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A Simulation Study of Collaborative Approach to Berth Allocation Problem under Uncertainty

Adi BUDIPRIYANTO[a], Budisantoso WIRJODIRDJO[b], I Nyoman PUJAWAN[c], Saut GURNING[d]

[a] *Doctoral Student at Industrial Engineering Department, Sepuluh Nopember Institute of Technology, Surabaya; Industrial Engineering Department, Bakrie University, Indonesia, E-mail:adi.budipriyanto@bakrie.ac.id (First Author)*
[b] *Professor, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia, E-mail:budisantosowirjodirdjo@gmail.com*
[c] *Professor, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia, E-mail:pujawan@ie.its.ac.id (Corresponding Author)*
[d] *Senior Lecturer, Sepuluh Nopember Institute of Technology, Surabaya, Indonesia, E-mail:sautg@its.ac.id*

A R T I C L E I N F O

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A B S T R A C T

The Berth Allocation Problem (BAP) is a critical issue for the efficient operation of a container terminal. While there are many works on berth allocation, most of the BAP models have used the assumption of a deterministic situation where arrival time and number of containers brought by a vessel are known in advance. Such a deterministic assumption, however, never holds true in real life. The purpose of this paper is to examine how collaboration between berth terminals could affect the port performance when dealing with uncertainty. Given the complexity of the problem, we have used discrete event simulation to model the system. Two major scenarios were evaluated, namely non-collaborative-response and collaborative-response. Collaborative-response is implemented by sharing resources such as berth, quay cranes and container yard among two terminals. The port performance was evaluated based on ship waiting time, container handling time and total ship turnaround time. The results show that collaborative strategy can reduce overall waiting time, container-handling time and total ship turnaround time; however, the impacts on each terminal vary.

1. Introduction

The port has an important role and function as a link in the distribution and transport systems (Tongzon, Chang and Lee, 2009). More than 80 percent of goods volume are delivered by sea, which means they pass through seaports (Asgari, Zanjirani and Goh, 2013; Feng, Mangan and Lalwani, 2011; Mason and Nair, 2013). Delivery of goods using sea transport is constantly increasing, which results in increases in ship traffic as well as in volume and frequency of loading and unloading at the terminals. However, this is not necessarily followed by an increase in terminal capacity. Resources and capacity of the terminal tend not to increase, which then stimulates uncertainty of service guarantee of ships calling at ports. Therefore, the increase in the volume of loading and unloading activities has created opportunities and challenges for terminal operators in allocating vessel (Lalla-ruiz, González-velarde, Melián-batista, and Moreno-vega, 2014), especially in a terminal with limited

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quay capacity when it is used jointly by several shipping lines (Imai, Nishimura, and Papadimitriou, 2008). Berth allocation is an important issue in the operations of the container terminal. Berth allocation problem (BAP) is the allocation of vessels to the berth as well as other resources during a certain agreed period of time in which the vessels can perform loading and unloading activities (Zhen and Chang, 2012).

There are many publications that address BAP. Initially, BAP only discusses the allocation of the ship to the berth in order to minimize handling time. Imai, Nagaiwa and Tat (1997), Lim (1998) and Imai, Nishimura and Papadimitriou (2001) developed a discrete BAP. In the discrete BAP, the berth is divided into several segments; one ship can occupy only one segment and one segment can only be occupied by one vessel. Discrete BAP has drawbacks because it does not always provide an efficient solution. This is because the berth is divided into several equal-size segments, while the ship size varies. Differences in ship size result in the non-optimal use of the berth. To overcome these weaknesses, Imai, Sun, Nishimura and Papadimitriou, (2005) developed a continuous BAP model. Berth allocation models are generally aimed at minimizing the ship turnaround time. However, ship turnaround time is not solely determined by the allocation of berth, but also influenced by the number of quay cranes (Park and Kim, 2003), as well as the distance between the berth and the yard (Hendriks, Lefeber, and Udding, 2013).

Berth allocation is becoming increasingly more complex because it is facing the challenges of uncertainty. Terminal operators allocate resources (berth, quay crane, yard and other resources) based on a predetermined schedule. This schedule has been agreed between the operator terminal and shipping lines, so that ships can only berth at certain terminals. The problem often arises because the ship may arrive outside of the agreed time slot.

This research is motivated by the need to find ways to reduce congestion in ports, particularly when two or more terminals operate independently, but they have the potential to collaborate. We believe that, while not much discussed in the literature, horizontal collaboration among terminals could be an alternative way of reducing congestions. We use the case of Tanjung Priok Port in Jakarta, Indonesia, as a base for developing the model. Tajung Priok is the largest and busiest container port in Indonesia. Tanjung Priok has two international container terminals, namely the Koja Container Terminal (Koja) and the Jakarta International Container Terminal (JICT). Koja and JICT are physically adjacent each other and currently operated by two different operators. They both use the same windows-slot system. In this system the shipping lines and terminal operators are bound by contracts and the terminal operators only serve ships that have contracts with a particular terminal. In the existing conditions, the two terminals operate independently; when one terminal is busy, the ships must be queued and they cannot berth at the other terminal even if the berth is available.

2. Literature Review

BAP can be either static or dynamic (Imai et al., 2001). The static BAP assumes all ships to have already arrived at the port when the allocation process begins, whereas the dynamic BAP considers not only ships that have already arrived, but also those that will arrive within the planning horizon. Depending on the spatial layout of the berth, BAP can be classified into two models: discrete and continuous (Imai et al., 2005; Lalla-ruiz et al., 2014). As to the discrete BAP, the quay is partitioned into a number of sections, where one ship can be handled at a time. Ship mooring is unable to be carried out across a berth boundary and multiple vessels are unable to occupy the berth at the same time. Whereas, in the continuous BAP, ships can be served wherever empty spaces are available.

Some researchers have conducted study of static discrete BAP, including Lai and Shih (1992), Imai et al., (1997) and Lim (1998). Lai and Shih (1992) developed a model of berth planning problem with different scenarios (existing, FCFS, the size of the vessel). Imai et al., (1997) developed a model involving two objectives in a nonlinear integer program to minimize the total vessel stay and service order. Lim, (1998) developed a model to minimize inter-ship clearance distance. Brown, Lawphongpanich and Thurman (1994) conducted observations in a naval port. An integer programming model was proposed to find the optimal ship-to-berth assignments. They conclude that, in order to generate an optimal allocation, the vessel is allowed to be shifted to another berth, even when the unloading process has not been completed. However, this may not be possible in the commercial ports where the loading and unloading activities should be completed until finished (Imai et al., 2001).

Imai et al. (2001) developed a dynamic approach of the BAP by using a Mixed Integer Programming. The model is solved using Sub Gradient Lagrangian Relaxation. However, the proposed solution is still complicated. Imai, Nishimura and Papadimitriou (2003) developed a model of nonlinear dynamic discrete BAP by adding the priority of scale. The model is solved using Genetic Algorithm. Golias, Boile and Theofanis, (2009) developed a model of discrete dynamic BAP which was formulated as a multi-objective combinatorial optimization problem where vessel service is differentiated upon priority agreements. A genetic algorithm-based heuristic was developed to solve the problem.

Dynamic discrete models focus on the objective of minimizing costs or minimizing the waiting and operations time. Some researchers are looking for methods to resolve berth allocation problems using different methods, such as Lagrangian Relaxation (Monaco and Sammarra, 2007), Variable Neighborhood Search (Hansen, Og, and Mladenovic, 2008), Heuristic (Hansen et al., 2008; Xu, Li, and Leung, 2012), Lambda Optimal (Golias, Boile, and Theofanis, 2010), Hybrid Meta Heuristic (Lalla-Ruiz, Melian-Batista, and Moreno-Vega, 2012), Simulated Annealing (Oliveira, Mauri, and Lorena, 2012), and Particle Swarm Optimization (Ting, Wu, and Chou, 2014). Meanwhile, Imai, Zhang, Nishimura and Papadimitriou, (2007) developed a two-objective model of BAP for the minimization of the total delay time and total service time. The model is solved using Sub Gradient Optimization and Genetic Algorithm. Legato, Mazza and Gullì, (2014) proposed the concept of integration between the tactical and operational levels using two separate models whereby the problem at tactical level was using mathematical programming and the operational level was using the simulation model. Other researchers developed models by adding other factors such as variable water depth and tidal condition (Xu et al., 2012).

Discrete BAP has drawbacks because it does not always provide an efficient solution. This is because the berth is divided into several segments with equal size, while the ships have different size. To minimize the space that is not utilized (the difference between the size of the ship and the size of segments), Imai et al. (2005) developed a model of continuous BAP. They used heuristic methods to solve these problems. Lee, Chen and Cao (2010) developed a continuous BAP to minimize total weighted flow time using Greedy Randomized Adaptive Search Procedure. Elwany, Ali and Abouelseoud, (2013) using the integrated heuristic-based solution for resolving the problem of continuous BAP. Frojan, Correcher, Alvarez-valdes, Koulouris and Tamarit (2015) developed integer linear models and solved using Genetic Algorithms, while Xiaolong, Gong and

Jo (2015) used Particle Swarm Optimization approach to solve the problem of continuous BAP.

Some researchers have focused on integrating berth allocation and crane allocation. Imai et al. (2008) developed a model of simultaneous berth and crane allocation problem with the aim to minimize the total time (waiting and handling time). They formulated the model as an integer model and solved using Genetic Algorithm. In this model, it was assumed that the quay crane cannot be moved until the loading and unloading processes have been completed. Liang, Huang and Yang (2009) addressed the dynamic berth allocation, considering a number of factors, including arrival time, berth location and number of quay cranes. The objective of the problem was to minimize the sum of the handling time, waiting time and the delay time. A hybrid evolutionary algorithm was proposed to find an approximate solution. The proposed algorithm was compared to the existing methods and the computational experiments showed that the proposed approaches were more applicable to solve dynamic BAP.

All BAP models presented above use the assumption that the arrival of the ship and the operation time are deterministic and known in advance. However, in a real situation, such an assumption is difficult to meet, particularly with limited quay capacities. While a large body of literature has discussed about uncertainty, only very few address the specific issue of BAP under uncertainty. Zhen, Hay and Peng (2011) conducted a study on BAP under uncertain arrival time and operation time. Their research not only concerns the proactive strategy to develop an initial schedule that incorporates a degree of anticipation of uncertainty during the schedule's execution, but also studies the reactive recovery strategy which adjusts the initial schedule to handle realistic scenarios with minimum penalty cost of deviating from the initial schedule.

Zhen and Chang (2012) conducted a study on berth allocation considering the uncertainty of arrival time and operation time with a focus on proactive strategy, which adds time buffer to the initial schedule. The goal is to anticipate the uncertainty of ships arrival and the operation time. Their study proposes a bi-objective optimization model for minimizing cost and maximizing robustness of schedules. Heuristic method is used to resolve the issue, while Golias, Portal, Konur, Kaisar and Kolomvos, (2014) conducted a study taking into account the uncertainty of vessel arrival and handling time. Zhen, (2015) proposed both a stochastic programming formulation that can cope with arbitrary probability distributions in the deviation of the ships operation time and a robust formulation that is applicable to situations in which limited information about probability distributions is available. Zhen (2015) also considered the uncertainty of the number of containers that need to be handled. Uncertainty in the number of containers causes uncertainty in operational time. This study integrates the tactical level to the operational level of berth allocation. The goal of this research is to minimize the deviation of the arrival and departure with the expected arrival time and the expected departure time.

The above literature showed great concern on the issues of berth allocation, particularly those that deal with the circumstance of uncertainty. To the best of our knowledge, there are few studies that discuss strategies to cope with uncertainty. Zhen and Chang (2012) proposed a pro-active strategy by adding buffer time. This strategy can improve the service level and flexibility. However, pro-active strategy will add resources that are not utilized, especially when time delay is significant or exceeds the windows slot. This strategy also cannot solve the problems where the vessel should be allocated and how to use resources that have been allocated, but not utilized.

Other researchers have approached the problem from more theoretical points of view, such as the development of conceptual framework (Bichou and Gray, 2004; Carbone and Martino, 2003; Cullinane, Wang, Song, and Ji, 2006; Notteboom and Winkelmans, 2001; Paixao and Marlow, 2003; Song and Panayides, 2008; Tongzon and Heng, 2005) and identification of factors affecting collaboration (Song and Panayides, 2008; Tongzon et al., 2009; Valentina and Marcella, 2003; Woo, Pettit, Kwak and Beresford, 2013). Some researchers address the performance of collaboration, including Hsu, (2013), Lorentz, (2008), Pramatari and Papakiriakopoulos, (2010), Yeo, Roe and Dinwoodie, (2011) and Feng et al., (2011).

Although some authors agree that collaboration can provide benefits in improving services to shipping lines (Adenso-Diaz, Lozano, Garcia-Carbajal and Smith-Miles, 2014; Cousins and Menguc, 2013; Juan, Faulin, Perez-Bernabeu, and Jozefowiez, 2014; Leitner, Meizer, Prochazka, and Sihn, 2011; Lozano, Moreno, Adenso-díaz, and Algaba, 2013; Mason and Nair, 2013; Yilmaz and Savasaneril, 2012), virtually none has specifically discussed collaboration strategies between the terminals in the port. One of the closest references is a study conducted by Imai et al. (2008) on berth allocation with the limited capacity of the quay. To avoid long waiting time, they proposed a model that allows ships to berth at another terminal. They used the assumption that the dock needed in the external terminal is always available. With these assumptions, the ship can be allocated as soon as possible. Another assumption of their model is that the arrivals of the vessel are considered deterministic. Both assumptions are difficult to fulfill given the fact that the dock is not always available and the ship's arrival is uncertain. In contrast, in this study we consider the uncertainty of the ship arrival and availability of the two terminals.

3. Problem Description

Terminal operators use the windows system to arrange the service of the vessels (Hendriks, Laumanns, Lefeber, and Tijmen, 2010). Windows system is binding among shipping lines and terminal operators, so that the ship must do berthing at the berth where the contract is agreed. However, due to the uncertainty, it is often difficult for the ship to arrive at the agreed time slot.

In this study, we model the case of Tanjung Priok Port that has two terminals, namely Koja and JICT. The two terminals are currently operated independently, where each has their own berth, quay crane and RTG, internal transporter and container yard. Fig. 1 shows the existing condition where ships do berthing, loading and unloading and stacking at the terminal where shipping lines have a contract with (windows slot). Terminal 1 serves only the ships that have a contract with this terminal.

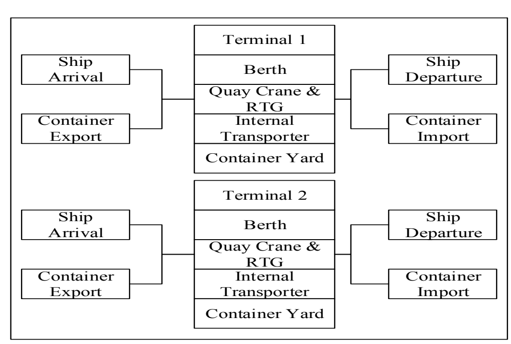

Fig. 1. Existing Model (Non Collaborative Model)

Likewise, terminal 2 serves only the ships that have a contract with terminal 2. Consequently, if the ship is delayed, they must wait until the berth where the vessel has a contract is available, even if the dock at another terminal is not being used.

To improve the service level and flexibility of service, terminal operators may collaborate on the use of their resources (Leitner et al., 2011). According to Nemati, Bhatti, Maqsal, Mansoor and Naveed (2010), when the resources or competencies required are not available in the company, it should be beneficial to seek and utilize external resources. In this study, we attempted to fill the gap by proposing a model of collaboration through the use of resources such as docks (berth), quay crane, internal transporters, container yard, as well as other resources. Fig. 2 shows a conceptual model of collaboration. Ships can do berthing anywhere in the available terminal. Collaboration allows a vessel which has a contract at a one terminal to do berthing and unloading at the other terminal.

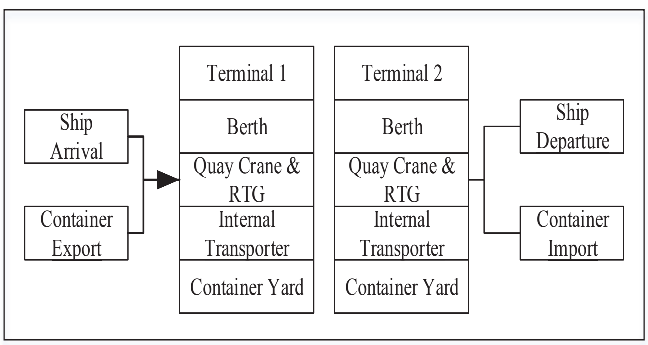

Fig. 2. Collaborative model

In general, container terminal operations consists of ship inbound and outbound, quay crane discharging and loading systems, internal transportation and container movement, container yard discharging and loading system, stacking system, gate system, and inbound and outbound process for containers. Fig. 3 illustrates the processes of a terminal operation. International container terminal uses a ships call system (Windows slots), where incoming ships to the terminal are expected to follow a regular schedule. In ideal circumstances, ships come in the terminal in accordance with a predetermined time. When the ship comes (either as scheduled or not), but the berth is not available, then the ship has to wait until the berth is available. After the ship is docked, quay cranes are allocated to serve the process of loading and unloading. Unloading time is highly dependent on the number and productivity of quay cranes deployed on every ship.

Import containers are brought into the container yard using internal transport (truck). The number of trucks deployed influences the time of loading and unloading. If the number of trucks deployed is less than the number of trucks required, the time period required for unloading becomes greater. The time needed for loading and unloading is also dependent on the distance between the location of berthing and the container yard. When the container arrives at the container yard, a rubber tyred gantry (RTG) is used to unload the container. The next process is container stacking. The truck then goes back to the berth to take the next container. This process is repeated until all the import containers are completed. Import containers are subsequently distributed using land transport modes.

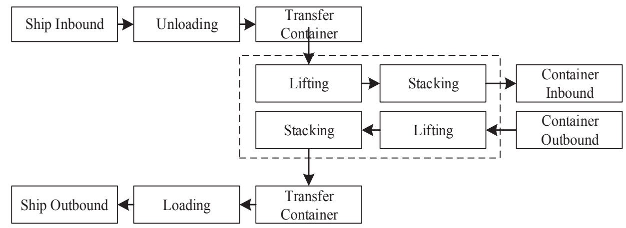

Fig. 3. Operation Process at Container Terminals

Before being transported to the ship, export containers (outbound container) may have to be at the terminal a few days before the ship arrives. Terminal operators will allow time for shipping lines to keep the container at the terminal. The time at which shipping lines begin the stacking process is called "open stack". Each terminal has a different policy towards "open stack". The aim is to ensure that all containers in the terminal are ready to be loaded onto the ship. It is also to avoid congestion at the terminal. The process of loading the export container to the vessel can be made after all import containers are completed. Conversely, the loading process undertakes the reverse order of the discharging process.

4. Research Methodology

In building a model of collaboration, we chose the simulation study as a research method which is based on a premise that simulation is a worthwhile, proven technique to assess various design alternatives. This is especially true when the system to be analyzed is operating in a highly uncertain and complex environment making the analytical techniques are difficult to be implemented (Pujawan, Arief, Tjahjono, and Kritchanchai, 2015).

Operations at the port normally involve setting some resources, such as quay cranes, rubber tyred gantry and internal transporter, categorized as issues that are very complex (Abadi, Baphana, and Ioannou, 2009; Kamrani, Mohsen, Esmaeil, and Golroudbary, 2014; Kia, Shayan, and Ghotb, 2002; Kotachi, Rabadi, and Obeid, 2013). According to Imai et al. (2008) berth allocation can be classified as a cutting-stock problem, while (Park and Kim, 2003) classify crane scheduling as a two-dimensional stock-cutting problem. Two-dimensional cutting-stock problem is a NP-hard problem category. Thus berth and crane scheduling can be classified as NP-hard problems (Park and Kim, 2003). According to Park and Kim, (2003), the berth allocation, yard allocation and crane allocation can be classified as NP-hard problems. According to Homayouni, Tang and Motlagh (2014), NP-hard problems are difficult to solve analytically, especially for entities in large quantities (Homayouni et al., 2014).

Simulation method has been used by some researchers, such as to model the planning and management system at the port, imitating port operations and estimating performance and outcome (Tahar and Hussain, 2013). Kotachi et al. (2013) used a simulation method for analysing multimodal in the port. Kulak, Polat, Gujjula and Gu (2013) used simulation methods to define strategies to enhance the performance of a container terminal. Tahar and Hussain (2013) used simulation methods to determine the berthing schedule. Meanwhile, Park and Dragovic (2009) used simulation methods to analyze queues and bottlenecks, container handling, internal transporter, ship schedules, container yard utilization and throughput at the port. Kia et al. (2002) used a simulation method to compare the location of the container yard in the port area (existing) to the container yard outside the port area (purpose). Abadi et al. (2009) used simulation methods to determine the influence of ship turnaround and transportation costs arising from the inspection of the container truck before entering the port. Pujawan et al. (2015) used simulation methods to integrate the decisions of delivery planning and storage capacity under uncertain demand situation. Some researchers use a combination of simulation with analytical methods. Arango, Cortés, Muñuzuri and Onieva (2011) developed a model that integrates the Genetic Algorithm with simulation. Zeng and Yang (2009) used the methods of integration between simulation with optimization to determine the schedule of loading and discharging at a container terminal.

We adapted the standard simulation methodology in this study (Altiok and Melamed, 2007; Kelton, Sawdoski, and Sawdoski, 2010). Fig. 4 shows the four major steps of our simulation study. The first is developing the simulation models and started with the observation of a real system, understanding the process and collecting the data for input parameters. In any simulation study, it is necessary to ensure that the model reflects the real system and the simulation logics work properly. Our second step, therefore, was the verification and validation of the simulation models. The third step was running simulation with two scenarios, namely non-collaborative and collaborative. Each scenario is run with five replications. The simulation results were used to evaluate the turnaround time and its components for each scenario. The details of each step will be elaborated in the following sections.

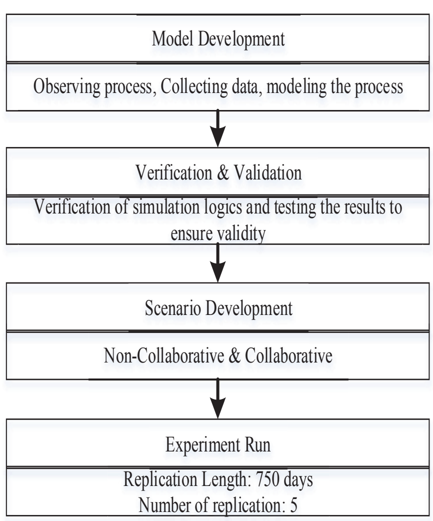

Fig. 4. Research Steps

4.1 *Model Development*

The basic idea in the process of developing the model in this paper is to determine the shortest ship turnaround time. Fig. 5 illustrates the process of loading and unloading and container movement. Before the ship is moving toward the berth, the ship has to wait until the berth is available. Once assigned, the ship goes through the so called pre-time state, which includes such activities as connecting with tugboat, preparing necessary documents, etc. When the dock is ready, the ship moves towards the berth, guided by a tugboat to make the berthing process. Based on field studies, it takes 30-90 minutes from the pilotage to the berthing process.

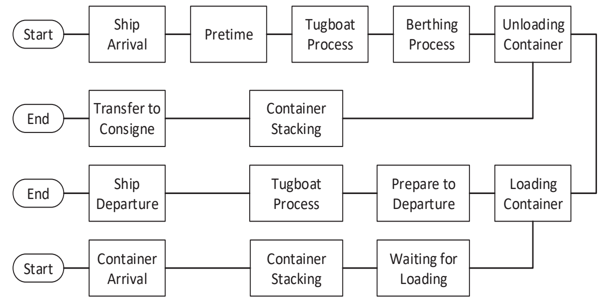

Fig. 5. Ship activities and container movement

The next process is unloading containers. The process of unloading is done by using a quay crane. In this paper, the number of quay cranes allocated in each terminal is fixed. Quay crane takes time to move a container from the ship to the truck. Furthermore, the container is taken to the container yard for stacking process and stored temporarily. Stacking process begins with lift on/off using RTG crane. After the process lift on/off, the truck returns to the berth to carry the next container.

After the unloading process is complete, the loading process begins. The loading process starts from the lift of the container from yard to truck, followed by a truck carrying the container to the berth, then the container is lifted to the vessel using quay crane. The time needed to process the lift on/off using the quay cranes are the same for both the loading and unloading process. The above process is then translated into simulation model. Fig. 6 shows the simulation process. We used ARENA® to model and simulate the process.

4.2 *Input Parameter*

Data were collected from the two terminals mentioned before. Table 1 shows the input variable, consisting of resources available in each terminal. The number of quay cranes allocated to each berth is different and does not change during the simulation period. Allocation of quay crane to each berth can be seen in

Table **2**. We also collected data on inter-arrival time of ships as well as loading and unloading time for each vessel. These data were then fitted into theoretical distribution. Table 3 and Table 4 show the distribution of ship inter-arrival time as well as the number of container loading and unloading for the two terminals. The type of distribution and the parameter values are associated to each vessel, as these vessels have different sizes and schedules and, thus, carry different quantity of containers.

Table 1
Resources at Koja and JCIT Container Terminal

Variable	Koja	JICT
Number of Services (unit)	10	19
Number of Berths (unit)	2	7
Number of Quay Crane (unit)	7	19
Number of Rubber Tyred Gantry Cranes (unit)	25	64
Number of trucks	48	141
Yard Capacity-Inbound (box)	9,555	11,781
Yard Capacity-Outbound (box)	8,820	15,414

Table 2
Quay Crane Allocated

Terminals	Koja		JICT						
Berth	1	2	3	4	5	6	7	8	9
Number of quay cranes	4	3	3	3	2	3	3	2	3

The number of yards in Koja and JICT are 25 blocks and 64 blocks, respectively. Each block has 12-35 slots, while each slot consists of 24 stacks. Each block is served by the RTG. Koja has 48 trucks, while JICT has 141 trucks. Trucks are deployed to transport containers from the wharf to the yard, and vice versa. Koja has 10 windows, with the arrival distribution, container loading and unloading as shown in Table 3. JICT has 19 windows with the distribution of inter-arrival time of each vessel as shown in Table 4.

Table 3
Distribution of Ship Inter-Arrival, Container Loading and Unloading at Koja

Vessel	Inter-Arrival	Container Loading	Container Unloading
ANX	NORM(122, 75.1)	NORM(617, 269)	TRIA(-0.001, 742, 1.4e+003)
APX	NORM(165, 25.8)	NORM(629, 214)	NORM(583, 166)
ASAL	32 + GAMM(49.4, 3.12)	-0.001 + 1.26e+003 * BETA(3.53, 8.18)	NORM(465, 166)
CAP	NORM(151, 82.8)	52 + GAMM(105, 2.14)	-0.001 + ERLA(35.3, 2)
FEEDER	123 + GAMM(14.2, 3.49)	TRIA(237, 635, 856)	-0.001 + 942 * BETA(1.08, 0.436)
INE	29 + GAMM(85.9, 2.35)	44 + WEIB(508, 2.17)	NORM(542, 110)
JSCO2	60 + 637 * BETA(0.725, 1.41)	NORM(494, 180)	-0.001 + 132 * BETA(1.99, 1.72)
KIS	56 + 1.51e+003 * BETA(0.595, 3.49)	NORM(559, 167)	NORM(521, 195)
KPI	NORM(186, 85.5)	NORM(818, 198)	-0.001 + 997 * BETA(0.264, 0.339)
KTX3	NORM(169, 41)	NORM(1.18e+003, 326)	NORM(1.45e+003, 379)

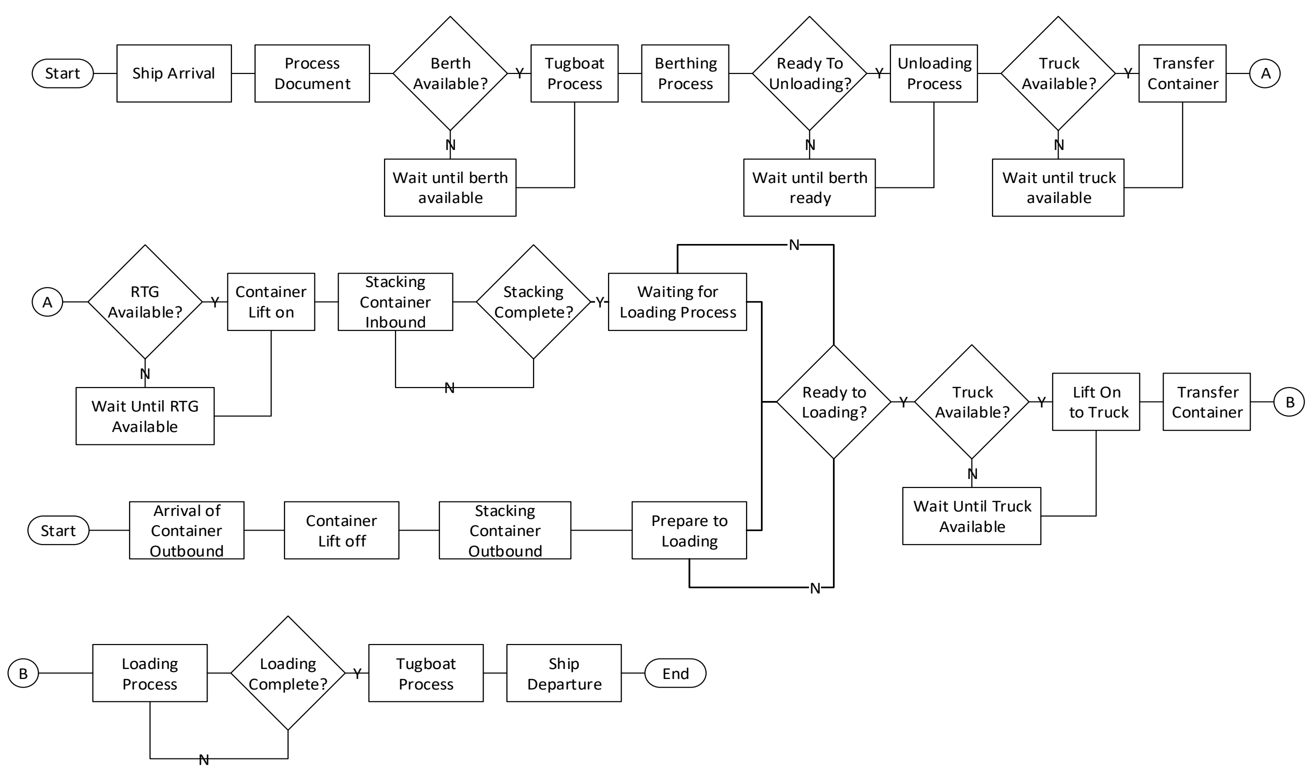

Fig. 6. Simulation Flowchart

Table 4
Distribution of Ship Inter-Arrival, Container Loading and Unloading at JICT

Vessel	Arrival	Container Loading	Container Unloading
CHS3	40 + GAMM(57.7, 3.5)	TRIA(-0.001, 872, 1.33e+003)	NORM(1.19e+003, 371)
CJS	145 + LOGN(42.9, 46)	NORM(1.19e+003, 223)	NORM(1.32e+003, 309)
CKI	270 * BETA(0.762, 1.7)	NORM(742, 239)	NORM(946, 272)
CKV	NORM(174, 53.9)	NORM(458, 147)	TRIA(-0.001, 493, 683)
CN1	NORM(85.9, 38.4)	NORM(465, 151)	-0.001 + 1.14e+003 * BETA(2.34, 1.8)
CSE	34 + GAMM(50.9, 2.97)	281 + 1.47e+003 * BETA(3.21, 3.11)	NORM(1.03e+003, 211)
CTI	NORM(147, 69)	34 + GAMM(150, 2.12)	TRIA(5, 537, 824)
IA4	47 + ERLA(59.8, 2)	NORM(598, 331)	-0.001 + 1.34e+003 * BETA(0.183, 0.532)
IA8	107 + ERLA(49.9, 2)	22 + WEIB(99.3, 1.58)	70 + WEIB(170, 1.36)
JAVA	0.999 + GAMM(62, 3.12)	NORM(410, 128)	-0.001 + 1.1e+003 * BETA(0.858, 4.01)
JTI	17 + 320 * BETA(2.13, 3.41)	27 + 1.63e+003 * BETA(0.327, 1.45)	57 + ERLA(186, 2)
JVS	120 + ERLA(17.4, 3)	NORM(747, 114)	NORM(658, 144)
LEON	NORM(166, 31.2)	NORM(1.54e+003, 364)	-0.001 + 2.24e+003 * BETA(5.82, 1.79)
PIL	NORM(87.4, 33.2)	TRIA(-0.001, 554, 752)	NORM(435, 155)
PJX1	NORM(171, 44.1)	-0.001 + 1.05e+003 * BETA(5.31, 2.03)	NORM(841, 185)
SEAE	NORM(242, 57.2)	-0.001 + 631 * BETA(1.99, 1.95)	TRIA(-0.001, 112, 450)
SEAR	1 + 329 * BETA(2.09, 3.19)	-0.001 + 577 * BETA(1.74, 1.71)	-0.001 + 618 * BETA(1.61, 6.76)
INA2	NORM(169, 16.4)	NORM(542, 153)	NORM(455, 132)
CIX	NORM(175, 54.4)	0.999 + 610 * BETA(0.296, 0.213)	NORM(283, 93.2)

4.3 *Verification and Validation*

To ensure that the model is built to work in accordance with the characteristics of the real system and the results of the simulation have a level of accuracy that is acceptable, the model must be verified and validated (Huynh, Walton, and River, 2005). Verification assesses the truth which is represented by the model. Verification can be done by checking the coding, performing the test runs and the test for statistical consistency. Validation is done to assess how realistic are the assumptions applied in the model. Validation can be done by comparing the performance of the model (prediction) with that of the system being studied (Altiok and Melamed, 2007).

In this study, verification consists of three main activities: (1) examining the logic of the simulation (program logic); (2) performing simulations with test runs and checking the output and graphs to check if the simulation logic is correct; (3) conducting a simple test to evaluate the consistency of the model, as well as more complex examinations by comparing the theoretical and statistical simulation results. Verification has been done by checking the animation, using a model of sanity checks verification and checking the performance of the queue.

Validation includes comparing the inter-arrival time of each vessel and the number of containers loaded and unloaded. In this simulation, the length of simulation run is set at 750 days (25 months) and each experimental cell is replicated five times. Using independent tests with significance level of 5 percent, it was proved that there was no statistical difference between the inter-arrival time of the empirical data and the inter-arrival time of the simulation results. For container loading, it can be concluded that there was no significant difference between the empirical data and the simulation results. The same applies for the number of containers unloaded. With this verification and validation we believe that our simulation model is credible.

4.4 *Scenario*

In this study, we compared two scenarios, namely the existing (non-collaborative) and the collaborative, between the two terminals. In the non-collaborative scenario, the ship can only do berthing at the terminal where the ship has a windows slot. On the other hand, in the collaborative scenario, the ship is not tied to one of the terminals. Ships can do berthing anywhere in the two terminals as long as either of the two terminals is available. In the current situation, there are ten shipping lines that are associated with Koja and 19 other shipping lines with JICT, as indicated by Table 3 and Table 4 above.

5. Analysis of Results

The analysis was done by two indicators: time and throughput. Time indicator consists of waiting time (queuing time), container-handling time and total ship turnaround time. Time indicator is used to determine whether the scenario of collaboration can reduce waiting times, as well as to evaluate the effect of a change in the number of containers carried by a vessel on ship turnaround time. The second indicator analyzed is throughput. Throughput analysis consists of two aspects. First is the analysis of the ship calls, which is conducted to determine whether there is a significant influence of collaboration on the number of ships serviced. Secondly we also looked at the change in the number of containers that each terminal can handle. The detailed analyses are presented in the following sub-sections.

5.1 *Queuing Time*

Table 5 presents the waiting time at Koja with non-collaborative and collaborative scenarios. In the non-collaborative scenario, the waiting time for vessel ANX is 8.04 hours, vessel APX is 7.36 hours, vessel ASAL is 7.53 hours, and so on. In the collaborative scenario, the average waiting time for vessel ANX, APX, and ASAL are 5.69 hours, 5.80 hours and 6.01 hours, respectively. The table suggests that, for most ships, the waiting time is lower in the collaborative scenario. On average, the waiting time reduces from 7.77 hours to 5.83 hours.

Table 6 shows the waiting time at JICT, comparing the scenario of non-collaborative and collaborative. As it is evident from Table 6, the waiting time of vessels is consistently lower under the collaborative scenario. The waiting time is reduced from the average of 7.31 hours to 5.70 hours.

Thus, if we take the grand average of all ships involving both terminals, there is a decrease in waiting time from 7.44 hours in the existing non-collaborative scenario to 5.77 hours in the collaborative scenario, which is equal to 1.67 hours per vessel or about 22.45%.

Table 5

Comparison of Queuing Time of the Two Scenarios at Koja

Vessel	Existing (non-collaborative)		Collaborative	
	Number of Ship Calls	Queuing Time	Number of Ship Calls	Queuing Time
ANX	734	8.04	732	5.69
APX	544	7.36	544	5.80
ASAL	474	7.53	483	6.01
CAP	589	8.90	590	6.04
FEEDER	521	6.53	518	5.43
INE	383	8.00	364	5.52
JSCO2	314	8.92	323	6.47
KIS	364	9.00	342	6.38
KPI	480	8.79	482	6.33
KTX3	534	4.61	527	4.65

Table 6

Comparison of Queuing Time of the Two Scenarios at JICT

Vessel	Existing (non-collaborative)		Collaborative	
	Number of Ship Calls	Queuing Time	Number of Ship Calls	Queuing Time
CHS3	371	7.00	383	5.55
CJS	476	6.67	478	4.62
CKI	1,053	7.62	1,085	6.40
CKV	518	7.40	507	5.72
CN1	1,026	7.36	1,047	5.70
CSE	477	7.48	489	5.58
CTI	598	7.70	642	5.96
IA4	544	7.16	541	6.12
IA8	435	7.79	437	5.99
JAVA	474	7.90	456	5.86
JTI	656	7.99	645	5.80
JVS	518	7.05	517	5.70
LEON	542	5.43	544	4.43
PIL	1,020	7.32	1,036	6.16
PJX1	525	6.67	523	5.27
SEAE	369	8.39	365	6.30
SEAR	698	8.22	672	6.42
INA2	520	6.51	523	5.07
CIX	370	7.22	371	5.68

5.2 *Handling Time*

Table 7 and 8 present the comparisons of the handling time between the non-collaborative and collaborative scenarios for Koja and JICT, respectively. The two tables indicate different change. In Koja, the handling time for the collaborative scenario is always longer than that in the non-collaborative scenario, while in JICT, the handling time is always lower in the collaborative scenario. This happens because, in the collaborative scenario, a few vessels were shifted from JICT to Koja. From the simulation results, we revealed that there are, on average, 148 ship calls, which is equivalent to 305,568 containers shifted from JICT to Koja during the simulation period, which represents 750 days of real time.

Table 7

Handling Time at Koja Terminal

Vessel	Existing		Collaborative	
	Number of Ship Calls	Handling Time	Number of Ship Calls	Handling Time
ANX	734	24.93	732	40.19
APX	544	21.85	544	33.35
ASAL	474	16.41	483	25.57
CAP	589	4.85	590	7.49
FEEDER	521	23.38	518	35.78
INE	383	19.43	364	30.14
JSCO2	314	7.10	323	10.04
KIS	364	19.28	342	28.16
KPI	480	20.09	482	29.56
KTX3	534	50.50	527	72.68

Table 8

Handling Time at JICT Terminal

Vessel	Existing		Collaborative	
	Number of Ship Calls	Handling Time	Number of Ship Calls	Handling Time
CHS3	371	64.76	383	55.09
CJS	476	76.21	478	71.06
CKI	1,053	53.96	1,085	49.72
CKV	518	26.25	507	23.25
CN1	1,026	36.87	1,047	32.60
CSE	477	61.75	489	56.07
CTI	598	27.03	642	24.11
IA4	544	25.34	541	24.02
IA8	435	13.07	437	11.60
JAVA	474	15.44	456	14.59
JTI	656	25.05	645	23.32
JVS	518	40.76	517	38.09
LEON	542	95.77	544	84.60
PIL	1,020	26.12	1,036	24.39
PJX1	525	49.08	523	45.53
SEAE	369	13.54	365	13.54
SEAR	698	10.69	672	9.68
INA2	520	65.08	523	58.57
CIX	370	69.9	371	66.49

5.3 *Ship Turnaround Time*

The comparison of ship turnaround time between the collaborative and non-collaborative scenarios is presented in Table 9 for Koja and in Table 10 for JICT. As we can see from these two tables, moving from non-collaborative to collaborative scenario results in increased turnaround time for Koja, but the opposite change is exhibited by JICT. However, if we take the aggregate data of the two terminals, the average turnaround time decreases by, on average, 0.93 hours. As explained above, the turnaround time consists of waiting time and handling time. As some vessels are shifted from JICT to Koja, it is logical that the vessel turnaround time increases in Koja, but decreases in JICT. However, the overall average decreases by 0.93 hours, indicating that the collaborative scenario is bringing benefits in terms of lower total turnaround time.

Table 9
Ship Turnaround Time at Koja Terminal

Vessel	Existing		Collaborative	
	Number of Ship Calls	Turnaround Time	Number of Ship Calls	Turnaround Time
ANX	734	37.38	732	50.04
APX	544	33.63	544	43.35
ASAL	474	28.32	483	35.75
CAP	589	17.81	590	17.50
FEEDER	521	34.37	518	45.37
INE	383	31.85	364	39.84
JSCO2	314	20.16	323	20.62
KIS	364	32.59	342	38.66
KPI	480	33.25	482	40.07
KTX3	534	59.64	527	81.54

Table 10
Ship Turnaround Time at JICT Terminal

Vessel	Existing		Collaborative	
	Number of Ship Calls	Turnaround Time	Number of Ship Calls	Turnaround Time
CHS3	371	76.05	383	64.84
CJS	476	87.27	478	79.92
CKI	1,053	65.88	1,085	64.68
CKV	518	38	507	33.09
CN1	1,026	48.59	1,047	42.47
CSE	477	73.58	489	65.86
CTI	598	39.07	642	34.18
IA4	544	36.73	541	34.23
IA8	435	25.07	437	21.67
JAVA	474	27.62	456	24.53
JTI	656	37.32	645	33.18
JVS	518	52.16	517	47.98
LEON	542	105.56	544	93.19
PIL	1,020	37.75	1,036	34.70
PJX1	525	60.14	523	55.01
SEAE	369	26.16	365	23.97
SEAR	698	23.09	672	20.14
INA2	520	75.92	523	67.85
CIX	370	81.41	371	76.39

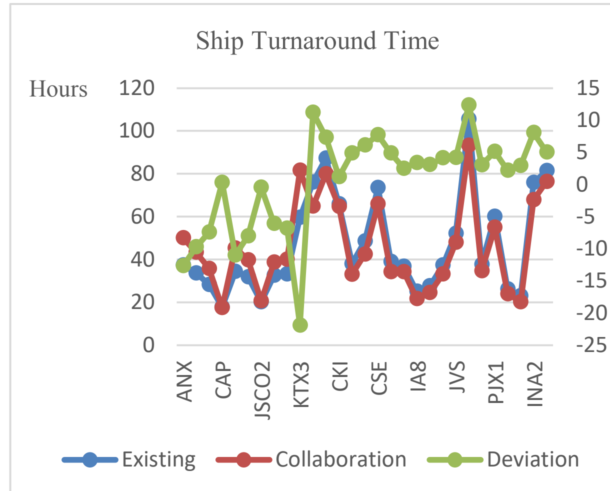

Fig. 7. Comparisons in Ship Turnaround Time

Differences in turnaround time are also depicted in Fig.7. The left scale in Fig.7 is for ship turnaround time for both existing and collaborative scenarios, while the right side is for the scale of the difference in ship turnaround time between the existing and collaborative scenarios. As can be recognized from the name of the vessels, the first ten are those that originally had a windows slot in Koja and the next 19 vessels were originally with JICT.

5.4 *Throughput*

As mentioned earlier in this paper, one of the consequences of the collaboration between terminals is the shift of berthing activity from one terminal to the other. Table 11 shows the changes in ship calls for the existing and collaborative scenarios in each replication of the simulation run. In the first replication, there are 3,182 ship calls, which consist of 972 in Koja and 2,210 in JICT. In the collaborative scenario, the number of ship calls is 3,224, which consist of 1,119 in Koja and 2,105 in JICT. The 42 difference in total ship calls is due to the random effect of the simulation process. Table 12 shows the corresponding number in terms of containers. Here, we see an obvious decrease in the number of ships to JICT (-105) and a significant increase to Koja (+147). Overall, all five replications show a similar pattern, where there is a significant shift of vessels from JICT to Koja, as already mentioned above.

Table 11
Ship Call at Koja and JICT

Rep	Scenario				Ship Calls (+/-)	Vessel Shifting	
	Existing		Collaborative				
	Koja	JICT	Koja	JICT		Koja	JICT
1	972	2,210	1,119	2,105	42	147	-105
2	987	2,240	1,137	2,102	12	150	-138
3	972	2,218	1,149	2,095	54	177	-123
4	1,004	2,258	1,143	2,107	-12	139	-151
5	1,002	2,262	1,129	2,080	-55	127	-182

Table 12
Container Shifting between terminals

Replication	Scenario				Container Increase/Decrease (Existing to Collaboration)	Container Shifting (Existing to Collaboration)	
	Existing		Collaborative				
	Koja	JICT	Koja	JICT		Koja	JICT
1	1,148,355	2,961,274	1,466,663	2,695,607	52,641	318,308	-265,667
2	1,182,980	2,965,062	1,474,836	2,710,666	37,460	291,856	-254,396
3	1,133,412	2,974,362	1,469,721	2,695,256	57,203	336,309	-279,106
4	1,195,319	3,000,141	1,476,180	2,722,181	2,901	280,861	-277,960
5	1,171,631	3,028,577	1,472,137	2,687,595	-40,476	300,506	-340,982

6. Discussion

Collaborative scenario can reduce queuing time and handling time, which, in turn, can reduce ship turnaround time. Although the handling time of some vessels increased, particularly vessels that have a windows slot in Koja, overall results show a decreased handling time. The increase in handling time in the collaborative scenario in Koja is the impact of the change (shifting) in the ship calls that were originally served in JICT. Handling time on a ship that has a windows slot in Koja increased, resulting in decreasing of the ship turnaround time. However, overall, the ship turnaround time for the collaborative scenarios decreased. This result supports our conjecture that collaboration brings benefits to the overall system, although, individually, the collaborating parties may either be better off or worse off.

Besides reducing the ship turnaround time, horizontal collaboration between terminals can also improve service flexibility, so that the ship does not always depend on the particular terminal. As we can see from Table 6 replication 1, the 1,119 vessels that did berthing in Koja are actually coming from 349 vessels that had windows in Koja, while 770 vessels originally had windows slot in JICT. Likewise, among the 2,105 vessels that did berthing in JICT, 1,466 are those that had a windows slot in JICT and 639 vessels that had a windows slot in Koja. In other words, horizontal collaboration allows ships to do berthing in any port depending on the condition at the time they arrive, no matter to which port they originally were associated. With the flexibility of these services, the waiting time decreases, as has been discussed above.

From the supply chain point of view, collaboration is often recommended, as it brings a positive impact for the collaborating parties as well as for the customers. In the context of port operations, customers, who could be the shippers, carriers (shipping lines) or the consignee, would be benefited by the reduced delivery time as a result of more efficient and timely operations in the ports. It has often been observed that the ship turnaround time is a significant component of the delivery time and the initiative to collaborate among port terminals would reduce the shipment lead time. When the ship turnaround time becomes shorter, it will also result in reduced operating costs for shipping lines. From a terminal operator point of view, faster handling time increases resource utilization. Increased utility of resources raises many advantages for the operator terminals. First, it provides a competitive advantage for the terminal. Secondly, it has the potential to attract new customers and, hence, generate more revenue.

Terminal operators do not necessarily get benefit with the decrease in the ship turnaround time. Therefore, it is necessary for the government, as the regulator, to provide incentives for the terminal operators to collaborate. As noted earlier, collaboration may have impacts on the change of ship calls and throughput. As an implication of collaboration between the terminal operators, there may be some challenges in the way they should share benefits and costs. The results presented above suggest that one terminal operator is better off, while the other is worse off as a result of collaboration. While the total system benefits, the individual party may resist collaborating unless there is a fair benefit and risk sharing mechanism available. The detailed discussion on the mechanism for the profit and risk sharing mechanism is beyond the scope of this paper.

7. Conclusion and Future Research

In this study, we address the issue of horizontal collaboration between port terminals. We used the example of Jakarta, where there are two terminals potentially collaborating each other. The idea is to improve services to the customers and, hence, improve the supply chain. We examined two different scenarios, non-collaborative (existing) and collaborative. Two indicators are used to assess the performance, the time and throughput. Based on the results presented above, the collaboration between the two terminal operators brings benefits to the total system in terms of reduced ship turnaround time, waiting time and handling time as well as improvement in throughput. However, the performance of each collaborating party does not necessarily improve and, hence, there is an issue related to the collaboration mechanism that needs to be properly designed. This study, however, has not addressed the issue of benefit and risk sharing, which is potentially an idea for future work. Port authorities may encourage two or more terminals within the port area to collaborate, but, then, there is a need for them to decide on benefit and a risk sharing mechanism.

The financial impacts of collaboration are another interesting issue to explore. If one terminal was initially very busy and the other was not, shifting vessels from the busy terminal to the less busy terminal would improve the operational performance in terms of reduced waiting time, but may not have an impact on the combined revenue of the two terminals. However, as the waiting time decreases, there may be cost savings for the shipping companies. This issue has not been explored in this study and would be an important and interesting topic for future work.

In addition, horizontal collaboration among the terminal operators would be possible if there is technical feasibility to shift vessels from one terminal to the other. This may not be easy unless the facilities are physically adjacent. In future work, various other collaborative scenarios, such as cranes sharing and the use of cranes that can move freely crossing both terminals, would be an important extension from this work. Scenarios can also be extended to explore queue discipline, from first come first service to priority service.

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