SIMULATION STUDY OF TWIN AUTOMATED STACKING CRANES OPERATION STRATEGY WITH DYNAMIC BUFFER AREA IN SEAPORT AUTOMATED CONTAINER TERMINAL

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ABSTRACT

Purpose:
The purpose of this research is to study the impact of dynamic buffer area operation strategy on the performance of Twin Automated stacking Cranes (ASC's) one of which operate inside landside and seaside zones. Buffer area is a container temporary storage in the middle of container yard (Gharehgozli A. H., 2017). One of ASC's will put container that it carries in buffer area. Then, it will be taken by another ASC's to be placed in the slot location. Today, buffer area which applied in automated container seaport terminal is fixed buffer.

Design/methodology/approach:
Three settings of simulation model are used to test ASC's performance. Those settings are without buffer area, with fixed buffer area, and with dynamic buffer area.

Findings:
Measured performance:
- total travel distance and total travel time of ASC's when fulfilling all requests
- total distance of unnecessary movements (not carrying a container)
- total waiting time of ASC's when there are other ASC's inside buffer area
- total energy cost produced by ASC operation.

Decision variables:
- container slot allocation
- ASC's scheduling
- buffer area location
- buffer area size
- buffer area shape

Research limitations/implications (if applicable): We assume that there is no reshuffling inside container yard and buffer area.

Practical implications (if applicable): A new seaport automated container terminal that use ASC's without significantly applied buffer area just opened in Indonesia. The planning and operation manager of that terminal can use this research to operate ASC's more efficiently.

Originality/value: Some parameters are being considered. Those parameters are:
- the arrival time of vessel and truck to deliver and receive the container.
- 20-ft and 40-ft containers
- the weight of the container
- dynamic buffer area that can be changed based on demand
- the shape of buffer area that can be changed

Keywords: Dynamic handske area, Simulation Model, Twin Automated Stacking Crane

INTRODUCTION

Indonesia Container Port Traffic

In the year of 2014, a new port named Terminal Teluk Lamong (TTL) port has been established in Surabaya city, the second largest city in Indonesia. The TTL port is a multipurpose semi-automatic terminal where all activities in the TTL port like trucking, handling, and others are conducted automatically. The port also claims as the first eco green port in Indonesia.

The Port has implemented advanced technology in eco-initiative efforts such as (i) The trucks which operate within the port area must use fuel Compressed Natural Gas (CNG); (ii) The Combined Tractor Terminal (CTT), which is such automated guided vehicles, run on electric energy and operates automatically in moving containers from the container yard (CY) to the dock and vice versa; and (iii) The usage of Automatic Stacking Cranes (ASCs) which can be operated for 24 hours a day without operator using minimum electric energy. This paper develops a model of operational strategies of ASCs in the container yard.

We focus on the discussion of the role of a buffer area, consist of two rows, which is required to serve as a temporary slot for both ASCs.

Container Yard

Container Terminal using twin automated staking cranes (ASCs) have different configurations compared to container terminals with single crane. Container terminal with single crane serving container from landside (gate area) and seaside (berth area) as pick-up and drop-off point or also called transfer point or input/output (I/O) point (Gharehgozli A. H., 2017). But at container terminals with ASCs have (I/O) points on the seaside and landside. We called container yard area serving container from landside with landside, but container yard area serving container from seaside with waterside. At I/O point of landside, pickup and delivery truck of containers. While at I / O point seaside, automated guided vehicle pick-up and delivery container. Since both ASCs have the same size then there is a possibility pass each other. When the landside ASC has a request close to the seaside, the seaside ASC must provide a space for the landside ASC to complete the request. This potentially increases the ASC travel time. To solve these problems, the ASCs can work together with a transfer zone in container stacking (one block of container yard). The transfer zone is called buffer area. The buffer area is a temporary container storage in 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 (Gharehgozli A. H., 2017). In our research, the buffer area we called buffer area. The L-ASC handles retrieval and storage container from and to landside and the S-ASC handles retrieval and storage container from and to seaside (Gharehgozli A. H., 2017). In our research each block equipped by two ASC to move containers in automated CY. The block side which is closer to the gate (entrance port) called as the landside area, while the other block closer to the berth called as the waterside area. Both ASC will move containers from landside to waterside (delivery container) and the other hand containers from waterside move to landside (receiving container). ASC closer to landside area called Landside ASC (LASC), while ASC closer to waterside area called Waterside ASC (WASC). The minimum safety distance between ASC at least 1 bay. The buffer area only 1 bay. The inter-row movements and reshufflings in this research are not considered. The size of container only 20-ft. The proposed strategies are scheduling of containers for each crane, prioritizing of cranes, selecting the size of the buffer area and selecting the number of buffer areas (Gharehgozli A. H., 2017).

Both ASC's size, function, and operating locating are nearly the same. Thus, they are called Twin Automatic Stacking Crane (Twin-ASCs). In order to operate, they need a buffer area within the block. The buffer area served as a transition area for the Twin-ASCs to pass container from the waterside area to landside area, and vice versa.In this case, the buffer area is two-row width and located in the middle of blocks (Figure 1). This buffer restricts the movement of ASC. For example, when a customer ordered to move a container from a waterside area to landside area,the waterside ASC picks a container from the waterside and drops it to the buffer area. Then, the waterside ASC moves back to the waterside area so that the landside ASC can enter the buffer area, picks the chosen container, and moves back to the landside ASC. Another operational restriction which limit the movement of the ASC is the minimum safety distance. The minimum safety distance is the distance between the locations of the twin-ASCs.

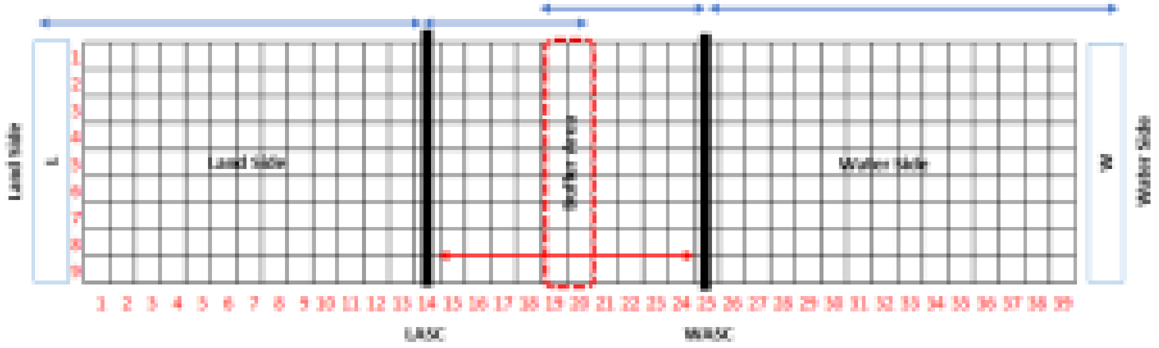

Figure 1 Container Yard Layout in Terminal Teluk Lamong

Both ASCs are used to arrange the containers while waiting for departure time. The arrangement of containers require some criteria to consider. The most widely used criteria are weight of containers, size of containers, type of containers, and container destination (vessel). Vessel and truck arrival time can be a key criterion in making the container arrangement.Container with the smallest departure time will be placed at the forefront in the waterside (vessel) or the landside area (truck). Containers arrangement affectsthe efficiencies of both automated CY and port service level. The efficiency of the automated CY is measured by the total movement distance of Twin-ASCs (total travel distance). In this case, the minimization of the total movement distance of the Twin-ASC will also reduce the electricity usage which results in a greener port.

This paper evaluates the Twin-ASCs operations in arranging containers in an automated CY with some modifications on the position of the buffer area. The paper is structured as follows: in Section 2, this paper describes the port Twin-ASCs problem, the issues to be resolved, and the conceptual models proposed; in Section 3, this paper explained the models and algorithms developed in this study. We also did numerical experiments and analysis about the proposed model and algorithm in Section 4, followed by the discussion of research findings and conclusion in the last sections.

PROBLEM DESCRIPTION

There exists several literature in container port operations especially in discussing container yard operations. Rei and Pedroso (2012) developed a mathematical model of the stacking problem in order to minimize the displacement of containers with regards to arrivals and retrieval of containers. In this system, the displacement was limited to one bay only. Rei and Pedroso (2012) developed a heuristic method with compare Conflict Minimization (CM), Flexibility Optimization (FO), and Flexibility Parameterized Optimization (PFO). In the same year, Izquierdo, Batista, and Vega (2012) developed the Lowest Priority First heuristic method to determine the location of containers in CY based on the priorities assigned by RMGC handling tool.

Twin-ASC-related scheduling research has been done by the Park, Choe, and Ok (2010), Choe (2011), and Gharehgozli et al. (2014). Park, Choe, and Ok (2010) developed a mathematical model of scheduling two RMGC with two objective: minimize the weighted delay time of Automated Guided Vehicle (AGV) and the weighted truck waiting time. Meanwhile, Choe (2011) developed a container movement scheduling algorithm within Twin-ASCsblock to minimize unnecessary movement of loading or unloading container. Hereafter, Gharehgozli et al. (2014) developed a mathematical model of scheduling Twin-ASC in a block to minimize the make spanof both ASC. The researcher conducted a pairwise calculation of travel time for each ASC. Furthermore, Putri et al. (2016) developed a simple mathematical model and heuristic algorithm to optimize the operation of Twin-ASCs by synchronizing the arrival time planning of vessel and truck.

This research developeda heuristic algorithm to optimize the operations of the Twin-ASCs in arranging containers in automated CY by utilizing a dynamic buffer area instead of a fixed buffer area. Currently, the position of the buffer area is located in the middle of automated CY, while the what if conditions used are modifications of the container amount coming from the waterside and the landside. The conceptual model, automated CY dimension, and slot size for this research can be seen in Figure 2, Table 1, and Table 2.

For this experiment, we use smaller number of bay than the real number of bay in Teluk Lamong Port. There are two types of ASC movement, the movement of ASCwhile carrying a container is called Necessary movement, but the movement of ASC without carrying a container is called unnecessary movement. The movement speed of the Twin-ASCs is a constant 270 m/min either carrying a load or not. The ASC lift speed without container is 90 m/min (45 m/min with container).

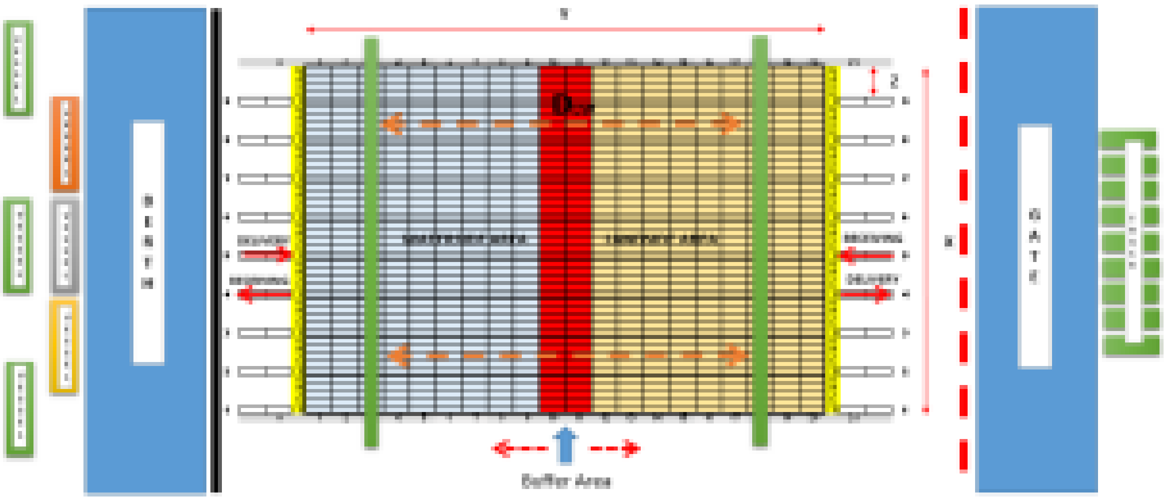

Figure 2 Automated Container Yard with Buffer Area and Twin-ASC Conceptual Model

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

Table 7. Block Dimensions

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

Table 8. Slot Size

MODEL & ALGORITHM DEVELOPMENT

Determining the Buffer Area and Slot Location for Container

Fixed buffer area has weakness in achieving efficiency when there is a tendency towards one of arrival or retrieval container. In the fixed system, usually the buffer areas are located in the middle of each block.

The travel distance of landside ASC will be farther than waterside ASC if the is tendency towards the arrival container, and vice versa. These conditions can make the total travel distance to be less efficient. Unlike the fixed one, dynamic buffer area will determine the location of the buffer area dynamically based on the container arrival pattern. The buffer area will be placed as close as possible to the side that has high container movement demand. Weekly container arrival planning data (both from vessels and trucks) will be checked daily at the last shift of each day. These data are used to determine buffer area location for tomorrow. In dynamic buffer area, the location of buffer area can be different each day. Let's see the illustration below.

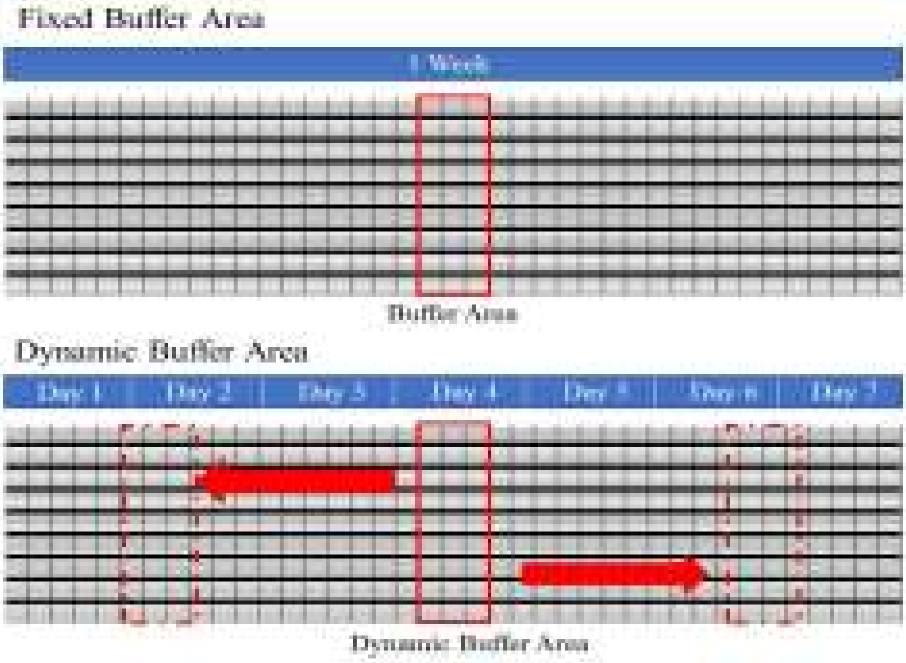

Figure 3 Fixed Buffer Area and Dynamic Buffer Area

Let's say in day 1 and day 2 the demand of landside jobs are higher than waterside, the buffer area will be moved closer to the landside. Starting in day 3 to day 5 the demand of landside jobs is equal to waterside jobs, so the buffer will be moved to the center. In day 6 and 7 the demand of waterside jobs is increase, then the buffer area will also be moved closer to waterside.

Beside the location of the buffer area, the location for temporarily storing the containers can also lead in to inefficiency. We have to decide the locations which minimize total distance between each container to I/O points. To calculate the distance, we used formula in Gharehgozli (2004) which is described below:

$$t_{ij} = max\{|x_i - x_j|, |y_i - y_j|\} + z_i + z_j \tag{1}$$

Notation
i : the location index i (i=1,2,...n);
j : the location index j (j=1,2,...m);
tij : ASC travel distance frome node i to node j (unit)
x : unit bay (x = 1,2,...9);
y : unit row (y = 0,1,2,...,21); where y=0 -landside I/O point; y=21 -waterside I/O point;
z : unit tier (y=1,2,...5);
(xi, yi, zi) : coordinate of node i
(xj, yj, zj) : coordinate of node j

There are some rules that must be met in allocating slots for containers. Those rules are:

a. Containers for different vessels should not be stacked up
b. Containers for vessel that depart later should not be placed in front of containers for vessel that depart earlier
c. Heavy container should not be stacked above the lighter one

RQ1. Scheduling ASCin Container Yard

The twin ASCs have several jobs in container yard. The first job is called seaside job, a job for moving container to be loaded or discharged from/to a vessel. The second one is landside job, which is done to move container from/to external trucks. Next is job for preparing container in container yard before loading to make seaside and landside jobs faster, this job is called remarshalling. Since each block is equipped with two equal-sized ASCs that cannot move across each other,the seaside jobs are exclusively done by the seaside ASC and the landside jobs exclusively by the landside ASC (Choe et.al, 2015).

Seaside and landside job are classified as main job that will be given priority in scheduling ASC. Remarshalling jobs are only done on ASC's idle time. A discharge container, either from a vessel or an external truck, will be placed temporally in the buffer area. Then it will be moved in the allocated slot by the other ASC.

The aim from scheduling ASC is minimize total energy cost of ASCs. Minimizing total energy cost will be gained from minimizing total travel time or distance. The formulation to calculate travel time and travel distance also following the formula from Gharehgozli (2004) as described in Table 3 and 4. The constraints of scheduling ASC are jobs priority and the distance that must be keep between ASCs. The ASCs cannot move across each other. A job of an ASC consists of four steps of crane movement: empty travel to the target container, picking up of the container, loaded travel to the destination, anddropping off of the container(Choe et.al, 2015).

ASC Activity	**t_{ij} (meter)**
ASC displacement to carry containers (necessary movement)	$max\{\lvert x_i - x_j\rvert L_s, \lvert y_i - y_j\rvert P_s\} + z_i H_s + z_j H_s$
ASC displacement without carrying containers (unnecessary movement)	$max\{\lvert x_i - x_j\rvert L_s, \lvert y_i - y_j\rvert P_s\} + z_i H_s + z_j H_s$

Table 9 Travel Distance (Meters)

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

Table 10 Travel Time (Minutes)

Notation
Ls : width of slot (meter)
Ps : length of slot (meter)
Hs : height of slot (meter)
Vmove : ASC speed (meter/minute)
Vfull : ASC full lift rate (meter/ minute)
Vempty : ASC empty lift rate (meter/ minute)

So, we can find the total travel distance using this formula:

$$TD = \sum_{n=1}^{N} NMD_n + \sum_{u=1}^{U} UMD_u \tag{1}$$

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

$$TT = \sum_{n=1}^{N} NMT_n + \sum_{n=1}^{N} UMT_n \tag{2}$$

Notation:
N : number of necessary movement event
NMD_n : ASC travel distance for necessary movement n (meter)
UMD_n : ASC travel distance for unnecessary movement n (meter)
TD : total travel distance of ASC for doing all activity (meter)
U : number of unnecessary movement event
NMT_u : ASC travel time for necessary movement u (minute)
UMT_u : ASC travel time for unnecessary movement u (minute)
TT : total travel time of ASC for doing all activity (minute)

The dynamic of the buffer area locations might reduce necessary and unnecessary movements of the ASCs. The shortened movements of an ASC will cause the increasing movements of the other ASC. We need to measure the combination of travel time of necessary/unnecessary movement reduction and the energy needed of lifting the container.

$$TE = \sum_{a=1}^{2} TT_a \times EC_a \times E \tag{3}$$

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

The algorithm of determining the buffer area and slot location for container and ASC scheduling is described in Figure 4 below.

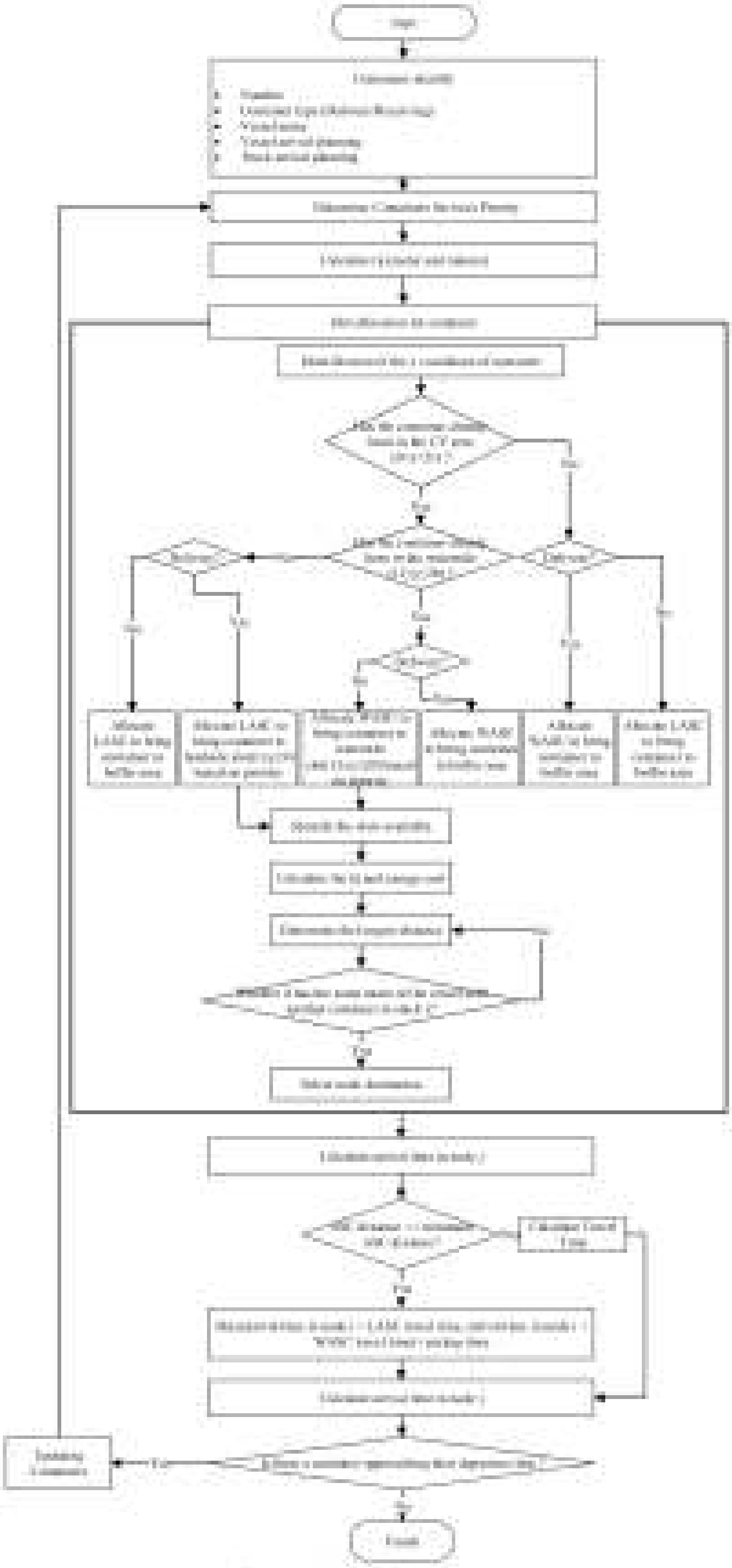

Figure 4 ASC Algorithm

NUMERICAL EXPERIMENT AND ANALYSIS

This section explains the performance analysis from the explained algorithm on Section 3. We did some experiments to find out about that. Aside for tested our algorithm, this experiment aims to evaluating the influence of operation strategic changing on our algorithm performance. Therefore, we did some experiments that are presented on Table 5.

Eksperimen	**Perbandingan Demand**	**Buffer 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 11 Experiments Detail

The three experiments we do in this chapter still usedfixed buffer area. The performances that are measured form this experiment such as:

1. Total travel distance (meter) of LASC and WASC for each experiments.
2. Total travel time (minute) of LASC and WASC for each experiments.
3. Total energy cost of LASC and WASC for each experiments.

For simplify the operation of our algorithm simulation we develop What If Simulation using VBA Excel.

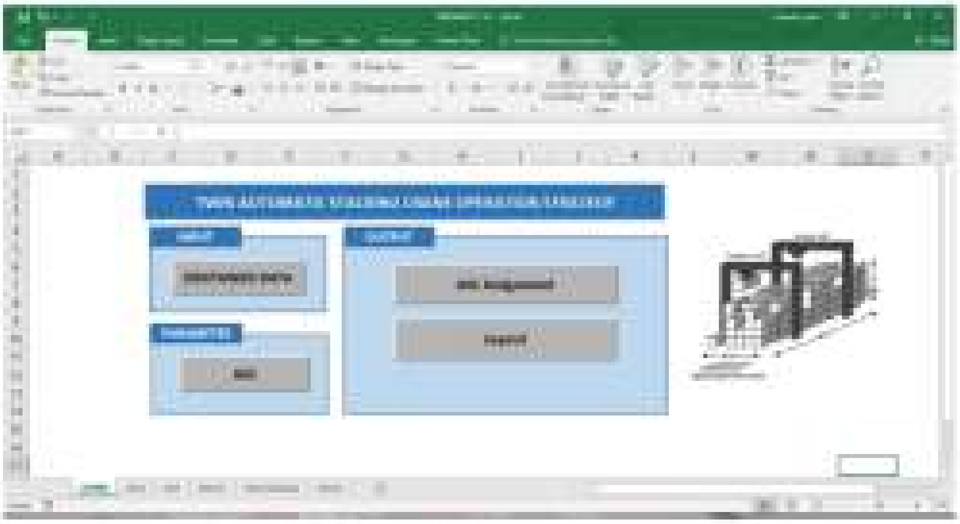

Figure 5 Interface of What If Simulation Using VBA Excel

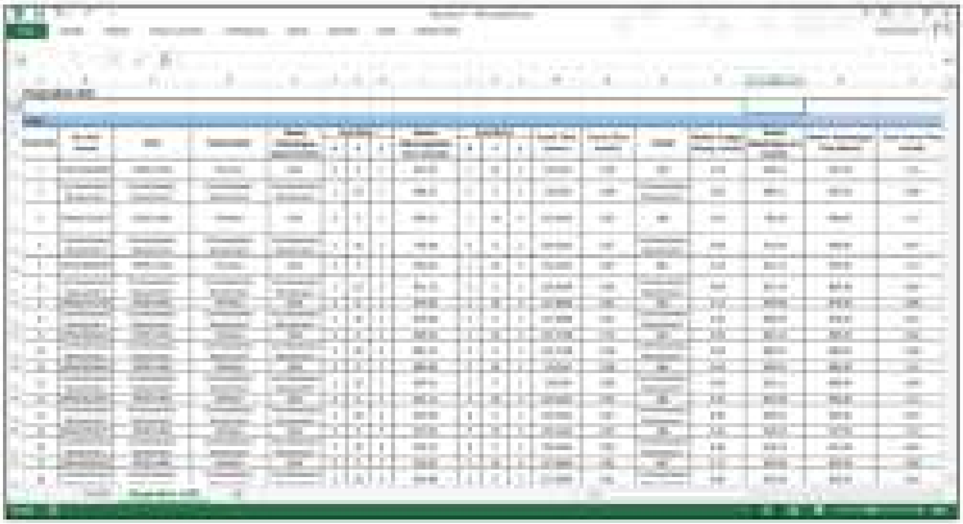

Figure 6 Simulation Process

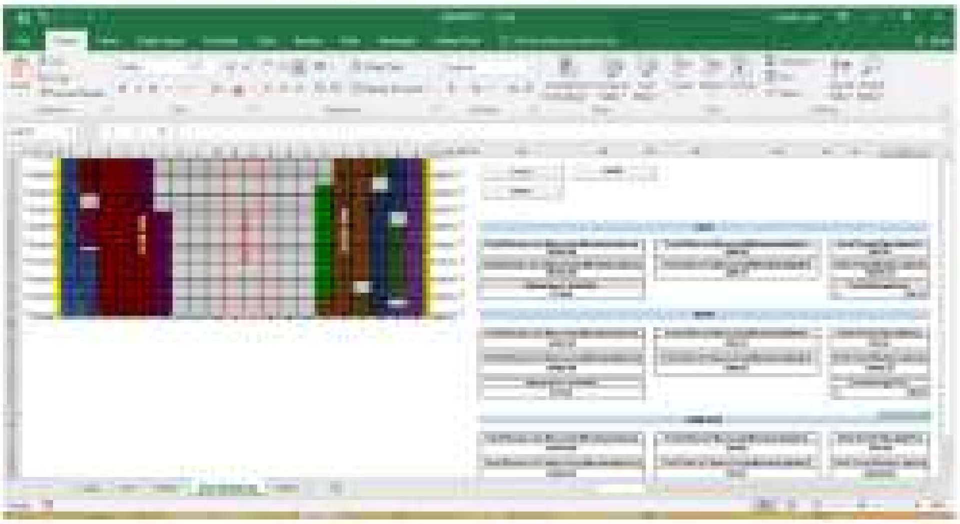

Figure 7 Simulation Result

In this experiment, we operate 1 block container yard with 9 columns, 20 rows, and 5 stacks. There are 6 vessels which coming consecutively (arrival time) in 6 work days that can be seen in Table 6. Those six vessels served by 1 block container yard. The total simulated container during simulation period is 500 containers, and limited on 20-ft dry containers. Table 7 shows the number of receiving and delivery container demand for each experiments. The vessel and container data is a real data form observational object. Observational object is a container port which using twin ASC and only operate for one year, so that, the number of demand has not been so much compared to other ports that have implemented twin ASC.

No.	Vessel Name	Arrival Time (Minute)
1	LUZON	1036
2	PAHALA	2424
3	MARINA STAR 1	3636
4	ALFA TRANS SATU	4818
5	MENTARI SUCCESS	5650

6	ELEGANCE	7971

Table 12 Vessel Data

Experiments		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
Jumlah Petikemas Delivery		250	200	150
Jumlah Petikemas Receiving		250	300	350
Jumlah Petikemas		500	500	500

Table 7 Number of Receiving and Delivery Container for Each Experiments

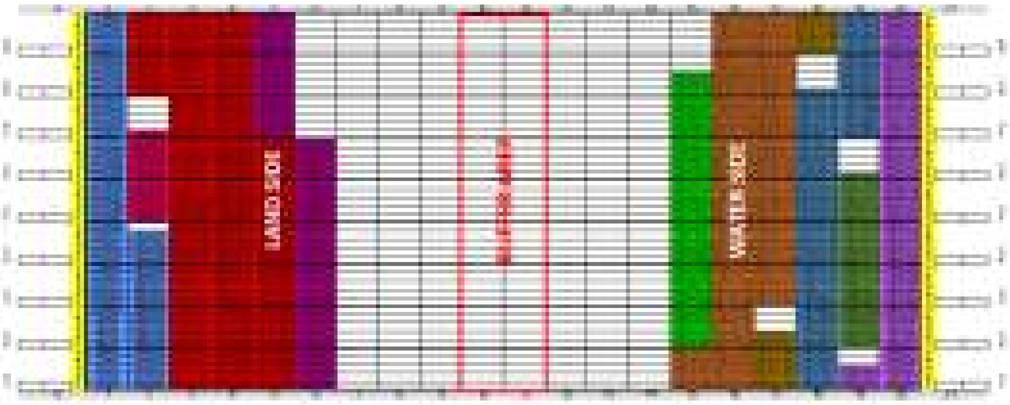

Figure 8 Slot Location from Experiments 1
(50% Receiving : 50% Delivery - Center Buffer Area)

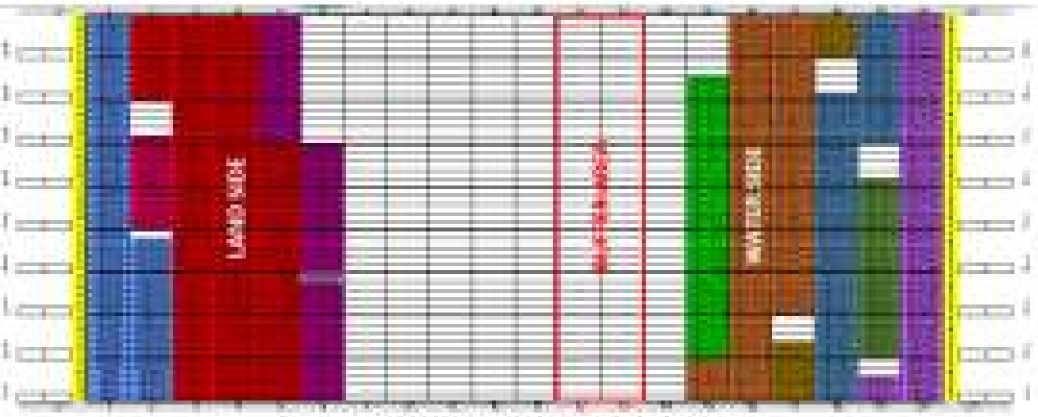

Figure 9 Slot Location from Experiments 1
(50% Receiving : 50% Delivery - Right Buffer Area)

No.	Container Number	Job Type	Vessel	Coordinate k			No.	Container Number	Job Type	Vessel	Coordinate k		
				X	Y	Z					X	Y	Z
1	SPNU2968850	DELIVERY	LUZON	4	2	1	21	SPNU2764522	DELIVERY	PAHALA	5	2	1
2	SPNU2857224	DELIVERY	LUZON	4	2	2	22	SPNU2792165	DELIVERY	PAHALA	5	2	2
3	SPNU2915721	DELIVERY	LUZON	4	2	3	23	SPNU2771440	DELIVERY	PAHALA	5	2	3
4	SPNU4616714	DELIVERY	LUZON	4	2	4	24	SPNU2791699	DELIVERY	PAHALA	5	2	4
5	SPNU2875845	RECEIVING	LUZON	7	20	1	25	SPNU2791451	DELIVERY	PAHALA	5	2	5
6	SPNU2868276	RECEIVING	LUZON	7	20	2	26	SPNU2748732	DELIVERY	PAHALA	6	2	1
7	SPNU2843318	RECEIVING	LUZON	7	20	3	27	SPNU2609963	DELIVERY	PAHALA	6	2	2
8	SPNU2871372	RECEIVING	LUZON	7	20	4	28	SPNU2797017	DELIVERY	PAHALA	6	2	3
9	SPNU2933284	RECEIVING	LUZON	7	20	5	29	SPNU2965208	DELIVERY	PAHALA	6	2	4
10	SPNU2918567	RECEIVING	LUZON	8	20	1	30	SPNU2777941	DELIVERY	PAHALA	6	2	5
11	SPNU2970523	RECEIVING	LUZON	8	20	2	31	SPNU2706531	DELIVERY	PAHALA	7	2	1
12	SPNU2839529	RECEIVING	LUZON	8	20	3	32	SPNU2684900	RECEIVING	PAHALA	2	19	1
13	SPNU2670830	RECEIVING	LUZON	8	20	4	33	SPNU2720437	RECEIVING	PAHALA	2	19	2
14	SPNU2829449	RECEIVING	LUZON	8	20	5	34	SPNU2680490	RECEIVING	PAHALA	2	19	3
15	SPNU2879521	RECEIVING	LUZON	9	20	1	35	SPNU2731730	RECEIVING	PAHALA	2	19	4
16	SPNU2905852	RECEIVING	LUZON	9	20	2	36	SPNU2683441	RECEIVING	PAHALA	2	19	5
17	SPNU2914670	RECEIVING	LUZON	9	20	3	37	SPNU2639942	RECEIVING	PAHALA	3	19	1
18	SPNU2687508	RECEIVING	LUZON	9	20	4	38	SPNU2612967	RECEIVING	PAHALA	3	19	2
19	SPNU2980481	RECEIVING	LUZON	9	20	5	39	SPNU2794677	RECEIVING	PAHALA	3	19	3
20	SPNU2891467	RECEIVING	LUZON	1	19	1	40	SPNU2650324	RECEIVING	PAHALA	3	19	4
21	SPNU2898157	RECEIVING	LUZON	1	19	2	41	SPNU2674460	RECEIVING	PAHALA	3	19	5

Table 13 Container Placement Position in CY

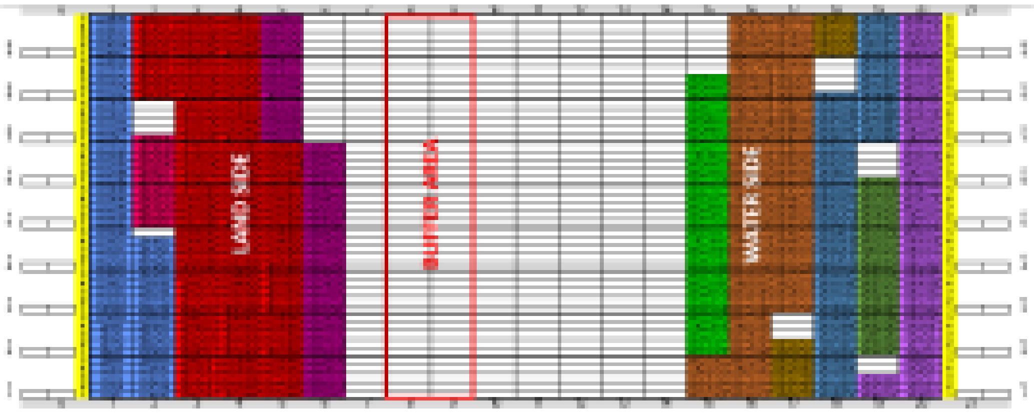

Figure 10 Slot Location from Experiments 1
(50% Receiving : 50% Delivery - Left Buffer Area)

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