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A monolithic approach to vehicle routing and operations scheduling of a cross-dock system with multiple dock doors

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ABSTRACT

Cross-docking is a logistic strategy for moving goods from suppliers to customers via a cross-dock terminal with no permanent storage. The operational planning of a cross-dock facility involves different issues such as vehicle routing, dock door assignment and truck scheduling. The vehicle routing problem seeks the optimal routes for a homogeneous fleet of vehicles that sequentially collects goods at pickup points and delivers them to their destinations. The truck scheduling problem deals with the timing of unloading and reloading operations at the cross-dock. This work introduces a mixed-integer linear programming formulation for the scheduling of single cross-dock systems that, in addition to selecting the pickup/delivery routes, simultaneously decides on the dock door assignment and the truck scheduling at the cross-dock. The proposed monolithic formulation is able to provide near-optimal solutions to medium-size problems involving up to 70 transportation orders, 16 vehicles and 7 strip/stack dock doors at acceptable CPU times.

1. Introduction

Cross-docking is a logistic strategy used by many companies to decrease storage costs and improve customer satisfaction through a shorter delivery lead-time. The storage of goods is expensive because of space requirements, inventory holding costs and labor-intensive order picking tasks. Cross-docking seeks to eliminate a large portion of such warehousing costs. A cross-dock is usually an I-shaped facility with strip and stack dock doors located at opposite sides of the terminal and minimal storage space in between. Inbound shipments arriving at the cross-dock are allocated to strip docks on one side of the distribution terminal. Once the inbound trucks have been unloaded, the freights are screened and sorted by destination. After that, they are moved across the terminal via a forklift or a conveyor belt to their designated stack dock doors. There, the loads are charged into departing trucks carrying them to their destinations. Clearly, the handling of freight in a cross-dock terminal is a labor intensive and costly task because workers must unload, sort, and transfer a wide variety of loads from incoming trucks to outgoing trailers. Some products are better suited to cross-docking like (a) products having a stable demand; (b) perishable bulk materials, including some chemical and food compounds, requiring immediate shipment; (c) frozen foods and other refrigerated products like pharmaceuticals that should be directly moved from cooled inbound to cooled outbound trucks to keep the cooling chain unbroken; (d) high-quality items not needing quality inspection during the receiving process and (e) pre-tagged products that are ready for sale to the customers. Besides, drums of hazardous chemicals and containers of waste materials are usually aggregated at cross-dock facilities and immediately transferred to remedy sites for treatment and disposal. Pharmaceutical, food and chemical industries are increasingly using cross-docking to gain competitive advantages. Chemical and manufacturing companies like Eastman Kodak Co., Goodyear GB Ltd. and Toyota have reported the successful implementation of cross-docking strategies (Van Belle, Valckenaers, & Cattrysse, 2012).

Thorough reviews on cross-docking can be found in Boysen and Fliedner (2010) and Van Belle et al. (2012). Research was first focused on both the location and the physical layout of a cross-dock facility (e.g., the shape and the number of dock doors) and the related truck scheduling, but neglecting the routing aspects of the problem. The truck scheduling (TS) problem deals with operational issues at the cross-dock terminal that mainly include the assignment of vehicles to dock doors, the processing sequence of trucks at every strip and stack door and the transfer of goods from inbound to outbound vehicles. Although the idea of cross-docking is to unload inbound trucks and immediately reload the freights into delivery vehicles, a temporary storage is always necessary. Goods do not arrive at the cross-dock in the sequence they must be reloaded into the departing vehicles because a perfect synchronization of limited numbers of pickup and delivery trucks is impossible.

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An early work introducing a bilinear programming model to deal with the truck scheduling (TS) was due to Tsui and Chang (1992). The efficiency of workers depends in large part on the cross-dock layout and how trailers are assigned to dock doors. A good layout reduces transfer distances without creating congestion. Bartholdi and Gue (2000) introduced a layout design model that also considers the dock door assignment problem. The model is formulated to minimize transfer time, material handling and congestion through an efficient design of the cross-dock layout. Yu and Egbelu (2008) presented two approaches to schedule the trucks at the dock and find the better exchange of items between inbound and outbound trucks. The transfer of goods among trucks and the docking sequences of inbound and outbound trucks were simultaneously determined. Li, Low, Shakeri, and Lim (2009) also focused on truck scheduling and door assignment but considering a multi-door cross-dock and a number of trucks higher than the number of doors. Then, there will be lines of trucks waiting for an empty door to start onload/offload operations. Two approaches consisting of a mixed integer programming (MIP) model from a door scheduling viewpoint, and a dependency ranking search (DRS) heuristic algorithm were proposed. The problem goal was to minimize the total cross-dock operating time. The MILP model cannot be used for practical cases due to the high computational cost, while the DRS heuristic algorithm was able to find good solutions in much shorter solution times. Arabani, Ghomi, & Zandieh (2011) tested five different meta-heuristics such as the genetic algorithm (GA), the tabu search (TS), the particle swarm optimization (PSO), the ant-colony optimization (ACO) and the differential evolution (DE) algorithms, by applying them to solve a large number of cases. Chen et al. (2006) studied the truck scheduling problem for a network of cross-docks taking into consideration delivery and pickup time windows, warehouse capacities and inventory-handling costs. They solved the truck scheduling problem using local search techniques like simulated annealing and tabu-search and claimed that the heuristics outperform optimization models for providing good solutions in realistic time scales. Lee, Jung, and Lee (2006) developed an MILP formulation that considers both cross-docking operations and the vehicle routing problem, assuming that all vehicles coming from suppliers arrive at the cross-dock simultaneously in order to avoid vehicle waiting times at the cross-dock. Wen, Larsen, Clausen, Cordeau, and Laporte (2009) proposed a mixed integer programming formulation for the VRPCD problem involving pickup and delivery tasks to be started within specific time windows in order to minimize the traveled distance. The transportation requests are defined in terms of two locations: the pickup node where the freight is loaded and the delivery node to which is destined. Miao, Yang, Fu, and Xu (2012) studied a multi-crossdock transshipment problem with both soft and hard time windows. The flows from suppliers to customers via the cross-docks are constrained by fixed transportation schedules. Cargoes can be delayed and consolidated in cross-docks, and both suppliers and customers may alternatively have hard time windows or less-restrictive soft time windows. The formulation aims to minimize the total cost of multi-crossdock distribution networks, including transportation, inventory handling and penalty costs. As the problem is NP-hard, the authors proposed two solution methods based on meta-heuristics called Adaptive Tabu search and Adaptive Genetic algorithm, respectively. Dondo and Cerdá (2013) introduced a monolithic formulation for the VRPCD that determines the pickup and the delivery routes simultaneously with the truck scheduling at the cross-dock terminal, by assuming an unlimited number of dock doors. To get a computationally efficient approach, a set of constraints mimicking the widely known sweep heuristic algorithm (Gillet and Miller, 1974) to assign vehicles to pickup/delivery routes was incorporated into the MILP model. The sweep-heuristic based formulation can find near-optimal solutions to large problems at very acceptable CPU times. However, dock door assignments and queues of trucks in front of the dock doors were ignored.

If a limited number of dock doors is available, the assignment of them to incoming and outgoing trucks determines the efficiency of the cross-dock operations. In fact, a precise coordination among pickup vehicle routes, cross-dock activities and delivery vehicle routes is required to avoid long queues of trucks waiting for unloading/loading their cargoes. To this end, this work presents a new monolithic MILP formulation that integrates the pickup/delivery vehicle routing and scheduling with both the assignment of dock-doors to incoming and outgoing trucks and the managing of truck queues at strip/stack doors. Additional constraints mimicking the sweeping algorithm and avoiding symmetrical solutions are embedded into the mathematical formulation. In this manner, an efficient hybrid approach capable of solving medium-size problem instances at acceptable CPU times has been developed.

2. Problem definition

The combined vehicle routing and cross-dock truck scheduling problem (e.g., the VRPCD-TS problem) is defined as the problem of transporting a set of requests R from pickup to destination points passing through an intermediate cross-dock facility at minimum routing cost (see Fig. 1). The cross-dock is assumed to have a limited number of receiving (strip) doors RD and shipping (stack) doors SD. When an inbound (outbound) truck arrives (departs) at (from) the cross-dock, it must be decided to which dock door is assigned to increase the cross-dock productivity and reduce the handling cost. The truck scheduling (TS) problem seeks to find the optimal assignment of inbound/outbound trucks to dock doors. Most contributions on the VRPCD problem assumed that there are at least as much dock doors as trucks, so each truck will be assigned to a different door and truck scheduling aspects can be ignored. If this condition is not fulfilled, the dock doors can be seen as scarce resources that have to be scheduled over time. Lines of trucks waiting for service can arise at every dock door. This is the so-called truck scheduling problem. As the simultaneous treatment of both the VRPCD and the truck scheduling (TS) problems can be quite complex, they are usually solved in a sequential manner. In contrast to previous approaches, we will assume a limited number of dock doors and solve both the VRPCD and the TS problems at the same time.

The set of data to be considered in the formulation of the VRPCD-TS problem are next presented. Each transportation request $r \in R$ is described by specifying the shipment size q_r and the related pickup and destination locations. The Euclidean distance between pickup/delivery locations of requests $(r, r') \in R$, given by $d^P_{r,r'}/d^D_{r,r'}$ and the Polar coordinates ($r^P_{w,r}/r^D_{w,r}$ and θ^P_r/θ^D_r) of the pickup/delivery sites of request $r \in R$ (with the system origin at the cross-dock terminal) are also known data. The pickup and delivery tasks are fulfilled by the same set of homogeneous vehicles V each having a known capacity Q. Every vehicle departs from the cross-dock w, serves the assigned pickup locations and returns to the terminal for unloading the collected goods on the assigned receiving door. After completing offload operations, the vehicle moves to the shipping door of the terminal, reload orders and departs to their final destinations. The cross-dock terminal comprises given sets of receiving (RD) and shipping (SD) dock doors. The vehicle transfer-time between an inbound door $d \in RD$ and an outbound door $d' \in SD$ is given by the parameter $tt_{d,d'}$. The service time at each pickup/delivery location has two components: a fixed time for shipment-preparation (ft^P_r/ft^D_r) and a variable part that is proportional to the load size q_r. The loading/unloading rate at each pickup/delivery node is given by (lr_r/ur_r). Similar parameters for