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Variable Neighborhood Search for a Dynamic Rich Vehicle Routing Problem with time windows ☆

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ABSTRACT

A Dynamic Rich Vehicle Routing Problem with Time Windows has been tackled as a real-world application, in which customers requests can be either known at the beginning of the planning horizon or dynamically revealed over the day. Several real constraints, such as heterogeneous fleet of vehicles, multiple and soft time windows and customers priorities, are taken into consideration. Using exact methods is not a suitable solution for this kind of problems, given the fact that the arrival of a new request has to be followed by a quick re-optimization phase to include it into the solution at hand. Therefore, we have proposed a metaheuristic procedure based on Variable Neighborhood Search to solve this particular problem. The computational experiments reported in this work indicate that the proposed method is feasible to solve this real-world problem and competitive with the best results from the literature. Finally, it is worth mentioning that the software developed in this work has been inserted into the fleet management system of a company in Spain.

1. Introduction

Many practical applications related to logistics in intelligent freight transportation systems lead to vehicle routing problems with varying degrees of difficulty regarding the problem constraints. The basic Vehicle Routing Problem (VRP) is composed of a set of customers that have to be served. A fleet of homogeneous vehicles dispatched from a single depot is used to serve them, returning to the same depot once the routes have been completed. The constraints associated to the problem are that vehicles can carry a maximum capacity and each customer has to be visited once by a single vehicle. Contrary to these classical static vehicle routing problems, real-world applications often include evolution, as introduced by Psaraftis (1980), which takes into consideration the fact that the problem data might change over the planning horizon. Latest developments in fleet management systems and communication technology have enabled people to quickly access and process real-time data. Therefore, Dynamic Vehicle Routing Problems (DVRPs) have been lately given more attention. The aim of DVRPs is to dynamically route customers taking into account not only the requests known at the beginning of the planning horizon, but also new customer requests that arrive over it. Last decade has been characterized by an increasing interest for DVRPs, with solution methods ranging from mathematical programming to metaheuristics. For a survey on DVRPs, we refer the interested reader to the reviews, books, and special issues by Gendreau and Potvin (2004), Ghiani, Guerriero, Laporte, and Musmanno (2003), Ichoua, Gendreau, and Potvin (2007), Larsen, Madsen, and Solomon (2008), and Pillac, Gendreau, Gueret, and Medaglia (2013).

The aim of this work is to solve a real-world DVRP that has been posed to the authors by some companies in the Canary Islands, Spain. The resulting software will be embedded into a fleet management system. The requirements provided by the companies lead to the consideration of several constraints, which have to be integrated into the standard DVRP. In the literature, there is a tremendous number of research papers related to VRP with additional constraints. With the purpose of collecting all these possible constraints, Vidal, Crainic, Gendreau, and Prins (2013) have given the notion of *attributes* of VRPs. Attributes refer to additional constraints that aim to better take into account the specificities of real-world applications. These attributes complement the traditional VRP formulations and lead to a variety of *Multi-Attribute Vehicle Routing Problems* (*MAVRPs*), which are supported by a well developed literature that includes a wide range of heuristics and metaheuristics (Glover, 1986). Furthermore, some MAVRPs combine multiple attributes together, yielding the so-called *Rich VRPs*

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(*RVRPs*) (Schmid, Doerner, & Laporte, 2013). The problem tackled in this work corresponds to this last class of RVRPs. The attributes that are taken into consideration in this work are summarized in the following items.

- *Heterogeneous fleet*. When the number of available vehicles is not limited, the problem is usually referred to as Vehicle Fleet Mix Problem (VFMP). In the case in which the fleet of vehicles is limited, a more difficult version of the problem, called Heterogeneous Fleet VRP (*HFVRP*), is revealed. This work handles a fixed set of heterogeneous vehicles. We refer to the so obtained problem as Fixed HFDVRP (*FHFDVRP*). Most literature papers assume an unlimited number of available vehicles, so that the objective is generally to obtain a solution that either minimizes the number of vehicles and/or total travel cost. However, the real-world problems arising in companies face several resource constraints such as a fixed fleet. Therefore, if there is not any feasible solution for the instance at hand regarding the number of available vehicles, it is required to determine what a good solution would then be for the company (adding more vehicles, letting the drivers work after their working shift, postponing services and maximizing the number of customers served, etc.).
- *Soft and Multiple time windows*. Additional constraints arise if time windows are associated to the depot and customers, obtaining the FHFDVRP with Time Windows (*FHFDVRPTW*). In the implementation carried out in this paper, multiple time windows for customers, which can differ among them, are taken into consideration (Ibaraki et al., 2005, 2008). In any case, each customer is served at maximum once during the planning horizon. Furthermore, the working shifts of the vehicles can be divided into time intervals, which may differ among vehicles. Finally, soft time windows and working shifts are considered, since some of them can be violated. Particularly, if the working shifts corresponding to the vehicles can be extended, extra hours are allowed for the drivers. This leads to additional salary costs; the extra time is more expensive.
- *Customer priority*. The companies under consideration in this work assign priorities to some customers. Depending on these priorities, some services can be postponed until the next day. Together with extending the working shifts of the vehicles, postponing customers services allows the system obtaining valid solutions for the companies. Therefore, in the case in which the fixed fleet of vehicles is not sufficient for serving all customers, allowing extra time and/or postponing customers service are possible alternatives if they are permitted by the companies.
- *Vehicle-Customer restrictions*. There are also vehicle-customer limitations, which indicate that some customers cannot be served by some vehicles. Therefore, there will be a set consisting of vehicle-customer constraints that can be due to several reasons such as road restrictions.

In the rest of the paper, we will refer to the problem considered in this work as Dynamic Rich Vehicle Routing Problem with Time Windows (DRVRPTW).

Additionally to these attributes, different objective functions can be required by the companies to solve the problem at hand. While the optimality criterion of minimizing the total traveled distance is the most commonly used in the VRP literature, more recent approaches use other objective functions. Jozefowiez, Semet, and Talbi (2008) provide an overview of the research into routing problems with several objectives. In addition to the minimization of the total traveled distance, important objectives are the minimization of the number of vehicles in use, the minimization of the total required time and some other objectives related to reach a balance between the routes. In this work, the main objective is to minimize the total traveled distance. Although the problem under consideration in not a multi-objective one, a set of other objective functions are considered together with the main one, as it will be explained below; particularly, minimizing the number of vehicles, extra hours, postponed services and cost. All these functions will be used following a lexicographical order.

Due to the difficulty for solving DRVRPTWs to optimality, heuristics and metaheuristics constitute an increasingly active research area in the literature. In our work, a General Variable Neighborhood Search algorithm (GVNS) (Hansen, Mladenovic, & Moreno Perez, 2010) is proposed. The main differences between the problem tackled in this paper and the ones proposed in the literature are related to the fact that we consider a fixed heterogeneous fleet of vehicles and several real-world constraints/attributes.

The main contributions of this paper rely upon the fact that theDVRPTW including several real-world constraints required by some companies has been tackled. A fixed heterogeneous fleet of vehicles is considered. Moreover, taking into account that the fleet is fixed, there might be customers which cannot be served during the planning horizon and the so obtained infeasibility has to be managed. Two alternative solutions are given in this work; extending the working shifts of the drivers or maximizing the number of customers served postponing the remainder. As far as we know, this is the first work in the literature that uses all the previously explained attributes together in DVRPTWs. Computational experiments over the most common instances in the literature are carried out in this paper. The obtained results are competitive if we compare them with the results in related works. Moreover, some preliminary experiments performed with the fleet management system are quite promising. It is worth mentioning that the static part of the solution method proposed in this work, implemented by means of metaheuristics, has already been integrated into the optimization tool used by the fleet management system of the company (De Armas, Melián-Batista, Moreno-Pérez, & Brito, 2015). Finally, it is important to notice that the algorithm proposed in this work can be run by deactivating any or all the attributes mentioned above. Therefore, it is a general purpose algorithm for solving DVRPTWs.

The rest of the paper is organized as follows. Section 2 reports the related works. Section 3 is devoted to describe the real-world Dynamic Rich Vehicle Routing Problem with Time Windows (DRVRPTW) tackled in this work. Section 4 summarizes the metaheuristic procedure developed to solve the problem at hand. Section 5 reports the computational experiments performed in this work. Finally, the conclusions and future works are given in Section 6.

2. Related work

In general, solution approaches for DVRPTWs can be divided into two main classes: those applied to dynamic and deterministic routing problems without any stochastic information, and those applied to dynamic and stochastic routing problems, in which additional stochastic information regarding the new requests is known. Given the fact that in the real-world application tackled in this paper, the information is dynamically given by a company fleet management system, we will focus on the first class of dynamic problems. In this case, solution methods can be based on either periodic or continuous re-optimization. Periodic optimization approaches firstly generate an initial solution consisting of a set of routes that contain all the static customers. Then, a re-optimization method periodically solves a static routing problem, either when new requests arrive or at fixed time slots (Chen & Xu, 2006). On the other hand, continuous re-optimization approaches carry out the optimization over the day by keeping