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Open vehicle routing problem with cross-docking

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ABSTRACT

The advantages of the cross-docking technique have been increasingly appreciated in literature and in practice. This appreciation, coupled with the advances of numerous applications in the vehicle routing problem (VRP) across numerous practical contexts, presents an opportunity to explore the open VRP with cross-docking (OVRPCD). We introduce a general example in retail wherein the capital expenditure necessary in vehicle acquisition can become a burden for the retailer, who then needs to consider outsourcing a logistics service as a cost-effective option. This practical scenario can be applied to create an open flow network of routes. This study considers a single product and single cross-dock wherein capacitated homogeneous vehicles start at different pickup points and times during pickup operations. The vehicles are scheduled to route in the network synchronously to arrive at the cross-dock center simultaneously. In the delivery operations, all customers must be served at most once and deliveries should be finished within a predetermined duration. We model OVRPCD as a mixed-integer linear program that minimizes the total cost (vehicle hiring cost and transportation cost). A simulated annealing (SA) algorithm is proposed to solve the problem. SA is first verified by solving benchmark instances for the vehicle routing problem with cross-docking and comparing the results with those obtained by existing state-of-art algorithms. We then test SA on three sets of OVRPCD benchmark instances and the results are compared with those obtained by CPLEX. Computational results show that both CPLEX and SA can obtain optimal solutions to all small and medium instances. However, the computational time required by SA is shorter than that needed by CPLEX. Moreover, for large instances, SA outperforms CPLEX in both solution value and computational time.

1. Introduction

Many companies are trying to develop efficient strategies to control the physical flow of their supply chain. The important aspects in finding new strategies is minimizing the total cost and achieving a high level of agility, flexibility, and reliability for various demands. Cross-docking is one innovative strategy to minimize unnecessary cost, particularly in terms of inventory and customer service level (Apte & Viswanathan, 2000). Cross-docking operations were pioneered in the US trucking industry in the 1930s and have since been in use in less-than-truckload (LTL) operations. The US military began utilizing cross-docking operations in the 1950s, and Wal-Mart began implementing cross-docking in the retail sector in the late 1980s. In the LTL trucking industry, cross-docking is conducted by moving freight from one transport vehicle directly into another one with minimal or no storage. In retail practice, cross-docking operations may utilize staging areas wherein inbound freight is sorted, consolidated, and stored until the outbound shipments are ready to leave. Another cross-docking activity in practice is the “hub and spoke” configuration, wherein freight is brought to one central location and then sorted for delivery to a variety of destinations. At the central location, deconsolidation is performed to break large shipments into small shipments for ease of delivery. The advantages of the cross-docking technique in supply chain management have been discussed in the last decade. Agustina, Lee, and Piplani (2010) noted that cross-docking is important for the efficient operation of a distribution network because it reduces or eliminates the storage activities that belong to the warehousing system. In general, the concept of cross-docking does not allow products to be stored at the cross-docking center but may occur whenever the inventory cost incurred is lower than the gain from consolidation or a delay of shipment (Vahdani, Soltani, & Zandieh, 2009).

In the supply chain, the classical vehicle routing problem (VRP) plays an important role in distribution management and logistics, as well as the costs associated with operating vehicles (Barbarosoglu & Ozgur, 1999). VRP finds optimal delivery or pickup routes from a depot to a set of customers subject to various side

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constraints (Eksioglu, Vural, & Reisman, 2009). Because of its importance, VRP has been studied extensively over the past decades with many extensions and different solution approaches (Braekers, Ramaekers, & Van Nieuwenhuyse, 2015). Among those studies, the integration of a cross-docking strategy has only been recently investigated. Several recent studies published VRP with cross-docking (VRPCD) as a variant of the classical VRP. Lee, Jung, and Lee (2006) considered such a variant to have synchronous product arrival times with stable demand for consolidation. Their objective was to find the optimal number of vehicles and routing schedule to minimize transportation cost. The results of the proposed tabu search (TS) algorithm were compared with those obtained by an enumeration method. On average, a 4% error existed in the near-optimal solutions from 1000 search iterations. Liao, Lin, and Shih (2010) proposed a new TS algorithm for the VRPCD. They used the TS algorithm to solve the set of benchmark problems introduced by Lee et al. (2006) and the results show improvements in terms of solution quality and computational time. The average improvement was as high as 10–36% for problems of various sizes compare to the results obtained by TS of Lee et al. (2006). Wen, Larsen, Clausen, Cordeau, and Laporte (2009) investigated another version of VRPCD slightly different from the one introduced by Lee et al. (2006) where asynchronous arrival is allowed. The dependency among the vehicles is determined by consolidation decisions. They modeled the problem to minimize the total distance traveled. Tarantilis (2013) and Morais, Mateus, and Noronha (2014) also investigated the same problem as defined by Wen et al. (2009). Tarantilis (2013) proposed a heuristic based on the adaptive multi-restart procedure associated with a TS heuristic to solve VRPCD, which provides better solutions than the solutions obtained by Wen et al. (2009) for 14 out of 20 instances. Morais et al. (2014) applied the iterated local search heuristic (ILS) to solve VRPCD. Their computational results showed that ILS outperformed the tabu search heuristic proposed by Wen et al. (2009) and the adaptive multi-restart TS heuristic of Tarantilis (2013).

Hasani-Goodarzi and Tavakkoli-Moghaddam (2012) applied the cross-docking strategy for a vehicle fleet that was allowed to make split deliveries and pickups in different nodes of the network. They called this variant the split VRP, which was formulated as a mixed-integer programming model that aims to minimize transportation cost by using the GAMS optimization software. Santos, Mateus, and da Cunha (2013) introduced the pickup and delivery problem with cross-docking (PDPCD), whereby instead of the usual stops at the cross-dock, vehicles are allowed to skip the stop at the cross-dock. The model considers two types of routes: (1) pickup and delivery routes when the vehicle does not stop at the cross-dock and (2) routes that stop at the cross-dock to exchange loads. The results from a branch and price algorithm showed that by having two-route options, the optimal solutions for PDPCD are on average at least 3.3% cheaper than those of their VRPCD counterparts. Mousavi and Tavakkoli-Moghaddam (2013) proposed the location and routing scheduling problems with cross-docking which aims to design a cross-dock location and a vehicle routing scheduling model. The algorithm based on a two-stage hybrid simulated annealing (HSA) with a tabu list in the TS algorithm is proposed to solve the problem. Mousavi, Tavakkoli-Moghaddam, and Jolai (2013) studied the location and VRP in the cross-docking distribution networks under uncertainty, and proposed a hybrid fuzzy pos sibilistic–stochastic programming solution approach. Agustina, Lee, and Piplani (2014) integrated cross-docking, vehicle scheduling and routing in food supply chain to ensure that food can be delivered to customers just in time. They formulated the problem as a mixed integer linear program and used the concepts of customer zones and hard time windows for delivery to reduce the solution space and then solved the problem by CPLEX. Dondo and Cerdá (2014) considered vehicle routing and cross-dock tuck scheduling simultaneously and formulated the problem as a mixed integer linear program. Recently, Dondo and Cerdá (2015) extended this problem to determine the routing and scheduling of a mixed vehicle fleet. Ahmadizar, Zeynivand, and Arkat (2015) presented two-level VRP with cross-docking in a three-echelon supply chain that includes suppliers, cross-docks and retailers. They considered two levels of routing in the network, the first-level involves suppliers and cross-docks and the second-level involves cross-docks and retailers. They hybridized genetic algorithm with local search procedure to solve the problem. Küçükoğlu and Öztürk (2015) introduced VRPCD with 2-dimensional truck loading. They hybridized TS with simulated annealing (SA) algorithm to solve the problem.

The combinatorial nature of VRP makes this type of problem an NP-hard problem. Thus, studies with the same intrinsic complexity usually use heuristic and meta-heuristic solution approaches. For example, Dondo and Cerdá (2013) proposed a sweep heuristic algorithm and Morais et al. (2014) used an iterated local search heuristic to solve VRPCD. Pisinger and Ropke (2007) used an adaptive large neighborhood search heuristic algorithm to solve five different variants of VRP, including the vehicle routing problem with time windows, capacitated vehicle routing problem, multi-depot vehicle routing problem, and site-dependent vehicle routing problem. Some studies employed meta-heuristic approaches to solve VRP and its variants, such as tabu search (Gendreau, Hertz, & Laporte, 1994; Gendreau, Laporte, Musaraganyi, & Taillard, 1999; Lee et al., 2006; Liao et al., 2010), genetic algorithm (Baker & Ayechew, 2003; Hwang, 2002; Kergosien, Lenté, Billaut, & Perrin, 2013), simulated annealing (Lin, Yu, & Chou, 2009; Wang, Mu, Zhao, & Sutherland, 2015; Yu & Lin, 2014, 2015a, 2015b; Yu, Lin, Lee, & Ting, 2010), particle swarm optimization (Ai & Kachitvichyanukul, 2009a, 2009b; Kachitvichyanukul, Sombuntham, & Kunnapapdeelert, 2015; MirHassani & Abolghasemi, 2011), and some recently developed hybrid heuristic algorithms (Goksal, Karaoglan, & Altiparmak, 2013; Ho, Ho, Ji, & Lau, 2008; Marinakis & Marinaki, 2010; Mousavi & Tavakkoli-Moghaddam, 2013; Subramanian, Penna, Uchoa, & Ochi, 2012; Subramanian, Uchoa, & Ochi, 2013; Yu, Ding, & Zhu, 2011). The computational results of these studies show that these hybrid approaches can find optimal or near-optimal solutions to large-scale problems in a competitive computational time.

The open vehicle routing problem (OVRP) has recently been introduced. OVRP is an extension of VRP and is characterized by an “open” network wherein the flow starts from a customer and ends at the depot or begins at the depot and finishes at one of the customers without returning to the depot. OVRP usually occurs in a company that does not have its own fleet of vehicles to service customers. Thus, the company contracts a third party logistic (TPL) company to provide vehicle fleets. From the contractee’s point of view, they only need to consider the cost associated with the trip between its depot and the last customer that the vehicle services. Sariklis and Powell (2000), Cao and Lai (2010), and Zachariadis and Kiranoudis (2010) discussed some practical applications of OVRP. The difference between OVRP and classical VRP is the network flow described earlier. Thus, OVRP is relevant in practice when the vehicle fleet is outsourced (Repoussis, Tarantilis, Bräysy, & Ioannou, 2010). Subsequent OVRP studies considered conditions that are related to the real-life transportation, logistics, and supply chain practices (Brito, Martínez, Moreno, & Verdegay, 2015; Sariklis & Powell, 2000; Schopka & Kopfer, 2016). Another practical extension of OVRP is multi-depot OVRP which arises when a company rents a large vehicle fleet and operates the vehicles from several depots or warehouses (Lalla-Ruiz, Expósito-Izquierdo, Taheripour, & Voß, 2015; Liu, Jiang, & Geng, 2014; Montoya-Torres, López Franco, Nieto Isaza, Felizzola Jiménez, & Herazo-Padilla, 2015).

This study focuses on the development of the distribution system, which is motivated both by the advantage of the cross-docking and