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A solution framework for the multi-mode resource-constrained cross-dock scheduling problem ☆

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ABSTRACT

In this paper we propose a framework for shift-level container scheduling and resource allocation decisions at a cross-dock facility. The Multi-Mode Resource-Constrained Cross-Dock Scheduling Problem (MRCDSP) approach minimizes material flow and schedules inbound and outbound containers to dock-doors such that the total processing time is minimized subject to the resource constraints at the cross-dock. While container scheduling and resource allocation problems at cross-dock facilities have been studied previously in isolation, our work is the first to consider a complete view of cross-dock operations providing optimal container to dock-door allocation, and a makespan minimizing schedule of containers to the cross-dock. We present a comprehensive framework that includes identification of container clusters to reduce the problem size, a container-to-dock-door assignment algorithm, and a container clusters scheduling model that is solvable for practically sized problems. In a comparative numeric study based on data simulating a cross-dock facility, our approach is shown to outperform current practice, reducing the average time required for processing a set of containers by 37% and reducing the weighted-distance material traveled within the cross-dock by 45%.

1. Introduction

Cross-docks are facilities in which inbound materials are rapidly consolidated, distributed, and transferred to outbound vehicles. Cross-docks reduce transportation costs by allowing for higher capacity utilization for inbound and outbound vehicles. Cross-docks also promote just-in-time (JIT) production methods by sending material to final destinations in small batches in the correct sequence to reduce inventory costs. A study by the Saddle Creek Corporation [11] reported a significant increase in the number of firms that utilize cross-docks as part of their supply chain. The same report noted that firms that had recently implemented the use of cross-docks within their supply chain reported a 14.3% reduction in annual transportation costs. The research presented in this paper is motivated by our work with a software firm that develops container packing software and with one of its clients, a large Canadian retailer, that uses cross-docking as its main means of transferring goods between suppliers and its retail locations.

There are two main operational decisions that drive the majority of operational costs at a cross-dock: (1) assigning containers to dock-doors; and (2) scheduling containers at the cross-dock (accounting for resource requirements and constraints). Both inbound and outbound containers at a cross-dock must be assigned to a specific dock-door for the processing of freight. Improper assignments of containers to doors can result in excessive travel costs within the cross-dock. The arrival times of containers must also be carefully managed to allow for efficient use of limited resources such as labor and machines. Previous research has limited its focus to either the assignment or the scheduling problem. Our work considers both problems simultaneously, and, to the best of our knowledge, is the first to provide a holistic solution approach that can be applied to real-world problems. The introduction of this holistic framework for cross-dock operations is the major contribution of this paper.

Our solution approach to this problem is a methodological framework which we refer to as the Multi-Mode Resource-Constrained Cross-Dock Scheduling Problem (MRCDSP) method. The MRCDSP can be broken down into four stages: (1) container clustering; (2) dock-door assignment; (3) workflow scheduling; and (4) container scheduling. Each of these four stages of the MRCDSP are described in details in Section 3. The flow of information and the relationship between the different stages of

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the MRCDSP are depicted in Fig. 1. The container clustering stage uses the material flow between containers data as input and provides disjoint sets of containers as output. The resulting clusters are then used as input to the dock-door assignment phase which provides a container to dock-door allocation as output. These results then serve as inputs to the workflow scheduling stage, along with the detailed material flow data. The outputs of the workflow scheduling stage are a variety of potential modes of execution (as explained in Section 3.4) and associated processing times, which serve, along with the layouts achieved in the dock-door assignment stage, as inputs to the container scheduling stage. The final result is a detailed allocation schedule of resources to containers that minimizes the makespan required to process all container clusters, while minimizing the weighted-distance that material travels by optimizing the allocation of containers to dock-doors. The MRCDSP is the first attempt to consider all of these aspects of cross-dock operations hierarchically, taking into account available resources at the cross-dock. Further, it is the first framework to provide a holistic approach for these cross-dock operating decisions. Using this framework achieves an optimal container to dock-door allocation, and a makespan minimizing schedule of containers to the cross-dock. A comparative numeric study based on test case data from a retail partner shows that our approach reduces, on average, the makespan by 37% and the weighted-distance-material-travels metric by 45% in comparison to methods commonly used in practice.

The remainder of the paper is organized as follows. In Section 2 we provide an overview of the literature relevant to our work. In Section 3 we describe our modeling approach in detail. We present results from a numerical study in Section 4, and we conclude with a brief summary in Section 5.

2. Review of related literature

Boysen and Fliedner [6], Vogt [29], Van Belle [28] provide recent surveys of the cross-docking literature. Our work targets a gap in the literature mentioned by each of these survey papers: the need to simultaneously address the issues of material flow and container scheduling at cross-docks. As our research is related to both the material flow and scheduling decisions, we briefly discuss relevant papers from the cross-docking literature. Specifically we focus on papers regarding material flow and handling performance at cross-docks, and those targeting operational issues related to the scheduling of containers to be processed at the cross-dock.

Early papers related to cross-dock management include the seminal papers by Tsui and Chang [26,27] who formulate the problem of assigning containers to dock-doors as a quadratic assignment problem (QAP) and suggest a branch-and-bound approach for solving this problem. Gue [13] relaxes the assumption that all inbound containers are assigned along one side of an *I*-shaped cross-dock. By relaxing this assumption, Gue achieves a significant reduction of the weighted-distance material travels within the cross-dock. Miao et al. [21] extend Gue's [13] work by relaxing the assumption that dock-doors are fixed for specified destinations; the authors also account for a notion of scheduling, as we describe below.

In the aforementioned papers, only very small instances of the QAP are solved to optimality due to the computational complexity of the problem. Therefore, many later papers offer heuristic solution approaches. Bartholdi and Gue [1] use a simulated annealing heuristic to investigate the effects of incorporating congestion and labor costs within the door assignment problem. The authors find that considering the complete cost structure might lead to a reduction in total cost. Bozer and Carlo [8] present a simulated annealing heuristic to solve the QAP in a cross-dock setting, assuming that the number of containers is exactly equal to the number of dock-doors. Rosales et al. [22] study the allocation of dock-doors to containers while balancing work load among the dock-doors. The authors focus on minimizing the total cost, accounting for material flow and workforce resources, under the assumption that a single person is assigned to each cross-dock door with the possibility of overtime and that each outbound shipment location is fixed and exogenous.

In our study, we use a computationally efficient formulation of the QAP, coupled with a reduction in problem size achieved via clustering of containers, to obtain an optimal solution. The idea of container clustering in cross-dock operations is not entirely new; it has been noted in both [17,23], where the focus is on finding a

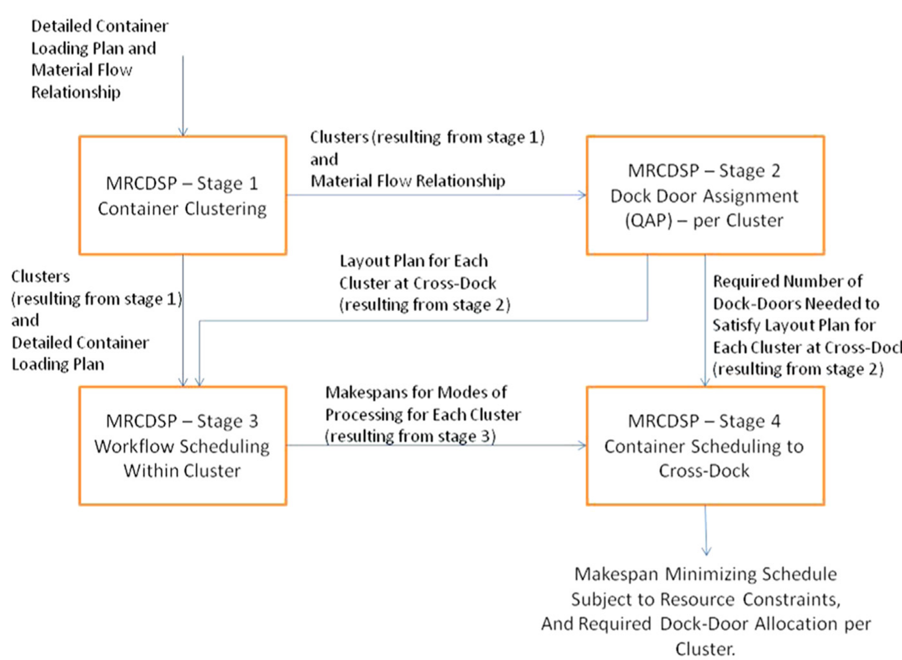

Fig. 1. Flow of information between MRCDSP phases.