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Joint planning of berth and yard allocation in transshipment terminals using multi-cluster stacking strategy

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ABSTRACT

In this work, a joint planning problem for berth and yard allocation in transshipment terminals is addressed. Multi-cluster stacking strategy is proposed to split each transshipment flow into a number of container clusters and then stack each cluster in different yard blocks. A mixed integer quadratic programming model is formulated to minimize the total distance of exchanging containers between mother vessels and feeders, and the workload imbalance among yard blocks. A novel three-stage heuristic solution approach is developed and extensive numerical experiments are conducted to show the effectiveness of the proposed approach and the benefit of the multi-cluster strategy.

1. Introduction

Transshipment, which is the operation of shipping goods to certain intermediate points before reaching their final destination, has been playing significant role in international sea freight transport over the past few decades (Vis and de Koster, 2003). Thanks to the introduction of containerization, as well as the fast growth of global trade, container transshipment activities have been increasing massively which thus leads to rapid development of such intermediate ports, also known as transshipment hubs. Generally, a transshipment hub is visited by two types of vessels, mother vessel carrying large shipments and feeder carrying small ones. At the port, small shipments unloaded from the feeders are combined into large shipment and then start a new journey with mother vessel. On the other hand, large shipment unloaded from the mother vessel is divided into small ones and then travel again with feeders. As such, transhipment hub is key to the performance of sea freight transport and thus calls for efficient management of port operations in order to remain competitive.

The efficiency of a container transshipment hub largely relies on the smooth handling of containers and efficient use of terminal resources. In a transshipment hub, various resources and the associate operations are involved, such as allocating berthing positions for visiting vessels, scheduling quay/yard cranes for loading and discharging containers, assigning yard space for temporary stacking, and using transfer equipments to move containers between quayside and storage yard. Since nowadays transhipment terminal is a very complex system and the volume of handling containers is usually huge, the port operators are always required to consider the associate terminal operations in an integrated manner so that the overall cost is minimized and terminal resources are made best use of. Centered on two most critical and limited port resources, namely berths and yard space, this work is concerned with the joint planning of berth allocation and yard allocation at tactical level

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with the aim of increasing the efficiency of handling the movement of containers between mother vessels and feeders as well as stacking and retrieving containers in storage yard.

Berth allocation and yard allocation planning at tactical level, also named berth template and yard template planning (Moorthy and Teo, 2006), are two most important decisions that need to be made in a transshipment terminal where containers are exchanged and stacked. Berth template planning concerns the allocation of berthing positions for visiting vessels and yard template planning decides the storage allocation for transshipment containers. In a word, both the templates specify the traveling route of a transshipment container flow which is firstly discharged from the berth of its inbound vessel, transferred to certain yard area for temporary storage and finally moved to the berth of its outbound vessel. Terminal operators strive to optimize the berth and yard template planning so as to minimize the travel distance of all containers because long travel distance not only causes high cost of yard trucks but also poses potential threat to the loading and discharging operations at the quayside. Thus, it is crucial to consider these two planning problems in an integrated manner.

In recent years, due to the much attention paid to the development and implementation of quayside equipment technology, the handling efficiency of containers at quayside has been improved dramatically. However, to increase the overall productivity of a container terminal and achieve a smooth container exchange process, fast storage and retrieval at the yard side should also be ensured. A typical container terminal yard is normally divided into a number of blocks, each of which consists of a series of contiguous slots. Each slot contains multiple rows and containers are stacked on the ground in several tiers. Yard stacking planning is expected to be able to facilitate the container handling at each yard block so as to achieve high overall terminal productivity together with the quayside. Thus, a well designed stacking strategy is essential for the planning. It is a common practice to group the containers with the same outbound vessel together in some dedicated area. However, this strategy is likely to result in the situation where at some specific time, the workload in some block is congested while in other blocks, the handling equipment is idle. As such, we propose to implement so-called multi-cluster strategy that divides the containers bound for the same vessel into multiple groups. Each group, also called cluster, is then stacked at a stretch of slots in a specific yard block. In this way, the workload is evenly distributed across the blocks and the handling equipment can be efficiently utilized (Ng et al., 2010). The stacking strategy aims to balance the workload among yard blocks so that the job and traffic congestion can be avoided.

In this research, we aim to implement multi-cluster stacking strategy for yard planning and address the berth template and yard template planning problems simultaneously for transshipment terminals. A mixed integer quadratic model is formulated for the joint planning problem with the aim of minimizing the total travel distance of exchanging containers as well as the workload imbalance among yard blocks over the planning horizon. Berth template planning and yard template planning are both well-known problems which have been attracting much research effort from academia due to the high problem complexity. To address this problem, a novel three-stage heuristic solution approach is proposed to decompose the original problem and help to efficiently find near optimal solutions. Numerical experiments are conducted to demonstrate the performance of our approach. It shows for real-world-like instances, the proposed algorithm is able to obtain very good results with reasonable computational effort.

The rest of the paper is organized as follows. Section 2 reviews relevant works in the literature. Section 3 describes the detailed planning problem and presents the mathematical model. A three-stage approach is developed in Section 4. Numerical experiments are conducted in Section 5 to show the performance of our method. Lastly, Section 6 concludes this work.

2. Literature review

Large attention from academia has been paid to the studies on optimization models and applications and in the field of container terminal operations. For a comprehensive overview, we refer the readers to Vis and de Koster (2003), Steenken et al. (2004), Günther and Kim (2006), Steenken et al. (2008) and Vacca et al. (2010). Our work draws on and contributes to the primary stream of the literature that are the decision problems on berth allocation and yard space planning in transshipment terminals. Particularly, the objective of this research is to simultaneously investigate these two problems at tactical level. As discussed in Moorthy and Teo (2006), tactical planning primarily concerns midterm issues on berth and yard allocation while operational planning generally focuses on more detailed equipment and manpower issues. In the following, the literature relevant to this study is reviewed.

Researchers have long been focusing on the very specific problems in container terminal operations and a large number of contributions have been dedicated to sophisticated models for single operational problems, such as berth allocation and yard planning problems. Studies on berth allocation problem (BAP) are usually conducted under the assumption that the berthing locations are discrete or continuous. The objective is to minimize the turnaround times of visiting vessels and constraints usually contain ship's length, berth's allowable draft, favorite berthing areas and time windows, etc. Publications on operational BAP, dealing with relatively short time horizon (up to one week), include Imai et al. (1997), Lim (1998), Imai et al. (2003), Kim and Moon (2003), Imai et al. (2005), Cordeau et al. (2005), Wang and Lim (2007), etc. Meanwhile, tactical BAP, usually with time horizon of up to one month, have also been receiving growing attention in recent years. Moorthy and Teo (2006) is the first work on berth template problem which concerns the allocation of home berths to multiple vessels calling at a terminal on a weekly basis. Their work considers the trade-off between service levels and costs. Moreover, re-planning of berth allocation due to the deviation of vessel arrival time is also enabled in the solution procedure. Giallombardo et al. (2010) address the TBAP that takes quay crane assignment into consideration. The objective is to