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Vehicle routing scheduling problem with cross docking and split deliveries

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ABSTRACT

One of the most important issues in managing a supply chain which makes the materials flow more efficiently from suppliers to customers is cross docking. In this paper a vehicle routing and scheduling problem in a network consisting of suppliers, customers and a cross dock is considered. A set of homogenous vehicles transfer products from suppliers to customers through a cross dock. Each vehicle has a limited capacity and both suppliers and customers must be visited within their time windows, also a customer can be visited more than once by different vehicles. A mixed integer non linear mathematical formulation of this problem is provided. A simulated annealing and a hybrid metaheuristic algorithm combining ant colony system and simulated annealing are proposed. These two proposed metaheuristics are implemented on different data sets. The experimental results show the superior performance of the hybrid algorithm compared with the proposed simulated annealing algorithm.

1. Introduction

In a supply chain, its different components need to be integrated so that the whole chain performs effectively. Different components of a supply chain are always looking for improving the material flow over the chain. The products that should be transferred from suppliers to customers usually go through a distribution centre. A distribution centre's role is to coordinate the pick up and delivery processes and also classifying and storing inventory. A cross dock is one of the recently introduced distribution centres which is being widely used by different companies. A cross dock is kind of a warehouse that performs as a transit point for inventories and products which often leave the cross dock in less than 24 h. This strategy was first proposed by Walmart. Products are continuously delivered to Walmart warehouses where they are selected, repacked and then delivered to stores, so no extra time is wasted in warehouses (Apte & Viswanathan, 2000). By reducing inventory cost and delivery lead times significantly, this strategy has improved Walmart's profit and market share. Although managing a cross docking system is not an easy task, it has huge upcoming benefits such as reducing inventory costs, delivery lead times and accelerating material flow over the distribution network.

Cross docking is mostly beneficial for large distribution systems where large quantities of products are picked up and delivered daily. Many less-than-truck-load demands of different suppliers are merged in vehicles and transferred to cross dock and then after some consolidation procedures according to product destinations, products will be dispatched to their corresponding customers.

Many studies have been done on cross docking and they usually include the strategic aspects such as determining the location of cross docks in a distribution network and also the cross dock layout and scheduling the incoming and outgoing vehicles and consolidation processes inside the cross dock.

Generally, according to Van Belle, Valckenaers, and Cattrysse (2012) the studies done in the field of cross docking can be categorized as follow: decisions related to the location of cross docks in a network, the lay out of the cross docking facility, assignment of trucks to doors, outbound transportation, truck scheduling, scheduling of resources inside the cross docking facility and loading/unloading of products in/from vehicles.

The decisions related to transportation and scheduling of trucks are the main focus of this study. The truck scheduling problem tries to optimally assign the incoming and outgoing trucks to dock doors and determines the sequence in which the trucks are processed at each dock door (Boysen, Fliedner, & Scholl, 2010;

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Golias, Saharidis, Boile, & Theofanis, 2012; Yu & Egblu, 2008; Zhang, Saharidis, Theofanis, & Boile, 2010).

The studies related to outbound transportation include the transshipment problem and the vehicle routing problem.

The transshipment problem considers the transportation of goods in a network and its objectives are determining an optimized distribution plan, including the number of products and the methods to deliver them from origins to destinations, which minimizes the sum of transportation and inventory costs. This kind of network can be called an open network which means the flow of goods begins from a supplier and after passing throw a cross dock, goods are delivered to the customers and the operations end. Chen, Guo, Lim, and Rodrigues (2006) considered the transportation problem in a network with multiple cross docks. Time windows are considered for pick up and delivery, also the capacity of the cross docks is limited. The purpose is finding a distribution plan which minimizes the transportation and inventory handling costs. An initial solution was found through a greedy search method and the problem was solved by SA, TS and a hybrid metaheuristics.

Lim, Miao, Rodrigues, and Xu (2005) considered a transshipment problem in a network consisting of suppliers, customers and cross docks. Soft and hard time windows are considered for suppliers and customers and also the capacity of the ware houses is limited. The objective is to determine the schedule and the volume of products that should be transshipped from suppliers to customers in order to minimize the transportation and inventory holding costs.

Derbes, Rabadi, and Musa (2009) also considered the transportation problem in the same network as Lim et al. (2005). The products can be delivered from suppliers to customers directly or through a cross dock facility. Moreover, the customers have delivery time windows. The provided mixed integer non linear model is solved by an ant colony algorithm.

Miao, Yang, Fu, and Xu (2010) considered the transshipment of a single type of product in a cross docking network. Both suppliers and customers have hard time windows. Also a set of soft time windows is considered for customers. The objective is minimizing the transportation and inventory costs and the penalty cost of late deliveries. Similar problems were considered by Ma, Miao, Lim, and Rodrigues (2011) and Musa, Arnaout, and Jung (2010) with the possibility of delivering the products directly or through the cross docks. Moreover, heuristics are provided to solve these NP-hard problems.

The second group of outbound transportation problems is vehicle routing and scheduling in a network consisting of suppliers, customers and a cross dock facility. Considering a vehicle routing problem for a network consisting of a cross dock and different suppliers and retailers was first discussed by Lee, Jung, and Lee (2006). They tried to solve a vehicle routing and scheduling problem in a network consisting of a set of pick up and delivery nodes coordinated through a single cross dock. The transportation process is done by a set of homogeneous vehicles, the pick up and delivery routes begin and end at cross dock and all of the pick up vehicles come back to the cross dock simultaneously. They used a tabu search metaheuristic in order to minimize the sum of transportation costs and fixed costs of the vehicles.

Wen, Larsen, Clausen, Cordeau, and Laporte (2007) considered the same problem as Lee et al. (2006) with two main differences; (1) there would be no obligation in simultaneous arrival of pick up vehicles to cross dock, (2) each customer and supplier has a specific time window to be visited. They provided a tabu search metaheuristic which is embedded within an adaptive memory procedure and compared their results with a lower bound.

Liao, Lin, and Shih (2010) considered exactly the same problem and formulation as Lee et al. (2006). Their tabu search algorithm results show a better performance in a shorter computational time compared with tabu search provided by Lee et al. (2006). Vahdani, Tavakkoli-Moghaddam, Zandieh, and Razmi (2010) also studied the Vehicle Routing with Cross Docking (VRPCD) defined by Lee et al. (2006) and provided a hybrid metahauristic including Particle Swarm Optimization (PSO), Simulated Annealing (SA) and Variable Neighbourhood Search (VNS). Their hybrid method outperforms the tabu search proposed by Lee et al. (2006). Santos, Mateus, and Salles da Cunha (2011) studied a different variant of VRPCD. In their problem no time windows are imposed on suppliers, customers and the cross dock. They also considered unloading/reloading costs in consolidation operations of cross dock and provided a branch and price algorithm to solve this variant of VRPCD.

Dondo and Cerda (2012) studied the same problem with assumptions as Wen et al. (2007). A service time consisting of fixed and variable components is considered at each node. A sweep based formulation of the problem is compared with the exact formulation which is very similar with the formulation proposed by Wen et al. (2007). The experimental results for data sets up to 50 pairs of supplier–customer showed the good performance of the sweep based approach in a short amount of time.

The problem studied in this paper is similar to the one studied in Wen et al. (2007) exactly with the same assumptions. However, in this study splitting loads in the delivery process is allowed which means the demand of a customer can be delivered by more than one vehicle and different metaheuristic approaches are proposed to solve the problem.

The remainder of the paper is organized as follows. Section 2 gives a detailed description of the problem and a mixed integer non linear formulation is provided. Two metaheuristic algorithms, SA (simulated annealing) and the hybrid ACS-SA (ant colony system algorithm and simulated annealing), are proposed to solve the VRPCD which are described in Sections 3–5. Section 6 presents the computational results and finally Section 7 concludes the paper and provides some suggestions for future studies.

2. Problem description

As can be seen in Fig. 1, there are a set of pick up and delivery nodes with specific amount of product demand that should be delivered from each pick up node to its corresponding delivery node through a cross dock by a set of homogenous vehicles. The vehicle routes begin and end at the cross dock. Each pick up, delivery node and the cross dock must be visited during their time windows. A vehicle begins its route from the cross dock and picks up products from the suppliers and comes back to the cross dock. After a set of consolidation processes according to the delivery routes, the vehicle begins its delivery route and after completing the routes comes back to the cross dock. The loads in delivery routes can be split which means the demand of a delivery node can be split between more than one vehicle.

The set of pick up nodes is denoted by $P = \{1, 2, ..., n\}$ and the set of delivery nodes by $D = \{n + 1, ..., 2n\}$. Each request is specified by $(i, i + n)$ pair in which i is the pick up node and $i + n$ is the corresponding

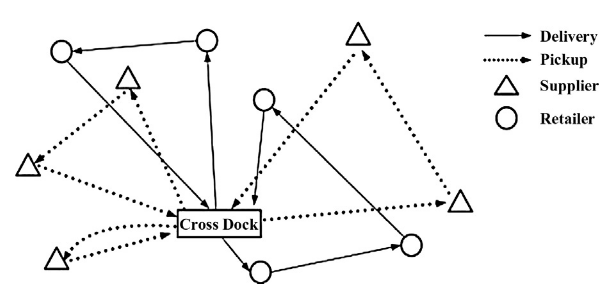

Fig. 1. A proposed network of cross docking (Liao et al.,2010).