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The customer-centric, multi-commodity vehicle routing problem with split delivery

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ABSTRACT

In this paper, we present the Customer-centric, Multi-commodity Vehicle Routing Problem with Split Delivery (CMVRPSD) whose objective is to minimize total waiting time of customers in distributing multiple types of commodities by multiple capacitated vehicles. It is assumed that a customer's demand can be fulfilled by more than one vehicle. Two classes of decisions are involved in this problem: routing vehicles to customers and quantifying commodities to load and unload. The CMVRPSD can be applied to distributing commodities in customer-oriented distribution problems for both peacetime and disaster situations. The problem is formulated in two Mixed-Integer Linear Programming (MILP) models, and a heuristic method is proposed by adapting and synthesizing Simulated Annealing (SA) and Variable Neighborhood Search (VNS) for large-scale problems. Experimental results show that the proposed hybrid algorithm outperforms other applicable algorithms such as SA, VNS, and Nearest Neighborhood heuristic.

1. Introduction

In today's competitive environment, customer satisfaction plays an important role in the success of service and manufacturing companies. One important aspect that increases customer's satisfaction in both service and manufacturing systems is the quickness in the delivery of services or products to customers. Research on Minimum Latency Problems (MLPs) has been conducted to achieve this goal from the transportation and logistics perspective. MLPs, also known as Cumulative Vehicle Routing Problems (Chen, Dong, & Niu, 2012) or Customer-Centric Vehicle Routing Problems (Martínez-Salazar, Angel-Bello, & Alvarez, 2014) are a class of routing problems whose objective is to minimize the waiting time of customers. The Traveling Repairman Problem (TRP) Bjelić, Vidović, and Popović (2013), also known as the Deliveryman Problem (Mladenović, Urošević, & Hanafi, 2013), is the basic problem in this class and is defined as follows: given a vehicle in a depot (origin), a set of demand locations, and travel times among demand locations, the problem is to find a path for the vehicle to visit every demand location exactly once and the goal is to minimize the sum of arrival times (latencies). While server-oriented Vehicle Routing Problems (VRPs) aim to minimize the total travel distance of the vehicles, MLPs are customer-oriented by minimizing the latency from the customers' viewpoint. To avoid confusion, we use the "TRP" as the basic problem in the class of Minimum Latency Problems, while "MLPs" refers to general problems in this class. MLPs have many real-world applications, such as humanitarian logistics for delivering food, water, and medical supplies to affected areas, dispatching ambulances to patients' locations (Campbell, Vandenbussche, & Hermann, 2008), repair and fix to minimize total downtime (Ribeiro, Laporte, & Mauri, 2012), and disk head scheduling to minimize total time of data retrieval on a disk (Blum et al., 1994).

Customer satisfaction and competitive business environment on one hand, and the increase in the number, scale, and severity of disasters on the other hand, are the key reasons why MLPs have recently received considerable attention from researchers. Different variants of the problem have been developed from 1986 to 2015: TRP on a straight line (Afrati, Cosmadakis, Papadimitriou, Papageorgiou, & Papakostantinou, 1986), TRP with non-zero service time (Tsitsiklis, 1992), the Dynamic-TRP (Bertsimas & Van Ryzin, 1991; Lee, 2011), capacitated MLP (Angel-Bello, Alvarez, & García, 2013; Ke & Feng, 2013; Lysgaard & Wøhlk, 2014; Mattos Ribeiro & Laporte, 2012; Ngueveu, Prins, & Wolfler Calvo, 2010), capacitated MLP with time window (Bjelić et al., 2013; Tsitsiklis 1992; Heilporn, Cordeau, & Laporte, 2010), and directed MLP (Nagarajan & Ravi, 2008). Some authors also presented different latency-based objective functions: minimize maximum latency (Campbell et al., 2008; Psaraftis, Solomon, Magnanti, & Kim, 1990) and maximize latency-based

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profit (Coene & Spieksma, 2008; Dewilde, Cattrysse, Coene, Spieksma, & Vansteenwegen, 2013).

Various formulations and algorithms have been proposed for MLPs. Bianco, Mingozzi, and Ricciardelli (1993) formulated the TRP based on the network flow problem in the context of time-dependent traveling salesman problem, and presented two exact algorithms. Heilporn et al. (2010) developed two formulations of the TRP with time window. The first formulation uses the arc flow problem and the second formulation utilizes the sequential assignment model. Authors proposed an exact algorithm using polyhedral analysis. Ngueveu et al. (2010) presented a mixed integer formulation of the capacitated MLP, and designed a Memetic algorithm to deal with the problem. Angel-Bello et al. (2013) proposed two formulations of the directed MLP by using permutation-based decision variables and utilized the mathematical models to solve small-size problems. Bjelić et al. (2013) formulated the heterogeneous capacitated MLP with time window using the arc flow network model, and developed a metaheuristic approach based on the Variable Neighborhood Search to solve the problem. Lysgaard and Wøhlk (2014) also formulated the capacitated MLP using the set partitioning formulation and proposed an exact algorithm.

Several heuristic and metaheuristic algorithms have been recently used to tackle MLPs. The first metaheuristic was proposed for the TRP by Salehipour, Sörensen, Goos, and Bräysy (2011) based on GRASP+VNS/VND. Silva, Subramanian, Vidal, and Ochi (2012) proposed a metaheuristic approach for the TRP, named GILS-RVND which uses Greedy Randomized Adaptive Search Procedure (GRASP) to generate solutions, and Variable Neighborhood Descent (VNDS) and Iterated Local Search (ILS) to improve the solutions. The algorithm is able to solve large-scale TRPs up to 1000 nodes efficiently and up to 50 nodes optimally in less than a second. Ke and Feng (2013) presented a two-phase metaheuristic which utilizes an exchange-based or cross-based operator in the first phase. Then, 3-opt and 4-opt based operators are used followed by a 2-opt search. Other metaheuristic algorithms used to solve MLPs include Genetic Algorithm Ban, Nguyen, Cuong Ngo, and Nguyen (2013), Camci (2014), Particle Swarm Optimization Camci (2014), Memetic algorithm (Ngueveu et al., 2010), VNS/VND (Mladenović et al., 2013; Mattos Ribeiro, & Laporte, 2012), and Tabu Search (Dewilde et al., 2013). The reader is referred to Moshref-Javadi and Lee (2013) for a taxonomy and review of MLPs. The taxonomy includes MLP characteristics, objective functions, and solution approaches.

The review of the literature on MLPs indicates that two cases have been mostly researched as follows:

- Traveling Repairman Problem: assumes an incapacitated vehicle distributing a single type of commodity to customers.
- Capacitated Multi-vehicle MLP: assumes multiple capacitated vehicles distributing a single type of commodity to customers.

The primary research in the MLP literature has been on the single commodity. However, the distribution of multiple types of commodities is common and they have to be considered together because of their interdependency rooted from the differences in size, type, and importance. In disaster relief, for example, water could have higher priority for distribution compared to cloths. Considering the heterogeneity of commodities, load and unload decisions need to be made in conjunction with and in addition to the routing decisions. Also, in real world, a customer's demand can be fulfilled by more than one vehicle and this assumption is called 'split' delivery. Fulfilling a demand by only one vehicle is not always feasible due to limited vehicle capacity and heterogeneity of vehicles. Researchers have shown that split delivery can contribute to cost savings in routing problems (Ambrosino & Sciomachen, 2007; Ho & Haugland, 2004; Sierksma & Tijssen, 1998; Song, Lee, & Kim, 2002). While the VRP with split delivery has been researched in the literature, the MLP with split delivery has gained no attention. In the VRP context, various split delivery problems have been formulated and authors have proposed several exact algorithms (Archetti, Bianchessi, & Speranza, 2014; Archetti, Bianchessi, & Speranza, 2015; Archetti, Bouchard, & Desaulniers, 2011; Silva, Subramanian, & Ochi, 2015; Stålhane, Andersson, Christiansen, Cordeau, & Desaulniers, 2012) and heuristics (Archetti, Speranza, & Hertz, 2006; Berbotto, García, & Nogales, 2014; Nowak, Ergun, & White Iii, 2008; Wang, Du, & Ma, 2014). Chen, Golden, and Wasil (2007) and (Archetti and Speranza (2012) reviewed the applications and algorithms for the split delivery VRPs.

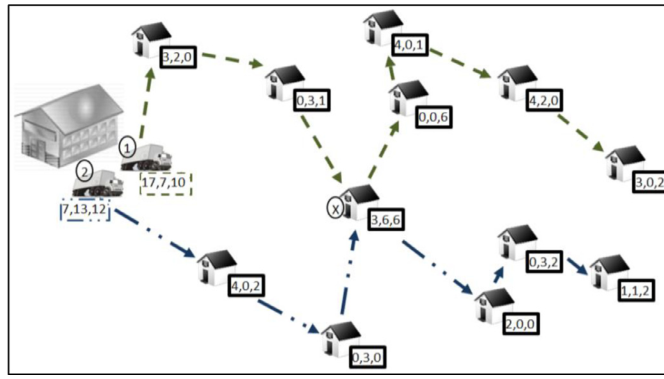

Fig. 1. The CMVRPSD schematic description.

MLP research on multi-commodity and split delivery is missing in the literature despite its practical importance. This paper introduces the *Customer-Centric, Multi-commodity Vehicle Routing Problem with Split Delivery (CMVRPSD)* and proposes two different mathematical formulations. Several optimality properties are investigated and utilized to design a heuristic algorithm for large-scale problems that synthesizes Simulated Annealing (SA) and Variable Neighborhood Search (VNS).

The remainder of the paper is organized as follows: Section 2 presents problem description. Two mathematical models based on network flow and assignment models are presented in Section 3. Section 4 describes the proposed hybrid algorithm and computational results are presented in Section 5. Finally, Section 6 concludes the paper.

2. Problem description

The CMVRPSD includes two classes of decisions: the first decision determines the vehicles' routes while the second decision determines the quantities of commodities to load and unload on the routes of vehicles. The goal is to minimize the total waiting time of customers. We assume that multiple vehicles distribute multiple types of commodities from a single depot. Customers can request any type of commodities and this demand can be fulfilled by more than one vehicle. Fig. 1 illustrates the problem schematically in which there is one depot with two vehicles distributing three types of commodities. The numbers in the boxes of customers indicate the requested commodities of each type while the boxes of vehicles show the quantities of commodities loaded on each vehicle. For example, the delivery to customer X is split between both vehicles; commodity 1 is delivered by vehicle 1 and commodities 2 and 3 are delivered by vehicle 2. More assumptions of the problem are as follows:

- Every vehicle is able to transport all types of commodities.
- Commodities differ with respect to their size and importance.
- Vehicles are heterogeneous in terms of carrying capacity.