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Multi-period yard template planning in container terminals

Lu Zhen[a,*], Zhou Xu[b], Kai Wang[c], Yi Ding[d]

[a] School of Management, Shanghai University, Shanghai, China
[b] Department of Logistics and Maritime Studies, The Hong Kong Polytechnic University, Hung Hom, Hong Kong
[c] Department of Industrial and Systems Engineering, National University of Singapore, Singapore
[d] Logistics Research Center, Shanghai Maritime University, Shanghai, China

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ABSTRACT

This paper is about yard management in container ports. As a tactical level decision-making tool in a port, a yard template determines the assignment of spaces (subblocks) in a yard for arriving vessels, which visit the port periodically. The objective of yard template planning is to minimize the transportation cost of moving containers around the yard. To handle yard template planning, a mixed integer programming model is proposed that also takes into account traffic congestion in the yard. A further complication is that the cycle time of the vessels' periodicities is not uniform and varies among them, perhaps being one week, ten days, or two weeks, etc. However, this multiple cycle time of the periodicities of vessel arrival patterns, which complicates the yard template decision, is also considered in the model. Moreover, a local branching based solution method and a Particle Swarm Optimization based solution method are developed for solving the model. Numerical experiments are also conducted to validate the effectiveness of the proposed model, which can save around 24% of the transportation costs of yard trucks when compared with the commonly used First-Come-First-Served decision rule. Moreover, the proposed solution methods can not only solve the proposed model within a reasonable time, but also obtain near-optimal results with about 0.1–2% relative gap.

1. Introduction

Since the 1990s, world container traffic has been growing at almost three times the world's GDP growth, due to the offshoring of manufacturing operations in Asia, in particular China (Meng et al., 2014). Port throughputs have increased even faster, because an increasing number of containers are transshipped (Fransoo and Lee, 2012). Efficient port operations that maximize the throughput (with ports being paid by a handling charge per container) are essential for port operators' profits.

With the advancement of quay side equipment and technologies (e.g., twin 40-ft quay cranes, indented berths), the bottleneck in port operations has moved from quay side to yard side (Stahlbock and Voß, 2008). The yard management of a port plays a significant part in its competitiveness within the global shipping network. For some large container transshipment ports such as the Port of Singapore, the yard management is significantly important because of its land scarcity, which results in a highly concentrated storage situation within the storage yard (Jin et al., 2014). The yard template is a concept applied in container ports, especially transshipment hubs, that utilizes consignment strategy. This strategy stores export and

* Corresponding author. Tel: +86 21 66137925; fax: +86 21 66134284.
E-mail address: lzhen@shu.edu.cn (L. Zhen).

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transshipped containers, which will be loaded onto the same departing vessel, at the same assigned storage locations. Yard template planning is concerned with the assignment to vessels of storage locations (subblocks) in the yard, with certain dedicated subblocks being reserved for each vessel. Yard template planning aims to minimize the transportation cost for moving containers from their incoming berths to the storage subblocks in the yard and then to their outgoing berths. Besides the yard template based consignment strategy, housekeeping strategy is also a commonly used yard management strategy in ports (Giallombardo et al., 2010). The housekeeping strategy is to retrieve the containers that will be loaded onto a vessel, move and store them in some areas near to the berthing position of the vessel before it arrives at the port. This strategy can also reduce the turnaround time of vessels but may need reshuffling when retrieving containers as well as additional movement of containers before the vessel arrives at the port. However, the yard template based consignment strategy can avoid the container reshuffling activities. In this study, we focus on the yard template based consignment strategy, since it can avoid container reshuffling activities.

Traffic congestion is the most significant issue that constrains the efficiency of yard side processes (Lee et al., 2006; Han et al., 2008; Zhen et al., 2013), and is a phenomenon that prevents yard trucks from traveling freely (Zhang et al., 2009). Typical events observed in this phenomenon are that a lot of yard trucks may crowd around certain small areas for loading (or unloading) containers from (or to) yard storage locations (i.e., subblocks), or a lot of yard trucks may travel along a particular passing lane simultaneously, which makes them have to slow down during travel. Without taking into account these traffic congestion issues, a single-period yard template planning decision is just a generalized assignment problem that is only concerned with decisions on a *spatial* dimension. However, the traffic issue brings about constraints on a *temporal* dimension, such that neighboring subblocks should not have heavy loading and unloading activities occurring at the same time, and that each passing lane should not have significant traffic flows at the same time. These two phenomena are affected by the yard template planning decisions.

Moreover, vessels (shipping liners) usually visit the port periodically, and have different cycle times. For example, some vessels have a weekly arrival pattern, but some may have ten-day or biweekly patterns (Moorthy and Teo, 2006). Nowadays, Daily Maersk even has a daily arrival pattern at each port of call, and many feeder services have twice-weekly (APL, 2015a) or thrice-weekly services (APL, 2015b). Moreover, even if a service is weekly, the ships that visit the port each week may be of different size. For the example of Columbus Loop in CMA-CGM shipping company, the ship size varies from 8197 TEUs (Twenty-foot Equivalent Units) to 9034 TEUs (CMA-CGM, 2015). In reality, the weekly pattern is the most common in actual practice. If all the vessels had a uniform cycle time, there would be no multi-period decision problem for the yard template planning. However, this paper studies the multi-period yard template planning problem by also considering the heterogeneous periodicities of vessels. It should be noted that the subblock assignment for each vessel can also vary in its periods, so a subblock needs to not be assigned to one vessel for the whole planning horizon. This dynamic nature of the subblock assignment within each vessel's multiple periods further complicates the aforementioned decisions problem involved with yard template planning. Moreover, an even more common situation is that only about half of container vessels arrive at ports on their planned day (in other words, about half of container vessels are delayed at least one day). Consequently, even if all ships are weekly pattern, port operators still have to adjust the yard templates every day, which further validates the necessity of considering the heterogeneous periodicities of vessels in the yard template decision.

This paper makes an explorative study of yard template planning in container transshipment hubs, considering both the yard traffic congestion and the multiple cycle time of the periodicities of vessel arrival patterns. This study proposes a model for multi-period yard template planning with traffic congestion constraints. A local branching based solution method and a Particle Swarm Optimization (PSO) based solution method are developed for solving the proposed model. Numerical experiments using real world like instances are conducted to validate the effectiveness of the proposed model and the efficiency of the proposed solution method.

The remainder of this paper is organized as follows: Section 2 reviews the related works. Section 3 elaborates on the background to the problem; a mathematical model is formulated in Section 4; and two solution methods are developed in Section 5. Results of the numerical experiments are addressed in Section 6, and closing remarks are then outlined in the last section.

2. Literature review

For an introduction to general port operations, we refer readers to the review works given by Vis and de Koster (2003), Steenken et al. (2004), and Stahlbock and Voß (2008). This paper is related to strategies used in allocating storage space in a yard to arriving containers. Plenty of studies have been performed on related problems. For example, Kim and Kim (1999) proposed a segregation strategy to allocate storage space for import containers. Kim et al. (2000) designed a methodology to determine the storage location of arriving export containers by considering their weight. Zhang et al. (2003) studied a storage allocation problem using a rolling horizon approach. Kozan and Preston (2006) proposed an iterative search algorithm for an integrated container transfer and allocation model to determine the optimal storage strategy. Caserta et al. (2011) defined a two-dimensional 'corridor', and developed a corridor method inspired algorithm for a blocks relocation problem in yard stacking systems. Jin et al. (2014) proposed the concept of 'yard crane profile', and used it in an integrated optimization model on yard storage management and yard crane deployment decisions. Different from the above studies, the yard management in this paper is based on a consignment strategy that was studied by Chen et al. (1995) and