Journal of Navigation and Port Research International Edition
Vol.32, No.9 pp. 737~742, 2008 (ISSN-1598-5725)

Allocation Model of Container Yard for ATC Optimal Operation in Automated Container Terminal

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Abstract : *In this paper, we deal with an allocation model of vertical type container yard for minimizing the total ATC (Automated Transfer Crane) working time and the equivalence of ATC working load in each block on automated container terminal. Firstly, a layout of automated container terminal yard is shown. The characteristic of equipment which work in the terminal and its basic assumption are given. Next, an allocation model which concerns with minimizing the total working time and the equivalence of working load is proposed for effectiveness of ATC working in automated container terminal. Also, a weight values on critical function are suggested to adjust the critical values by evaluating the obtained allocation plan. For ATC allocation algorithm, we suggest a simple repeat algorithm for on-line terminal operation*

Key words : *Allocation model, Load equivalence, Minimization, ATC, Container terminal*

1. Introduction

On growing the larger container vessel size and the faster container vessel speed, many containers quickly have to be stevedored in the lay days according to increased international trade quantity. However, because of the limit of manual equipments in the conventional container terminal, the automation for operation and the full-automation for equipment are on an increasing trend.

Generally, container handling works are divided into the land side work and the sea side work. In former case, according to the change of vessel draft, tide, wind and container loading status, it is more difficult to make full-automation system. But in the future, the productivity in container terminal will be decided by the size and the efficiency of handling equipments. Beside in latter case, the handling work is automated by AGV(Automated Guided Vehicle) which is an equipment to move the container to the apron and the container yard. In this case, the full automation is attained technically possible level by transfer crane (T/C) automation.

The optimal yard operation will be decided by the container productivity between vessel loading/discharging work and gate works in container terminal system. So, the productivity of container terminal is able to be maximized by automated terminal yard. However, few studies were researched in the container allocation problem for the container yard in automated container terminal.

Chung et. al. (1988) proposed a practical use for buffer space in the apron area to improve the operating rate of container handling equipment and evaluated the performance through the computer simulation. Taleb-Ibrahim (1989) presented the various plans for allocating yard space in the container terminal. Kim et. al. (2002) suggested a method of determining the optimal amount of storage space and the optimal number of transfer cranes for handling import containers. Bish (2003) developed a heuristic algorithm based on formatting the problem for multiple-crane-constrained scheduling problem. Zhang et. al. (2003) studied the storage space allocation problem in the storage yards of terminals, where minimizing the total distance to transport the containers between the storage blocks and the vessel berthing locations. Ng and Mak (2005) studied the scheduling problem for yard crane to perform a given set of loading/discharging jobs with different ready times. Imai et. al. (2006) suggested a ship's container storage and loading plans that satisfy the ship stability and minimum number of container re-handles.

Choi and Ha (2006) compared the productivity of container handling in the three kinds of container terminals, horizontal layout with parallel berth, vertical layout with parallel berth and horizontal layout with indented berth, and showed that the horizontal layout of parallel berth indicates a excellence as compared with vertical layout.

Recently Shin et. al. (2008) suggested a Y/T pooling system based on TRLS (Real Time Location System) and

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applied to conventional container terminal.

However, these results have only considered the fixed size container for allocating container yard space and also limited the horizontal container yard. Also the load equivalence for equipments is in close concern with mainly vessel works in container yard, and it is very important to minimize the total time which effects to the delay of vessel loading/discharging works. Thus, the problem of allocation of container yard in this paper is very important factor to improve productivity of container terminal. Also, when allocating the container yard, it requires the study of pooling system for yard equipments through minimizing the total working time and the balancing the working load.

In this paper, we will compare the main characteristics between automated container terminal and conventional one and describe the features of equipment. Considering the equivalence of ATC working time and minimizing the total time in the allocation model of container yard, we propose the objective function and show that weighting rate can regulate to take the present state of container yard.

For ATC assignment model for equipment pool system, we consider the minimization of total work time, equivalence of ATC working load, equalization of work finish time, minimization of AGV waiting time, and minimization of Y/T waiting time. Lastly, we briefly show the ATC allocation algorithm in on-line works.

2. Description of Container Terminal

Container terminal is a place where vessel alongside the pier, and containers can be loaded/discharged. Generally it is consist of container yards, berths, and gates. Also, the operation system of container terminal is divided with loading and discharging, transfer, container yard and gate systems.

The operation system of T/C work is deeply important factor, because all of generated working in the container terminal becomes continuously accomplished though a container yard. Due to variable condition and severely congestion of container yard, it is difficult to define clearly T/C operation.

2.1 Conventional Container Terminal

Generally, the allocation type for terminal yard is a parallel with berth which horizontal form in the conventional container terminal as in Fig. 1. The export block allocate container yard near by berth, while the import block allocate next to the export block. And the behind of the import block allocate a special and empty container. The container transportation work proceeds by T/C and straddle carrier in the container yard.

2.2 Automated Container Terminal

Fig. 2 shows the automated container terminal with one berth which deal with whole in this paper. Container yard constitutes the perpendicular berth, where the each block will be operated by two intersectable ATCs and few AGVs (Automated Guided Vehicle). AGV takes charge of container transportation for vessel work, while Y/T (Yard Track) takes the container transportation between container yard to gate.

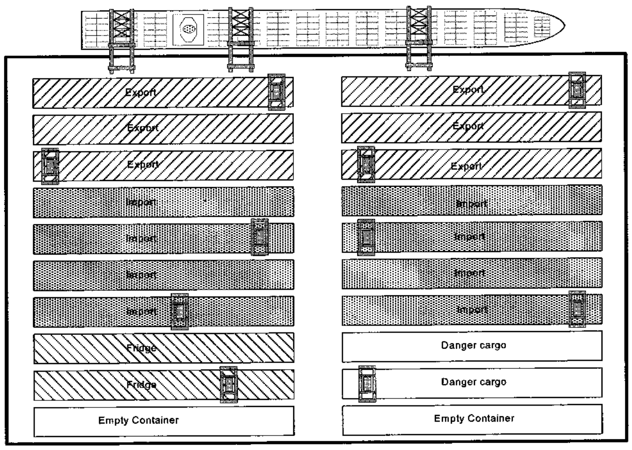

Fig. 1 Horizontal Assignment in Container Yard

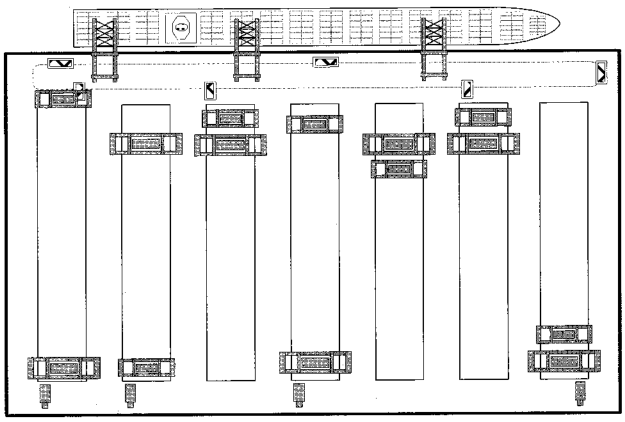

Fig. 2 Vertical Assignment in Automated Container Yard

The main features of equipment are as follows:

(a) ATC: It is able to loading/discharging 5×10 container at each block in the container yard. two intersectable ATCs are used in the container terminal. As the average speed is 6[m/s], the waiting time for loading/discharging work regards as 10[s].

(b) AGV: It is able to loading 20ft, 40ft, 45ft and twin

20ft, respectively. The maximum loading weight is 60[ton], the total weight with vehicle is designed 82[ton]. 2 number of axle is placed before and behind, respectively, and it acts driving and braking by 4-wheel. Also, AGV must be operated separately without effect on ATC and G/C.

(c) Y/T: This equipment is linked carrying export and import container by terminal gate into each block in container yard.

3. Assignment Model of ATC for Allocation of Container Yard

On allocating container yard, the important factor for the effectiveness of the container yard is considering the distributions of container. In case of export container yard, the containers arrived in berth at several days, it show the peak time of container arriving at the day before loading. Allocation of container yard is divided fundamentally into a planning stage and a control stage as follows:

(a) Allocation of rough space: By making the estimation of input and output in container yard, it performs to prevent absolute over and shorts.

(b) Allocation of block space: According to the schedule of vessel loading/discharging, it performs to assign storage site for classify by the vessel, the port of destination (POD), the size, and the kind.

(c) Allocation of bay space: After classification into POD and size, it performs to function allocate by each bay.

(d) Site allocation: Base on the information of the actual input/output and loading/discharging, it performs to decide the position of storage.

3.1 Assumption of Allocation Model

First of all, we will make assumption for the allocation model of container yard and shown as follows:

(a) 2 intersectable ATCs convey the container in the block of container yard and it does not affect to each other for there working.

(b) AGV carry out the container between vessel and container yard, and the route of AGV is fixed in each berth. Also AGV does not affect the working of ATC and G/C.

(c) The information of loading/discharging container in the each vessel is previously known.

(d) After loading the container to vessel, the empty space in the container yard will be re-planning.

(e) In allocating container yard, the different size of container can not be located in same bay.

(f) In case of the different POD, the container can be loaded within limited bay space.

3.2 Formulation of Allocation Model

The aims of this paper are minimize the total working time and make the equivalence of ATC working time to improve the efficient ATC working by allocation of the container yard. The objective function is given by follows.

$$J = w_T J_T + w_L J_L \tag{1}$$

where J_T is the objective function for the total working time, J_L is the objective function for the equivalence of working time, and w_t and w_L represent the weighting rate for the mentioned above the evaluation functions, respectively

$$J_T = \sum_{i=1}^{m} W_i = \sum_{i=1}^{m}\sum_{j=1}^{2} W_{ij}, \quad j=1,2$$
$$J_L = \max(W_i) - \min(W_i), \quad i=1,\cdots,m$$

where W_i is the total working time of each ATC in i block, and m is the number of block.

Next step is to calculate the working time of j th ATC w_{ij}. So, the individual working time of each container can be formulated as follows.

$$w_{ij} = \sum_{k=1}^{a}(d_k + t_k + a_k) \tag{2}$$

where a is the number of carried container at j th ATC in i block, and d_k is the working time, t_k denote the waiting time, and a_k is the movement time for preparing the work, respectively.

And, the working time for container transportation into each sub-block can be written follows.

$$W_i = \sum_{j=1}^{m_i}\sum_{k=1}^{n}((2 \times d_{ij_k}/v_a) \times B_{ij_k}) \tag{3}$$

where m_i is the number of block $(=m_{Ei}+m_E)$ at the i block n is the number of bay allocated at each sub-block, and d_{ij_k} is the center distance of container which allocated at k the of j th sub-block in the i block. Also, v_a is the average traveling speed of ATC, and B_{ij_k} is the number of container allocated at k th bay of j th sub-block in the i block.

3.3 Allocation Model of Container Yard

Fig.3 shows the change of the containers quantity which located in export block for transportation to the each vessel.

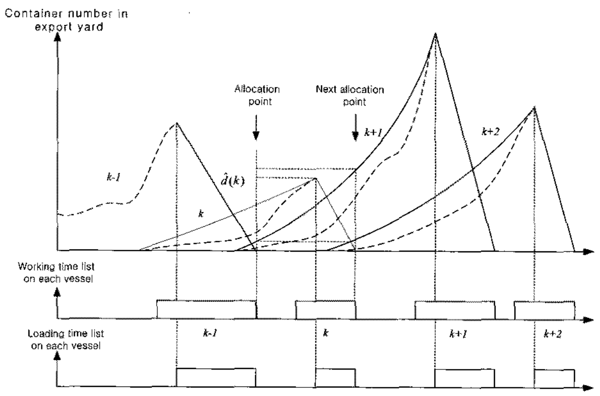

Fig. 3 Distributions of Container Quantity in Export Yard

In Fig. 3, after loading the container into vessel it is desirable to carry out allocation planning for the export container block, because the empty space is utilized positively in this container yard.

Therefore, the following procedures can be confirmed for the allocation of the export container block.

(a) Estimate the next allocation point by allocated the export container block.

(b) Calculate the number of vessel k_a which will be considered to the next allocated container block.

(c) Forecast the required yard space $\hat{d}(k)$ by considering the distributions of container yard for each vessel.

(d) Calculate $d(k)$ to minimize Eq. (3.1) within the actual space of $h(k)$.

The allocation space in working station k must exceed the accumulated storage space in the container yard for the loading work within limited space an $d(k)$ must not exceed the maximum space within the each block. From this reason, the following restriction for allocating the export container yard can be obtained as follows.

$$J = \min\left[\sum_{i=1}^{m}\sum_{j=1}^{2} w_T W_{ij} + w_L\{\max(w_i) - \min(w_i)\}\right] \quad (4)$$

subject to

$$W_i = \sum_{j=1}^{m_i}\sum_{k=1}^{n}\{(2 \times d_{ij_k}/v_a) \times B_{ij_k}\}$$

$$\sum_{i=k}^{k+k_n} h(i) \geq \sum_{i=k}^{k+k_n} \hat{d}(i)$$

$$\sum_{i=k}^{k+k_n} h(i) \leq \sum_{i=1}^{m}\sum_{j=1}^{m_{Ei}} Q_{Eij}$$

The required import container yard space is determined by considering the number and the size of container which discharged from the vessel. For efficient utilization, it is proper to make the allocated point of import container yard right away before discharging container. The following procedures show the allocation of import container yard.

(a) Calculate the demanded space of import container yard by the container information from the vessel.

(b) Assign yard space to minimize Eq. (1) which satisfy the available storage space of present container yard from the above (a).

In discharging the container of the vessel k, the allocation space for import container yard can not exceed the maximum yard space in each block. i.e., the restriction for assignment of the import container yard can be obtained as follows.

$$J = \min\left\{\sum_{i=1}^{m}\sum_{j=1}^{2} w_T W_{ij} + w_L\{\max(W_i) - \min(W_i)\}\right\} \quad (5)$$

subject to

$$w_i = \sum_{j=1}^{m_i}\sum_{k=1}^{n}\{(2 \times d_{ij_k}/v_a) \times B_{ij_k}\}$$

$$e(k) \leq \sum_{i=1}^{m}\sum_{j=1}^{m_{Ij}} Q_{Ij}$$

where k is working section of vessel (station number), $d(k)$ is the quantity of arrived container and transfer container for section k, $\hat{d}(k)$ is the estimated quantity of arrived container and the transfer container for section k, $h(k)$ is the allocated space of container yard for loading/discharging at the section k, and $e(k)$ is required space of import container yard for discharging the k th vessel, respectively

4. ATC Assignment Model for Equipment for Pooling System

In the automated container terminal, two intersectable ATCs have to be assigned in each block of container yard and must be response to the working schedule in the block properly. However, the allocation of container yard is generally divided by the POD, the size, the shipper, the custom and etc., and the container is loaded into each correspondently container yard. In this case, there will be happen the intensively ATCs working load. It will be make a unbalanced load, especially at deadline time for vessel.

Furthermore, these situations affect the working time on cargo handling of vessel and gate, and increase the waiting time of AGV and Y/T. Therefore, this chapter will deal with the detail assignment model within the above mentioned ATC assignment and the allocation of each block.

4.1 ATC Assignment Model

Arrange the evaluation period for each vessel firstly. That is, we have to evaluate the ATC working time for loading/discharging from gate and vessel in each block, because the number of container for loading/discharging is different from the size of vessel, sailing route, and berthing time. The evaluation factor is obtained by the minimization of the total working time during berthing, the equivalence of ATC working load in each block, the equalization of finished time in each block, the AGV waiting time, and the Y/T waiting time.

Each objective functions are denoted as follows.

· Minimization of total working time during berthing:

$$J_T = \min(\sum_{i=1}^{m}\sum_{j=1}^{2} W_{ij}) \tag{6}$$

· Equivalence of ATC working load in each block:

$$J_L = \min(\overline{w} - \underline{w}) \tag{7}$$

· Equalization of finished time in each block:

$$J_F = \min\left(\overline{W_F} - \underline{W_F}\right) \tag{8}$$

· Minimization of AGV waiting time:

$$J_{DA} = \min(\sum_{i=1}^{m}\sum_{j=1}^{2} D_{Aij}) \tag{9}$$

· Minimization of Y/T waiting time:

$$J_{DT} = \min(\sum_{i=1}^{m}\sum_{j=1}^{2} D_{Tij}) \tag{10}$$

Considering each weighting factors, the objective function is written as follows.

$$J = w_T J_T + w_l J_L + w_F J_F + w_{DA} J_{DA} + w_{DT} J_{DT} \tag{11}$$

In case of actual ATC allocation, since the finished time can not be calculated directly, we have to estimate the time by using the required working time for import and export works in container yard. That is,

$$W_{Fi} = W_i - W_i \tag{12}$$

where w_i denotes the expected total working time for import and export works in i block of container yard.

On the other hand, in case that G/C handle the average container in each vessel work, the AGV arrival time can be decided as same time in each block since the repeat time of AGV can be assumed as same. Thus, the waiting time from AGV service can be written as:

$$D_{Aij} = t_{ATC} - t_{AGV} \tag{13}$$

where t_{AGV} is the fixed AGVs waiting time, and t_{ATC} is the ATC arrival time, respectively.

Also, Y/T waiting time, which denotes the waited time for serviced by AGV, can be defined as

$$D_{Tij} = t_{ATC} - (d_{TRA}/v_{TRA}) \tag{14}$$

where v_{TRA} denotes the average speed of Y/T, and d_{TRA} denotes the distance from gate to designated place in container yard. Assume that average speed of Y/T includes the stopping and the parking time of the Y/T.

4.2 ATC allocation algorithm

As mentioned in the previous chapter, the aim of this chapter is to allocate the ATC in container yard according to the vessel's loading/discharging schedule or the container information of loading/discharging from gate. The detail procedure is shown as follows.

(a) Initialize all the variable which used in the objective function according to the operation finish-time for vessels.

(b) Wait the working order (i.e., the scheduled loading/ discharging order for vessel works or the container information for loading/discharging from gate).

(c) Calculate the operation time w_{ij} and predicted finish time w_{Fi} for all ATC in each block of the workstation.

(d) Calculate the predicted waiting time for AGV and Y/T which capable present works.

(e) Allocate ATC by minimization of the objective function (4.6).

(f) Order to allocated ATC and check the ATC operation.

(g) Repeat (b) while continuous the loading/discharging of the container.

5. Conclusion

In this paper, we have dealt with the ATC allocation model for minimizing the total working time and equalizing the working load in each block in automated vertical type container yard. Under the assumption of the adequate AGV control and the basic conditions, the objective function for minimizing the total working time and equalizing the working load of ATC have proposed, respectively. By considering the characteristics of the each container terminal yard, the assignment method for yard space has proposed by adjusting the weight function according to the each terminal strategy.

Furthermore, the objective function for minimizing the total ATC working time during berthing, the equivalence of ATC working load in each block, the equalization of finished time in each block, the AGV waiting time, and the Y/T waiting time are considered.

In future, the proposed algorithm for ATC allocation model will be verified by computer simulation. And an algorithm which includes the mixed allocation model in ATC considering POD in same bay will be studied in future. Also the efficiency of total working time have to be checked.

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Received 20 November 2008
Revised 25 December 2008
Accepted 29 December 2008