Advanced Engineering Informatics 34 (2017) 101–113

Contents lists available at ScienceDirect

Advanced Engineering Informatics

journal homepage: www.elsevier.com/locate/aei

Storage yard management based on flexible yard template in container terminal

Caimao Tan[a], Junliang He[b,*], Yu Wang[c]

[a] Institute of Logistics Science & Engineering, Shanghai Maritime University, Shanghai 201306, PR China
[b] Engineering Research Center of Container Supply Chain Technology, Ministry of Education, Shanghai Maritime University, Shanghai 201306, PR China
[c] College of Mechanical Engineering, Tongji University, Shanghai 201804, PR China

ARTICLE INFO

Keywords:
Storage yard management
Flexible yard template
Mixed integer programming
Yard template generation
Yard crane deployment

ABSTRACT

With the bottleneck of port operation moving from the quay side to the yard area, storage yard management is becoming increasingly important in the container terminal. This paper studies on storage yard management in container terminal, a flexible yard template strategy is proposed instead of the fixed yard template strategy. Based on the strategy, an integrated optimization model simultaneously considering space allocation and yard crane deployment for the tactical storage yard management is formulated. Besides, Numerical experiments are conduced to verify the effectiveness of the proposed strategy and mathematical model.

1. Introduction

With the development of container transportation, the competition between container terminals increased rapidly. In recent years, the pace of large-scale container ship is developing continuously and it puts forward a higher requirement for the operational efficiency of container terminal. Under current situation, there is no doubt that the container terminal operating efficiency has become an important factor in competition with other terminals. Meanwhile, with advancements of quay side equipment and technologies, the bottleneck of port operations has moved from quay side to yard side [3,11]. Therefore, storage yard management in container terminal will play an increasingly important role in the following period of time.

Yard storage space and yard crane (YC) equipment are the core resources in the yard area of container terminal. Therefore, the storage yard management usually involves two interrelated problems: (1) the storage space allocation problem, which is to determine the storage space for the incoming vessels; (2) the YC deployment problem, which is to decide the number of YCs handling in each block and the YCs movements among different blocks [18]. Storage space allocation assigns the yard storage space for incoming containers. It will not only determines the transport distance of container but also affects the traffic congestion in the container terminal. YC deployment determines the movement plan among yard blocks, it affects efficiency of yard crane during the entire periods. The overall efficiency of a container terminal is measured by the average vessel discharging/loading time. The maximum efficiency can only be achieved if yard planning and crane development are well designed and coordinated [20].

Generally speaking, these two interrelated problems should be integrating considered, since the storage allocation plan determines the distribution of YC workload over the entire yard and affects YC deployment decisions. In reality, however, yard manager usually solves these two problems in such a way that yard space allocation is determined first and the resulting workload information is used to the latter accordingly.

In addition, as a frequently-used strategy in the field of storage space allocation, yard template could evidently reduce the number of reshuffles, vessels' turnaround time and YC moving distance [35], but this strategy has two undeniable imperfections: (1) the yard template excessively limits the space to pairing of the yard (details are performed in the section of *Problem Description*; (2 it is difficult to determine an optimal yard template for container terminals, the relevant studies are rarely be found in current literatures. Therefore, it is necessary to change this situation and improve the level of integrated storage yard management.

Another issue is the efficiency matching of QCs and YCs of vessels during the loading and unloading process. Due to the efficiency difference between QC and YC handling, the number of QCs and YCs assigned to each vessel should be reasonably matched. This is a key point for the efficient operation of the container terminal, but it is often overlooked.

This paper tries to relieve the limitation of the fixed yard template strategy and probe an integrated storage yard management method for container terminal. A relatively flexible template strategy is proposed

* Corresponding author at: 1550 Haigang Avenue, Logistics Engineering School, Shanghai Maritime University, Shanghai 201306, PR China.
E-mail address: soldierlianglian@163.com (J. He).

http://dx.doi.org/10.1016/j.aei.2017.10.003
Received 10 April 2017; Received in revised form 30 September 2017; Accepted 13 October 2017

instead of the fixed yard template strategy. Furthermore, an integrated mathematical model for storage space allocation and YC deployment, together with the efficiency matching of QCs and YCs consideration is formulated. The contribution of this paper includes the following:

(1) Instead of the fixed yard template, a flexible yard template strategy is proposed which allows each block in the yard has different pairing combination of space. (2) An integrated mathematical optimization model that simultaneously considering storage space allocation and YC deployment for the tactical storage yard management is formulated. (3) The efficiency matching of QCs and YCs is introduced and then implemented it in the integrated mathematical model.

The remainder of this paper is organized as follows. Relevant literature is reviewed in Section 2. Section 3 presents the detailed problem description of storage yard management and the corresponding mathematical model is given in Section 4. Computational experiments are conducted in Section 5 to evaluate the effectiveness of the proposed model. Conclusions and future research are given in the last section.

2. Literature review

There are numerous studies on the optimization of container port operation, the methodologies included mathematical optimization [28,30,33,32] simulation optimization [1,2,12,25,14], informatics engineering [6,7] and knowledge engineering [31], etc. For a comprehensive overview, we refer readers to the review works given by Vis and de Koster [29], Steenken et al. [27], Stahlbock and Voβ [26]. In this section, a brief review of studies highly related to storage space allocation and YC deployment in container terminal is provided.

2.1. Storage space allocation

Storage space allocation can be analyzed in different levels according to the storage space unit considered: yard section, yard block, yard sub-block, yard bay and individual slot [18]. Considering that the storage yard management should allocate the yard space in the tactical level, storage space unit of this paper is in the sub-block level. Therefore, the works researched yard space allocation in sub-block level will be introduced minutely in this section.

The concept of *yard template* is first mentioned by [23] when their study on berth allocation planning problem, it is based on the consignment strategy which was researched by Chen et al. [5] and Dekker et al. [9]. Fig. 1 shows a typical yard configuration with a type of fixed template. Lee et al. [21] studied how to optimize the yard storage space allocation with the yard template plan is given. To reduce traffic congestion, a new workload balancing protocol is proposed. Han et al. [10] presented a yard storage strategy for minimizing traffic congestion. Based on this strategy, the concept of yard template is applied. Jiang et al. [15] attempted to optimize the yard template and the yard storage allocation plans simultaneously and proposed a space sharing strategy to improve the land utilization and operational efficiency. Zhen [35] studied yard template planning problem under uncertain maritime market, in this paper, random numbers of containers that will be loaded onto incoming vessels that visit the port periodically are considered. Zhen et al. [38] studied berth template planning and yard template planning for transshipment hubs in the tactical level, an integrated model is proposed. Zhen et al. [38] researched the vessels arriving at container terminal with different periodicities, a multi-period yard template planning is presented. Zhen [37] investigated the influence of yard congestion in the yard template optimizing, a model minimizes the total expected travel time of moving containers is formulated.

2.2. Yard crane deployment

Since container terminals generally cannot keep a fixed number of YCs in each block during the whole cycle on account of investment expense, YCs are usually deployed in a way such that one YC serves more than one block by moving back and forth among blocks. Therefore, the YC deployment should determine the YCs assigned to each block and movements among blocks. The main basis of YC deployment is the workload of each block in each period. For a detailed YC deployment description in actual container terminal, we refer readers to the study given by Petering and Murty [24].

Zhang et al. [34] addressed YC deployment problem with the forecasted workload of each block in each period is given, The objective is to find the times and routes of crane movements among blocks so that the total delayed workload in the yard is minimized. With the same objective, Cheung et al. [8] removed the restriction that yard crane movements must be completed within a period, an alternate model for the interblock crane deployment problem is presented and the computational complexity of the problem is analyzed. Linn et al. [20] and Linn and Zhang [22] loosen the restrictions in Zhang et al. [34] that each block should be deployed not more than two cranes, the YC deployment problem is formulated as a mixed integer linear program. A heuristic algorithm is developed to solve problems of practical size by the latter paper. In the above-mentioned researches, the type of the yard crane is a single E-RTG system. Cao et al. [4] focused on the deployment problem of double-rail-mounted gantry yard crane system, an integer programming model is formulated and a greedy heuristic algorithm as well. Unlike the literatures mentioned above, the YC deployment system is considered by Petering and Murty [24], interblock YC moves are allowed to be initiated at any time, not just at regular time intervals and the simulation optimization is used instead of mathematical optimization.

2.3. Integrated storage yard management

Integrated storage yard management considers storage space allocation and YC deployment as a system, it solves the two decision problems simultaneously instead of sequentially in a way that storage space allocation is determined first and then YC deployment accordingly.

Kim and Kim [19] proposed a method to determine the optimal sizing space and the optimal number of YCs for import containers, the model objective consists of the storage space cost, the investment cost of YCs and the operating cost of handling facilities. But the method for export and transshipment containers is not involved. Lee et al. [40] addressed on the integrated bay allocation and yard crane scheduling for transshipment container terminal, the receiving operation and retrieving operation in the storage yard are considered simultaneously to achieve a more efficient operation of the YC. However, it is in fact that the bay allocation focused on the management of block rather than yard overall prospect. Jiang et al. [16] and Jiang and Jin [17] researched storage yard management in transshipment hub port, but both of these two papers based on a given yard template, since they focused on the short-term planning level. Jin et al. [18] studied the daily storage yard management problem, five YC deployment profiles are defined and container traffic congestion in the storage yard is taken into accounted in this paper. It should be noted that the objective of this paper is to minimize YC operating cost and interblock movement cost, the cost of storage yard allocation is not considered. In addition, Won et al. [39] proposed an integrated decision-making framework for the yard planning that simultaneously considers storage space, yard crane and traffic area in the container terminal.

2.4. Research gaps

Although plenty of efforts have been made in the field of storage yard management, however, there are still research gaps in storage yard management. Three gaps are given as follows: