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Iterated local search heuristics for the Vehicle Routing Problem with Cross-Docking

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ABSTRACT

This work addresses the Vehicle Routing Problem with Cross-Docking (VRPCD). The problem consists in defining a minimum cost set of routes for a fleet of vehicles that meets the demands of products for a set of suppliers and customers. The vehicles leave a single Cross-Dock (CD) towards the suppliers, pick up products and return to the CD, where products can be exchanged before being delivered to their customers. The vehicle routes must respect the vehicle capacity constraints, as well as the time window constraints. We adapted a constructive heuristic and six local search procedures from the literature of VRP, and made them efficient in the presence of the synchronization constraints of VRPCD. Besides, we propose three Iterated Local Search (Lourenço et al., 2010) heuristics for VRPCD. The first heuristic is a standard implementation of ILS, while the second extends the classic ILS framework by keeping a set of elite solutions, instead of a single current solution. The latter set is used in a restart procedure. As far as we can tell, this is the first ILS heuristic in the literature that keeps a population of current elite solutions. The third heuristic is an extension of the second that relies on an intensification procedure based on an Integer Programming formulation for the Set Partitioning problem. The latter allows a neighborhood with an exponential number of neighbors to be efficiently evaluated. We report computational results and comparisons with the best heuristics in the literature. Besides, we also present a new set with the largest instances in the literature of VRPCD, in order to demonstrate that the improvements we propose for the ILS metaheuristic are efficient even for large size instances. Results show that the best of our heuristics is competitive with the best heuristics in the literature of VRPCD. Besides, it improved the best solution known for half of the benchmark instances in the literature.

1. Introduction

The Vehicle Routing Problems (VRPs) are well known and much-studied problems in the fields of Operations Research and Combinatorial Optimization. The whole class of VRPs deals with optimization problems in which a group of destinations (customers, suppliers, deposits, etc.), must be visited by a fleet of vehicles in order to satisfy their demands. The importance of this class of problems can be verified by observing the large number of studies that had been presented for more than half a century now (Golden, Assad, & Wasil, 2001, 2008; Laporte, 2009) and by the applications in the solid waste, beverage, food, dairy, and newspaper industry (Golden et al., 2001). Motivated by applications that arise in real-world, several variants of VRPs were suggested in the literature. Among these variants we can cite, for instance, the VRP with Time Windows (Kallehauge, 2008; Nagata, Bräysy, & Dullaert, 2010; Savelsbergh, 1985; Vidal, Crainic, Gendreau, & Prins, 2013), the VRP with Pickup and Delivery (Savelsbergh & Sol, 1995; Subramanian, Drummond, Bentes, Ochi, & Farias, 2010), Distance-constrained VRP (Laporte, Desrochers, & Nobert, 1984, 1985), and the VRP with Backhauls (Thangiah, Potvin, & Sun, 1996). The VRP and variants have been faced daily by courier services (e.g., Federal Express, United Parcel Service, and Overnight United States Postal Service), distribution, maintenance, delivery, local trucking and transport companies. Toth and Vigo (2001) concludes that the use of optimization approaches in distribution planning results in 5% to 10% savings in transportation costs.

The decision-making process is usually categorized according to the following structure (Bradley, Hax, & Magnanti, 1977): strategic planning, tactical planning, and operations control. Strategic planning deals with long-term decisions, tactical planning seeks effective resource allocation to satisfy the demand on a medium-range time horizon, and operations control is concerned with short-term decisions. Moreover, depending on the scenario, the constraints

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and the problem size, different solution approaches may be required, with an unavoidable tradeoff between computational complexity, running time, and solution quality. In this context, the VRP and variants are proposed to cover tactical and operational decisions.

The recent advances in distribution systems have motivated logistics companies to extend the capabilities of their warehouses. The real reason for this is not only to store more products, but also to allow them to organize products in order to improve their distribution along the logistic system. An example of such strategy is the use of cross-docking warehouses (Apte & Viswanathan, 2000).

Cross-docking is a practice related to the inventory and products flow management in a transportation system. Products from distinct suppliers arrive at a Cross-Dock (CD), where they are relocated among the vehicles and dispatched to the final customers in order to minimize the transportation cost. The process of handling products in a CD and the relocation of these products to a fleet of vehicles is called *consolidation*. We refer to Napolitano (2002) and Yu and Egbelu (2008) for more details about cross-docking and its application in a number of combinatorial optimization problems.

The real-world problem resulting from the integration of routing decisions with cross-docking strategies, named Vehicle Routing Problem with Cross-Docking (VRPCD), was introduced by Lee, Jung, and Lee (2006). The VRPCD is a multi-source Vehicle Routing Problem with a Cross-Docking facility, in which the critical aspect is the flow synchronization at the CD that impacts on the pickup and delivery activities. Moreover, a fleet of capacitated homogeneous vehicles, considering time window constraints, must leave the CD towards the suppliers, picks up products and returns to CD, where products can be consolidated before being delivered to their customers. Therefore, the VRPCD involves decisions for cross-docking operations (in terms of loading, unloading and consolidation) and vehicle route design among suppliers, customers and CD.

The VRPCD is an example of VRP with synchronization constraints (Drexl, 2012). It makes use of the same fleet of vehicles in both pickup and delivery routes. In this context, an explicitly set of dependency rules must be considered, in which loading or unloading a vehicle depend directly of the consolidation process and of the pickup and delivery route planning. So, in the VRPCD, in contrast with standard VRPs, a change in a route may affect on other routes; in the worst case, a change in a route may render others routes infeasible. For that reason, standard solution techniques for VRPs cannot be applied directly to VRPCD.

In this paper, we extend a constructive heuristic and six local search procedures from the literature of VRP, in order to make them efficient in the presence of the synchronization constraints of VRPCD. Besides, we propose three Iterated Local Search (Lourenço, Martin, & Stutzle, 2010, chap.12) heuristics for VRPCD. The first heuristic is a standard implementation of ILS, while the second extends the classic ILS framework by keeping a set of elite solutions, instead of a single current solution. The latter set is used in a restart procedure. As far as we can tell, this is the first ILS heuristic in the literature that keeps a population of current elite solutions. The third heuristic is an extension of the second that relies on an intensification procedure based on an Integer Programming formulation for the Set Partitioning problem. The latter allows a neighborhood with an exponential number of neighbors to be efficiently evaluated. We report computational results and comparisons with the best heuristics in the literature. Besides, we also present a new set with the largest instances in the literature of VRPCD, in order to demonstrate that the improvements we propose for the ILS metaheuristic are efficient even for large size instances. Results show that the best of our heuristics is competitive with the best heuristics in the literature of VRPCD. Besides, it improved the best solution known for half of the benchmark instances in the literature.

The remainder of the paper is organized as follows. In the following section, we present a literature review on VRPCD and related problems. In Section 3, we formally define the version of VRPCD addressed in this paper and present a numerical example. The proposed heuristics are described in Section 4. Next, computational results on benchmark instances from the literature and on the set of large instances proposed in this paper are reported in Section 5. Then, concluding remarks are drawn in the last section.

2. Related works

Different variants of the VRPCD are considered in the literature. In particular, one can impose time windows constraints on suppliers and customers to ensure them to be visited by a vehicle in a proper interval. In general, the consolidation process could be done simultaneously, after the last vehicle arrives at the CD, or not. However, the central point around this kind of problem is how to model the consolidation in terms of the routing process, i.e., what is the impact of the consolidation on the planning time horizon and on the total transportation cost. In this section, we present the main works related to Vehicle Routing Problems with cross-docking.

The first version of VRPCD was proposed by Lee et al. (2006). They consider that all vehicles start the consolidation simultaneously, after the last vehicle arrives at the CD. A fixed cost to manipulate the products in the CD is also considered. Then, the objective is to minimize the transportation and operational costs, respecting the vehicle capacity constraints as well as the time window constraints. Lee et al. (2006) and Liao, Lin, and Shih (2010) proposed a mathematical formulation and tabu search heuristics (Glover & Laguna, 1977) to solve the problem and a new set of instances to evaluate their algorithms.

Wen, Larsen, Clausen, Cordeau, and Laporte (2009) proposed a similar VRPCD from that introduced by Lee et al. (2006). However they relaxed the imposition of the original problem in which all vehicles must start the consolidation simultaneously. A mixed Integer Programming formulation and also a tabu search heuristic were proposed. To evaluate their heuristic a new set of instances based on real data was introduced, for which the tabu search heuristic found solutions with optimality gaps of at most 5%. Tarantilis (2013) addressed the same problem as defined by Wen et al. (2009). He proposed a heuristic based on an adaptive multi-restart procedure associated with a tabu search heuristic. The local searches 2-Opt, 1–0 Relocate and 1–1 Exchange were used by his heuristic. The heuristic of Tarantilis (2013) found better solutions than those of Wen et al. (2009) for 14 (out of the 20) instances evaluated.

Another version of VRPCD was proposed by Santos, Mateus, and da Cunha (2011b, 2011a). They take into account a fixed cost to manipulate products in the CD. However, they do not consider time window constraints. As Lee et al. (2006), they assume that the consolidation process starts only after all vehicles arrive at the CD. Their main contributions are mathematical formulations, Column Generation procedures, and Branch-and-Price algorithms. Optimal solutions are obtained for instances with up to 61 nodes and 30 requests.

Santos, Mateus, and da Cunha (2013) introduced the Pickup and Delivery Problem with Cross-Docking (PDPCD). Two types of routes are considered: *pickup-CD-delivery routes* and *pickup–delivery routes*. In the pickup-CD-delivery routes, a vehicle starts the pickup route at the CD, goes through a subset of suppliers, returns to the CD, consolidates products, and then visits a subset of customers. In pickup–delivery routes, the vehicle starts at the CD, visits a subset of suppliers and after the last one, starts delivering