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Decision Support

A branch-and-cut algorithm for the truck dock assignment problem with operational time constraints

Shahin Gelareh[a,*], Rahimeh Neamatian Monemi[b], Frédéric Semet[c], Gilles Goncalves[a]

[a] Université d'Artois, Laboratoire de Génie Informatique et d'Automatique, Béthune F-62400, France
[b] IFSTTAR, Université Lille Nord de France, rue lise Reclus 20, Villeneuve dAscq, Lille 59666, France
[c] CRIStAL, UMR 9189-CNRS, Ecole Centrale de Lille, Villeneuve dAscq, Lille 59651, France

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A B S T R A C T

In this paper, we address a truck dock assignment problem with operational time constraint which has to be faced in the management of cross docks. More specifically, this problem is the subproblem of more involved problems with additional constraints and criteria. We propose a new integer programming model for this problem. The dimension of the polytope associated with the proposed model is identified by introducing a systematic way of generating linearly independent feasible solutions. Several classes of valid inequalities are also introduced. Some of them are proved to be facet-defining. Then, exact separation algorithms are described for separating cuts for classes with exponential number of constraints, and an efficient branch-and-cut algorithm solving real-life size instances in a reasonable time is provided. In most cases, the optimal solution is identified at the root node without requiring any branching.

1. Introduction

Cross-docks play a key role in modern distribution systems. They are logistic terminals where deliveries are unloaded from inbound trucks, sorted and moved from one dock to another—within the cross dock—until they are finally loaded on the outbound trucks towards the next destination within the distribution network. Cross docks are often used to perform rapid transhipment activities and usually do not carry out any further processing of the shipments (see Fig. 1). An important problem in a cross dock is the *dock assignment* of inbound and outbound trucks, given the characteristics of cross dock (such as layout, installations, resources, capacity, etc.) and those of clients (such as time windows within which the trucks are present at cross dock, origin–destination volumes of flow, etc.).

In the *truck dock assignment problem*, given the time windows defined by the arrival and the departure times of every truck (as well as capacity of the cross dock), we aim at finding an optimal assignment of the trucks to the docks in such a way that the number of deliveries being processed is maximized. A delivery from an inbound truck that has not succeeded to leave the cross dock using an outbound truck in the same day, leads to impose some holding costs at the cross dock until being delivered to its destination in the next call of the outbound truck (which is usually the next day). Every inbound truck usually has shipments to several different destinations. Whether an inbound truck will be able to deliver deliveries to an outbound truck via cross dock depends on, (1) feasibility of time windows (i.e. the outbound truck does not leave before the inbound arrives), (2) the arrival time of incoming truck plus the dock-to-dock transfer time within the cross dock, which should not exceed the departure time of the outbound truck, and (3) the available capacity at the cross-dock during the visit time window of the inbound trucks.

As mentioned, the transfer of shipments from inbound truck i to outbound truck j depends on the transfer time between the two docks k and l where i and j, respectively, are assigned. A sub-optimal solution to the truck dock assignment problem can cause significant waiting times for other arriving trucks, which will eventually miss the same-day-service of their shipment. However, an optimal assignment can minimize the intra cross dock (i.e. inter-dock) operational cost, including the costs for drivers and vehicles that carry out in-house pickups and deliveries and also the handling costs for sorting and consolidating cargo. In presence of capacity, the total volume of deliveries present at the cross dock at every point in time is restricted.

In this paper, we propose a new model for the dock assignment problem. Then, we identify the dimension of the corresponding polytope. We introduce several classes of valid inequalities and prove that some of those valid inequalities are in fact facet-defining ones. We propose then separation procedures which are embedded in an efficient branch-and-cut algorithm. This method is capable of providing

* Corresponding author. Tel.: +33 0786647334.
E-mail address: shahin.gelareh@gmail.com, shahin.gelareh@univ-artois.fr (S. Gelareh).

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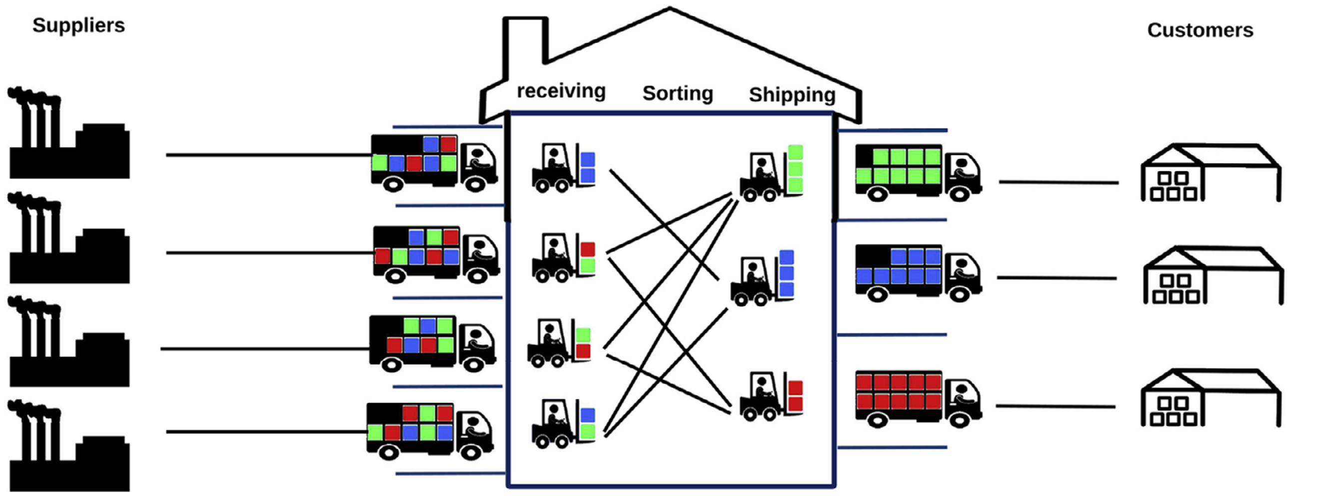

Fig. 1. Cross docking in a distribution network.

optimal solution to real-life size instances of the problem in a reasonable computational time.

The paper is structured as follows. In Section 2, we review the relevant literature on the cross dock management. In Section 3, we introduce our mathematical model and discuss the relation with a related presented in Miao, Lim, and Ma (2009). Section 4 is reserved to present some classes of valid inequalities for the problem. Section 4.2 reports some polyhedral properties. Section 5 describes the proposed solution method and Section 6 reports some computational results and analysis. Section 7 summarizes the work, presents a conclusion and pinpoints some further research directions. Some elaborated details are also provided in Appendix A.

2. Literature review

The truck dock assignment problem, as many other optimization problems arising in cross dock management, has been receiving an increasing attention during the last decade. This is evidenced by several recent surveys (Boysen & Fliedner, 2010; Gu, Goetschalckx, & McGinnis, 2007; Van Belle, Valckenaers, & Cattrysse, 2012) devoted to operations management and to scheduling in cross docks.

Lim, Miao, Rodrigues, and Xu (2005a) studied the transshipment problem with supplier and customer time windows where flow is constrained by transportation schedules and warehouse capacities with the objective to minimize total cost, including inventory costs. Tsui and Chang (1992) proposed a bilinear model for the truck dock assignment of a shipping company. Lim, Ma, and Miao (2006b) proposed a tabu search as well as a CPLEX-based GA for the same problem as in Lim et al. (2005a). Miao et al. (2009) proposed an integer programming formulation for the truck dock assignment problem in which the cross dock capacity over the time planning horizon is taken into account explicitly over the time-horizon. Two meta-heuristics based on tabu search and on genetic algorithms are proposed. Recently, Miao, Cai, and Xu (2014) proposed a different model and an adaptive tabu search algorithm to address the uncapacitated case. Berghman, Leus, and Spieksma (2014) presented a model for a dock assignment problem. They assumed that the trailers need to be assigned to the gates for a given period of time for loading or unloading activities. The parking lot is used as a buffer zone. Transportation between the parking lot and the gates is performed by tractors owned by the terminal operator. They examine several integer programming formulations. Cohen and Keren (2009) discussed the existing approaches and proposed a formulation and a new heuristic for assigning cross dock doors to trailers. Deshpande, Yalcin, Zayas-Castro, and Herrera (2007) introduced a dock assignment heuristic. They integrated the tactical level decision-making process and the operational aspects in LTL terminals to evaluate the performance of the system. Liao, Egbelu, and Chang (2013) studied the problem of determining simultaneously the dock assignment and the sequence of inbound trucks. They consider a multi-door cross docking operation with the objective to minimize the total weighted tardiness, under a fixed outbound truck departure schedule. The problem is solved by six different metaheuristic algorithms, which include simulated annealing, tabu search, ant colony optimization, differential evolution, and two hybrid differential-evolution algorithms. Shakeri, Low, and Li (2008) addressed the two problems of truck scheduling and truck-to-door assignment jointly in a mixed integer programming model. Yu and Egbelu (2008) seek the best truck docking or scheduling sequence for both inbound and outbound trucks to minimize the total operation time when a temporary storage buffer is located to hold items temporarily at the shipping dock. In this work, the product assignment to the trucks and the docking sequences of the inbound and outbound trucks are determined simultaneously. Boloori Arabani, Fatemi Ghomi, and Zandieh (2011) proposed meta-heuristics to find the best sequence of inbound and outbound trucks, so that the objective, which is minimizing the total operation time called makespan, can be satisfied. Arabani, Ghomi, and Zandieh (2010) deal with scheduling problem of inbound and outbound trailers in a cross docking system according to just-in-time approach.

Ou, Hsu, and Li (2010) dealt with air cargo and formulated the problem as a time-indexed integer programming problem. They showed that even with limited number of unloading docks at the terminal, the problem is quite difficult to solve. They also proposed an exact solution procedure to determine an optimal unloading sequence for the shipments carried by each truck, together with a Lagrangian relaxation-based heuristic for assigning the trucks to the docks and determining the trucks arrival time. Some similar models with application in airport gate assignment have been reported in Babic, Teodorovic, and Tošic (1984), Ding, Lim, Rodrigues, and Zhu (2004), Ding, Lim, Rodrigues, and Zhu (2005), Oh, Hwang, Cha, and Lee (2006) and Lim, Rodrigues, and Zhu (2005b). Agustina, Lee, and Piplani (2010) address the distribution planning problem of cross docking network, considering transshipment possibility among the cross docks and tardiness permission for some pickups. The problem is formulated as a bi-objective integer programming model minimizing the total transportation, holding costs and the total tardiness. A heuristic procedure to construct an initial solution and three metaheuristics are proposed. Kim, Feron, and Clarke (2013) considered a problem of minimizing the total cost of the multi-cross dock distribution network, including transportation cost, inventory