Research on Allocation for Block Workload of Container Yard under Multi-ship Delivery

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***Abstract*—With ever increasing containerization in global supply chain, the competition among container terminals has become critical. Functioned as a place to store import/export containers, planning and scheduling of container yard is an important problem of container terminals. In this paper, in order to solve the yard allocation problem, which is an important element of container yard planning, an optimization model of import/export containers' workload allocation for yard blocks is proposed. First, a heuristic algorithm based on balancing dynamically the workload of terminal equipment is developed to generate the initial solution. Then a tabu search algorithm is used to further search the better solution. The experimental results show that the proposed model and its algorithm is a promising tool for allocating yard blocks' workload.**

Keywords-container terminal; heuristic algorithm; tabu search algorithm

I. Introduction

In the modern global environment, the planning and management of supply chains is one of the most important issues for companies to be competitive. With ever increasing containerization in global supply chain, the competition among container terminals has become critical.

In a container terminal, a yard stock is a special place which is used to store containers. In general, the yard stock is separated into different blocks. Each block consists of 20-30 yard-bays. Each yard-bay contains several rows [1]. Therefore, the configuration of a block could be specified by three parameters, the number of bays, the number of rows, and the number of tiers.

Stacking logistics has become increasing important, because more and more container ships seek for a reduction of the staying time in ports, and stacking space is limited [2]. What's more, efficient stacking is necessary to ensure that the loading/unloading operations of containers can be carried out effectively [3]. As a result, container yard planning and scheduling plays an important role in the container terminals' overall performance.

A great deal of research has been done in the field of yard allocation problem, which is an important element of container yard planning. Bazzazi proposed a genetic algorithm to solve the storage space allocation problem, with an aim to balance the workload between yard blocks in order to minimize the storage/retrieval times of containers [4]. Lim and Xu studied a critical-shaking neighborhood search for the yard allocation problem [5]. Considering the weight of export containers, Kim formulated a dynamic programming model to determine the storage location to minimize the number of relocation movements expected for the loading operation of export containers. A decision tree is developed to support real time decisions [1]. Kim and Park also proposed a method to determine the storage location of export containers. A mixed-integer linear program is formulated with two heuristic algorithms to obtain the efficiency of space utilization and loading operations [6]. Preston and Kozan discussed the optimal storage strategy for various container-handling schedules. Solved by genetic algorithm, a container location model is developed, with an objective function of minimizing the turn-around time of container ships [7]. Zhang also studied the storage space allocation problem in the storage yards of terminals. Using a rolling-horizon approach, the problem is decomposed into two levels and each level is formulated as a mathematical programming model [8]. Kim and Hong discussed the storage and pickup operations in block stacking systems with the heuristic rules for relocating blocks [9]. In order to improve operational efficiency, Lee and Chao studied a heuristic algorithm to pre-marshal the containers in such an order that fits the loading sequence [10]. Yu and Lu proposed a systematic method of container yard to solve both storage space allocation problem and yard crane scheduling problem [11].

In this paper, we focus on the yard allocation problem, that is, allocation of workload of loading/unloading operations for import/export containers' distribution among different yard blocks.

The paper is organized as follows. The optimization model for block workload allocation problem is described in section 2. A heuristic algorithm based on dynamically balancing workload of terminal equipment over the time zone is given out in section 3. On basis of the proposed heuristic algorithm, a tabu search algorithm is discussed in section 4. Section 5 demonstrates the numerical experiments and their results. The final section is the conclusion.

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II. Optimization Model

Container terminals work under multiple operational objectives. The most critical performance measure for rating the container terminals is the ship turnaround time, which is the average time the terminal takes to load/unload a berthed container ship [12].

In our optimization model, in consideration of the multi-ship delivery, a dynamic batch could be generated for each planning epoch. That is, ships arrive successively, which exhibit an overlapping in each period of time. Therefore, we define a batch as a dynamic period of time during which all overlapping container ships successively arrive, e.g. $batch_1$, $batch_2$ as illustrated in Fig. 1.

During each batch period, each ship has both release time (r_i) and due date (d_i). Furthermore, this batch could be divided into several time zones, e.g. t_1, t_2,…, t_{2s-1} in $batch_1$. There could be two states for each time zone in terms of the property of its endpoint. We define the "*Starting point*" as the point which is the initial endpoint of one time zone, e.g. t^s_1, t^s_2,…, t^s_{2s-1} in $batch_1$, and the "*End point*" is defined as the point which is the terminal endpoint of one time zone, e.g. t^e_1, t^e_2,…, t^e_{2s-1} in $batch_1$.

Taking into account the multi-ship delivery, which is the real circumstance of maritime port, the optimization of yard allocation model is carried out based on one batch within its planning horizon.

What's more, in consideration of integrating container terminal as a whole system, hypothesis that the operation of quay cranes is a bottleneck is quite reliable. As a result, the subset of operated yard cranes should be decided according to the corresponding operation time of quay cranes in order to balance the workload of the whole container terminal system.

Therefore, two problems should be solved to balance the workload of the container terminal system. One is to determine the matching number of blocks to be run for loading/unloading operation over a given time zone. The other is to allocate the appropriate number of containers to the assigned blocks.

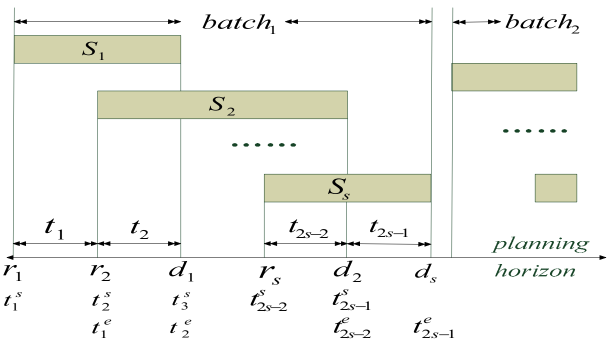

Figure 1. Batches of container ships.

A. Indices

i ($i \in I = \{1,2,...,s\}$) is ship index. j ($j \in J = \{1,2,...,n\}$) is import container index, while j' ($j' \in J' = \{1,2,...,n'\}$) is export container index. And k ($k \in K = \{1,2,...,b\}$) is block index.

B. Problem Data

s is the total number of arriving container ships over the batch period. b is the total number of blocks in container yard. n is the total number of import containers to be unloaded, while n' is the total number of export containers to be loaded. xs_i is the X coordinate of the berth in which container ship i berthed, while ys_i is the Y coordinate of the berth in which container ship i berthed. qc_i is the maximum number of containers loaded/unloaded per hour for container ship i, while yc_k is the maximum number of containers loaded/unloaded per hour in block k. ns_i is the total number of import containers to be unloaded from container ship i, while ns'_i is the total number of export containers to be loaded to container ship i. vm_k is the maximum number of containers could be stored in block k according to current block status. xb_k is the X coordinate of block k, while yb_k is the Y coordinate of block k. nb'_k is the number of export containers taken out from block k, and nsb'_{ik} is the number of export containers that are taken out from block k and loaded to container ship i. v is the average speed of transport vehicle between berth and container yard. P^1_{ik} is the average operation time for one loaded/unloaded container of container ship i, which is determined by the capability of quay cranes operated for container ship i. P^3_{ik} is the average operation time for one loaded/unloaded container of block k, which is determined by the capability of yard cranes operated for block k. P^2_{ik} is operation time for transporting one operated container from container ship i to block k, $p^2_{ik} = (|xs_i - xb_k| + |ys_i - yb_k|)/v$.

C. Decision Variables

NB_k is the number of import containers allocated to block k, while NSB_{ik} is the number of import containers that are unloaded from container ship i and allocated to block k.

D. The Objective Function

For each batch period, the objective of the optimization model of yard allocation problem is to minimize the sum of earliness time of all container ships.

$$Min\sum_{i\in I} Max\{(d_i-(r_i+\max_{k\in K}((NSB_{ik}+nsb'_{ik})\cdot p^1_{ik})$$
$$+\max_{k\in K}((NSB_{ik}+nsb'_{ik})\cdot p^2_{ik})$$
$$+\max_{k\in K}((NSB_{ik}+nsb'_{ik})\cdot p^3_{ik}))),0\} \quad (1)$$

Subject to

$$\sum_{k=1}^{b} NB_k = n \quad (2)$$

$$\sum_{i=1}^{s} NSB_{ik} = NB_k,\ \forall k\in K \quad (3)$$

$$\sum_{k=1}^{b} nb'_k = n' \quad (4)$$

$$\sum_{i=1}^{s} nsb'_{ik} = nb'_k,\ \forall k\in K \quad (5)$$

$$\sum_{i=1}^{s} ns_i = n \quad (6)$$

$$\sum_{k=1}^{b} NSB_{ik} = ns_i, \forall i\in I \quad (7)$$

$$\sum_{i=1}^{s} ns'_i = n' \quad (8)$$

$$\sum_{k=1}^{b} nsb'_{ik} = ns'_i, \forall i\in I \quad (9)$$

$$NB_k - vm_k \le 0,\ \forall k\in K \quad (10)$$

NSB_{ik}, NB_k, non-negative integer values. (11)

In order to reduce the time in berth of container ships, it is necessary to accomplish all container jobs according to their due dates (d_i). The strategy of regarding the container terminal as a whole system leads to a matching performance between container terminal equipment, such as, quay cranes, and yard cranes. Redundant utilization of yard cranes, which will result in the earliness of container ships, should also be avoidable.

Constraints (2) - (5) are quantity constraint for containers in yard. Constraints (6) - (9) are quantity constraint for containers of ships. Constraint (10) defines the storage capacity for yard blocks.

III. A Heuristic Algorithm for the Initial Solution

In our problem, owing to the different arriving container ships as well as their different carried import/export containers, workload of equipment of container terminal over planning horizon is dynamic and changeable.

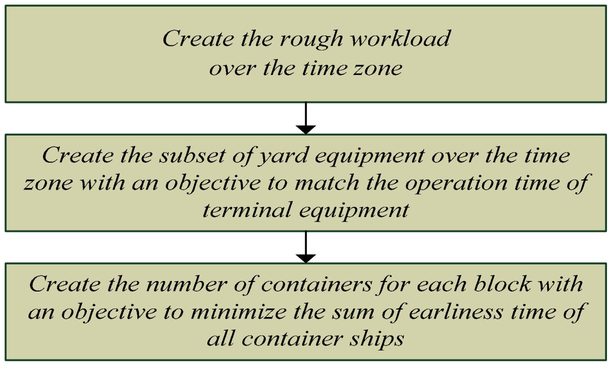

Figure 2. The framework of the heuristic algorithm.

Our strategy is to dynamically balance the workload of terminal equipment over the time zone, that is, loading/unloading operations for import/export containers among different yard blocks.

In this section, a heuristic algorithm for the initial solution is developed to allocate the certain number of storage blocks for each batch of arriving container ships, and then to allocate the appropriate container quantity for each corresponding block.

The framework of the heuristic algorithm is described in Fig. 2.

In this paper, we only explain the sub-problem of *Creation of the Subset of Yard Equipment for Each Time Zone* in detail.

A. Creation of the Subset of Yard Equipment for Each Time Zone

Based on the actual circumstance, quay crane is usually the bottleneck of container terminals system. Therefore, the problem is to determine the subset of yard cranes, in order to match the operation time of quay cranes.

The determination of the subset of yard equipment for each time zone could be divided into the following steps:

Step 1: Schedule all yard blocks according to the nearest principle.

Define bk_i as block vector for container ship i.

$$bk_i = \{b_k, i\in I=\{1,2,...,s\}, k\in K=\{1,2,...,b\}\}, s.t.$$
$$(|xs_i - xb_k| + |ys_i - yb_k|)_k \le (|xs_i - xb_{k'}| + |ys_i - yb_{k'}|)_{k'},$$
$$i\in I, \forall k, k'\in K, k\langle k'$$

Step 2: Estimate the quantity of yard equipment NYC_m of time zone m.

$$NYC_m = \sum_{i=1}^{s} qc_i / \sum_{k=1}^{b} yc_k,$$
$$m\in M=\{1,2,...,2s-1\}$$

Step 3: According to the integration of loading and unloading operation principle, create the active set of yard for active ship set over the time zone.

3.1: Create the available set of blocks bk^a_{mi}, which is a block vector set could be run for active ship i of time zone m.

Define bk^e_{mi} as block vector for export containers loaded to active ship i of time zone m.

$$bk^e_{mi} = \{b_k, m \in M, i \in AS_m, k \in K, \forall j \in J^{'} = \{1,2,...,nsb^{'}_{ik}\}\}$$

Then, we have a block vector bk^a_{mi} for active ship i of time zone m.

$$bk^a_{mi} = \{bk_i - bk^e_{mi}, i \in AS_m, m \in M\}$$

3.2: Create the intersection set of blocks BK^t_m, which is a block vector for active ship set AS_m of time zone m.

$$BK^t_m = \{bk^a_{mi} \cap bk^a_{mi^{'}}, m \in M, i, i^{'} \in AS_m, i \neq i^{'}\}$$

3.3: Create the combined set of blocks BK^c_m, which is a block vector for export containers loaded to all active ships of time zone m.

$$BK^c_m = \{bk^e_{mi} \cup bk^e_{mi^{'}}, m \in M, i, i^{'} \in AS_m, i \neq i^{'}\}$$

3.4: Obtain the remaining available set of blocks BK^r_m, which is a block vector for active ship set AS_m of time zone m.

Define $bk^{'}_{mi}$ as block vector for active ship i of time zone m.

$$bk^{'}_{mi} = \{bk^a_{mi} - BK^t_m, m \in M, i \in AS_m\}$$

For all active ships, we have a block vector BK^r_m of time zone m.

$$BK^r_m = \{bk^{'}_{mi} \cap bk^{'}_{mi^{'}}, m \in M, i, i^{'} \in AS_m, i \neq i^{'}\}$$

3.5: Create the active set of yard blocks $ABK^{'}_m$, which is a block vector for active ship set AS_m of time zone m.

$$ABK^{'}_m = BK^t_m \cup BK^r_m \cup BK^c_m = \{abk^{'}_{mk}, m \in M, k \in K\}$$

Step 4: Choose the first NYC_m block elements from the active set of blocks $ABK^{'}_m$ of time zone m.

$$ABK_m = \{abk^{'}_{mk}, m \in M, k = \{1,2,..., NYC_m\}\}$$

IV. A Tabu Search Algorithm for the Optimized Solution

In order to optimize the initial solution, which is discussed by the last section, a tabu search algorithm is further developed in this section to solve the block workload allocation problem.

A. Initial Solution

Initial solution X for allocating certain number of containers for specific blocks is created by the heuristic algorithm of dynamically balancing the load of container terminal equipment over the time zone. $X = \{NSB_{ik}, i \in I = \{1,2,..., s\}, k \in K = \{1,2,..., b\}\}$.

B. Neighborhood

Neighborhood of tabu search is defined as *SWAP* operation. For container ship i, the element in container quantity sequence corresponding to each block, is swapped each other at random, e.g. $(NSB_{ik}, NSB_{ik^{'}}, k, k^{'} \in K, k \neq k^{'})$.

C. Tabu List and Search Strategy

The tabu list is a *FIFO* sequence with length L. It is composed of the current solution X, its E neighbors and their corresponding objective value, which is defined as (1) in section 2. The strategy is to search the "*best*" value among E candidates of the current solution X.

D. Stop Criterion

There are two stop criteria of tabu search. One is the maximum times m for iteration; the other is the tolerance criterion.

If the difference between new solution X^* and the previous solution X is not larger than the defined tolerance D within m, that is, $|X - X^*| \leq D$, stop iteration and output the outcome.

V. Case Study

To testify the effectiveness of the proposed optimization model and its heuristic algorithm for yard allocation problem, some numerical experiments for one container terminal is put forward in this section.

According to different occurrences of ship arrival, we discuss 8 cases, ranging from relatively idle terminal resource utilization to busy terminal resource utilization, which could reflect the real workload distribution of yard block.

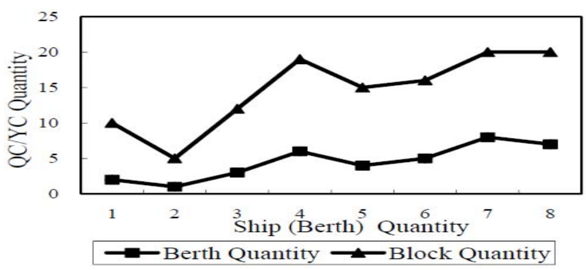

Figure 3. Change of utilization of container terminal equipment.

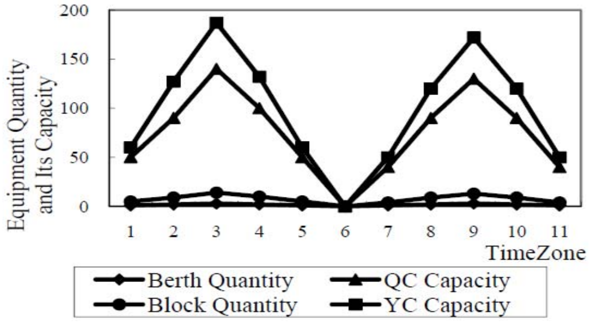

Figure 4. Change of capacity of terminal equipment over the time zone.

For each case, we first generate the initial solution by the proposed heuristic algorithm, then we conduct the tabu search to obtain the optimized solution.

The development platform of the case is Windows XP. The programmable language used is C#, and the database system chosen is SQL Server. All calculations run on an IBM T43 notebook.

We discuss our heuristic algorithm over one batch period and over corresponding time zones separately.

We could find some phenomena:

A. Similar Change of Utilization of both Quay Cranes and Yard Cranes during One Batch Period

According to different occurrences of ship arrival, we can find that with the increasing utilization of quay cranes during one batch period, as a result, the utilization of yard cranes increases as well, see in Fig. 3.

B. Consistent Change of both Quay Cranes and Yard Cranes over Each Time Zone

We can find that over each time zone, the change of capacity of yard cranes is fully consistent with the change of quay cranes, as shown in Fig.4.

VI. CONCLUSION

In the modern global transportation network, the need for optimization in container terminals has become not only prevalent but also necessary. A reasonable planning of container yard is really an important issue of container terminals.

In our study, a heuristic algorithm is proposed to solve the yard allocation problem. The proposed algorithm, which not only has a better initial solution but also has a quick convergence speed to obtain the satisfied solution, is showed to be appropriate and effective.

Aimed at the next phase of container yard planning and scheduling, practical heuristic algorithm will be suggested as an extension of this study to create an appropriate position for each container.

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