each vehicle can make several trips per day.

Gendreau, Laporte, Musaraganyi, and Taillard (1999) have proposed a tabu search algorithm for the FSMVRP. The initial solution is obtained through the GENI (Generalized Insertion) algorithm. A post-optimization phase known as US (Unstringing and Stringing) is implemented after GENI. The tabu search is based on an adaptive memory procedure (AMP) developed by Rochat and Taillard (1995), and new variants of the tabu search for the FSMVRP are developed by Wassan and Osman (2002). These variants use a mix of different components, including reactive tabu search concepts, variable neighborhoods, special data memory structures and hashing functions.

Several insertion-based savings heuristics for the fleet size and mixed vehicle routing problem with time window constraints (FSMVRPTW) were described by Liu and Shen (1999). Their method is a generalization of the traditional insertion viewpoint instead of the combination concept used in the savings-based heuristics of Clarke and Wright (1964). A certain number of candidate fleet compositions are recorded in the construction phase, followed by application of a composite improvement scheme to enhance the solution quality. The heuristics were tested on 168 sample problems. Dullaert et al. (2002) proposed three insertion-based heuristics for the FSMVRPTW. The heuristics are an extension of Solomon's (1987) sequential insertion heuristic I1 with adapted formulations of Golden et al's savings concepts. The heuristics were tested on the same problem set as that in Liu and Shen's work.

Taillard (1999) has presented a heuristic column generation method for solving the heterogeneous fixed fleet vehicle routing problem (HFFVRP). The method was also used to solve the fleet size and mix vehicle routing problem. A new meta-heuristic known as BATA (back-tracking adaptive threshold accepting) was developed by Tarantilis, Kiranoudis, and Vassiliadis (2004) to solve the HFFVRP. Other methods were also proposed for the HFFVRP, including a tabu search (Brandão, 2011), a multistart adaptive memory programming (MAMP) approach and a path re-linking approach (Li, Tian, & Aneja, 2010).

In this paper, we have developed a new scatter-search algorithm to solve the Fleet Size and Mixed Vehicle Routing Problem