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Discrete Optimization

Heuristic algorithms for a vehicle routing problem with simultaneous delivery and pickup and time windows in home health care

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ABSTRACT

This paper addresses a vehicle scheduling problem encountered in home health care logistics. It concerns the delivery of drugs and medical devices from the home care company's pharmacy to patients' homes, delivery of special drugs from a hospital to patients, pickup of bio samples and unused drugs and medical devices from patients. The problem can be considered as a special vehicle routing problem with simultaneous delivery and pickup and time windows, with four types of demands: delivery from depot to patient, delivery from a hospital to patient, pickup from a patient to depot and pickup from a patient to a medical lab. Each patient is visited by one vehicle and each vehicle visits each node at most once. Patients are associated with time windows and vehicles with capacity. Two mixed-integer programming models are proposed. We then propose a Genetic Algorithm (GA) and a Tabu Search (TS) method. The GA is based on a permutation chromosome, a split procedure and local search. The TS is based on route assignment attributes of patients, an augmented cost function, route re-optimization, and attribute-based aspiration levels. These approaches are tested on test instances derived from existing VRPTW benchmarks.

1. Introduction

This paper considers a special vehicle routing problem with simultaneous delivery and pickup and time windows in home health care. Home hospitalization organizations have been created for patients requiring long and regular health cares in order to provide quality health service at their home while reducing the bed requirements at hospitals. Home hospitalization initially focused on nursing cares and has been extended to complex and technical cares such as chronic cares, rehabilitation, end-of-life palliative cares, and home chemotherapy. Home health care services are provided in France by Home Health Care (HHC) companies. Each day, a HHC company has various logistic activities including delivering drugs and medical devices from its pharmacy (also called depot in this paper) to patients at their home. It also takes some special drugs, such as chemotherapy drugs and blood products, from hospitals to patients. On the other hand, the HHC also needs to pick up materials from patients and deliver to different locations. Blood samples of the patients are collected and delivered to a medical lab. Medical wastes, unused drugs and medical devices are collected and brought back to the HHC or the depot. As HHC companies are usually small but serve rather large number of patients with dispersed locations, it is crucial to carefully design the routes of the HHC vehicles in order to reduce its operating cost while improving the service quality to patients.

Since an HHC patient may be a delivery and a pickup client simultaneously and have both pickup and delivery demands, the design of HHC vehicle routes is related to the *vehicle routing problem with simultaneous pickup and delivery and time windows* (VRPSDPTW) introduced by Hokey (1989). The VRPSDPTW is a hard and challenging problem in the field of vehicle routing problem (VRP). It considers clients that require simultaneous pickup and delivery service. Some common constraints must be satisfied in both HHC's vehicle scheduling problem and the VRPSDPTW. For example, each client must be visited and served in a given time window; the load on a vehicle must always be below the vehicle capacity. However, the problem faced by the HHC company is more complex than the classical VRPSDPTW. The first reason is the complexity of its logistic operations with different types of pickup and delivery demands of patients. According to the origins and destinations, both pickup and delivery demands can be divided into two subclasses. The pickup demands include: (i) picking up the material from patients' homes and deliver to a lab, e.g., biological samples and (ii) picking up some materials from the patients' homes and bring back to the depot, e.g., medical waste. Similarly, there

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are two subclasses of delivery demands required by the patients: (i) delivering the products from the company's depot to patients and (ii) delivering some materials from a hospital to patients' homes, e.g., special drugs for cancer treatment. In the classical VRPSDPTW all delivery goods are loaded at the depot and all pickup goods have to be transported to the depot. In our HHC vehicle scheduling problem besides the depot, goods can be transported from a hospital to patients and from the patients to a lab. Clearly, the composition of vehicles' loads in our case is more complex than VRPSDPTW. Furthermore, different from the classical VRPSDPTW, each route of our problem must satisfy some *precedence constraints*, e.g., for a patient who needs drugs provided by the hospital, the vehicle visiting the patient has to visit the hospital first. Such special constraints are similar to the pairing and precedence constraints in classical *pickup and delivery problem* (PDP), in which each customer request is defined by an origin location and a destination, the origin must visited before the destination by the same vehicle. However, the PDP is less complicated than our problem, since the origins as well as the destinations of transportation requests in the PDP are locations other than the depot, and a customer in the PDP only has either pickup or delivery request. Thus, in this paper the HHC vehicle scheduling problem is rather a special VRPSDPTW variant which has never been studied before. Since both the VRPSDPTW and PDP are NP-hard problems, our problem is more complex than these problems and is also NP-hard. To the best of our knowledge, we have not found any existing work dealing this special simultaneous pickup and delivery problem in HHC industry.

In this paper, we first perform a literature review, propose two mathematical formulations of our problem, and then develop two heuristic algorithms for this special vehicle scheduling problem. The rest of this paper is organized as follows. Section 2 introduces the relevant literature. Our problem is formally defined and two mathematical models are given in Section 3. Section 4 proposes a Genetic algorithm (GA) for our problem. Section 5 proposes a Tabu Search (TS) algorithm for solving the problem. Computational experiments are described in Section 6. Section 7 concludes the paper.

2. Literature review

As stated before, two main bodies of vehicle routing literature are relevant to our problem. The first is the *vehicle routing problem with simultaneous pickup and delivery and time windows*, in which goods are transported by a fleet of vehicles between the depot and customers within their time windows. The second one is the *pickup and delivery problem with time windows* (PDPTW) problem, in which goods are transported between *n* pickup and *n* delivery locations, and the vehicle visiting each location must be within an associated time window. We survey the literature in two parts.

The VRPSDPTW is an extension of the VRPSDP, and has been much less studied than the VRPSDP. The VRPSDP can be seen as an extension of the *vehicle routing problems with backhauls* (VRPB). In the VRPB, the set of customers are divided in two subsets consisting of *linehaul* and *backhaul* costumers, where a linehaul customer requires a given quantity of product to be delivered from the depot, and a backhaul customer requires a given quantity of product to be picked up to the depot. In the VRPB, it is assumed that the vehicles only pick goods up (serve backhaul customers) after they have finished delivering their entire load (serve linehaul customers) (Toth and Vigo, 1997a; Goetschalckx and Jacobs-Blecha, 1989). One reason for this assumption is the difficulty to re-arrange delivery and pickup goods on the vehicles. The objective of the VRPB is to design a set of minimum cost routes so that on each route neither the total load of linehaul customers nor that of backhaul customers exceed the vehicle capacity. The VRPB is a NP-hard problem in strong sense and a number of algorithms are proposed for this problem. Exact methods for the VRPB are proposed by Yano et al. (1987), Toth and Vigo (1997a), and Mingozzi et al. (1999). Heuristics have been developed by Goetschalckx and Jacobs-Blecha (1989), Toth and Vigo (1999), Osman and Wassan (2002), Tavakkoli-Moghaddam et al. (2006), and Gajpal and Abad (2009b). If the linehaul and backhaul customers can be freely mixed within a route, the VRPB is transformed to the *vehicle routing problem with mixed backhauls* (VRPMB). Clearly, the vehicle capacity check in the VRPMB is more complicated than the VRPB. Exact solution methods for the VRPMB have only been developed for the single vehicle case (Eilam Tzoreff et al., 2002; Süral and Bookbinder, 2003; Baldacci et al., 2003). Heuristics for the VRPMB were given by Nagy and Salhi (2005), Salhi and Nagy (1999), Wade and Salhi (2004), and Reimann and Ulrich (2006). Based on the VRPMB, if we allow customers to have both pickup quantity and delivery quantity, then, there exist two special problems: the *vehicle routing problem with divisible delivery and pickup* (VRPDDP), and *the vehicle routing problem with simultaneous delivery and pickup* (VRPSDP). The difference between the VRPDDP and VRPSDP is the number of times a customer is visited. In the VRPDDP customers do not have to be visited exactly once, i.e., a customer can be visited twice, once for pickup and once for delivery service. The VRPSDP requires that each customer is visited only once by a vehicle. The VRPDDP instances can be transformed to VRPMB by modeling every customer's pickup and delivery service as two separate customers. One exact method for the VRPSDP was designed by Dell'Amico et al. (2006). Dethloff (2002) proposes an extension of the cheapest insertion heuristic to the VRPSDP. Several tabu search algorithms for VRPSDP were proposed in Alfredo Tang Montané and Galvão (2006), Chen and Wu (2005), Bianchessi and Righini (2007), and Crispim and Brandão (2005). Recently, Ai and Kachitvichyanukul (2009), Gajpal and Abad (2009a), and Subramanian et al. (2010) have proposed several metaheuristics to solve VRPSDP.

Contrary to the VRPB, VRPMB, and VRPSDP, only a fewer researchers consider the time window constraints in these problems, especially for the VRPSDP. For example, an exact algorithm was designed for the *VRPB with time windows* in Gélinas et al. (1995). Duhamel et al. (1997), Reimann et al. (2002), Thangiah et al. (1996), and Zhong and Cole (2005) proposed heuristics for this problem. For the *VRPMB with time windows*, Hasama et al. (1998), Kontoravdis and Bard (1995), and Zhong and Cole (2005) designed heuristics, with the primary objective of minimizing the number of the vehicles and the second objective of minimizing traveling distances. For the most complex one, VRPSDPTW, only Angelelli and Mansini (2002) proposed an exact method and Mingyong and Erbao (2010) and Wang and Chen (2012) proposed genetic algorithms.

Compared with VRPSDPTW, there is an abundant body of research on the second related problem PDPTW. The PDPTW originates from the basic PDP (Savelsbergh and Sol, 1995). In the PDP, a customer order consists of two parts: a pickup at one location and a delivery at another location. The PDP has been intensively studied in the past three decades. For survey on the PDP, the reader is referred to Savelsbergh and Sol (1995), Berbeglia et al. (2007), and Parragh et al. (2008). For the PDPTW, several exact approaches have been designed. Dumas et al. (1991), Savelsbergh and Sol (1998), Xu et al. (2003), and Sigurd and Pisinger (2004) used branch and price schemes for the PDPTW. Cordeau (2006) and Ropke et al. (2007) developed branch and cut approach for the PDPTW. Ropke and Cordeau (2009) introduced a new branch and cut and price algorithm for the PDPTW. Meanwhile, many heuristics have been proposed for the PDPTW. Jaw et al. (1986), Madsen et al. (1995), Diana and Dessouky (2004), and Lu and Dessouky (2006) presented various insertion-based heuristics for solving the PDPTW. Toth and Vigo (1997b), Nanry and Wesley Barnes (2000),