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Model of Twin Automatic Stacking Crane Operation Strategy with Dynamic Handshake Area in an Automated Container Terminal

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Abstract: This paper proposes a new idea for allocating a handshake area of an automated container yard. A block of automated container yards (CY) consists of two areas, which are the import (waterside) and export (landside) areas. The CY has two major activities (loading and unloading), where both are served by Twin Automatic Stacking Cranes (Twin-ASCs). A handshake area in the middle of the CY serves as a temporary slot for both ASCs. This situation causes an imbalance between the ASCs when the demands of each side differ significantly. Thus, we proposed using a dynamic location of the handshake area corresponding to the proportion demand of export and import containers. We developed a heuristics model and algorithms of ASC's operations to compare the efficiency of the ASC operations between the fixed and the dynamic location. Based on our model and algorithm, we developed simulation software. Finally, we explored some numerical experiments to compare the performance of both policies in dealing with different export and import demand scenarios. Our result showed that the proposed approach outperformed the existing one in reducing unnecessary ASC movements.

Keywords: Automated container yard, twin automatic stacking cranes, dynamic handshake area, simulation.

Introduction

Teluk Lamong Terminal (TTL) is a container port in Indonesia that has implemented Green Port since 2014. TTL is a multi-purpose and semi-automatic terminal where all activities such as trucking, handling, and others are carried out automatically. This port is also claimed to be Indonesia's first environmentally friendly port.

The port has implemented advanced technology in eco-initiative efforts, such as Compressed Natural Gas (CNG) fuel for trucks operating within the port area. Combined Tractor Terminal (CTT), an automated guided vehicle, uses electric energy and automatically moves containers from the container yard (CY) to the dock and vice versa. Automatic Stacking Cranes (ASCs) use electrical power and can operate 24 hours a day without an operator. This paper develops a model of Twin ASCs' operational strategies in the container yard. We focus on the discussion of the role of a handshake area, consisting of two rows, which are required to serve as a temporary slot for both ASCs.

The container yard (CY) using Twin ASCs have different configurations than container terminals with a single crane. CY, with a single crane, serves containers from the landside (gate area) and waterside (berth area) as a pickup and drop-off point, also called the transfer point or input/output (I/O) point [1]. However, the ASCs have (I/O) points on the waterside and landside. Therefore, we classified CY as an area serving containers from the gate area with the landside and an area for serving containers from the berth area with the waterside. There are pickup and delivery trucks at the I/O point of the landside. And the automated guided vehicles will stop for pickup and delivery of containers at the I / O point waterside. Since both ASCs have the same size, they cannot pass each other. When the landside ASC (L-ASC) has a request close to the waterside, the waterside ASC (W-ASC) must provide a space for the landside ASC to complete the request. This problem potentially increases the ASC's travel time. To solve this problem, the ASCs can work with a transfer zone in container stacking (two bays). The transfer zone is called the handshake area. The handshake area is temporary container storage in the container yard so that one ASC may leave the container and request another ASC to take the container and proceed to the next slot destination [1]. The L-ASC handles the retrieval and storage container from and to the landside, and the W-ASC handles the retrieval and storage container from and to the waterside. In our research, each block has two ASCs to move containers in automated CY. The minimum safety distance between the ASCs is at least one bay. The handshake area is only two bays. However, this research does not he inter-row movements and reshufflings. There are two sizes of containers, 20-ft and 40-ft. The proposed strategies are scheduling containers for each crane, prioritizing cranes, selecting the size of the handshake area, and selecting the number of handshake areas [1].

In this case, the handshake area is two bays in the middle of blocks (Figure 1.). This area restricts the movement of ASCs. For example, when a customer orders to move a container from a coastasl area to a landside area, the W-ASC picks a container from the waterside and drops it into the handshake area. Then, the W-ASC moves back to the coastal area so that the L-ASC can enter the handshake area, pick the chosen container, and return to the landside. Another operational restriction that limits the movement of the ASC is the minimum safety distance. The minimum safety distance is the distance between the locations of the twin ASCs.

Both ASCs are used to arrange the containers while waiting for the departure time. The arrangement of containers requires some criteria to consider. The most widely used measures are the container's weight, size, type, and destination (vessel). Vessel and truck arrival time can be a crucial criterion in making the container arrangement, where the container with the shortest departure time will be placed at the front of the waterside (vessel) or the landside (truck). Containers arrangement affects the efficiencies of both automated CY and port service levels. The efficiency of the automated CY is measured by the total movement distance of the Twin-ASCs (total travel distance). In this case, the minimization of the entire movement distance of the Twin-ASC will also reduce electricity usage, which results in a green port.

Several works of literature study cover container port operations, particularly container yard operations. Carlo *et al.* [2] classified scientific journals on CY operation between 2004 and 2012, considering storage space assignment, yard layout, material handling equipment dispatching and routing, and reshuffling decisions. There are some researches on operation optimization in the automated container terminal focused on the minimize inefficiency activity in the yard area, which are reshuffle activity. He *et al.* [3] developed a dynamic yard allocation method for Automated Container Terminals (ACT) by considering the mixed stacking of containers in one block and multiple yard cranes. Speer *et al.* [4] compared the scheduling results of four different automated yard crane systems. Yu *et al.* [5] did a literature review that concluded that yard management is essential for ACT. Nossack *et al.* [6] used a branch-and-cut approach to determine the allocation containers to minimize the make span and prevent crane interferences. Yu *et al.* [7] developed a bay-sharing strategy to optimize yard space allocation. Park *et al.* [8] proposed heuristic-based and local-search-based real-time scheduling methods for twin rail-mounted gantry cranes. Hu *et al.* [9] formulated a mixed-integer linear program (MILP) to position the handshake bay and schedule the twin ASC. Kim *et al.* [10] developed an N-RTS to optimize the storage yard of ACT. Yu *et al.* [11] set a stack-based allocation with multi batches in the same bay to improve the handling efficiency. Kon *et al.* [12] reviewed some articles about the global trends of ACT. ACT technology could increase production efficiency, cost reduction, and environmental sustainability [12], [13]. Zang *et al.* [13] developed an optimization model to optimize resource allocation schedules in quay crane double cycling. Yu *et al.* [14] used simulation-embedded optimization to allocate the terminal container yard space for a batch of arrived inbound containers to minimize total Automated Guided Vehicle (AGV) and external truck waiting time. Yang et al. [15] proposed integrated scheduling for equipment coordination and AGV routing. Wang *et al.* [16] analyzed and designed an ACT layout to achieve sustainable development of the port. Zhong *et al.* [17] combined AGV conflict-free path planning with quay and rail-mounted gantry cranes to schedule multi-AGV. Covic [18] proposed an online rule-based method to re-marshal problems with and without terminal appointment systems.

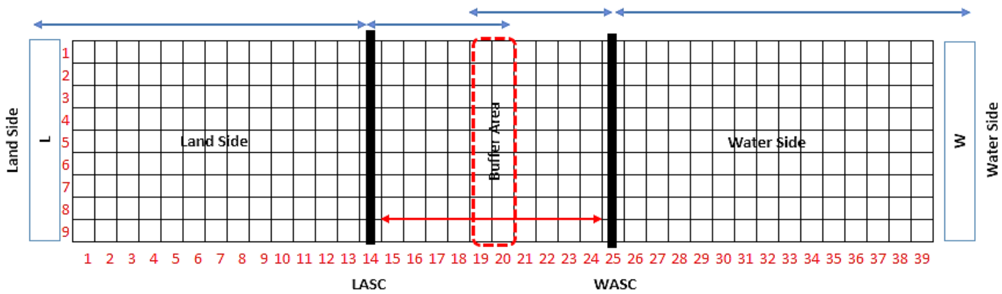

Figure 1. CY layout in Port of Terminal Teluk Lamong

Rei and Pedroso [19] developed a mathematical model of the stacking problem to minimize the displacement of containers concerning arrivals and retrieval of containers. In this system, the displacement was limited to one bay only. Rei and Pedroso [19] developed a heuristic method by comparing Conflict Minimization (CM), Flexibility Optimization (FO), and Flexibility Parameterized Optimization (PFO). Izquierdo *et al.* [20] developed the Lowest Priority First heuristic method to determine the location of containers in CY based on the priorities assigned by the RMGC handling tool. Nurminarsih *et al.* [21] developed a dynamic container yard template with a space-sharing strategy considering uncertainty on the number of receiving containers for increasing the utilization of CY.

Twin-ASC-related scheduling research has been done by Park et. al. [22], Choe *et al.* [23], and Gharehgozli *et al.* [24]. Park *et al.* [8] developed a mathematical model for scheduling two RMGCs with two objectives: minimizing the weighted delay time of Automated Guided Vehicle (AGV) and the weighted truck waiting time. Meanwhile, Choe *et al.* [8], [22] developed a container movement scheduling algorithm within the Twin-ASC block to minimize the unnecessary movement of loading or unloading containers. Hereafter, Gharehgozli *et al.* [24] developed a mathematical model of scheduling Twin-ASC in a block to minimize the make span of both ASCs. In addition, the researcher conducted a pairwise calculation of travel time for each ASC.

This paper evaluates the Twin-ASCs operations strategy in arranging containers in an automated CY with some modifications on the position of the handshake area based on the container yard template of TTL. TTL has CY with a vertical layout. CY operates with Twin ASCs of the same size in 1 block and works semi-automatically. Because of this, a minimum safety distance between the ASCs is required in their movement. The handshake area will be changed dynamically by considering the ratio of the number of containers received and delivered. This research will also determine the CY template and the coordinates of container placement to minimize the unnecessary movements of Twin ASC. The purpose of implementing this strategy is to minimize the total energy lifting by combining the reduced travel distance and travel time of the Twin ASC. This research developed an algorithm to determine the container's handshake area and slot location and also an algorithm for scheduling the movement of Twin ASC. The paper is structured as follows: in Section 2, this paper describes the container stacking problem; in Section 3, this paper explains the issues to be resolved, the conceptual models proposed, and the models and algorithms developed in this study. We also did numerical experiments and analysis on the proposed model and algorithm in Section 4, followed by the discussion of research findings and conclusion in the last sections.

Problem Description

This research aims to develop a heuristic algorithm to optimize the operations of the Twin-ASCs in arranging containers in automated CY by utilizing a dynamic handshake area instead of a fixed handshake area. Currently, the position of the handshake area is in the middle of an automated CY. This research observes the possibilities should the conditions used be modified regarding the number of containers coming from both the waterside and the landside. The conceptual model, automated CY dimension, and slot size for this research can be seen in Figure 2, Tables 1 and 2. Figure 2 illustrates the vertical layout of the CY. First, there are the coastal area, handshake area, and landside area. Green lines represent two units of ASC. Receiving containers come from land to sea (unloaded from trucks), while delivery containers come from sea to land (unloaded from ships). The x-axis represents the bay (y), the y-axis represents the row (x), and the z-axis represents the tier (z).

We used a smaller number of bays for this experiment than the actual number in TTL. There are two types of ASC movement; the movement of ASC while carrying a container is necessary, while the movement of ASC without having a container is an unnecessary movement activity. The movement speed of the Twin-ASCs is constant at 270 m/min for both with and without having a load. The ASC lift speed without the container is 90 m/min (45 m/min with a container).

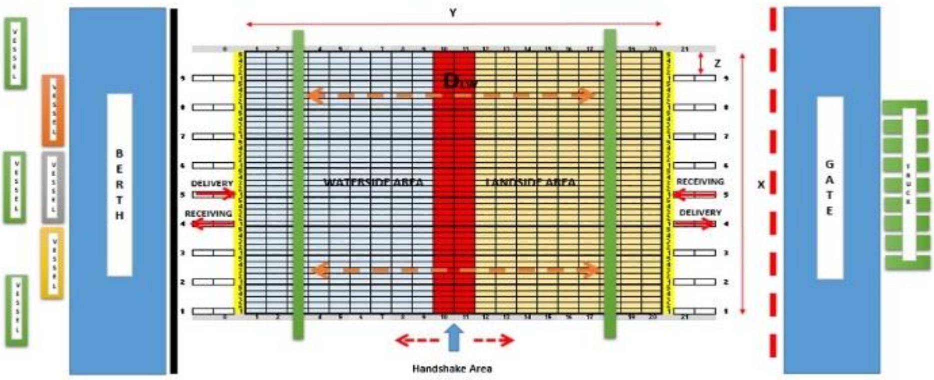

Figure 2. Automated container yard with handshake area and Twin-ASC conceptual model

Table 1. Block dimensions

Dimension	Number of slot
Row (x)	9
Bay (y)	20
Tier (z)	5

Table 2. Slot size

Slot size	Unit (ft)	Unit (meter)
Length	20	6,096
Width	8	2,438
Height	8.5	2,591

Methods

Container Stacking Problems

CY is in the form of a rectangular shape and is divided into several storage areas called blocks. CY blocks are generally divided into three types: domestic block, block import, and block export. The location of a 20 ft container unit within a block is called a slot. In one block, it consists of several rows (width) as the X coordinate, bays (length) as the Y coordinate, and tiers (height) as the Z coordinate [1]. The structure of the CY block is described in Figure 3.

In each block, it can be used by two or three ASCs with one railroad track or a separate rail. By using more than one ASCs in one block, a handshake area is needed where ASC 1 and ASC 2 can pass through it. The ASC can reach seven to ten lines with one to five levels, and the length can be willing to get thirty-six to sixty TEUs [26]. In this study, the observed block is a block that serves container imports and exports at the same time because it uses Twin-ASC.

The problem of structuring goods in warehouses is a subject that has been discussed previously in research. This problem can occur when goods enter the warehouse, when the goods are in the warehouse, or when the goods will come out of the warehouse using transportation equipment. The same can be implied for container arrangements in a container yard. The container arrangement problem is often called the container stacking problem [25]. Stacking containers is a classic problem, and it is not an easy problem to solve either. The primary purpose of researching a container stacking problem is to maximize the number of containers in the container yard and minimize the crane movement during the arrangement [26].

According to Steenken *et al.* [26] there are three types of strategies in container selection, and these are:

a. Re-marshalling stacking: when the container comes to the container yard, it will be placed in a temporary location without considering its attributes. After stowage planning is obtained, the container will be moved to the pre-marshaling area by considering the stowage planning position and container attributes until the ship arrives.
b. Reservation stacking: the customer has booked the place before the container arrives. With the order, the storage capacity of the container yard is reduced by the order.
c. Scattered stacking: each ship has its container yard.

Several container attributes must be considered in carrying out the arrangements, such as the type, size, weight, destination, ship used, and stowage planning. However, according to Dekker *et al.* [27], there are two methods for making container selection:

a. Random stacking: containers are grouped by size (20 ft / 40 ft). If the size is the same, the placement can be done randomly but following the purpose function.
b. Category stacking: container storage is grouped into several categories, including based on type, size, weight, and purpose.

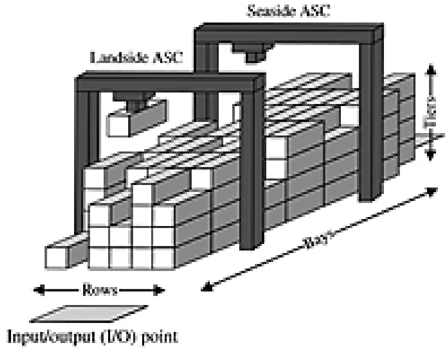

Figure 3. Structure of CY block [1]

Model and Algorithm Development

The models and algorithms developed are divided into two stages: 1) determining the location of the container handshake area and container by considering the proportion of W-ASC and L-ASC jobs, arrival time planning of vessels and trucks, and the destination or the origin port of the containers; 2) scheduling Twin-ASC in CY by considering travel distance and travel time required by W-ASC and LASC to do each job.

Determining the Handshake Area and Slot Location for Container

Fixed handshake area is weak in achieving efficiency when there is a tendency towards an arrival or retrieval of a container. In the fixed system, the handshake areas are usually in the middle of each block. Therefore, the travel distance of L-ASC will be further than W-ASC if there is a tendency towards the arrival container, and vice versa. These conditions can make the total travel distance to be less efficient.

Unlike the fixed one, the dynamic handshake area will dynamically determine the location of the handshake area based on the container arrival pattern. The handshake area will be placed as close to the side with high demand for container movement. Weekly container arrival planning data (from vessels and trucks) will be checked daily at the last shift of each day. This data is used to determine the handshake area location for tomorrow. In a dynamic handshake area, the location of the handshake area can be different each day. These are illustrated in Figures 4 and 5.

For example, on day one and day two, the demand for the landside jobs is higher than the waterside, moving the handshake area closer to the landside. From day 3 to day 5, the demand for landside jobs equals water-side employment. Therefore, the handshake area will be moved to the middle of CY. On days 6 and 7, the demand for water-side jobs increases. Thus, this will also impact the handshake area closer to the waterside. The algorithm for determining the location of the handshake area is shown in Figure 6.

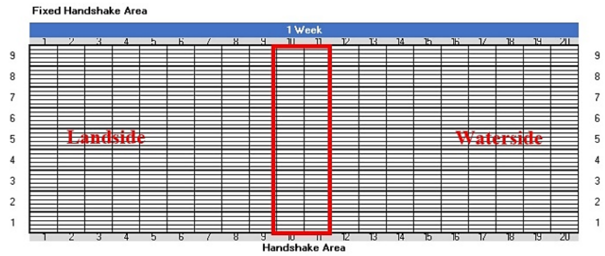

Figure 4. Fixed handshake area

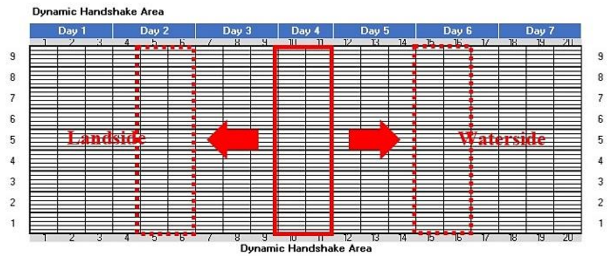

Figure 5. Dynamic handshake area

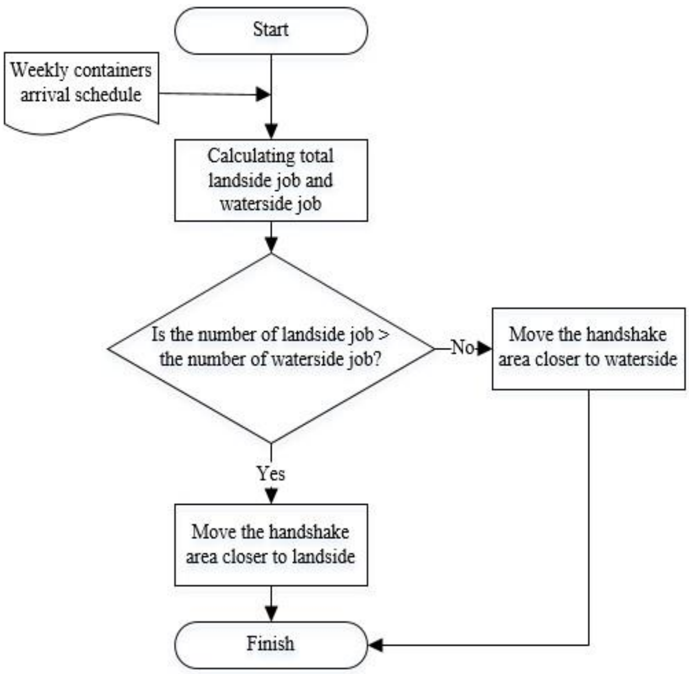

Figure 6. Algorithm for determining the location of handshake area

Besides the location of the handshake area, the location for temporarily storing the containers can also lead to inefficiency. Therefore, we must decide the locations that minimize the total distance between each container and I/O points. The ASC travels from location i to location j. The formulation to calculate travel distance (d_{ij}) can also be referred to the formula from Gharehgozli *et al.* [24] as described in Equation 1.

$$max\{|x_i - x_j|L_s, |y_i - y_j|P_s\} + z_i H_s + z_j H_s \quad (1)$$

Notation
x : coordinates x
y : coordinates y
z : coordinates z
L_s : width of slot (meter)
P_s : length of slot (meter)
H_s : height of slot (meter)

The algorithm for determining the container's slot location is shown in Figure 7. First, the algorithm will sort the containers based on the earliest arrival time of trucks and vessels. Then, the algorithm will track the empty slots of CY and calculate. There are some rules for allocating slots for containers:
1. To minimize the loading process from ASC to trucks and vessels, the selected slot is the closest slot to the loading area (maximum d_{ij}).
2. Containers 40 ft being stacked in the same bay with container 40 ft (coordinate z-1).
3. Containers 20 ft being stacked in the same bay with container 20 ft (coordinate z-1).
4. Containers for different vessels should not be stacked up.
5. Containers for vessel that depart later should not be placed in front of containers for vessel that depart earlier.

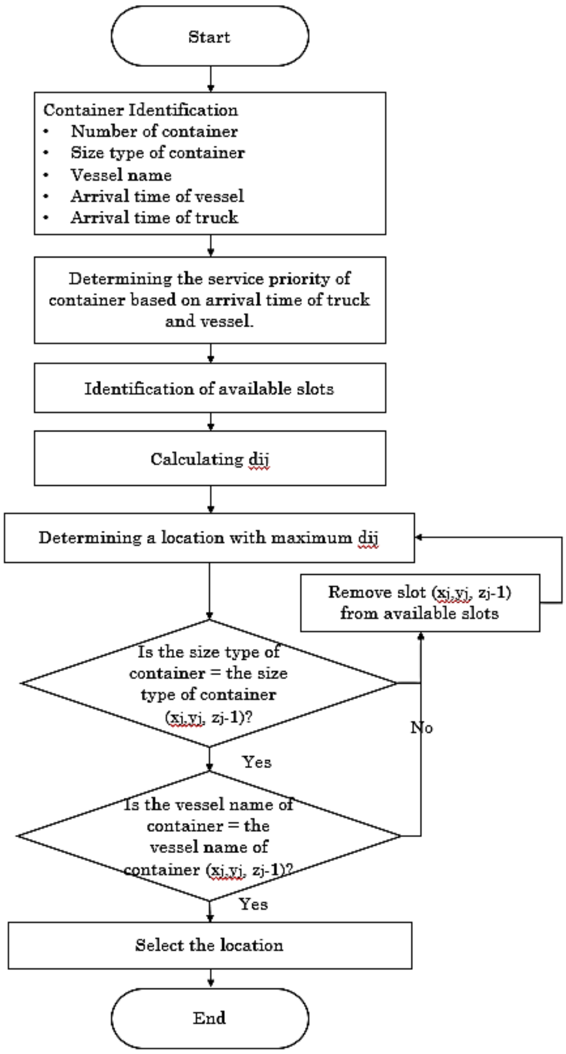

Figure 7. Algorithm for determining the containers slot location

Scheduling Twin ASC in CY

The Twin ASCs have several jobs in the CY. The first job is the waterside job, where containers to be loaded or discharged are moved from/to a vessel. The second is the land-side job, which moves containers from/to external trucks. Next, the Twin ASCs prepare containers in the CY before being loaded to make waterside and land-side jobs faster, known as re-marshaling. Since each block has two equal-sized ASCs that cannot move across each other, the W-ASC exclusively does the waterside jobs, and the land-side jobs exclusively by the L-ASC [28].

The waterside and land-side jobs are classified as the main jobs that will be given priority in scheduling ASC. Re-marshaling jobs are only done on ASC's idle time. A discharge container from a vessel or an external truck will be placed temporally in the handshake area. Then it will be moved to the allocated slot by the other ASC.

The objective function of scheduling Twin ASC is to minimize the total energy cost of Twin ASCs. Total energy cost will be minimized by reducing travel time or distance. The formulation to calculate travel time [25] is described in Table 3. The constraints of scheduling ASC are job priority and the distance that must be kept between the Twin ASCs. The Twin ASCs cannot move across each other. The job of an ASC consists of four steps of crane movements: empty travel to the target container, picking up of the container, loaded travel to the destination, and dropping off the container [24].

Table 3. Travel time (minutes)

ASC Activity	t_{ij} (minute)
ASC displacement to carry containers (necessary movement)	$max\left\{\frac{\lvert x_i - x_j \rvert L_s}{V_{move}}, \frac{\lvert y_i - y_j \rvert P_s}{V_{move}}\right\} + \frac{z_i H_s}{V_{full}} + \frac{z_j H_s}{V_{full}}$ (2)
ASC displacement without carrying containers (unnecessary movement)	$max\left\{\frac{\lvert x_i - x_j \rvert L_s}{V_{move}}, \frac{\lvert y_i - y_j \rvert P_s}{V_{move}}\right\} + \frac{z_i H_s}{V_{empty}} + \frac{z_j H_s}{V_{empty}}$ (3)

Notation
V_{move} : ASC speed (horizontal movement)
V_{full} : ASC lifting speed when carrying container (vertical movement)
V_{empty} : ASC lifting speed when not carrying container (vertical movement)

Hence, we can find the total travel distance of ASC using this formula:

$$TD_a = \sum_{n=1}^{N} NMD_n + \sum_{u=1}^{U} UMD_u \quad (2)$$

And we can also calculate the total travel time of ASC by using this formula:

$$TT_a = \sum_{n=1}^{N} NMT_n + \sum_{u=1}^{U} UMT_u \quad (3)$$

Notation
N : number of necessary movement event
U : number of unnecessary movement event
a : ASC; $a = 1$ (LASC); $a = 2$ (WASC)
TD_a : total travel distance of ASC a for doing all activity (meter)
TT_a : total travel time of ASC a for doing all activity (minute)
NMD_n : ASC travel distance for necessary movement n ($n = 1, 2, \dots, N$) (meter)
UMD_n : ASC travel distance for unnecessary movement u ($u = 1, 2, \dots, U$) (meter)
NMT_u : ASC travel time for necessary movement n ($n = 1, 2, \dots, N$) (minute)
UMT_u : ASC travel time for unnecessary movement u ($u = 1, 2, \dots, U$) (minute)

The dynamic of the handshake area locations might reduce the necessary and unnecessary movements of the ASCs. However, an ASC's shortened activities will cause the other ASCs' moves to increase. Therefore, we need to measure the combination of the travel time of necessary/unnecessary movement reduction and the energy required to lift the container.

$$TE = \sum_{a=1}^{2} \frac{TT_a}{60} \times EC_a \times E \quad (4)$$

Notation
a : ASC; $a = 1$ (LASC); $a = 2$ (WASC)
TE : total energy cost of Twin ASC ($)
EC_a : ASC energy consumption (kWh)
E : energy cost per kWh

The algorithm for scheduling Twin ASC is described in Figure 8. The simulation was conducted for T days. These rules of the algorithm are:

1. To minimize TD, TE, and TT.
2. Scheduling the main job and moving container at handshake area when the container arrives at t and the LASC and WASC idle.
3. When the container arrives, and the main job should be done in time, schedule the re-marshaling job and move to the allocated slot.
4. At the end of the workload, both ASCs will return to normal, and the handshake area will be moved again to the center.

To better understand the algorithm, please refer to the example where the daily container arrival schedule is shown in Table 4.

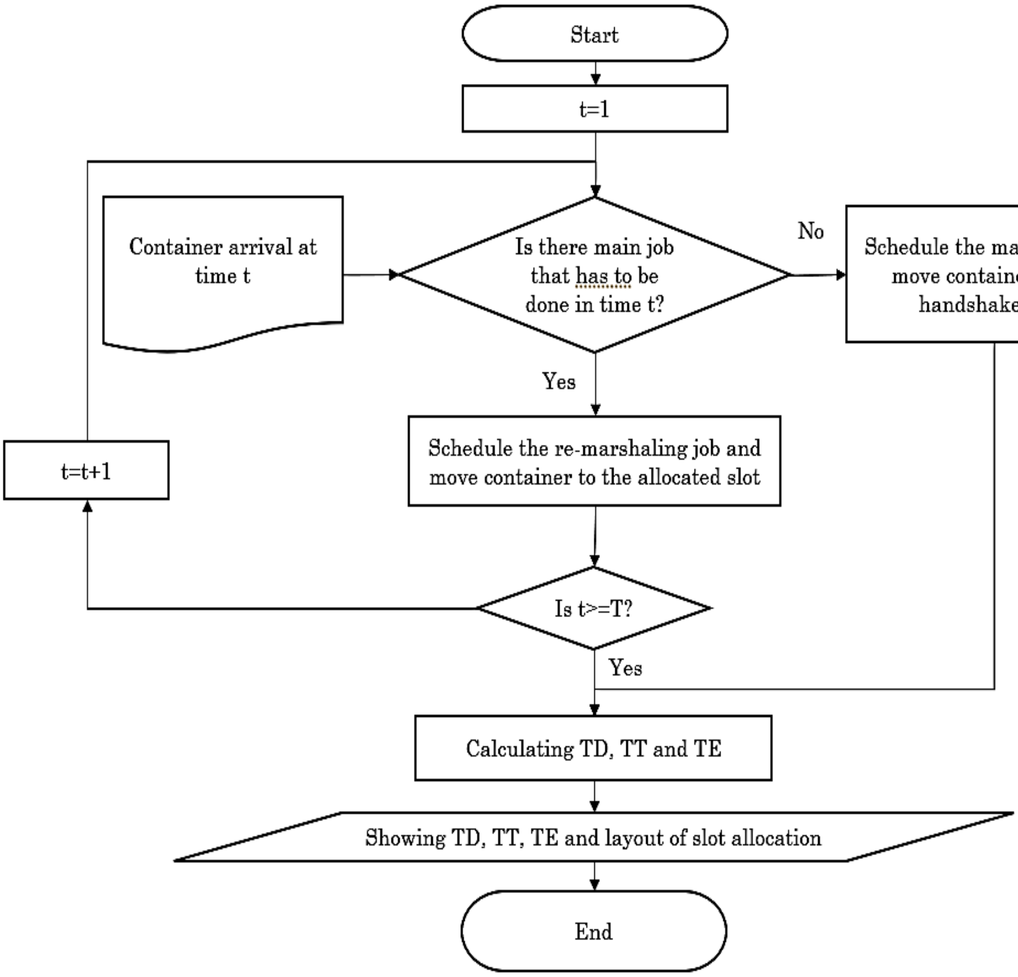

Figure 8. Algorithm for scheduling Twin ASC

Table 4. Daily container arrival schedule

Date	Land-side Jobs (TEUs)	Water-side Jobs (TEUs)	Vessel	Arrival/Departure Date
1/5/2017	10		LUZON	6/5/2017 depart
2/5/2017	40		LUZON	6/5/2017 depart
2/5/2017		300	PAHALA	2/5/2017 arrive
3/5/2017	50		LUZON	6/5/2017 depart
3/5/2017	100		PAHALA	2/5/2017 arrive
4/5/2017	100		LUZON	6/5/2017 depart
4/5/2017	100		PAHALA	2/5/2017 arrive
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Results and Discussions

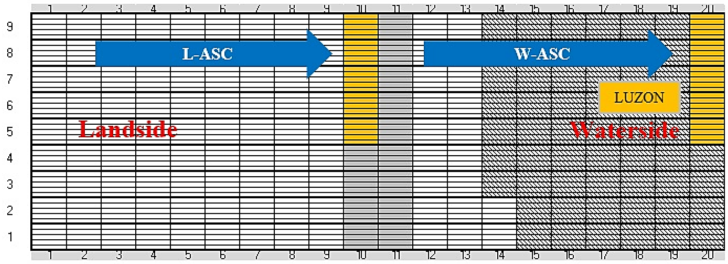

Figure 9. The first day simulation

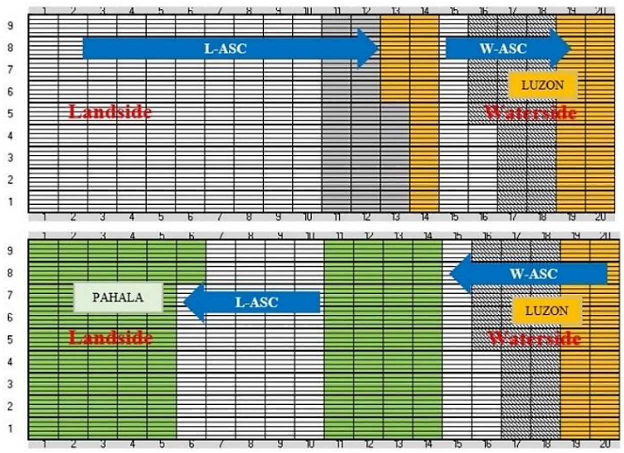

Figure 10. The second day simulation

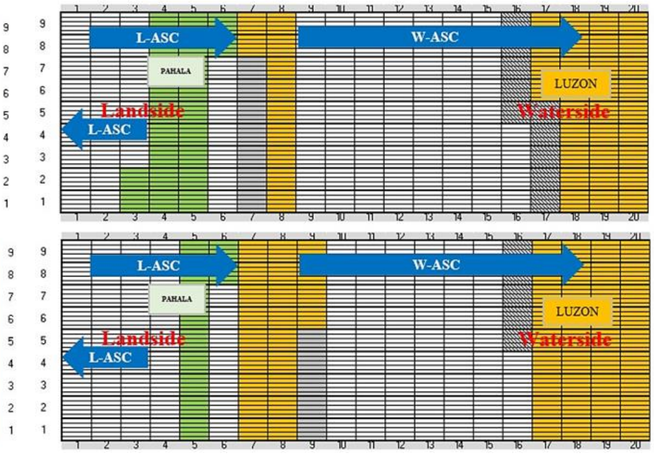

Figure 11. The third day simulation

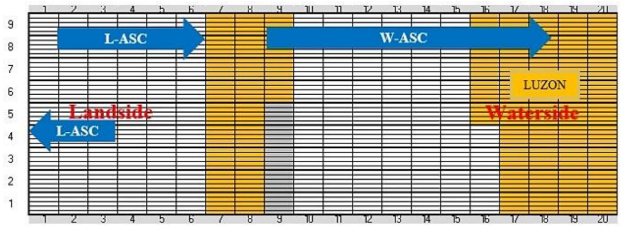

Figure 12. The fourth day simulation

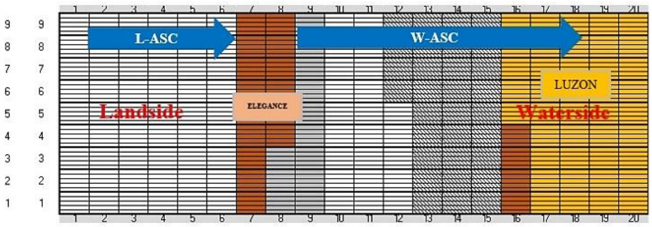

Figure 13. The fifth day simulation

On day 1, since the demands are only moving containers for LUZON from the landside to their allocated places, the jobs of W-ASC and L-ASC will be equal, and the handshake area will be in the middle of CY—the illustration of the first-day simulation explained in Figure 9.

On the second day, the handshake area will be shifted closer to the waterside since containers arrived from the PAHALA vessel, giving more tasks to the W-ASC. Then we moved to the handshake area to balance the work of L-ASC and W-ASC. The illustration of the second-day simulation is explained in Figure 10.

From the third until the fifth day, the handshake area will be shifted closer to the land side because the L-ASC will be occupied by delivering containers from the PAHALA vessel towards the external trucks. On the fifth day, we can see that although some containers from the LUZON vessel still have not arrived, the arriving containers for the ELEGANCE vessel cannot be placed in the area that has been booked for containers from the LUZON vessel due to the constraint which states that containers for the vessel that departs at a last time should not be placed in front of containers for the vessel that leave earlier. The illustration of the third-day simulation is explained in Figure 11. The description of the fourth-day and fifth-day simulations illustrated in Figures 12 and 13.

On day six, the LUZON vessel arrived. Hence the containers for the LUZON vessel will be loaded onto the vessel itself. Consequently, this will increase the job for WASC. We need to shift the handshake area closer to the waterside to balance the workload of both ASCs—the illustration of the sixth-day simulation is explained in Figure 14.

For the seventh day, both ASCs' workloads will return to normal. Accordingly, the handshake area will be moved again to the centre. The illustration of the seventh-day simulation is explained in Figure 15.

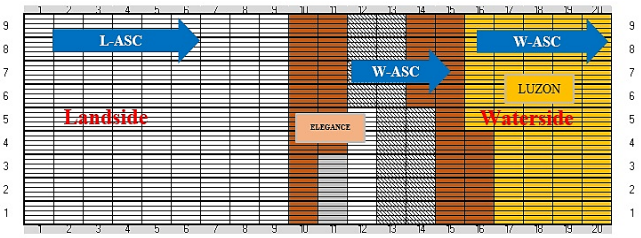

Figure 14. The sixth day simulation

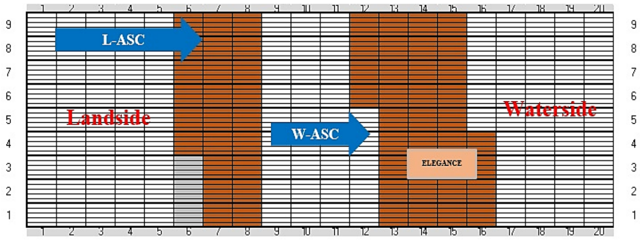

Figure 15. The seventh day simulation

Numerical Experiment and Analysis

This section explains the performance analysis from the presented algorithms in Section 3, where we did further experiments to observe these algorithms in further detail. Besides testing our algorithm, this experiment aims to evaluate the influence of how operation strategies change our algorithm performance. Therefore, we did some scenarios that are presented in Table 5.

The performances that are measured from this experiment are:
a. Total distance travelled (meter) performed by LASC and WASC for each scenario.
b. Total time travelled (minute) performed by LASC and WASC for each scenario.
c. Total energy cost for LASC and WASC for each scenario.

To simplify the operation of our algorithm simulation, we developed a What If Simulation using VBA Excel. Tables 6-8 show the appearance and simulation process of our program currently being developed.

In this experiment, we operated one block container yard with nine columns, 20 rows, and five stacks. Six vessels are coming consecutively (arrival time) in 6 workdays, presented in Table 9. These six vessels are served by one block container yard. The total number of the simulated container during the simulation period is 500 and is limited to 20-ft and 40-ft dry containers. Table 10 shows the number of received and delivered container demand for each scenario. The vessel and container data are actual data obtained from observational objects. The observational thing is a container port that uses Twin ASC and only operates for one year. Consequently, the demands have decreased compared to the other ports implementing Twin ASC (Figure 16).

Table 5. Experiment detail

Experiment	Demand comparison	Handshake area	
		Position	Row
1	50% (receiving): 50%(delivery)	Center	10 and 11
		Right	12 and 13
		Left	8 and 9
2	60% (receiving): 40%(delivery)	Center	10 and 11
		Right	12 and 13
		Left	8 and 9
3	70% (receiving): 30%(delivery)	Center	10 and 11
		Right	12 and 13
		Left	8 and 9

Table 6. What if simulation process

Event No	Container No	Type	Ship Name	Arrival Time (minute)	*i* Coordinate			Departure Time from *i* (minute)	*j* coordinate		
					x	*y*	*z*		*x*	*y*	*z*
1	SPNU2684900	RECEIVING	PAHALA	2424	5	0	1	697.00	1	18	1
2	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	1	18	1	698.41	5	0	1
3	SPNU2720437	RECEIVING	PAHALA	2424	5	0	1	699.11	1	18	2
4	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	1	18	2	700.38	5	0	1
5	SPNU2680490	RECEIVING	PAHALA	2424	5	0	1	850.00	1	18	3
6	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	1	18	3	851.13	5	0	1
7	SPNU2731730	RECEIVING	PAHALA	2424	5	0	1	879.00	1	18	4
8	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	Unnecessary Movement	1	18	4	879.98	5	0	1
…	…	…	…	…	…	…	…	…	…	…	…

Table 7. What if simulation process (continued)

Event No	Travel Distance (meter)	Travel Time (minute)	Sequence	Waiting Time (minute)	Arrival Time in j (minute)	Truck Arrival Time (minute)	Total Travel Time (minute)
1	135.636	0.98	659	0.43	698.41	697.00	1.41
2	135.636	0.69	Unnecessary Movement	0.00	699.11	697.00	0.69
3	133.0452	0.92	660	0.35	700.38	698.00	1.27
4	133.0452	0.67	Unnecessary Movement	0.00	701.04	698.00	0.67
5	130.4544	0.87	661	0.26	851.13	850.00	1.13
6	130.4544	0.64	Unnecessary Movement	0.00	851.76	850.00	0.64
7	127.8636	0.81	662	0.17	879.98	879.00	0.98
8	127.8636	0.61	Unnecessary Movement	0.00	880.59	879.00	0.61
…	…	…	…	…	…	…	…

Table 8. What if simulation process (continued)

Event No	Activity		Empty space available	Empty space available (%)	Total				
	Necessary movement	Unnecessary movement			Necessary movement (meter)	Necessary movement (minute)	Average empty slot availability space	Unnecessary movement (meter)	Unnecessary movement (minute)
1	1.00	0.00	359.00	99.72%	135.64	1.41	1.00	0.00	0.00
2	0.00	1.00	359.00	99.72%	135.64	1.41	1.00	135.64	0.69
3	1.00	0.00	358.00	99.44%	268.68	2.68	1.00	135.64	0.69
4	0.00	1.00	358.00	99.44%	268.68	2.68	1.00	268.68	1.36
5	1.00	0.00	357.00	99.17%	399.14	3.81	1.00	268.68	1.36
6	0.00	1.00	357.00	99.17%	399.14	3.81	0.99	399.14	2.00
7	1.00	0.00	356.00	98.89%	527.00	4.79	0.99	399.14	2.00
8	0.00	1.00	356.00	98.89%	527.00	4.79	0.99	527.00	2.60
…	…	…	…	…	…	…	…	…	…

Table 9. Vessel data

No.	Vessel name	Arrival time (Minute)
1	LUZON	1035
2	PAHALA	2424
3	MARINA STAR 1	3636
4	ALFA TRANS SATU	4818
5	MENTARI SUCCESS	5650
6	ELEGANCE	7971

Table 10. Number of receiving and delivery container for each experiment

Experiment		1	2	3
Luzon	Delivery	64	31	31
	Receiving	48	81	81
Pahala	Delivery	11	11	11
	Receiving	21	21	21
Marina Star 1	Delivery	130	129	79
	Receiving	51	52	102
Alfa Trans Satu	Delivery	45	29	29
	Receiving	12	28	28
Mentari Success	Delivery	0	0	0
	Receiving	85	85	85
Elegance	Delivery	0	0	0
	Receiving	33	33	33
Number of the delivered containers		250	200	150
Number of the received containers		250	300	350
Number of containers		500	500	500

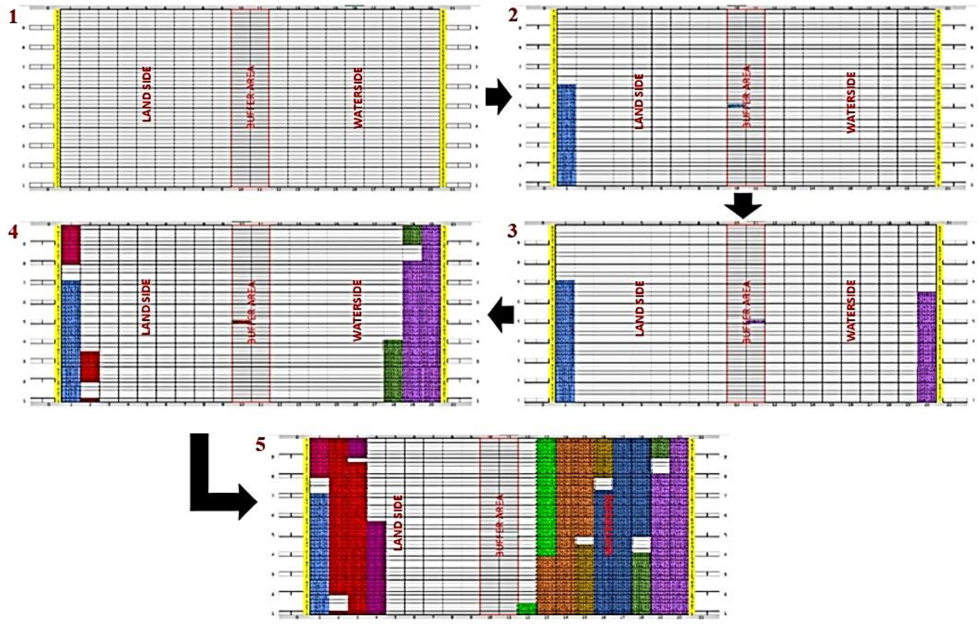

Figure 16. Simulation process

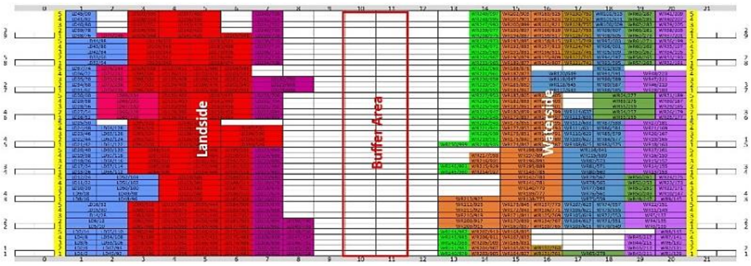

Figure 17. Slot location from experiments 1 (50% receiving: 50% delivery – center handshake area)

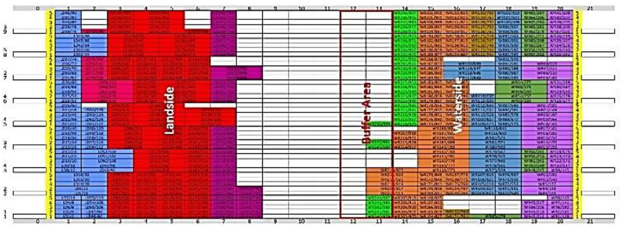

Figure 18. Slot location from experiments 1 (50% receiving: 50% delivery - right handshake area)

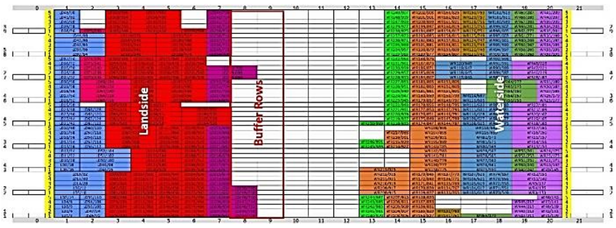

Figure 19. Slot location from experiments 1 (50% receiving: 50% delivery – left handshake area)

The simulation result shows the position of the container placement in CY before being sent to the vessel or taken by the container truck. Based on this result, the movement path from L-ASC and W-ASC was obtained. Table 11 shows the position of container placement from the simulation. Containers are placed based on the departure or arrival schedule of the vessel. Delivery containers with the earliest vessel arrival schedule will be placed in a position approaching the CY exit gate on the land side. While waiting to receive containers with the earliest vessel, departure schedules will be placed in a position closing the CY exit on the waterside. Table 6 portrays LUZON vessel will arrive and depart first before PAHALA the vessel. Thus, the delivery cargo from the LUZON vessel will be placed closer to the CY exit on the landside than the PAHALA vessel. The same can be inferred when receiving the container, where the receiving LUZON container will be placed closer to the CY exit on the waterside than PAHALA.

Figures 17-19 shows that the LUZON delivery containers are located from bay 1, row 1, stack one until bay 2, row 5, stack 4. At the same time, the PAHALA delivery containers are placed from bay 2, row 6, and stack 1. Due to the different vessels (different destinations), the stacks of delivery containers for the LUZON and PAHALA vessels are separated. The Luzon receiving containers are located from bay 20, row 1, and stack one until bay 19, row 5, stack 5, whereas the receiving containers from the PAHALA vessel are placed in bay 19, row 6, stack 1. Due to different vessels (different destinations), the pile between LUZON and PAHALA delivery containers is separated.

Table 11. The result of algorithm for determining the containers slot location

Container number	Job type	Vessel	Coordinate *k*		
			X	Y	Z
SPNU2848726	DELIVERY	LUZON	1	1	1
SPNU2802474	DELIVERY	LUZON	1	1	2
SPNU2604139	DELIVERY	LUZON	1	1	3
SPNU2993160	DELIVERY	LUZON	1	1	4
SPNU2779517	DELIVERY	LUZON	2	1	1
SPNU2923183	RECEIVING	LUZON	1	20	1
SPNU2813036	RECEIVING	LUZON	1	20	2
SPNU2853379	RECEIVING	LUZON	2	20	1
SPNU2887070	RECEIVING	LUZON	2	20	2
SPNU2884678	RECEIVING	LUZON	2	20	3
…………………	………………	………...	…	…	…

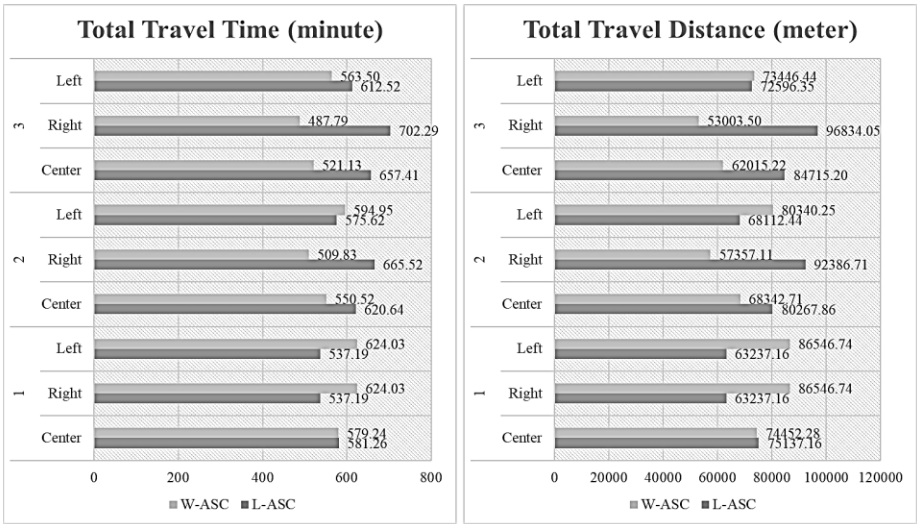

Figure 20. Total travel distance and total travel time for experiment 1,2, and 3

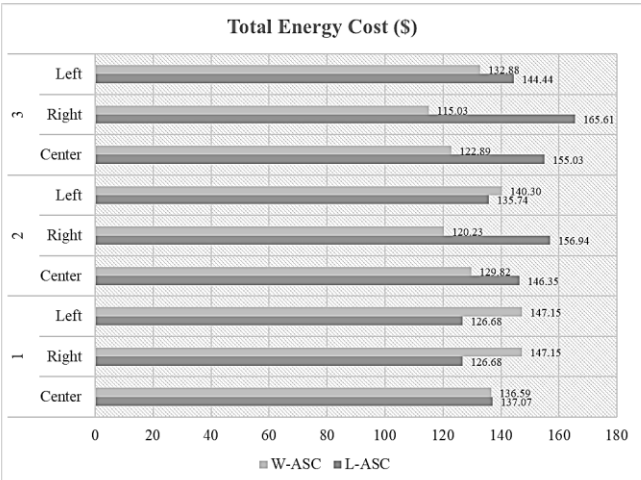

Figure 21. Total energy cost

Figure 20 depicts that the total travel distance covered by L-ASC in Experiment 1-center is 75,137.16 meters, Experiment 2-center is 80,267.86 meters, and Experiment 3-center is 84,715.20 meters. While the total travel distance covered by W-ASC in Experiment 1-center is 74,452.28 meters, Experiment 2-center is 68,342.71 meters, and Experiment 3-center is 62,015.22 meters. The more significant number of containers causes the total travel distance covered by W-ASC shorter than L-ASC. This condition also occurs during the whole travel time. This result shows that the proportion of received and delivered container demand can affect travel distance and time.

In addition to the demand proportion, the handshake area location also affects each ASC's total distance travelled and the whole time travelled. It can be seen from Figure 21 that the total distance travelled covered by W-ASC in Experiments 1-right is 86,546.74 meters, 2-right is 57,357.11 meters, and 3-right is 53,003.50 meters. On the other hand, the total distance travelled covered by L-ASC in Experiments 1-right is 63,237.16 meters, 2-right is 92,386.71 meters, and 3-right is 96,834.05 meters. The more significant number of receiving containers and the nearer the handshake area with the waterside caused the total travel distance covered by W-ASC to be shorter and vice versa, the total travel distance of L-ASC to increase. The longer the total travel distance and the type of activity will require tremendous energy, making the power costs more expensive simultaneously, as described in Figure 21.

From all the tests conducted, it can be concluded that there is a reduction in the total travel time, the total travel distance, and the total energy cost in scenarios of the right and left handshake area since the handshake area tends to be closer to the areas with the most significant demand. Accordingly, the total travel distance, travel time, and energy cost with the right and left handshake area has improved compared to the existing condition (Table 12).

Although the reduction is insignificant since it is in the initial phase of the port operations, it also means the port still needs to operate at its maximum capacity. Therefore, the policy to apply right or left handshake areas would benefit the port in the future, particularly when it begins operating at its total capacity.

Experiment 4

Three experiments have been described in the previous sections to consider only the demand proportion every six days and use a fixed handshake area. Next, it was attempted to undergo the experiment regarding the demand proportion on each day. Experiment 4 is described in Table 13.

These data in Table 13 were used to conduct the experiments with different operating systems, including center handshake areas (rows 10 and 11), right handshake areas (rows 12 and 13), left handshake areas (rows 8 and 9), and dynamic handshake areas. Dynamic handshake areas are handshake areas that are dynamic each day. Handshake areas are moved by considering the number of delivery and receiving requests. Experimental results 1, 2, and 3 show that the handshake areas are approaching demand and have more significant number will result in reducing the total distance travelled. Thus, handshake areas will move towards the side with more order in the dynamic areas. Figures 23 and 24 illustrate the result from Experiment 4.

Table 12. Experiment Result

Scenario		1			2			3		
Demand		50% (receiving): 50%(delivery)			60% (receiving): 40%(delivery)			70% (receiving): 30%(delivery)		
Handshake Area		Center	Right	Left	Center	Right	Left	Center	Right	Left
Total travel time (minute)	L-ASC	0.0%	-7.58%	-7.58%	0.0%	7.23%	-7.25%	0.00%	6.83%	-6.83%
	W-ASC	0.0%	7.73%	7.73%	0.0%	-7.39%	8.07%	0.00%	-6.40%	8.13%
	Twin ASC	0.0%	0.06%	0.06%	0.0%	0.36%	-0.05%	0.00%	0.98%	-0.21%
Total travel distance (meter)	L-ASC	0.0%	-15.84%	-15.84%	0.0%	15.10%	-15.14%	0.00%	14.31%	-14.31%
	W-ASC	0.0%	16.24%	16.24%	0.0%	-16.07%	17.55%	0.00%	-14.53%	18.43%
	Twin ASC	0.0%	0.13%	0.13%	0.0%	0.76%	-0.11%	0.00%	2.12%	-0.47%
Total energy cost	L-ASC	0.0%	-7.58%	-7.58%	0.0%	7.23%	-7.25%	0.00%	6.83%	-6.83%
	W-ASC	0.0%	7.73%	7.73%	0.0%	-7.39%	8.07%	0.00%	-6.40%	8.13%
	Twin ASC	0.0%	0.06%	0.06%	0.0%	0.36%	-0.05%	0.00%	0.98%	-0.21%

Table 13. Data of Experiment 4

	Day 1		Day 2		Day 3	
	Del*	Rec*	Del*	Rec*	Del*	Rec*
Demand	31	31	18	26	100	43
Proportion	50%	50%	41%	59%	70%	30%
	Day 4		Day 5		Day 6	
	Del*	Rec*	Del*	Rec*	Del*	Rec*
Demand	42	28	35	42	28	35
Proportion	60%	40%	30%	70%	50%	50%
	Delivery Demand				259	
	Receiving Demand				241	
	Total Demand				500	

*) Del = Delivery; Rec=Receiving

Figure 22 shows the total travel distance covered by the Twin ASC with the existing operational strategy (center handshake areas), which shows that it is longer than the other operating strategies (right, left, and dynamic handshake areas). On the contrary, using the dynamic operational strategy resulted in much shorter operating strategies than the other due to the regions for the dynamic handshake approaching the side, which has more demand using a dynamic handshake. This result minimizes the idle ASC as it waits for the other ASC to move and is proportional to the total time travelled by the twin ASC covers, as shown in Figure 23.

The energy costs used when using a dynamic handshake area are much smaller than the other operating strategies, with the total travel distance and travel time being much lower. Figure 25 shows that to run one block of CY for six days with a dynamic handshake area, up to 24.89% can be saved from existing conditions or equivalent to \$ 68.13. If the experiment is conducted for one month, the savings obtained reach \$ 272.52.

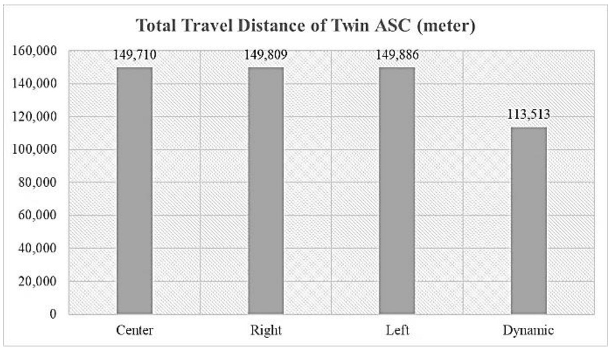

Figure 22. Total travel distance of Twin ASC (Meter)

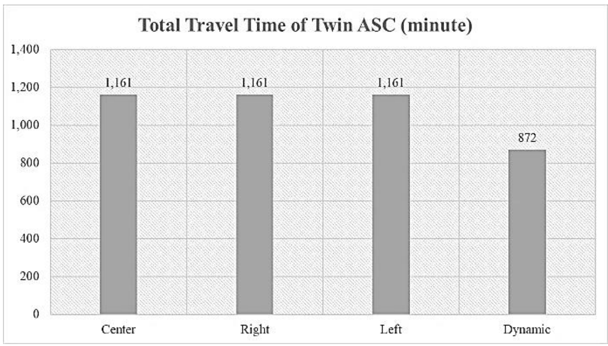

Figure 23. Total travel time of Twin ASC (Minute)

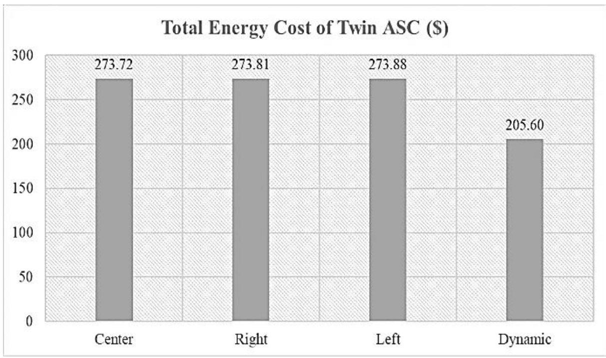

Figure 24. Total energy cost of Twin ASC (\$)

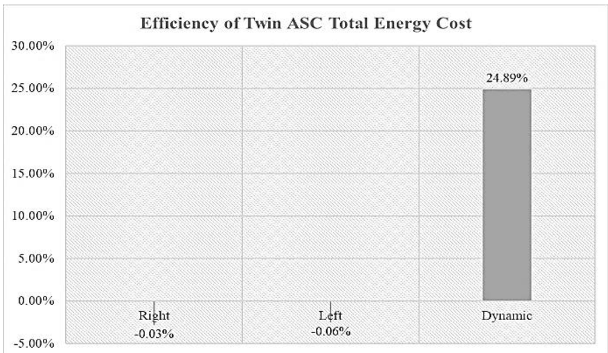

Figure 25. Efficiency of Twin ASC total energy cost

Conclusion

This study is the leading example of container yard operation for a green container yard (Port of Terminal Teluk Lamong). We developed a heuristics model and algorithms for ASC's operations to compare the efficiency of the ASC operations between the fixed and the dynamic location. Based on our model and algorithm, we developed simulation software. We explored some numerical experiments to compare the performance of both policies in dealing with different export and import demand scenarios. For efficient energy, the Port of Terminal Teluk Lamong used Twin ASC with a combination of export and import block in a block. This research is preliminary in evaluating the possibility of a dynamic handshake area location instead of a fixed one. A small sample of the experimental results shows that the handshake area location should be moved closer to the area with a more significant demand proportion. This proposed strategy results in a more efficient CY than the previous one, measured in movement and electricity. Shortening the distance between the buffer area and with IO point will also make small necessary and unnecessary activities of ASC within the buffer area. It was caused by the shortening of ASC movement to buffer the area and increase the activity of other ASC. When the movement distance of ASC with buffer area is decreased, it will lower the travel time of ASC where buffers are and twin ASC (total). The dynamic handshake area can reduce 24.2% of the total travel distance by 24.9% full travel time than the previous strategy (center handshake area). The dynamic handshake areas can save up to 24.89% of total energy costs compared to the center, right, and left places. The containers' movement is more efficient, so the energy cost can also be reduced by using a dynamic buffer strategy. In this research, we use the algorithm only in homogenized containers. For future work, the level of the dynamic location should be analyzed in the full capacity of the port) in terms of actual operations, energy, and time costs, a more accurate model is needed.

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References

[1] A. H. Gharehgozli, F. G. Vernooij, and N. Zaerpour, “A simulation study of the performance of twin automated stacking cranes at a seaport container terminal,” *European Journal of Operational Research*, vol. 261, no. 1, 2017, doi: 10.1016/j.ejor.2017.01.037.

[2] H. J. Carlo, I. F. A. Vis, and K. J. Roodbergen, “Storage yard operations in container terminals: Literature overview, trends, and research directions,” *European Journal of Operational Research* vol. 235, no. 2, 2014, doi: 10.1016/j.ejor.2013.10.054.

[3] J. He, X. Xiao, H. Yu, and Z. Zhang, “Dynamic yard allocation for automated container terminal,” *Annals of Operations Research*, 2022, doi: 10.1007/s10479-021-04458-6.

[4] U. Speer and K. Fischer, “Scheduling of different automated yard crane systems at container terminals,” *Transportation Science*, vol. 51, no. 1, 2017, doi: 10.1287/trsc.2016.0687.

[5] H. Yu, Y. Deng, L. Zhang, X. Xiao, and C. Tan, “Yard operations and management in automated container terminals: A review,” *Sustainability (Switzerland)*, vol. 14, no. 6. 2022. doi: 10.3390/su14063419.

[6] J. Nossack, D. Briskorn, and E. Pesch, “Container dispatching and conflict-free yard crane routing in an automated container terminal,” *Transportation Science*, vol. 52, no. 5, 2018, doi: 10.1287/trsc.2017.0811.

[7] H. Yu, M. Huang, L. Zhang, and C. Tan, “Yard template generation for automated container terminal based on bay sharing strategy,” *Annals of Operations Research*, 2022, doi: 10.1007/s10479-022-04657-9.

[8] T. Park, R. Choe, S. M. Ok, and K. R. Ryu, “Real-time scheduling for twin RMGs in an automated container yard,” *OR Spectrum*, vol. 32, no. 3, 2010, doi: 10.1007/s00291-010-0209-0.

[9] Z. H. Hu, X. D. Tian, Y. Q. Yin, and C. Wei, “Positioning a handshake bay for twin stacking cranes in an automated container terminal yard block,” *Journal of Advanced Transportation*, vol. 2022, 2022, doi: 10.1155/2022/5738254.

[10] J. Kim, E. J. Hong, Y. Yang, and K. R. Ryu, “Noisy optimization of dispatching policy for the cranes at the storage yard in an automated container terminal,” *Applied Sciences (Switzerland)*, vol. 11, no. 15, 2021, doi: 10.3390/app11156922.

[11] H. Yu, M. Huang, J. He, and C. Tan, “The clustering strategy for stacks allocation in automated container terminals,” *Maritime Policy and Management*, 2022, doi: 10.1080/03088839.2022.2119616.

[12] W. K. Kon, N. S. F. Abdul Rahman, R. Md Hanafiah, and S. Abdul Hamid, “The global trends of automated container terminal: A systematic literature review,” *Maritime Business Review*, vol. 6, no. 3, 2020, doi: 10.1108/MABR-03-2020-0016.

[13] X. Zhang, H. Li, and M. Wu, “Optimization of resource allocation in automated container terminals,” *Sustainability (Switzerland)*, vol. 14, no. 24, 2022, doi: 10.3390/su142416869.

[14] M. Yu, Z. Liang, Y. Teng, Z. Zhang, and X. Cong, “The inbound container space allocation in the automated container terminals,” *Expert Systems with Applications*, vol. 179, 2021, doi: 10.1016/j.eswa.2021.115014.

[15] Y. Yang, M. Zhong, Y. Dessouky, and O. Postolache, “An integrated scheduling method for AGV routing in automated container terminals,” *Computers and Industrial Engineering*, vol. 126, 2018, doi: 10.1016/j.cie.2018.10.007.

[16] N. Wang, D. Chang, X. Shi, J. Yuan, and Y. Gao, “Analysis and design of typical automated container terminals layout considering carbon emissions,” *Sustainability (Switzerland)*, vol. 11, no. 10, 2019, doi: 10.3390/su11102957.

[17] M. Zhong, Y. Yang, Y. Dessouky, and O. Postolache, “Multi-AGV scheduling for conflict-free path planning in automated container terminals,” *Computers and Industrial Engineering*, vol. 142, 2020, doi: 10.1016/j.cie.2020.106371.

[18] F. Covic, “Re-marshalling in automated container yards with terminal appointment systems,” *Flexible Services and Manufacturing Journal*, vol. 29, no. 3–4, 2017, doi: 10.1007/s10696-017-9278-6.

[19] R. J. Rei and J. P. Pedroso, “Heuristic search for the stacking problem,” *International Transactions in Operational Research*, vol. 19, no. 3, 2012, doi: 10.1111/j.1475-3995.2011.00831.x.

[20] C. Expósito-Izquierdo, B. Melián-Batista, and M. Moreno-Vega, “Pre-Marshalling problem: Heuristic solution method and instances generator,” *Expert Systems with Applications*, vol. 39, no. 9, 2012, doi: 10.1016/j.eswa.2012.01.187.

[21] S. Nurminarsih, A. Rusdiansyah, and M. M. Putri, "Space-sharing strategy for building dynamic container yard storage considering uncertainty on number of incoming containers," *Jurnal Teknik Industri*: *Jurnal Keilmuan dan Aplikasi Teknik Industri*, vol. 19, no. 2, 2018, doi: 10.9744/jti.19.2.67-74.
[22] T. Park, R. Choe, Y. Hun Kim, and K. Ryel Ryu, "Dynamic adjustment of container stacking policy in an automated container terminal," in *International Journal of Production Economics*, 2011. doi: 10.1016/j.ijpe.2010.03.024.
[23] R. Choe, T. Park, M. S. Oh, J. Kang, and K. R. Ryu, "Generating a rehandling-free intra-block remarshaling plan for an automated container yard," *Journal of Intelligent Manufacturing*, vol. 22, no. 2, 2011, doi: 10.1007/s10845-009-0273-y.
[24] A. H. Gharehgozli, G. Laporte, Y. Yu, and R. De Koster, "Scheduling twin yard cranes in a container block," *Transportation Science*, vol. 49, no. 3, 2015, doi: 10.1287/trsc.2014.0533.
[25] J. Wiese, L. Suhl, and N. Kliewer, "Planning container terminal layouts considering equipment types and storage block design," *Operations Research/ Computer Science Interfaces Series*, vol. 49, no. 1, 2011, doi: 10.1007/978-1-4419-8408-1_12.
[26] D. Steenken, S. Voß, and R. Stahlbock, "Container terminal operation and operations research - A classification and literature review," in *Container Terminals and Automated Transport Systems: Logistics Control Issues and Quantitative Decision Support*, 2005. doi: 10.1007/3-540-26686-0_1.
[27] R. Dekker, P. Voogd, and E. Van Asperen, "Advanced methods for container stacking," *OR Spectrum*, vol. 28, no. 4, 2006, doi: 10.1007/s00291-006-0038-3.
[28] R. Choe, T. S. Kim, T. Kim, and K. R. Ryu, "Crane scheduling for opportunistic remarshaling of containers in an automated stacking yard," *Flexible Services and Manufacturing Journal*, vol. 27, no. 2–3, 2015, doi: 10.1007/s10696-013-9186-3.