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A unified-adaptive large neighborhood search metaheuristic for periodic location-routing problems

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ABSTRACT

This paper introduces three variants of the Periodic Location-Routing Problem (PLRP): the Heterogeneous PLRP with Time Windows (HPTW), the Heterogeneous PLRP (HP) and the homogeneous PLRP with Time Windows (PTW). These problems extend the well-known location-routing problem by considering a homogeneous or heterogeneous fleet, multiple periods and time windows. The paper develops a powerful Unified-Adaptive Large Neighborhood Search (U-ALNS) metaheuristic for these problems. The U-ALNS successfully uses existing algorithmic procedures and also offers a number of new advanced efficient procedures capable of handling a multi-period horizon, fleet composition and location decisions. Computational experiments on benchmark instances show that the U-ALNS is highly effective on PLRPs. The U-ALNS outperforms previous methods on a set of standard benchmark instances for the PLRP. We also present new benchmark results for the PLRP, HPTW, HP and PTW.

1. Introduction

Depot location and vehicle routing are two crucial decisions for companies. The well-known Location-Routing Problem (LRP) combines two decisions: determining the locations of depots and designing vehicle routes supply from these depots. More than fifty years have elapsed since the Facility Location Problem and Vehicle Routing Problem (VRP) have been studied jointly (see Von Boventer, 1961).

Despite its relevance in many application areas such as raw material supply, refuse collection, parcel delivery, telecommunication network design and drink distribution, the literature on the Periodic LRP (PLRP) is relatively scarce. This problem integrates the LRP and a multi-period horizon, in which a set of possible combinations of delivery days or patterns is associated with each customer. Customer demands vary over the days of a pattern, and each customer can be served by different depots over the planning horizon. The problem consists of opening a subset of depots over the planning horizon, and determining a subset of customer visit for each period, the assignment of customers to open depots and the routes serving the customers assigned to each depot. Before we proceed with our study, we briefly review the relevant literature.

1.1. A brief review of the literature

Solving location and routing decisions independently may lead to highly suboptimal planning results, even if the location decisions must be made for the long term. LRPs particularly arise in situations where location and routing decisions are on

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the same level. Over the past years, several heuristic algorithms have been developed for the LRP and its variants such as population (Prins et al., 2014; Duhamel et al., 2010; Karaoglan and Altiparmak, 2015; Koç et al., 2016a), neighborhood (Duhamel et al., 2011), tabu search (Aras et al., 2011), simulated annealing (Karaoglan et al., 2012), and adaptive large neighborhood search (ALNS) (Hemmelmayr et al., 2012; Taş et al., 2014; Mancini, in press). Several mathematical programming based solution methods have also been developed (Albareda-Sambola et al., 2005; Baldacci et al., 2011; Karaoglan et al., 2011). Özyurt and Aksen (2007) proposed Lagrangian relaxation for the multi-depot LRP. Aksen and Altinkemer (2008) described a Lagrangian-based solution method for a LRP with the conversion to the "click-and-mortar" retailing. For further details on the LRP, its variations and solution methods, the reader is referred to the surveys of Laporte (1988), Min et al. (1998), Nagy and Salhi (2007), Prodhon and Prins (2014), Albareda-Sambola (2015) and Drexl and Schneider (2015).

In the last decades, several algorithms are developed for the Periodic VRP (PVRP), PLRP and their variations. Cordeau et al. (1997) developed a tabu search algorithm to solve the PVRP, the Periodic Traveling Salesman Problem, and the Multi-depot VRP. Michallet et al. (2014) introduced the PVRP with time windows and time spread constraints on services and proposed a multi-start iterated local search heuristic. The problem can be considered as a PLRP with single depot, no-wait time windows and irregular arrival times. The objective is to minimize the total route cost and dispersing arrival times where the constraint that the time of any two visits to the same customer must differ by a given time constant. Most recently, Rahimi-Vahed et al. (2015) developed a new modular heuristic algorithm for the Multi-depot VRP, PVRP and Multi-depot PVRP. For further details on the PVRP and its variations, the reader is referred to the recent book chapter of Irnich et al. (2014).

The PLRP was first introduced by Prodhon and Prins (2008). These authors developed a memetic algorithm with population management. The algorithm was able to solve large-size instances of the PLRP. The method was tested on three cases: one-day horizon (LRP), one depot (PVRP) and the PLRP. Pirkwieser and Raidl (2010) described a variable neighborhood search for the PLRP which is integrated within integer linear programming-based very large neighborhood searches. The authors conducted experiments on the benchmark instances of Prodhon and Prins (2008) and obtained many best known solutions. Prodhon (2011) later developed a hybrid evolutionary algorithm for the PLRP with both capacitated depots and vehicles. The method combines an evolutionary local search and a randomized extended Clarke and Wright algorithm. Experiments were conducted on several special cases such as a one-day horizon (LRP) and a single depot (PVRP) and on new generated benchmark instances. The results clearly outperformed those of the previous algorithms for the PLRP. A variant of the PLRP which considers decoupled time scales is studied by Albareda-Sambola et al. (2012) where patterns are no longer used because each customer now specifies its days of delivery. The authors described two heuristics and an approximation without losing the capability of finding well located facilities with the sets of customers along the time horizon. Most recently, Tunalıoğlu et al. (in press) studied a PLRP arising in the collection of olive oil mill wastewater. The authors developed an ALNS and applied on a case study drawn from one of the major olive oil producing countries.

Real-world distribution problems are often performed by heterogeneous vehicle fleets rather than homogeneous ones (Hoff et al., 2010). Several researchers have worked on the heterogeneous vehicle routing for more than thirty years. The problem and its variations are reviewed by Baldacci et al. (2008) and by Koç et al. (2016b). To our knowledge, several studies indirectly consider heterogeneous fleet within the context of the LRP but without taking time windows into account (see Ambrosino et al., 2009; Wu et al., 2002). Most recently, Koç et al. (2016a) integrated for the first time the heterogeneous fleet and time windows within the LRP and introduced the Fleet Size and Mix Location-Routing Problem with Time Windows (FSMLRPTW). The authors developed a population-based algorithm and introduced several new heuristic procedures. Experiments were conducted on a new set of benchmark instances with up to 100 nodes and 10 potential depots, and the proposed method was able to obtain high quality solutions.

The PLRP, arises in the operation if several companies that must make location and routing decisions over several time periods. One such company is FedEx (2016). This logistics provides deliveries to more than 220 countries and territories in 2016. The company uses a global air-and-ground network to speed up the single or periodic delivery of time-sensitive shipments, usually within a guaranteed delivery time. The FedEx serves more than 375 airports with 688 heterogeneous aircraft, the delivery fleet includes more than 100,000 heterogeneous vehicles, the company owns 1250 operating facilities and 12 air express hubs (FedEx, 2016).

1.2. Scientific contributions and structure of the paper

This brief review shows that three variations of the PLRP with or without heterogeneous fleet, multi-period horizon and time windows have not been previously addressed. Two main contributions of this paper are as follows. Our first contribution is to introduce the Heterogeneous PLRP with Time Windows (HPTW), along with two particular cases: the Heterogeneous PLRP (HP) and the homogeneous PLRP with Time Windows (PTW). Our second contribution is to develop a unified metaheuristic, namely the Unified-Adaptive Large Neighborhood Search (U-ALNS), capable of efficiently solving these three problem categories.

The remainder of this paper is structured as follows. Section 2 formally defines the problem and presents a mixed integer programming formulation. Section 3 presents a detailed description of the metaheuristic. Computational experiments are provided in Section 4, and conclusions follow in Section 5.