The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/2397-3757.htm

Yard and berth planning efficiency with estimated handling time

Etsuko Nishimura
Graduate School of Maritime Sciences, Kobe University, Kobe, Japan

Received 31 August 2019
Revised 9 October 2019
Accepted 13 October 2019

Abstract

Purpose – To achieve a high container handling efficiency at transshipment hub ports, there are a variety of scheduling problem as ship-to-berth assignment (BAP), container-to-yard arrangement (YAP), etc. As it is difficult to acquire the actual data of an existing terminal under various circumstances, this study aims to develop the time estimation model of container handling. Additionally, to achieve an efficient handling of containers at the yard, this study proposes the way to optimize the yard arrangement along with the berth allocation simultaneously by using estimated handling time.

Design/methodology/approach – To obtain the handling time based on various situations of the terminal operated, the discrete simulation model of container handling is constructed. The model to estimate the handling time of a quay crane assigned to a relevant ship by multiple regression analysis is developed. To find a feasible solution to minimize the total service time which includes YAP and BAP simultaneously, a genetic algorithm based on heuristics is developed.

Findings – The proposed regression model has high performance to estimate the time spent of container handling. In the total service time, the proposed approach outperformed the existing 2-step process approach.

Originality/value – As it is difficult to acquire the actual information of an existing marine terminal under various circumstances, the paper contains a regression model to estimate the container handling time based on simulation data, and the regression model is used in an optimization model to minimize the ship turnaround time.

Keywords Genetic Algorithm, Optimization, Container terminal, Multiple regression analysis, Handling time, Yard arrangement

Paper type Research paper

1. Introduction

Nowadays economies rapidly have developed, total cargoes of 10.7 billion tons were moved by maritime transportation, UNCTAD estimates that 752.2 million TEUs have moved at container ports worldwide in 2017 (UNCTAD, 2018). The scale of trade and quantities of shipping goods has caused ship size to expand to size never previously seen. By August 2018, there were 87 mega-containerships with a capacity of 18,000 TEU and over. There were 215 those ships including ships with a capacity of 14,000 TEU and over. As the volume of maritime freight transport has increased so significantly, the liner shipping companies have also benefited from the containerization and mega-vessels era. Dulebenets (2017) describes that such a significant increase in the international containerized trade volumes requires the container terminal (CT) operators to improve the terminal productivity and efficiency. To be fully effective in using mega-containerships, most cargoes to be handled at

© Pacific Star Group Education Foundation. Licensed re-use rights only.

The author would like to thank the referees for their constructive comments. This work was supported by JSPS KAKENHI 18K04609. This financial support is gratefully acknowledged. I would like to deeply thank Ms Chen, L. and Ms Wang, L. who are graduates of Graduate School of Maritime Sciences, Kobe University for their support.

Maritime Business Review
Vol. 5 No. 1, 2020
pp. 5-29
Emerald Publishing Limited
2397-3757
DOI 10.1108/MABR-08-2019-0034

the terminal where those ships call are transshipped from origin to destination ports via that terminal. To decrease the turnaround time of ships calling at that terminal, smooth handling of operations is of major importance.

For such as the above terminal, there are the scheduling problems for ship-to-berth allocation and container-to-yard arrangement etc. In those studies, it is given in advance that the time spent of container handled from the ship berthing position to the container storage location in the yard. In general, at the small size terminal which is operated by one or two berths, the handling time spent for a ship is determined by the number of containers handled and the number of quay cranes (QCs) assigned to a ship. And the handling time of each QC assigned to a ship is determined by the number of containers handled. However, this study considers the above scheduling problems at the terminal with long quay consisted of multiple-berth ranged in a line. Thus this study proposes the model to estimate the handling time of each QC assigned to a ship.

Additionally, to achieve an efficient handling of containers at the yard, there are several ways to improve the quality of container handling. One of them is more QCs assigned to each ship. However, this means that more yard trailers are also assigned, and may bring a high congestion at the foot of QC at the apron area. Thus, yard management on how to assign containers to yard blocks is needed. This is a key factor to reduce the handling time, and depends on the distance from the ship berthing position to the blocks in the yard. To cope with complicated terminal operation of containers as described above, it will be considered that the yard arrangement problem (YAP) with the ship-to-berth assignment problem (BAP) simultaneously. Then this study proposes the model for the yard arrangement plan with berth utilization efficiency.

The paper is organized as follows. Section 2 reviews the past studies related to YAP, BAP and the simulation model for CT and also describes the flow of this study. Section 3 develops the model to simulate the container handling operation. Section 4 analyzes the model to estimate the time spent for container handling. Section 5 introduces the problem definition and formulations. Section 6 describes the solution procedure by using the genetic algorithm (GA). In Section 7, the data used in the computational experiments are introduced, and the results are analyzed in detail. Finally, Section 8 concludes with a summary of the contributions and findings of this study.

2. Literature review

The first purpose of this study is to propose the model for the yard arrangement plan with berth utilization efficiency. The existing studies about the YAP can be organized into two sub-groups, individual containers and groups of containers by the container treatment unit. The treatment unit is influenced by the target area in focus and adds to the complexity of finding a solution. The type of the objective function is dependent on the container treatment unit. Issues of containers grouped by destination, type and size of containers are described in various studies (Han *et al.*, 2008; Lee *et al.*, 2006; Lim and Xu, 2006; Nishimura *et al.*, 2009; Yang and Kim, 2006; Zhang *et al.*, 2003; Jin *et al.*, 2014; Sharif and Huynh, 2013).

Some studies related to a BAP. Christian and Frank (2010) classify the BAP by handling time attribute: fix, berthing position, QCs assigned and QC operation schedule. Imai *et al.* (2007) and Imai *et al.* (2008) consider the problem with discrete locations. Imai *et al.* (2005) consider the problem with the continuous locations. For busy hub ports, it is assumed that the handling time of a ship depends on its berthing position.

In recent years, some studies considered the issues about both the YAP and the BAP. Zhen *et al.* (2011), Lee *et al.* (2012) and Lee and Jin (2013) emphasized the berthing time and berthing position of arrival ships have great influence on container transit time in

transshipment terminals. Those studies consider the YAP for the container group. Zhen *et al.* (2011) studied the two tactical level decisions arising in the berth template and the yard template. They consider the berth template with the cylinder as the planning horizon. The solution to this model contains the yard block assignment, the berthing position and berthing time with QC assignment. The solution procedure consists of three stages: finding berth template, finding yard template and local refinement. In the local refinement process, it is refined that the berth template and yard template by an iterative process. First, the yard template is fixed to optimize the berth template, and then, under the improved berth template is fixed, the yard template is optimized. That iterative process is repeated until no improvement. Lee *et al.* (2012) concerned the container transshipment flow problem in multiple terminals. Basing on the tactical terminal and YAP, they present an integer programming model for the terminal and the YAP in a large transshipment hub with multiple CTs. The objective function is to minimize the handling cost resulted from reallocation to the yard, and the transportation cost for the unloading/loading operations. The ship-to-terminal assignment is solved by the neighborhood search, and the containers-to-yard block assignment is solved by the tabu search-based heuristic. There is no iteration process between the ship-to-terminal assignment and the containers-to-yard block assignment. Lee and Jin (2013) proposed the heuristic approach combining the GA and the tabu search. To minimize the total moving distance between the quay side and the yard, and also to minimize the gap between highest and lowest workload during the planning horizon, the feeder vessel berthing position and the container storage allocation are determined. The above studies consider the handling time is dependent on the travel distance between QC position and container location, those studies do not discuss the way to give the time information of container handling.

As described in Section 1, the second purpose of this study is used to estimate the handling time spent for a ship. Then this study reviews the related works about the simulation model for a CT. The studies related to simulation model for the CT operation are as follows. As described in Steenken *et al.*'s (2004) study, the purpose of simulation model development is to improve terminal operation and performance. There are mainly two types of simulation models such as strategic and operational levels. Strategic level simulation is applied to compare the different types of terminal layout and also compare the different types of handling equipment. Operational level simulation is applied to evaluate the proposed algorithm for scheduling problem of handling equipment and vehicles. There are Vis and Harika (2004) etc. in the strategic level simulation related works, and Hartmann (2004) etc. in the operational level simulation related works. Branislav *et al.* (2017) also reviews the available research literature on the application of simulation models in port operation. That study focuses on the identification of research fields, application areas, simulation tools and other critical features. In analysis by research fields, the journal papers are classified through grouping journals on basic their theme such as computer science, operations research, maritime transport etc. In analysis by application area, the number of journal papers published per year on simulation modeling in seaports and seaport CTs continues to increase on an annual basis, is shown. In analysis by simulation tool, the various types of simulation tool employed for port application area are shown. However, the purpose of simulation model development in this study is to obtain the handling time under various situations, this point of view is different from the other related works.

First of all, this study develops the model to estimate the time spent for container handling. To obtain the handling time based on various situations of the CT operated, there is very little amount of information if it is used only actual data from the existing terminal in a specific time period as the data set. Therefore, it is constructed that the discrete simulation

model for container handling at the CT. For this, it is considered that the flow of this study is shown in the following steps.

Step 1: The input data for the target ships during the planning horizon is prepared with as follows: the number of containers handled, the number of QCs assigned, the container storage arrangements in the yard etc.

Step 2: The model to simulate the container handling at the terminal is constructed.

Step 3: The handling time spent for a ship and the handling time of each QC is obtained by the simulation run.

Step 4: The multiple regression analysis is conducted as the independent variables used in Step 1 and the dependent variables obtained in Step 3.

Step 5: The model to estimate the handling time spent for a ship and the handling time of each QC assigned to a ship is developed.

This study concerns the YAP and the BAP simultaneously, to minimize the total service time of ships, includes the waiting time until beginning of ship services, by using the estimated time of container handling. Nishimura *et al.* (2009) is the previous work of this study, the storage space management in a transshipment terminal is considered as this study. Although the previous work concerns only one way with the container flow from the containership to feeders, this study concerns both ways with the container flow between inbound and outbound ships. The related studies consider both YAB and BAP separately and iteratively. Therefore, this study proposes the heuristic approach to optimize the BAP and YAP simultaneously.

3. Model to simulate container handling operations

Various types of container handling equipment have been used to CTs in the world to be able to depart the relevant ship from the terminal as soon as possible. From our investigation, this study constructs the model to simulate the ship handling operation at the terminal where Rubber Tyred Gantry (RTG) crane is most often used in the world. One of the purposes of this study is to examine how the handling time of each QC assigned to the ship depends on the factors like the geographic relationship between the ship berthing position and the container storage location in the yard. Therefore, it must be prepared that the handling time data set when a particular ship is serviced at a certain berth position and also at some other positions. However, it is costly and even impossible to obtain such statistics in the place different from the ship berthing position serviced in an actual CT. Therefore, a simulation model is developed as a substitute of an actual CT.

3.1 Scope of simulation model

There are two types of handling operations being undertaken at the terminal, which are as follows:

(a) discharging containers from a ship and loading containers to the relevant ship; and

(b) handling containers for delivery trucks that come to the terminal from hinterlands.

For the efficient yard operation, the entire container storage is divided into two parts: one for import containers and the other for export ones. Each part consists of several blocks that are arranged by the voyage, so that the traffic of delivery trucks is unlikely to interfere in discharging and loading tasks of ships.

In this simulation model of container handling at a terminal, it is expressed that arrival and departure of ships during the planning horizon, discharging and loading operations by QCs, transferring containers between the quay side and the yard side by yard trailers, and moving containers between the yard trailer and yard blocks by RTG. This working sequence is conducted on increasing order of the arrow's number in Figure 1.

Arrows #1 and #8 mean that a ship arrives and departs from the terminal, respectively. Arrow #2 shows that a QC lifts a container from the ship and makes it move to the quay side, and arrow #7 means the opposite process of arrow #2. Arrow #3 shows that a yard trailer transfers the container from the quay side to a block in the yard, and arrow #6 means the opposite process of arrow #3. Arrow #4 shows that a RTG lifts a container on a yard trailer to any block, and arrow #5 means the opposite process of arrow #4. It is assumed that the capacity of one block consists of six rows and five tiers. As shown in Figure 1, a yard trailer can be one way moved between blocks.

3.2 Parameter setting

The parameters used in the simulation model are as follows. It is assumed that the relevant terminal has four berths consisted of a 400 meter-berth and its distance vertical to quay line is 400 meters. The planning horizon is set to two weeks. The average intervals of ship arrival are 3 and 4 hours, and ships' arrival pattern is based on exponential distribution. In general, containers are often stored near the ship that those are loaded, in order not to extend the handling time spent for the ship. However, if the ship's arrival is delayed, this delay may make a change in the schedule of succeeding ships. In such a case, if that ship can be serviced at another berth, it might be able to control the handling time of a succeeding ship appropriately. Therefore, it is assumed that the ship berthing position is given randomly. In addition, it is also assumed that the storage location of containers handled to a ship is given by the block consists of multiple containers. That is generated in randomly.

It is assumed that the speed of yard trailers is given, and the actual survey at the port of Osaka in Japan is as shown in Table I. In addition, the working cycle time by the spreader of RTG and QC which takes from picking a container up to picking the next another one up is

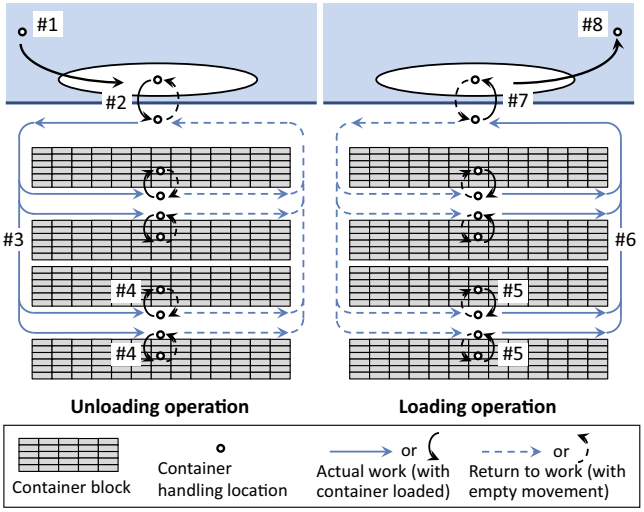


Figure 1. Working sequences for container handling

as shown in Table II. It is assumed that the maximum number of QCs assigned to a ship is four; four yard trailers are assigned to a QC.

4. Model to estimate time spent for container handling

By simulating the model for container handling built in the previous section, the handling time spent from the beginning of unloading operation to the completion of loading operation for each ship is measured. Then this section finds out the factor which affects handling time length among the parameters given in simulation run to develop the model to estimate the handling time spent for a ship and the handling time of a QC assigned to a relevant ship.

4.1 Multiple regression analysis for time estimation of container handling

First, this study develops the regression model to estimate the handling time spent for a ship as following dependent variables:

- the number of containers handled (referred to as NUMC);
- the distance between the ship berthing position and the container storage location (referred to as DIS); and
- the number of QCs assigned to the ship (referred to as NUMQC).

To develop the model with high performance, the original value of data, exponential or logarithmic transformation value of data is used as the independent and dependent variables. As the results, the highest R-squared value could obtain if the combination is as follows; the DIS is the original value of data, the NUMC and NUMQC are logarithmically transformed. Therefore, the regression model to estimate the handling time spent for a ship is as shown in equation (1) and transformed it as shown in equation (2).

$$\ln f_{\mathrm{SHIP}} = a_0 + a_1 \ln x_1 + a_2 x_2 + a_3 \ln x_3 \tag{1}$$

$$f_{\mathrm{SHIP}} = e^{a_0} {x_1}^{a_1} e^{a_2 x_2} {x_3}^{a_3} \tag{2}$$

The results of the best-fit regression analysis are presented in Table III. This model has R-squared value of 99 per cent and high performance. Results of F-test are statistically significant at the 0.05 level, because F-values at this model have much more 2.605 of F-value. The sign of the regression coefficient for the NUMC is positive and also those for the DIS

Table I. Speed and capacity of the yard trailer

Speed	Straight: 20 km/h; Curve: 5 km/h; Acceleration and deceleration: 1 km/hour
Load capacity	Only one box can be loaded regardless of container size.

Table II. Working cycle time and distribution function by QC and RTG

Handling equipment		Container loaded		Return to work	
		k - Erlangian distribution	Average (seconds)	k - Erlangian distribution	Average (seconds)
QC cycle	Unloading operation	$k = 16$	48	$k = 15$	42
	Loading operation	Normal distribution	48	$k = 35$	36
RTG cycle		$k = 19$	72	$k = 6$	54

and NUMQC are positive and negative, respectively. It means that the handling time spent for a ship becomes longer if the NUMC becomes much more and the DIS becomes longer. On the contrary, the more QCs are assigned to a ship, the shorter handling time spent for a ship becomes. This result reaches a suitable conclusion. Results of t-test are statistically significant at the 0.05 level, because the absolute values of t-values for all independent variables at the model have much more 1.645 of t-values. Thus, it is clear that all independent variables are useful.

Additionally, it is developed that the model to estimate the handling time of a QC assigned to the relevant ship as following dependent variables: the NUMC and the DIS. As the results, the highest R-squared value could obtain if the combination is as follows; the DIS is the original value of data, the NUMC is logarithmically transformed as shown in Table IV. This model has R-squared value of 99 per cent and high performance. Results of F-test are statistically significant at the 0.05 level, because F-values at this model has much more 2.605 of F-value. The sign of the regression coefficient for the NUMC is positive and also that for the DIS is positive. It means that the handling time of a QC assigned to a relevant ship becomes longer if the NUMC are much more and the DIS becomes longer. This result reaches a suitable conclusion. Results of t-test are statistically significant at the 0.05 level, because the absolute values of t-values for all independent variables at the model have much more 1.645 of t-values. Thus, it is clear that all independent variables are useful.

4.2 Comparison between the proposed model and actual data

The proposed model used by regression coefficients shown in Tables III and IV is as the equations (3) and (4).

	Independent variable: Handling time spent for a ship (hours) $\ln(f_{SHIP})$			
	Dependent variables	Regression coefficients a_i ($i = 0, \ldots, 3$)	Std. Regression coefficients	t-values
R-squared 0.994	Constant	$a_0 = 0.518$		52
	$\ln(x_1)$	$a_1 = 0.996$	0.77	313
F-value 54,798	x_2	$a_2 = 0.308$	0.26	104
	$\ln(x_3)$	$a_3 = -0.909$	−0.48	−194

Notes: x_1: Number of containers handled (*100 boxes); x_2: Distance between ship berthing position and containers' storage location (km); x_3: Number of QCs assigned to the relevant ship

Table III. Model to estimate the ship handling time

	Independent variable: Handling time spent for a ship (hours) $\ln(f_{SHIP})$			
	Dependent variables	Regression coefficients a_i ($i = 0, \ldots, 3$)	Std. Regression coefficients	t-values
R-squared 0.994	Constant	$a_0 = 0.583$		150
	$\ln(x_1)$	$a_1 = 0.991$	0.95	586
F-value 191,508	x_2	$a_2 = 0.282$	0.25	154

Note: x_1: Number of containers handled (*100 boxes); x_2: Distance between ship berthing position and containers' storage location (km)

Table IV. Model to estimate the QC operating time

$$f_{\mathrm{SHIP}} = e^{0.518} x_1^{\,0.996} e^{0.308x_2} x_3^{\,-0.909} \tag{3}$$

$$f_{\mathrm{QC}} = e^{0.583} x_1^{\,0.991} e^{0.282x_2} \tag{4}$$

Under the conditions, which one QC is assigned to a ship, the times estimated by f_{SHIP} and f_{QC} are compared with the actual time observed at the existing CT. The information used in this session is obtained at the Oi CT which consisted of two berths in Tokyo for five days of September 2002. Figure 2 shows that the actual handling time for each QC assigned to total six ships serviced at the existing terminal, and the handling time estimated by both regression models. From the results, the estimated time was less than the observed time at all cases. This reason is as follows. The observed time is from arrival to departure of the relevant ship, however, the estimated time is from ship arrival to the completion of handling operation. Actually, the observed time may include the extra time before and after the container handling of the ship. Thus, the above result is investigated. Additionally, comparing the estimated time by f_{SHIP} with that time by f_{QC}, the estimated time by f_{QC} was closer to the observed time of a QC assigned to a ship. Therefore, f_{QC} will be useful for the YAP in the next section.

5. Problem definition and formulations

5.1 Container handling and yard arrangement

According to our knowledge, the yard area of relevant terminals where containers are stored is divided roughly by the direction of container movement such as import, export or transshipment. As this study deals with transshipment containers from ships calling at the terminal, it is assumed that there is less interference between transshipment containers and the others.

First, the container treatment is described as follows. Each container has the information about the destination port, inbound and outbound ships, weight class and so on posted on it. Some containers may have the same information as others. If an individual container is considered for the YAP, it must include some issues, such as precedence constraints in the working sequence and the location for ship stowage, and also re-handling caused by work sequence and storage allocation in the yard. Therefore, to simplify constraints, it is assumed that multiple containers with the same destination, or the same inbound and outbound ships, as one container group. For instance, a container group for a ship which consists of one hundred containers is stored in a block in the yard. The inbound and outbound ships for each container group are given in advance. After the relevant container arrives from its

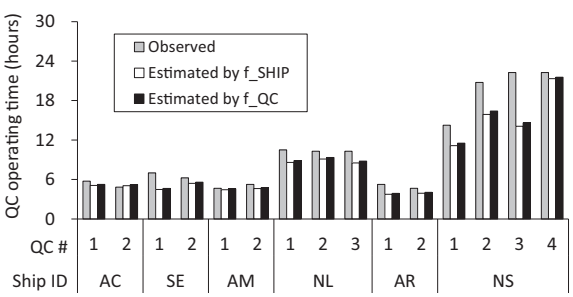


Figure 2.
Comparison between observed and estimated times

inbound ship, it stays in the terminal until its outbound ship arrives. Then, the relevant container group is loaded onto the outbound ship.

Second, the target area of this YAP is described via the container flow into a terminal. In fact, containers need to be stored in the yard for several reasons:

(1) to arrange the time difference between ships' arrival;

(2) to reposition containers for ship stowage; and

(3) to modify the work sequence of container handling.

This study considers the container flow in two ways: from one ship to any block in the yard and from that block in the yard to other ships.

Third, the QC allocation for each ship is described. As mentioned in Nishimura *et al.* (2009), to shorten the handling time for ships departure, several QCs will be assigned to those ships simultaneously. In addition, the number of QCs assigned to a ship depends on the handling container volume. The ships can depart from the terminal after all QCs assigned to the relevant ship complete the handling operation. QCs, yard cranes and yard trailers do not have a mutual influence on one another. Thus, the model development with multiple QCs assignment is more complicated. Therefore, to simplify the problem in this step of the research project, it is assumed that only one QC is assigned to a ship.

5.2 Problem formulations

The determinants, the objective function and constraints of this problem are as follows:

- *The determinants* are the location of transhipment container groups stored in the yard, and the berthing position of ships served.
- *The objective function* is the total service time including waiting time for all ships until beginning of service.
- *Constraints* are that, each container group is stored exactly once in the yard; multiple container groups can be shared in a block in the yard without exceeding the capacity limit; only one ship is serviced at any one berth at a time; a ship must be serviced after a relevant ship arrival; and beginning time of ship service must satisfy the FCFS policy at each berth.

In this section, a mixed integer programming formulation combining the YAP with BAP (referred to as YAPB) is presented as follows:

$$[\text{YAPB}]\ \text{Minimize}\, Z = \sum_{j \in V} (f_j - A_j) \tag{5}$$

Subject to:

$$\sum_{t \in T} x_{ijt} = h_{ij} + 1 \quad \forall i \in B, j \in V \tag{6}$$

$$\sum_{j \in V} x_{ijt} \leq 1 \quad \forall i \in B,\ t \in T \tag{7}$$

$$\sum_{i \in B} y_{ij} = 1 \quad \forall j \in V \tag{8}$$

$$b_j \geq A_j \quad \forall j \in V \tag{9}$$

$$f_j = \max_{t \in T} \left\{ t \sum_{i \in B} x_{ijt} \right\} \quad \forall j \in V \tag{10}$$

$$b_j \leq f_j - \sum_{i \in B} h_{ij} \quad \forall j \in V \tag{11}$$

$$b_j \leq t + \left(1 - \sum_{i \in B} x_{ijt} \right) M \quad \forall j \in V, t \in T \tag{12}$$

$$\sum_{l \in Y} w_{gl} = 1 \quad \forall g \in G, \tag{13}$$

$$h_{ij} = \min \left\{ \sum_{g \in G} \sum_{l \in Y} C_{ijl} U_{gj} w_{gl} + \sum_{g' \in G} \sum_{l' \in Y} C_{ijl'} L_{g'j} w_{g'l'} \, , \, y_{ij} M \right\} \quad \forall i \in B, j \in V \tag{14}$$

$$n_l^p \leq CAP_l \quad \forall p \in P, l \in Y \tag{15}$$

$$\sum_{p \in P} \alpha_j^p = 1 \quad \forall j \in V \tag{16}$$

$$f_j \geq E^{p-1} \alpha_j^p \quad \forall p \in P, j \in V \tag{17}$$

$$f_j \leq E^p + \left(1 - \alpha_j^p \right) M \quad \forall p \in P, j \in V \tag{18}$$

$$n_l^p = n_l^{p-1} + \sum_{j \in V} \sum_{g \in G} AR_j^p U_{gj} w_{gl} - \sum_{j' \in V} \sum_{g' \in G} L_{g'j'} w_{g'l} \alpha_{j'}^p \quad \forall p \in P, l \in Y \tag{19}$$

$$x_{ijt} \in \{0, 1\} \quad \forall i \in B, j \in V, t \in T \tag{20}$$

$$y_{ij} \in \{0, 1\} \quad \forall i \in B, j \in V \tag{21}$$

$$b_j, f_j \geq 0 \quad \forall j \in V \tag{22}$$

$$w_{gl} \in \{0, 1\} \quad \forall g \in G, l \in Y \tag{23}$$

$$h_{ij} \geq 0 \quad \forall i \in B, j \in V \tag{24}$$

$$n_l^p \geq 0 \quad \forall p \in P, l \in Y \tag{25}$$

$$\alpha_j^p \in \{0, 1\} \quad \forall p \in P, j \in V \tag{26}$$

where:

as parameters

i (=1,. . ., $|B|$)$\in B$ = set of berthing positions;
t (=1,. . ., $|T|$)$\in T$ = set of time points (in minutes);
j (=1,. . ., $|V|$)$\in V$ = set of ships which arrive during the whole planning horizon;
l (=1,. . ., $|Y|$)$\in Y$ = set of blocks;
p (=1,. . ., $|P|$)$\in P$ = set of time periods (in days);
g (=1,. . ., $|G|$)$\in G$ = set of container groups unloaded from ships which arrive during the whole planning horizon;
U_{gj} = 1 if container group g is unloaded from ship j, = 0 otherwise;
L_{gj} = 1 if container group g is loaded to ship j, = 0 otherwise;
A_j = arrival time of ship j (in minutes);
AR_j^p = 1 if ship j arrives during time period p, = 0 otherwise;
C_{ijl} = handling time when a container group which is unloaded from or loaded to ship j serviced at berth i, is stored at yard block l (in minutes);
CAP_l = storage capacity of yard block l;
E^p = completion time of time period p (in minutes); and
M = very large number.

as variables

x_{ijt} = 1 if ship j is serviced at berth i on time point t, = 0 otherwise;
y_{ij} = 1 if ship j is serviced at berth i, = 0 otherwise;
b_j = beginning time of ship j service (in minutes);
f_j = departure time of ship j (in minutes);
h_{ij} = handling time spent by ship j serviced at berth i (in minutes);
w_{gl} = 1 if the container group g is stored at yard block l, = 0 otherwise;
n_l^p = number of containers to be stored at yard block l at the end of time period p; (n_l^0 number of containers to be stored at time period 0 is given in advance); and
α_j^p = 1 if ship j leaves the terminal at time period p, = 0 otherwise.

The objective function (5) minimizes the total service time; that is the sum of handling time and waiting time for all ships during the planning horizon. Constraint set (6) defines the relationship between variables x_{ijt} and h_{ij}, which expresses the handling time spent for ship j serviced at berth i. Constraints (7) mean that only one ship is serviced at one berth at a time point. Constraints (8) mean that each ship is serviced at any berth exactly once. Constraints

(9) mean that a ship must be serviced after a relevant ship arrives. Constraints (10) define the relationship between variables f_j and x_{ijt}, which means the departure time of ship j is the maximum number of time point t on x_{ijt} =1.

Constraints (11) define the beginning time for ship j that is obtained by the departure time minus service time for ship j. Constraints (12) defines the relationship between variables b_j and x_{ijt}, which means the beginning time is less than or equal to time point t on $x_{ijt} = 1$.

Constraints (13) ensure that a container group must be stored at a block in the yard exactly once. Constraints (14) define the relationship between variables h_{ij} and y_{ij}, which means the handling time of ship j serviced at berth i. If $y_{ij} = 1$, the handling time of a ship defines the sum of time spent for containers unloaded from and loaded to a relevant ship. If $y_{ij} = 0$, the handling time of a ship defines 0.

Constraints (15) ensure that a block at any time period is not exceeded the capacity limit. Constraints (16) ensure that a ship leaves the terminal at any time period exactly once. Constraints (17) and (18) ensure the relationship between variables f_j and α_j^p. Variable α_j^p is defined by the context between the completion time at time period p and the departure time of ship j. If $\alpha_j^p = 1$, constraints (17) and (18) mean the range as $E^{p-1} \leq f_j \leq E^p$. If $\alpha_j^p = 0$, constraints (17) and (18) mean the range as $0 \leq f_j \leq M$.

Constraints (19) define the condition of containers stored at a relevant block l at the completion time of time period p.

Figure 3 describes the relationship between variables E^p and f_j. It is divided into three cases (a), (b) and (c). And each case presents the service time of ship j from beginning time b_j to departure time f_j, in three time periods from $(p-1)$ to $(p+1)$. Base on the constraints (17)

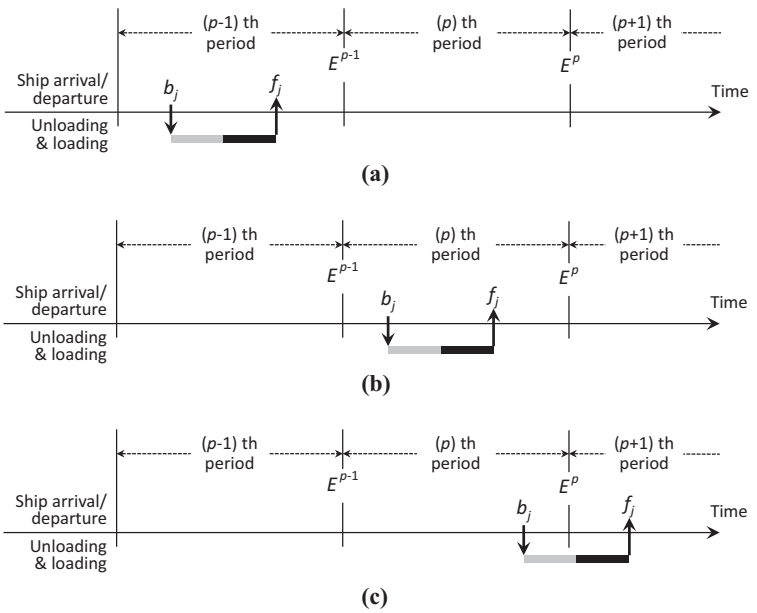


Figure 3.
Relationship between variables E^p and f_j

Notes: (a) The case as $f_j < E^{p-1}$; (b) The case as $E^{p-1} < f_j < E^p$; (c) The case as $E^p < f_j$

and (18), the digit of decision variable of α_j^p depends on different constraints. In case (a) of Figure 3, the range of f_j is $0 \leq f_j \leq \infty$ by $\alpha_j^p = 0$. In case (b), the range of f_j is $E^{p\text{-}1} \leq f_j \leq E^p$ by $\alpha_j^p = 1$. Additionally, in case (c), the range of f_j is $0 \leq f_i \leq \infty$ by $\alpha_j^p = 0$. Then, the constraints (17) and (18) show the relationship between variables E^p and f_j.

6. Solution procedure

As previously described, problem formulations are complicated because this problem combines both the YAP and BAP. Therefore, to find a better solution in a reasonable computational time, it is proposed that a new heuristic approach using a GA. As described in Sait and Youssef (1999), GA is invented by John Holland *et al.* Holland has incorporated features of natural evolution to propose a robust, computationally simple, and powerful technique for solving difficult optimization problems.

This section explains that chromosome representation in GA is expressed as a solution representation in this problem. Specifically, the way to reflect information of both the BAP and YAP in chromosome representation is explained. Furthermore, the way of obtaining objective function and an assumption of GA parameters is introduced.

6.1 Chromosome representation

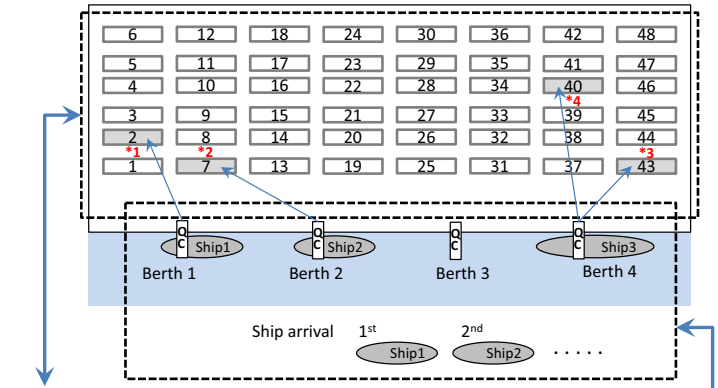
For each container group, the ship that it is unloaded from (referred to as inbound) and the ship that it is loaded to (referred to as outbound), are given in advance. This problem assumes that the planning horizon is one week, and one time period is one day. For an example, there are three time periods as a part of one solution, shown in Figure 4. On the first day of planning horizon, container groups 1, 2, 3 and 4 are unloaded from inbound ships 1, 2, 3 and 3, respectively. These containers will be stored at blocks in the yard area until their outbound ships arrive and have completed their unloading operations. Each block has a limited capacity. Therefore, the block for each container group to be stored at is randomly determined so as not exceed the limitation of storage capacity. In this example, inbound ships 1, 2 and 3 are randomly determined to serve at berths 1, 2 and 4, respectively.

Container groups 1, 2, 3 and 4 are randomly determined to store in blocks 2, 7, 43 and 40, respectively. After the container groups are stored in the yard, they will be loaded to their reserved outbound ships after they arrive in a later period. In the example shown in Figure 4, container groups 1 and 3 will be loaded to outbound ship 4, and container group 4 will be loaded to outbound ship 5.

One solution is composed of two types of chromosome; YAP and BAP. Figure 5 details the chromosome structure and the other information needed. In this example, container groups 1, 2, 3 and 4 are selected randomly to be located in the blocks 2, 7, 43 and 40, where each block does not exceed its storage capacity. Then the YAP chromosome can be expressed as 2, 7, 43 and 40 as read from the left side. Ships 1, 2 and 3 arrive at the relevant terminal in the 1st period of planning horizon, and the ships are serviced at berths 1, 2 and 4,

	1st period				2nd			3rd		...	
Container group No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**		
Inbound ship No. (given)	1	2	3	3	4	5	5	6	7		
Outbound ship No. (given)	4	7	4	5	8	6	10	11	12		
Yard block No.	**2**	**7**	**43**	**40**	**14**	**24**	**2**	**21**	**4**		
Berth No.	**1**	**2**	**4**	**4**	**3**	**2**	**2**	**1**	**2**		

Figure 4. Chromosome representation



YAP chromosome

	1st period				2nd			3rd		...
Container group No.	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**...**
Inbound ship No.										...
Outbound ship No..										...
Yard block No.	**2**	**7**	**43**	**40**	**14**	**24**	**2**	**21**	**4**	**...**
Berth No.										...

BAP chromosome

	1st period				2nd			3rd		...
Container group No.										...
Inbound ship No.	**1**	**2**	**3**	**3**	**4**	**5**	**5**	**6**	**7**	**...**
Outbound ship No.										...
Yard block No.										...
Berth No.	**1**	**2**	**4**	**4**	**3**	**2**	**2**	**1**	**2**	**...**

Figure 5.
Relationship between the this problem and the chromosome structure

respectively. In the 2nd period, ships 4 and 5 arrive at the relevant terminal, and are serviced at berths 3 and 2, respectively. The BAP chromosome can be expressed as 1, 2, 4, 3 and 2 in order from the left-side.

In this problem, the planning horizon is one week consisting of seven time periods. Additionally, each block has a limited capacity, the container volume stored there fluctuates over time, as ships arrive and depart from the relevant terminal. However, to simplify the model, it is assumed that the block capacity can be updated at the end of each time period. In addition, it is assumed that the outbound ship for a specific container group arrives in the next time period and after the inbound ship arrival. Therefore, chromosomes are generated in each time period while the block capacity must be checked, to determine the location by looking for vacant spaces.

Figure 5 shows the information for all container groups and all ships serviced during the planning horizon. The parameters given in advance will be explained as follows:

- number of ships that arrive in each period;
- number of container groups unloaded in each period;
- number of container groups loaded to each ship;
- arrival time of each ship; and
- handling time of each container group, unloaded from the berthing location for the inbound ship, and also loaded to the berthing location for the outbound ship, operated by RTG.

The first three days of the planning horizon as the example is shown in Figure 5. The coding sequence is from left to right. In the BAP chromosome, this means that ships 1 to 7 arrive at the relevant terminal over three days, and are serviced at berths 1, 2, 4, 3, 2, 1 and 2, respectively. The remaining time periods will be coded in the same way.

In the BAP chromosome coding, the gene is expressed by each ship, the BAP at one time period can be determined without considering other time periods, because the total number of ships at one time period is not so much. If the ship cannot be serviced immediately at the berth assigned because another ship occupies the same berth, the relevant ship will wait until the other ship departs. Of course, the objective function, the total service time will become longer.

However, in the YAP chromosome coding, since the gene is expressed by each container group, the total number of container groups at one time period is much more than the number of ships. Therefore, even if the container group cannot be immediately serviced the block assigned because other container groups occupy the same block, the relevant container group cannot waits until other container groups leaves and must be serviced at some other vacant block. Since yard blocks have a limited storage capacity, the location of a container stored at one time period has to be determined to look for blocks with vacant space(s). As mentioned above, the block storage capacity will be updated at the end of each time period. Then in the YAP chromosome coding, it must be guaranteed that the capacity is not exceeded in any time period.

To realize GA procedure, multiple chromosomes must be generated in each generation (meant as iteration). Those chromosomes are called as the population, and the number of chromosomes is called as the population size. One chromosome is different from others in the each generation.

The objective function is defined as that which, minimizes the total service time (including waiting time). The algorithm to obtain the total service time including waiting time as the objective function value is shown in Appendix.

6.2 Genetic algorithm operators and the whole algorithm

This study applies the GA with tournament selection, uniform crossover and mutation. In this section, the whole algorithm of our proposed approach which also contains GA operations and elite preservation will be explained.

Step 1: Initialization. Set to generation = 0. The initial population composed of the chromosome including BAP and YAP parts is generated.

Step 2: Objective function. The total service time which is the sum of handling time plus waiting time for all ships is obtained as the objective function by Appendix.

Step 3: Fitness value. The objective function value for each chromosome is transformed to the fitness value. Since this study is to minimize the total service time, the reciprocal of the objective function value becomes the fitness value.

Step 4: Termination. If the current generation is terminated, then go to Step 10. Otherwise, go to Step 5.

Step 5: Selection. The tournament strategy is applied as the selection operator. From all chromosomes in the population, two chromosomes are randomly selected. One with higher fitness value can become one of parent-pair used to generate new chromosomes. This process repeats two times to form one pair. In each pair, the chromosome selected must differ from another one. It is assumed that total amount of selected chromosomes is set to the population size.

Step 6: Crossover. The uniform crossover is applied as the crossover operator. As mentioned in Section 6.1, there are two types of chromosomes in BAP and YAP parts.

(1) *BAP*: the crossover is applied in the whole planning horizon.
(2) *YAP*: the crossover is applied in randomly selected one day.

One crossover mask is generated for one pair. Crossover mask formed with 0 and 1 is randomly generated. After the crossover applies YAP chromosome, if the container group has just stored now is exceeded to the block capacity, the relevant container group has to be re-arranged to the block.

Step 7: Mutation. The real number is randomly generated from 0 to 1 for each new chromosome. If its number is less than the mutation rate, the mutation operator is applied to the relevant chromosome. Here as well as the crossover, two types of mutation are applied in BAP and YAP parts.

(1) *BAP*: the mutation is applied in the whole planning horizon.
(2) *YAP*: the mutation is applied in randomly selected one day.

Two genes in BAP chromosome and also in YAP chromosome will be selected and exchange their positions with each other. After the mutation is operated, if the total number of container groups stored is exceeded to the capacity, then has to re-arrange another block.

Step 8: Objective function and Fitness value. The objective function value for new chromosomes is obtained by Appendix. The objective function value for each chromosome is transformed to the fitness value.

Step 9: Elite preservation. To choose the new individuals in next generation, the half and half elite preservation is applied. This means that the half size of population will be chromosomes with have the highest fitness value in ranking. Another half size of population will be randomly selected in the remaining of chromosomes. And each chromosome has to differ from the others. Update generation = generation +1, then go back to Step 4.

Step 10: Best solution. The best solution with the total service time is obtained.

To apply the GA procedure and to find the better solution, the GA parameters should be set. Then the preliminary experiments are conducted on 100 case studies at the 3-h and 4-h average intervals of ship arrival. From the results, 50 as the population size, and 100,000 generations are needed as the termination for completing the convergence of all cases. In addition, the mutation rate 0.07 is needed as the termination.

7. Numerical experiments

First, to realize the effect of the proposed approach for solving the YAPB, the parameters used as the input data are described. Second, the effect of considering the BAP along with the YAP is discussed. Additionally, the proposed approach is compared with the existing approach used by other literatures.

7.1 Experimental design

The parameters used for the input data of numerical experiments, consists of terminal layouts, the planning horizon, ship arrival patterns, container treatment and the handling time spent by each container group. These parameters will be described in detail.

According to our knowledge, most marine CTs over the world have a rectangular configuration. Thus in this study, it is assumed that the terminal configuration is rectangular, and consists of a quay length of 1,600 meters with four berths and a depth of 400 meters. As mentioned in Section 4, it is considered that a block has a maximum storage capacity, and multiple container groups can be stored if the capacity is not exceeded. Each block has a capacity of four container groups.

As the paths used for yard trailers and RTGs movement are including the quay length of 1,600 meters, then the space remaining from the paths is used for blocks in which containers are stacked. In this experiment, it is assumed that each block has thirty bays, and a single block has a capacity of 720 TEUs. This study considers the yard arrangement for container groups, and so the size of an individual container is not considered. Therefore, it is assumed that our available storage capacity is around half of the whole capacity of a block, in the planning horizon. Thus, it is assumed that the storage capacity of single block has four container groups, with each container group consists of one hundred containers.

In this paper, it is assumed that the planning horizon is set as a week with seven days, each one time period is set to one day. Generally, most container shipping services are provided weekly on a fixed day of the week. Trade lanes are operated by a shipping operator or an alliance of multiple shipping operators. Considering the transshipment containers movement, those containers unloaded from the relevant ship, will be stored at any block in the yard area temporarily. After that, the containers will be loaded to other ships that belong to other lanes.

To simulate congestion, three types of ship arrival pattern such as 3-h, 4-h and 5-h average intervals of ship arrival on exponential distribution, were prepared. The higher congestion in a terminal might bring longer handing times of each ship. In other words, this situation also might effect on the balance of empty space and the storage capacity of a block. The longer interval of ship arrival brings lower workload handling of containers. On the contrary, the shorter interval of ship arrival brings higher workload handling of containers, and this makes a difference in finding a storage location for those containers.

As mentioned above, it is assumed that the container treatment is for container groups consists of multiple containers. That time is controlled by the number of QCs assigned to each ship. Additionally, from knowledge obtained from the terminal operators, around forty containers can be handled by a QC per hour. It also takes around 1.5 to 2 min to handle each container. If it takes 1.5 min to handle a single container, around one thousand containers can be handled by one QC in 24 h. This handling of containers includes both unloading and loading operations. Therefore, it is assumed that 500 containers are unloaded from the ship and then other 500 containers are loaded to the relevant ship by one QC. Here, it is also assumed that one container group consists of 100 individual containers. From this assumption, one to five container groups can be unloaded from or loaded to one ship.

The estimated handling time per QC developed in Section 4 is used in this problem and is shown in Constraint (27).

$$C_{BS_jl}(=f_{\mathrm{QC}}) = e^{0.583} \times NUMC^{0.991} \times e^{0.282 \times DIS} \tag{27}$$

where:

BS_j = berthing location where ship j is serviced C_{BS_jl} handling time when a container group is unloaded from or loaded to ship j serviced at berth BSj, is to or from block l (in hours), respectively;

$NUMC$ = total amount of container groups (= 1 because one container group consists of one hundred containers in this study); and

DIS = travel distance between ship berthing location and yard blocks by any yard trailer (in kilo meters).

7.2 Computational results

7.2.1 Effect of considering ship-to-berth assignment on YAP. To verify the effect of considering the BAP on YAP, it will be shown that the computational results obtained by the YAP along with the BAP, as YAPB are compared with those done by optimizing only YAP.

In the YAP, the position where ships are serviced must be determined in advance. Two types of ship berthing situation are prepared as follows;

(1) YAP_R: ship berthing position is randomly generated using a random seed.

(2) YAP_W: ship is assigned systematically and repeatedly to any berth 1, 2, 3 or 4 based on its arrival order so as to be served as soon as possible and to reduce waiting.

Table V shows the total service time (referred to as TST) obtained by the YAPs and YAPB. From the results, the TST obtained by YAPB was less than that done by YAPs at all cases. In comparison with the TST between YAP_R and YAP_W, the TST obtained by YAP_W

Case #	YAP_R (hours)	YAP_W (hours)	YAPB (hours)	Difference (YAP_R) (%)	Difference (YAP_W) (%)
3-h average interval of ship arrival					
1	2013.5	1520.4	1351.5	32.9*	11.1*
2	3257.4	1737.3	1621.3	50.2	6.7
3	2716.4	2204.4	1871.4	31.1*	15.1*
4	1750.5	1362.4	1160.4	33.7	14.8*
5	2194.1	1614.5	1382.1	37.0*	14.4*
6	2306.2	1417.4	1285.4	44.3*	9.3
7	2402.3	1337.4	1124.5	53.2*	15.9
8	2204.5	1549.5	1391.3	36.9*	10.2*
9	2006.4	1531.5	1320.5	34.2	13.8*
10	2549.4	1845.5	1608.2	36.9	12.9*
Average	*2340.1*	*1612.0*	*1411.7*	*39.0*	*12.4*
4-hour average interval of ship arrival					
1	993.5	775.4	714.5	28.1	7.9
2	1839.5	847.5	768.3	58.2*	9.3*
3	1284.4	1018.4	917.5	28.6	9.9
4	1068.4	667.4	606.4	43.2*	9.1
5	993.5	769.3	670.2	32.5	12.9
6	1185.4	764.3	672.1	43.3	12.1*
7	970.5	662.4	562.5	42.0	15.1
8	1057.5	724.5	676.3	36.0	6.7
9	1094.3	738.4	654.5	40.2	11.4
10	1146.5	873.4	804.1	29.9	7.9
Average	*1163.4*	*784.1*	*704.6*	*38.2*	*10.2*
5-hour average interval of ship arrival					
1	663.5	531.3	483.3	27.2	9.0
2	930.4	520.5	477.2	48.7	8.3
3	794.4	616.4	544.5	31.5	11.7
4	485.5	438.5	383.5	21.0	12.5
5	621.4	499.4	452.4	27.2	9.4
6	582.4	438.5	407.4	30.0	7.1
7	659.2	454.4	412.2	37.5	9.3
8	582.3	456.5	416.5	28.5	8.8
9	805.4	496.3	455.5	43.4*	8.2
10	772.4	513.5	476.2	38.3*	7.3
Average	*689.7*	*496.5*	*450.9*	*33.3*	*9.2*

Notes: * shows the case with the largest TST difference among three average intervals of ship arrival

Table V. Total service time by YAPB and YAPs

was less than that done by YAP_R. The differences between the results obtained by YAPs and those done by YAPB are calculated by equation (28).

$$\text{Difference}\,(\%) = \frac{(\text{TST obtained by YAP}) - (\text{TST obtained by YAPB})}{\text{TST obtained by YAP}} \times 100 \tag{28}$$

From the average of TST, the largest TST difference was found in 3-hour average interval of ship arrival under port congestion. As shown by "*" in Table V, it is investigated that the number of cases which the difference is largest among three average intervals of ship arrival. Many cases which the difference is largest were found in 3-h average interval of ship arrival under port congestion. In the situation where many ships are calling during the planning horizon, the effect of taking BAP into consideration to YAP is high.

Additionally, it will be shown whether the time spent in unloading and loading operations of each ship could be shortened by considering the YAP along with the BAP. Table VI shows the average handling time per ship (referred to as AHT). Comparing the computational results obtained by YAPs with those done by YAPB, the AHT obtained by YAPB was less than that done by YAPs. Taking BAP into consideration to YAP could also reduce the AHT. The difference between YAP and YAPB in the AHT is calculated by the following equation (29).

$$\text{Difference}\,(\%) = \frac{(\text{AHT obtained by YAP}) - (\text{AHT obtained by YAPB})}{\text{AHT obtained by YAP}} \times 100 \tag{29}$$

From the average of AHT, the largest AHT difference was found in 5-hour average interval of ship arrival. In the situation which is not busy, the effect of taking BAP into consideration to YAP is high for the AHT difference. As shown by "*" in Table VI, it is investigated that the number of cases which the difference is largest among three average intervals of ship arrival. Many cases which the difference is largest were found in 5-h average interval of ship arrival. This reason is because more candidate locations for container storage could be found under the situations which are not busy. From this, containers could be stored to the block near the relevant ship's berthing location in more cases.

7.2.2 Comparison of proposed approach and 2-step process. As mentioned in Section 2, there are two studies by Zhen *et al.* (2011) and Lee *et al.* (2012) that are concerned about the problem of combining a BAP and a YAP. Those studies dealt with more complicated assumption than this study. Thus, as shown in Figure 6(a), they proposed the solution procedure that first a BAP is optimized and next a YAP is optimized. In BAP optimization, the YAP for each container group is given in advance. Based on the containers have already stored in the yard, first the BAP is optimized and a good BAP solution can be obtained. This best solution of BAP is given in advance, and next the YAP is optimized and a good YAP solution can be obtained. After this YAP optimization, the first iteration completes. After that, as this YAP will be given in advance, the BAP will be optimized again. This process will be repeated until reach the termination. The YAP is optimized separately the BAP as shown in Figure 6(a). Then, this existing process is referred to as "2-step process" in this study. On the contrary, the proposed approach in this study is to optimize the BAP and the YAP simultaneously as shown in Figure 6(b). In GA parameters of the 2-step process, 10,000

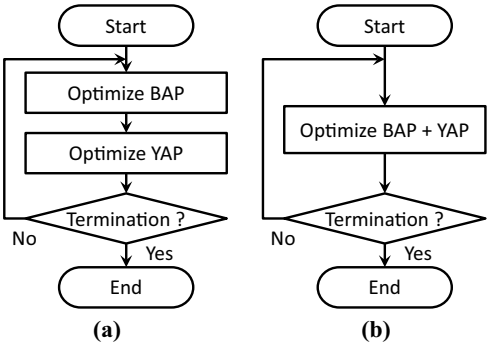
Table VI. Average handling time per ship by YAPB and YAPs

Case #	YAP_R (hours)	YAP_W (hours)	YAPB (hours)	Difference (YAP_R) (%)	Difference (YAP_W) (%)
3-h average interval of ship arrival					
1	12.0	12.1	11.7	2.5	3.3
2	13.2	12.7	12.3	6.8*	3.1
3	13.5	13.5	13.0	3.7	3.7
4	11.5	11.6	11.2	2.6	3.4
5	12.3	12.0	11.8	4.1	1.7
6	11.9	12.2	11.8	0.8	3.3
7	11.9	11.6	11.2	5.9	3.4
8	11.9	12.2	12.1	−1.7	0.8
9	11.3	11.5	11.2	0.9	2.6
10	12.8	12.9	12.3	3.9*	4.7
Average	*12.2*	*12.2*	*11.9*	*3.0*	*3.0*
4-h average interval of ship arrival					
1	12.0	12.1	11.6	3.3	4.1
2	12.2	12.0	11.8	3.3	1.7
3	13.9	13.7	13.1	5.8	4.4
4	10.9	10.8	10.4	4.6	3.7
5	11.9	11.6	10.9	8.4*	6.0
6	12.1	12.1	11.4	5.8	5.8
7	10.8	10.8	10.3	4.6	4.6
8	11.4	11.7	11.0	3.5	6.0
9	11.1	11.3	10.9	1.8	3.5
10	12.2	12.7	12.2	0.0	3.9
Average	*11.9*	*11.9*	*11.4*	*4.1*	*4.4*
5-h average interval of ship arrival					
1	11.7	11.6	10.7	8.5*	7.8*
2	11.0	11.5	10.8	1.8	6.1*
3	12.8	12.5	11.9	7.0*	4.8*
4	9.9	10.0	9.3	6.1*	7.0*
5	10.9	11.2	10.5	3.7	6.2*
6	10.2	10.3	9.6	5.9*	6.8*
7	10.4	10.0	9.4	9.6*	6.0*
8	10.3	10.7	9.9	3.9*	7.5*
9	10.8	10.7	10.3	4.6*	3.7*
10	11.5	11.9	11.2	2.6	5.9*
Average	*11.0*	*11.0*	*10.4*	*5.4*	*6.2*

Notes: * shows the case with the largest AHT difference among three average intervals of ship arrival

generations for the BAP, 20,000 generations for the YAP and 10 iterations for whole process are needed as the termination for completing the convergence of all cases, from the preliminary computation results.

Table VII shows the objective function value, the total service time (hereinafter referred to as TST) obtained by the proposed approach and 2-step process. In addition, it also shows the improvement by proposed approach to 2-step process. At all cases, the TST obtained by the proposed approach was less than that done by the 2-step process. The proposed approach outperforms the 2-step process on TST. Table VII also shows the improvement by the proposed approach from the 2-step process is calculated by the following equation (30).



Notes: (a) 2-step process; (b) proposed approach

Figure 6. Difference between the proposed and the existing approaches

$$\text{Improvement}\,(\%) = \frac{(\text{TST obtained by 2-step proc.}) - (\text{TST obtained by Proposed app.})}{\text{TST obtained by 2-step proc.}} \times 100 \tag{30}$$

From these results, the TST obtained by the proposed approach are less than that done by the 2-step process. The largest TST difference between proposed approach and 2-step process was found in the 3-hour average interval of ship arrivals. The higher the port congestion, the greater the TST by the proposed approach from the 2-step process was reduced. As shown by "*" in Table VII, it is investigated that the number of cases which is the largest improvement among three average intervals of ship arrival. Most of cases which the improvement is largest were found in 3-h average interval of ship arrival under port congestion.

8. Conclusion

To achieve a high container handling efficiency at transshipment hub ports, there are a variety of scheduling problems as ship-to-berth assignment (BAP), container-to-yard arrangement (YAP) and so on. As it is difficult to acquire the actual information of an existing marine terminal under various circumstances, this study develops the regression model for estimating the time spent for container handling by using the results from the simulation model instead of the actual data. Additionally, this study also addresses the YAP for transshipment containers, to operate effectively and smoothly the connection between main routes and feeder services at a terminal. In most existing works about the YAP, the ship-to-berth assignment is often given in advance. On the contrary, in most existing works about the BAP, the yard arrangement for containers associated is often given in advance. Therefore, this study proposes the way to optimize the YAP along with the BAP simultaneously. According to the existing works considering the YAP along with BAP, the 2-step process which first a BAP is optimized and next a YAP is optimized is iterated in turn, is proposed. Thus, this paper proposed the way to optimize YAP along with BAP (YAPB).

The contributions of this study are as follows.

- The proposed regression model has high performance to estimate the time spent of container handling.

To verify the necessary of BAP consideration on the YAP, the contributions obtained by this study are made from the computational results as follows.

Table VII. Total service time by proposed approach and 2-step process

Case #	2-step process (hours)	Proposed approach (hours)	Improvement (%)
3-h average interval of ship arrival			
1	1452.4	1351.5	6.9
2	1781.8	1621.3	9.0
3	2243.0	1871.4	16.6*
4	1337.2	1160.4	13.2*
5	1634.9	1382.1	15.5*
6	1473.2	1285.4	12.7*
7	1242.3	1124.5	9.5*
8	1547.2	1391.3	10.1*
9	1540.8	1320.5	14.3
10	1788.2	1608.2	10.1*
Average	*1604.1*	*1411.7*	*11.8*
4-h average interval of ship arrival			
1	779.1	714.5	8.3*
2	864.6	768.3	11.1*
3	1038.0	917.5	11.6
4	680.1	606.4	10.8
5	714.8	670.2	6.2
6	700.5	672.1	4.1
7	615.2	562.5	8.6
8	760.8	676.3	11.1*
9	733.1	654.5	10.7
10	840.2	804.1	4.3
Average	*772.6*	*704.6*	*8.7*
5-h average interval of ship arrival			
1	504.0	483.3	4.1
2	510.4	477.2	6.5
3	585.5	544.5	7.0
4	409.5	383.5	6.3
5	474.5	452.4	4.7
6	430.4	407.4	5.3
7	424.4	412.2	2.9
8	435.1	416.5	4.3
9	481.4	455.5	5.4
10	509.2	476.2	6.5
Average	*476.4*	*450.9*	*5.3*

Notes: * shows the case with the largest TST improvement among three average intervals of ship arrival

- Total service time and Average handling time per ship obtained by the proposed YAPB were less than those done by YAP only.

The proposed approach that optimizes the YAP along with the BAP was applied in the GA. The existing 2-step process, which first optimizes BAP and then optimizes YAP, is iterated.

- The proposed approach outperformed the 2-step process.

As the limitation of this study, this paper focuses on the yard arrangement for transshipment containers. In general, containers handled at a marine CT include not only transshipment containers, but also import and export containers. Therefore, in the near future, the yard arrangement for all those containers with berth utilization efficiency will be attempted.

References

Christian, B. and Frank, M. (2010), "A survey of berth allocation and quay crane scheduling problems in container terminals", *European Journal of Operational Research*, Vol. 202 No. 3, pp. 615-627.

Dulebenets, M.A. (2017), "A novel memetic algorithm with a deterministic parameter control for efficient berth scheduling at marine container terminals", *Maritime Business Review*, Vol. 2 No. 4, pp. 302-330.

Han, Y., Lee, L.H., Chew, E.P. and Tan, K.C. (2008), "A yard storage strategy for minimizing traffic congestion in a marine container transshipment hub", *OR Spectrum*, Vol. 30 No. 4, pp. 697-720.

Hartmann, S. (2004), "Generating scenarios for simulation and optimization of container terminal logistics", *OR Spectrum*, Vol. 26 No. 2, pp. 172-192.

Imai, A., Nishimura, E., Hattori, M. and Papadimitriou, S. (2007), "Berth allocation at indented berths for mega-containership", *European Journal of Operational Research*, Vol. 179 No. 2, pp. 579-593.

Imai, A., Nishimura, E. and Papadimitriou, S. (2008), "Berthing ships at a multi-user container terminal with a limited quay capacity", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 44 No. 1, pp. 136-151.

Imai, A., Sun, X., Nishimura, E. and Papadimitriou, S. (2005), "Berth allocation in a container port: using a continuous location space approach", *Transportation Research Part B: Methodological*, Vol. 39 No. 3, pp. 199-221.

Jin, J.G., Lee, D.H. and Cao, J.X. (2014), "Storage yard management in Maritime container terminals", *Transportation Science*, Vol. 50 No. 4, pp. 1300-1313.

Lee, L.H., Chew, E.P., Tan, K.C. and Han, Y. (2006), "An optimization model for storage yard management in transshipment hubs", *Or Spectrum*, Vol. 28 No. 4, pp. 539-561.

Lee, D.H. and Jin, J.G. (2013), "Feeder vessel management at container transshipment terminals", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 49 No. 1, pp. 201-216.

Lee, D.H., Jin, J.G. and Chen, J.H. (2012), "Terminal and yard allocation problem for a container transshipment hub with multiple terminals", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 48 No. 2, pp. 516-528.

Lim, A. and Xu, Z. (2006), "A critical-shaking neighborhood search for the yard allocation problem", *European Journal of Operational Research*, Vol. 174 No. 2, pp. 1247-1259.

Nishimura, E., Imai, A., Janssens, G.K. and Papadimitriou, S. (2009), "Container storage and transshipment marine terminals", *Transportation Research Part E: Logistics and Transportation Review*, Vol. 45 No. 5, pp. 771-786.

Sait, S.M. and Youssef, H. (1999), "3.1.1 GA basics", Chapter 3, *Genetic Algorithms (GAs)", Iterative Computer Algorithms with Applications in Engineering: Solving Combinatorial Optimization Problems*, IEEE Computer Society Press, CA.

Sharif, O. and Huynh, N. (2013), "Storage space allocation at marine container terminals using ant-based control", *Expert Systems with Applications*, Vol. 40 No. 6, pp. 2323-2330.

Steenken, D., VoB, S. and Stahlbock, R. (2004), "Container terminal operation and operations research – a classification and literature review", *OR Spectrum*, Vol. 26, pp. 3-49.

UNCTAD (2018), *Review of Maritime Transport 2018*, United Nations Publication, Geneva.

Vis, I.F.A. and Harika, I. (2004), "Comparison of vehicle types at an automated container terminal", *OR Spectrum*, Vol. 26 No. 1, pp. 117-143.

Yang, J.H. and Kim, K.H. (2006), "A grouped storage method for minimizing relocations in block stacking systems", *Journal of Intelligent Manufacturing*, Vol. 17 No. 4, pp. 453-463.

Zhang, C., Liu, J., Wan, Y.W., Murty, K.G. and Linn, R.J. (2003), "Storage space allocation in container terminals", *Transportation Research Part B: Methodological*, Vol. 37 No. 10, pp. 883-903.

Zhen, L., Chew, E.P. and Lee, L.H. (2011), "An integrated model for berth template and yard template planning in transshipment hubs", *Transportation Science*, Vol. 45 No. 4, pp. 483-504.

Further reading

Dragovic, B., Tzannatos, E. and Park, N.K. (2017), "Simulation modeling in ports and container terminals: literature overview and analysis by research field, application area and tool", *Flexible Services and Manufacturing Journal*, Vol. 29 No. 1, pp. 4-34.

Appendix. Algorithm for obtaining the total service time including waiting time

```
Initialization: the storage capacity CAP_l of block l is given;
                the number of container groups already stored at
                block l is given as CS_l ;
                the total service time TST = 0.
For p: = 1 to (the whole planning horizon)
    For i: = 1 to (the total number of berths operated)
        For k: =1 to (the total number of ships serviced at berth i)
            Get the relevant ship as ship J_ik; set of container
            groups unloaded from ship J_ik is given as UC_Jik; set of
            container groups loaded to
            ship J_ik is given as LC_Jik.
            If ship J_ik calls at berth i on the 1st time period,
            then it can be served immediately:
                Beginning time of ship J_ik to be served = Arrival
                time of ship J_ik,
                Go to Step 11.
            Otherwise: go to Step 09.
            If arrival time of J_ik ≥ departure time of J_i,k−1:
                Beginning time of ship J_ik to be served = Arrival
                time of ship J_i,k−1.
            Otherwise:
            Beginning time of ship J_ik to be served = Departure
            time of ship J_i,k-1.
            For g: =1 to |UC_Jik|
                Find the block number l randomly.
                If the storage capacity CAP_l > CS_l + 1: go to
                Step 12.
                Otherwise: container group g is stored at block
                l, and the number of containers to be stored is
                updated as CS_l: = CS_l + 1.

            Endfor g
            For g′: = 1 to |LC_Jik|
                Container group g′ is loaded to ship J_ik.
                Find block l′ where Container group g′ is
                stored, the number of container groups stored
                is updated as CS_l′: = CS_l′ - 1.
            Endfor g′
            Ship J_ik departs from the terminal, obtain the
            departure time of ship J_ik.
            The estimated handling time per QC developed at the
            section 4 is used as the handling time of ship J_ik.
            Departure time of ship J_ik = Beginning time of ship
            J_ik to be served + Handling time of ship J_ik .
```

```
                Service time including waiting of ship J_ik =
                Departure time of ship J_ik - Arrival time of ship J_ik .
                TST = TST + Service time including waiting of ship J_ik
            Endfor k
        Endfor i
Endfor p
Return the total service time including waiting time TST
```

About the author

Etsuko Nishimura is working as an Associate Professor in Department of Global Transportation Sciences in Graduate School of Maritime Sciences at Kobe University, Kobe, Japan. Her research interests include container transportation, marine terminal, terminal operation, optimization and scheduling. Her research field is scheduling problems occurred at marine container terminals. A mathematical programming and numerical analysis are used to solve the problems by optimizing yard area use for transshipment containers, designing the stack arrangement of container block at the yard with arbitrary configuration and optimizing vehicle dispatch for marine container drayage. Etsuko Nishimura can be contacted at: e-nisi@maritime.kobe-u.ac.jp

For instructions on how to order reprints of this article, please visit our website:
www.emeraldgrouppublishing.com/licensing/reprints.htm
Or contact us for further details: **permissions@emeraldinsight.com**