8-27-2011

Analysis of proper capacity at Jakarta international container terminal

Dwipoyono Bagus

WORLD MARITIME UNIVERSITY

Shanghai, China

ANALYSIS OF PROPER CAPACITY

AT JAKARTA INTERNATIONAL CONTAINER TERMINAL

By

BAGUS DWIPOYONO

Indonesia

A research paper submitted to the World Maritime University in partial fulfillment of the requirements for the award of the degree of

MASTER OF SCIENCE

INTERNATIONAL TRANSPORT AND LOGISTICS

2011

DECLARATION

I certify that all the material in this research paper that is not my own work has been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this dissertation reflect my own personal views, and are not necessarily endorsed by the University.

…………………….

Bagus Dwipoyono

…………………….

Supervised by

Professor Liu Wei

Shanghai Maritime University

Assessor

World Maritime University

Co-Assessor

Shanghai Maritime University

ACKNOWLEDGEMENT

I am thankful to the World Maritime University, Shanghai Maritime University and my company, Indonesia Port Corporation II for giving me this opportunity to study.

I am profoundly grateful to Prof. Liu Wei for all the times and guidance that he has given to me, from the beginning of this study, during the work, until the completion of this thesis. I also appreciate the kindness of Prof. Daniel Moon, who has given a lot of input in the beginning I started this research project.

I would like to thank Joint Educational Program Department staff and all my classmates for the guidance and assistant throughout the year I studied.

Last but not least, I am very grateful to my parents for their support and prayer. I am very grateful to my beloved wife for her patience and support especially for taking care of my children during me studied in Shanghai and also to my children for their understanding for not having a chance to play together during the year.

ABSTRACT

Title of Dissertation: **Analysis of Proper Capacity at Jakarta International Container Terminal**

Degree: **Master of Science in International Transport and Logistics**

As a facility with high capital investment, container terminal tends to be operated with maximum capacity by using high utilization of facilities and equipment rather than a proper throughput. However, a high utilization is leading to the ships waiting time and as consequence lowering the service level. Therefore a study is needed to determine the proper capacity by considering the interest of the two parties both the terminal operator who want to optimize the utilization of their facilities and the customer who want to minimize waiting time.

The research paper will study the impact of the number and utilization of facilities and equipment to the average number of ship served in the terminal and their average waiting time by using a queuing model. A statistical test is also conducted to examine the arrival rate and service rate pattern in the terminal which is required to define an appropriate queuing model. Furthermore, to accommodate the two interests of both terminal operator and customer, a total cost which is the combined cost between service cost and waiting costs will be analyzed to obtain the minimum cost.

The concluding chapter presents the optimum number and utilization of facilities and equipment should be used in the terminal to provide a proper container terminal capacity. A number of recommendations are made regarding the result of the study and the need to conduct further research in the subject.

KEYWORDS: proper container terminal capacity, queuing model, arrival rate pattern, service rate pattern, utilization, waiting cost, service cost.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

IT	Internal Trailer
JICT	Jakarta International Container Terminal
K-S Test	Kolmogorov Smirnov Goodness of Fit Test
LPC	Lift per Call
LOA	Length Overall
PCTC	Proper Container Terminal Capacity
QC	Quay Container Crane
RMGC	Rail Mounted Gantry Crane
RTG	Rubber Tire Gantr Crane
TEUs	Twenty Equivalent Units
XT	External Trailer

Chapter 1 INTRODUCTION

1.1. Background

Geographically, Indonesia is a country consisting of thousands of islands. As an archipelago country, Indonesia is strongly dependent on maritime transport. Indonesia's seaway transportation has very important role in connecting communities and transporting goods both for domestic and international trade. Therefore, seaport as multimodal interface between the sea and land transport is a critical infrastructure to ensure smooth flow of goods which has a direct impact on country welfare and economic development.

Tanjung Priok Port is a major gateway port with the largest and the busiest cargo traffic in Indonesia. The cargo in the port is dominated by containerized cargo which continues to grow rapidly. To handle this type of cargo there are several dedicated container terminals in Tanjung Priok Port. One of the largest terminals is Jakarta International Container Terminal (JICT) which serves as Indonesia's national hub port.

Due to efficiency reason, Indonesian Government is going to develop Tanjung Priok Port as an International hub port where through this port all of export and import cargo will be transported directly to and from its destination and origin. Currently most of export and import cargo from and to Indonesia will be transshipped first to an International hub port in other country such as Singapore and Malaysia.

This policy would impose a big challenge to JICT as the largest International Container Terminal in Indonesia. To be able to compete with the existing International hub port, it is required to provide a high level of service. One of the most important service level for the ship owner is ship turn round time in port. Hence, the terminal must perform with effective and efficient operation by minimizing waiting time of the ships and the cargo. Adequate capacity of facilities and equipment in the terminal is key factor to minimize the ship waiting time. As the containerized cargo traffic continue to grow, at a certain point its volume will reach maximum terminal capacity. When the maximum capacity is achieved by fully utilization of facilities and equipment, it will make the terminal unable to cope with the increasing cargo and will lead to traffic and port congestion. As a result, the terminal cannot compete in the business due to its low level of service and will loss the customer. This problem needs to be anticipated by careful and thorough planning and development of proper container terminal capacity (PCTC).

1.2. Research Problem

The objective of the container terminals management is to provide a sufficient terminal capacity where loading and discharging of containers can be handled with a minimum waiting time and a maximum efficiency. The capacity is limited by the number and utilization of the berths, container handling equipment, and stacking yards in the terminal. Thus, all of these facilities and equipment in the container terminal should be comprehensively analyzed to achieve a proper container terminal capacity. Inadequate facilities and equipment will give an impact for container terminal management and the ship owner. For container terminal, an excess in number and low utilization of facilities and equipment will cause uneconomic use of terminal resources which is provided with a high capital investment. Therefore, the terminal operator prefers to have a high throughput capacity using high utilization of facilities. However, a high utilization will cause unexpected ship waiting time and lowering the service level. As consequence, it will add the cost of ship due to a longer ship stay in the terminal which is undesired by the ship owners. Regarding this reason, ship owners prefer to have a lower throughput capacity in order to receive better service from the terminal.

To achieve a proper capacity by providing an adequate number of facilities and equipment with a proper utilization, the two conflict interests from container terminal views regarding the service facilities related cost and ship owner views regarding waiting time related cost should be considered in balance. In order to determine a proper capacity, the container handling activities in the terminal will be analyzed using mathematical model in queuing theory by considering arrival pattern of the vessels and service time rate.

1.3. Expected Contribution

The purpose of the study is to determine the proper terminal capacity at Jakarta International Container Terminal by providing an adequate number of facilities and equipment with an optimal utilization. Proper capacity enables the terminal to achieve minimum total cost which is resulted from the tradeoff between cost of waiting and cost of service facilities. Furthermore, with this optimum cost, the terminal management not only satisfies their own requirement to make the best use of their investment in terminal facilities but also meet ship owner requirement to minimize the waiting time. The study can be used by the terminal management as reference for a better capacity planning and development in order to catch the opportunities anticipating the rapid growth of containerization and to be able to compete in the business. The analysis in this study can support the container terminal management to appraise an investment plan in expansion of the terminal facilities and equipment.

1.4. Problem Limitation

As regards the research problem, some limitation is required to sharpen scope of the study and conduct the analysis specifically. The limitations of the study is explained as follows,

a. Object of the study is in Jakarta International Container Terminal specifically in Terminal II which is assumed only handle Full Container Load and there is no the transshipment container (due to the transshipment container is very small less than 3% of the overall Throughput).

b. Scope of container handling activities which is studied are started from the arrival of container ship in the terminal, loading/unloading operation, quay transfer operation, lift on/off at the container yard and ends with receiving/delivery operation in the container yard, without includes the gate operation.
c. Terminal facilities and container handling equipment which will be analyzed are berth, container yard, Quay Container Crane, trailer and Rubber Tire Gantry Crane.
d. The primary data for this study is collected from several institutions base on the data in the year of 2010.
e. Cost analysis of the vessels and containers is conducted base on an approach of a sample of data.
f. Due to the limitation of time, the study is carried out without taking into account the forecasting of container traffic flow future demand.

1.5. Structure of Thesis

Aiming to explain the study in a systematic order the thesis will be presented in the following chapter,

Chapter 1 INTRODUCTION

The thesis is initiated by the introduction which will describes the background of the study, statement of research problem, the expected contribution and the limitation of the problem.

Chapter 2 LITERATURES RIVIEW & CONCEPTUAL FRAMEWORK

Aiming to carry out a comprehensive analysis, in this chapter the discussion will continue to present several literatures and findings related to this research. Referring to this review then will be developed a conceptual framework for the study.

Chapter 3 RESEARCH METHODOLOGY

This chapter presents a detail explanation for several methods which will be applied in this research both in quantitative and qualitative method.

Chapter 4 DATA COLLECTION

This chapter presents collection of data both general description of the research object, that is Jakarta International Container Terminal and specific data required in this research which consist of quantitative data in container handling activities and data related to the cost of terminal facilities and equipment, ship and cargo.

Chapter 5 ANALYSIS

The analysis of the data collected from the field research is presented in this chapter, focusing on the analysis of arrival rate and service rate pattern in the container terminal, queuing model for several container handling operation, the total cost model and proper terminal capacity.

Chapter 6 CONCLUSION & RECOMMENDATION

Finally, this chapter will present brief conclusion which can be drawn from this research and suggest some recommendations.

Chapter 2 LITERATURE REVIEW & CONCEPTUAL FRAMEWORK

To support this research, in this section will be presented some literatures related to container terminal operation. Following, another related previous research topics, namely container terminal operation, container terminal capacity, and application of queuing theory in container terminal activities will be discussed as reference. Finally, a conceptual framework of this research will be provided to describe how this project will be done.

2.1. Container Terminal Operation

Container terminal has a critical function in the logistics chain. Kozan (1997) define a container terminal as a point where containers are moved from one mode of transport to another. Its function as interface has an important role to ensure the containers flows efficiently between modes of transport. An overview of container terminal operation is started by two main literatures, namely Vis and de Koster (2003) and Steenken et al. (2004). Vis and de Koster (2003) explain the main logistics processes in container terminals while Steenken et al. (2004) presents an overview of optimization methods in container terminal operations.

As a complex system, operation in a container terminal can be divided into two sides, quay side and land sides as described in figure 2.1. On the quay side there is ship-to-shore operation which associate with a process of discharging or loading containers from a ship to the quay or vice versa by using Quay Cranes (QCs). On the land side there are three subsystems, i.e. transfer operation, storage and receiving/delivery. For import/inbound containers, after being discharged from the ship, the containers then transferred from the apron to the stacking yard. This transfer process is called transfer operation and commonly handled by transfer equipment such as internal trailers or straddle carriers (SCs). If trailer is used for transfer process, by using yard cranes which may be Rubber Tire Gantry Cranes (RTGC) or Rail Mounted Gantry Cranes (RMGC), in the stacking yard the containers will be lifted off from the trailer and temporarily stored at designated stacking lane. While if transfer process is handled by Straddle Carrier, it can also store the containers in the stacking yard by itself. After stored for a certain period, the containers will then be retrieved from the stacking yard by using cranes and delivered for the next journey by other modes of transport such as external trucks, trains or barges, whereas in transshipment containers will exchanged between mother vessels and feeders. The same process in opposite order is also happened for export/outbound containers that will be loaded onto the ship.

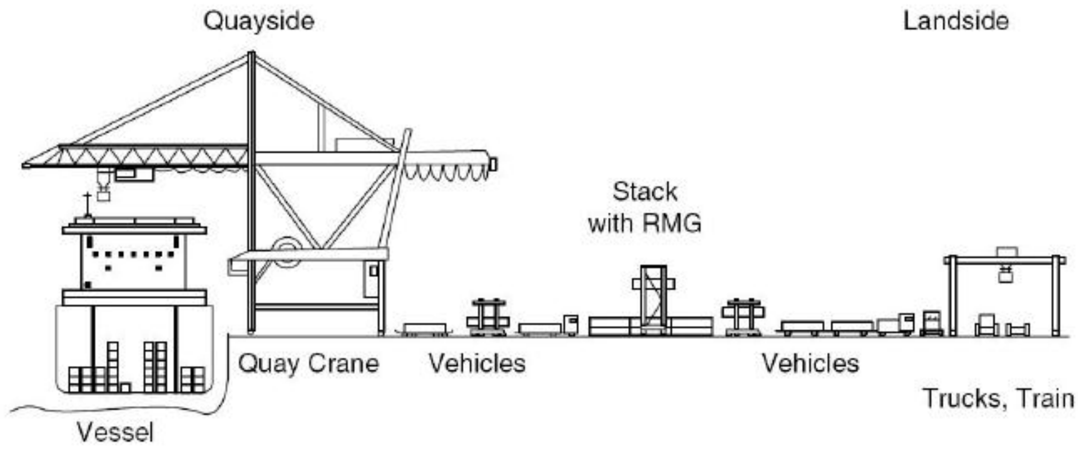


Figure 2.1 - *Schematic representation of a container terminal*

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

In order to maintain the logistics process in the container terminal flows efficiently, all sub systems in the terminal which is interdependent each other should be executed simultaneously with balance operation. Certainly, it is needed a decision support for each sub system problems and many studies in operation research have been done to solve it. Stahlbock and Voß (2007) and Vacca et al. (2010) have analyzed various operation research literatures in optimization of the container terminal operation as presented in the following.

Aiming to provide a more detail and accurate analysis, some researchers are focusing their research only on a single specific problem. Daganzo (1989), Lim et al. (2004), Kim and Park (2004), Moccia et al. (2006), Sammarra et al. (2007) and Lee et al. (2008) carry out a study focusing on the quay crane scheduling problem. While on berth allocation problem, Lim (1998), Imai et al. (2001), Imai et al. (2003), Kim and Moon (2003), Cordeau et al. (2005), Imai et al. (2005), Monaco and Sammarra (2007), Imai et al. (2008) and Imai, Nishimura, Hattori and Papadimitriou (2007) and Dai et al. (2008) conduct a research with different scenarios. Kozan (2000), Liu et al. (2004), Cheng et al. (2005), Vis et al. (2005), Lee et al. (2007) focusing their work in transfer operations. Furthermore, Kim and Bae (1998), Kim and Kim (1999), Kim and Kim (2002), Kim et al. (2000), Kim et al. (2003), Kim and Park (2003), Ng and Mak (2005), Ng (2005), Kim and Hong (2006), Kim and Lee (2006), Kang et al. (2006), and Yang and Kim (2006) specialized their research in yard operations.

Due to each sub system in the container terminal operation affects each other, some researchers try to combine the optimization problems and provide an integrated solution. Park and Kim (2003), Meisel and Bierwirth (2006), and Imai, Chen, Nishimura and Papadimitriou (2008), Giallombardo et al. (2010), and Bierwirth and Meisel (2010) combine the berth allocation and quay crane scheduling problems. In other area, Bish et al. (2001), Kozan and Preston (2006), and Lee et al. (2009) conduct a study to combine yard block allocation and container transfers problems. Goodchild and Daganzo (2006), and Goodchild and Daganzo (2007) carry out an integrated research on the impact of double cycling quay cranes on loading/discharging operations. Finally, a research on integrated scheduling of handling equipment in a container terminal is conducted by Chen et al. (2007) and Lau and Zhao (2007).

Although consisting of several subsystems, a container terminal should be viewed as a whole system rather than the individual subsystems. In order to imitate the interaction between a complex processes in the containers terminal, some researchers propose an optimization study using simulation and queuing theory in complete terminals operation. Gambardella et al. (1998), Maione and Ottomanelli (2005), and Henesey (2006) develop a simulation model for a whole system in the container terminal to optimize the flow of containers. While Legato and Mazza (2001) and Canonaco et al. (2007) propose a simulation model for integrated berth planning.

2.2. Container Terminal Capacity

A container terminal are required to have enough facilities such as berths, stacking yards, gates, and various handling equipment such as quay cranes, transfer vehicles and yard cranes. The requirement of these resources is different for every terminal depends on its own scale of business which can be measured by the ship's calling frequency and the container volume. All of these resources will limit the capacity of the terminal. Huang et al. (2008) define a container terminal capacity as the throughput level beyond which the terminal cannot sustain operations because of either of the overflow of containers at the yard exceeds certain acceptable levels, or the Berth-On-Arrival (BOA) rate drops below the target percentage. In another expression, Ding (2010) defines container terminal capacity as the maximum theoretical throughput, which is limited by the capacities of the berths, equipment, stacks and transportation.

Insufficient capacity will cause a major problem in a container terminal operation. Hence, Ng and Wong (2006) state that the container terminal capacity is crucial in planning and designing a container terminal. The objective of container terminal planning is to establish a proper container terminal throughput capacity (PCTC) which is defined by Moon (2010a) as a handling capacity to cope with incoming containers with no congestion which leads to the port with competitive edge.

Henesey (2006) describes a relation of each subsystem capacity in the terminal as shown in figure 2.2. Container terminal consists of four main sub systems i.e. ship-to-shore operation, transfer operation, storage and receiving/delivery. These subsystems are interrelated so that the effectiveness of one subsystem will affect the performance of the other subsystem. The PCTC is a combine capacity of the berth capacity, transfer capacity, yard (storage) capacity, and gate (receiving/delivery) capacity. Whichever capacity is lower which commonly known as bottleneck is considered as PCTC. When the storage capacity and the gate capacity are sufficient enough, the PCTC will mainly be determined by the berths capacity and transfer equipment.

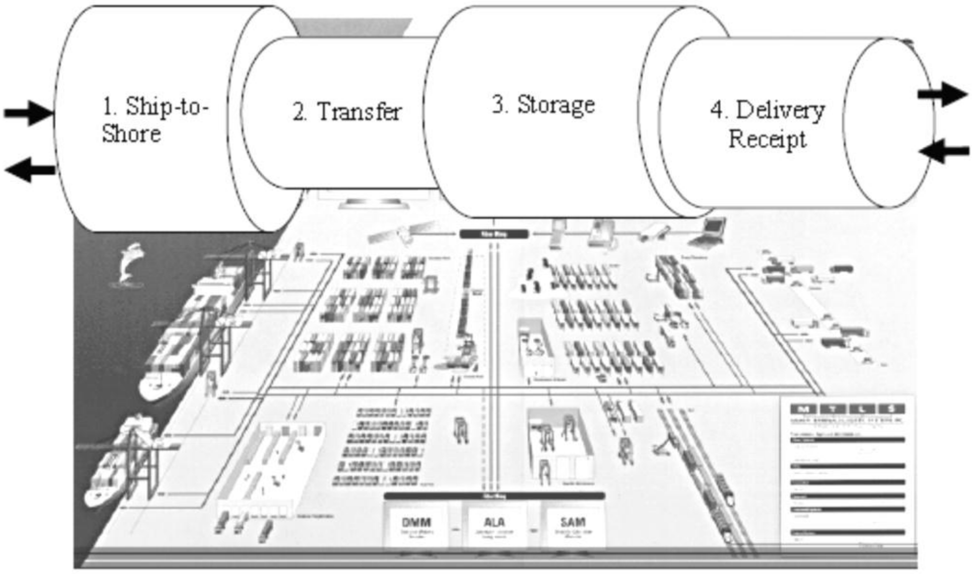


Figure 2.2 - Diagram of Container Terminal Subsystems (Henesey, 2006) Source : Henesey, L. (2006). *Multi-agent Container Terminal Management*, PhD thesis, Karlshamn, Blekinge Institute of Technology.

Moon (2010a) notes there are basically two methods for calculating PCTC, i.e. traditional method and simulation method. Traditional method uses UNCTAD mathematical formulation by comparing berth capacity with yard capacity. Other mathematical model that can be used is queuing theory by considering the distribution of ship's arrival and service time. While, Simulation method is used to emulate complexity of container terminal characteristic such as capacity of container yard (CY), gate and future lift per call (LPC) i.e number of loading and unloading container per ship which is not taken into consideration in traditional method.

Furthermore, simulation model can also capture the essential interactions among the container terminal subsystems (Huang, 2008).

A container terminal throughput capacity can be calculated by using a formula focusing on berth capacity as used by Ding (2010),

$$CC = \alpha_1 . \alpha_2 . \alpha_3 . N . V_q . E_q . t \qquad (2.1)$$

where, C is the throughput capacity of a container terminal in a year (TEUs/year); α_1 is the conversion coefficient of TEU per Move which effected by the types of the containers; α_2 is the rate of the quay cranes in good condition; α_3 is the ratio of terminal operation time per day (hours/day); N is the total number of the quay cranes at a container terminal; V_q is the utilization rate of the quay cranes; E_q is the average operation efficiency of quay cranes (Moves/hour); t is the total terminal operation hours in a year.

Related to the yard capacity, Dally (1983) propose a formula to calculate the throughput capacity of a container yard as follow,

$$CC = \frac{Tgs . H . U . K}{DT . PF} \qquad (2.2)$$

Where CC is yard throughput in a year; Tgs is total ground slot; H is average stacking height; U is land utilization ratio; K is service days of the yard, usually 365 days; DT is dwell time of containers; PF is peaking factor.

Many studies have been conducted for estimating the optimum terminal capacity and the optimum number of terminal facilities. Kim and Kim (1998) propose an optimization model to determine the container yard space and the number of transfer cranes in a container terminal. Zhang *et al.* (2003) work on storage space allocation by considering all container terminal resources. Murty *et al.* (2005) propose a decision support system for container terminal operation to optimize the use of resources and minimize vessels berthing time and waiting time. Imai (1997), Imai (2001) and Nishimura (2001) work on berth allocation for incoming ships by considering the optimal utilization of the berth. Liu et al. (2002) develop a simulation model in order to evaluate an automated container terminal performance. Yamada et al. (2003) develop a mathematical model with the queuing theory for determining optimal container handling systems in order to minimize the total cost incurred in a container terminal. Ding (2010), use a simulation model to estimate the throughput capacity in a container terminal by considering vessels arrival pattern which influence the utilization rates of the berth and quay cranes.

2.3. Queuing Theory

Queuing theory is a branch of applied probability theory which can be used to design a system that enable organizations to perform optimally according to some criteria such as maximum profits and desired service level (Moon, 2010b). Queuing models provide a tool to understand and quantify the effect of variability in arrival and service processes in the system. A queuing system consists of several elements, i.e. input source, arrival pattern, queue discipline, queue length, service pattern and output as described in figure 2.3. Input source is related to the sequence of request

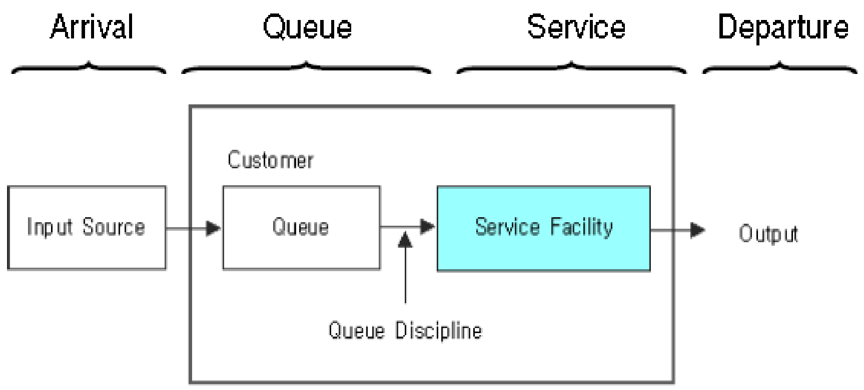


Figure 2.3 - General Structure of Queuing System

Source: Moon, S. H. (2010b). Port Logistics (Queuing Theory), Unpublished lecture handout, WMU, Malmo, Sweden.

for service, often specified in terms of inter-arrival time. Queue discipline is disposition of customers who find all servers are busy which may leave the system immediately, wait for service in a queue (FIFO, LIFO, etc.) or wait for service in a queue for a certain time. Service facility is related to the number of servers and service time.

Kendall introduced a notation to characterize this queuing system using the format of A/B/m/N–S (Willig, 1999, p.5). Where A is arrival distribution, B is service time distribution, m is number of servers, N is maximum size of the waiting line (means unlimited if notation omitted) and S is queue discipline (means FIFO if notation omitted). The arrival and service time distribution can be notated with one of the following, M (Markov) for exponential distribution, D (Deterministic) when all customers have the same value, G (General) for general distribution, E_k (Erlang–k) for erlangian distribution or H_k (Hyper-k) for hyper-exponential distribution.

Queuing theory is one of the most useful tools for analyzing the behavior of ships waiting by investigating the components of a multiple operation system (Branislav and Nam, 2006). Vessels arrive at port with a random pattern. After arriving they may be berthing directly to a berth or have to wait until a berth becomes empty. This random pattern is also occurred for vessel service time in a berth which depends on lift per call (number of loading and unloading cargo per ship) and the capacity of facilities. Since the ship arrivals occurs randomly and independently of other arrivals (pass arrivals do not influence future arrivals), Tadashi (2003) approximates the arrival pattern of ships by a poisson distribution. In other study, El-Naggar (2010) also describe the ships inter arrivals time at a sea port follows a negative exponential distribution which means that the number of arrival has a poisson distribution, and berth service time is approximated by exponential distribution. Hence, a queuing model of M/M/k can be applied to analyze the ships behavior in a port. It means that a queuing system has a poisson arrivals, exponential service times, and k unit servers. For this model, the operating characteristics are as follows:

$$P_0 = \frac{1}{\sum_{n=0}^{k-1}\frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n + \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k\left(\frac{k\mu}{k\mu-\lambda}\right)} \tag{2.3}$$

$$W_q = \frac{\left(\frac{\lambda}{\mu}\right)^k \mu}{(k-1)!(k\mu-\lambda)^2} P_0 + \frac{1}{\mu} \tag{2.4}$$

$$L_q = P_0 \frac{\left(\frac{\lambda}{\mu}\right)^k}{k!} \frac{\rho}{(1-\rho)^2} \tag{2.5}$$

$$\rho = \frac{\lambda}{k\mu} \tag{2.6}$$

$$W = W_q + \frac{1}{\mu} \tag{2.7}$$

$$L = \lambda\left(W_q + \frac{1}{\mu}\right) = L_q + \frac{\lambda}{\mu} \tag{2.8}$$

Where,

λ	:	Average rate of arrival (no. of customers per unit time)
μ	:	Average rate of service (no. of customers per unit time)
s	:	Number of server
ρ	:	Utilization rate for each server
P_0	:	Probability that there are no customer in the system
L	:	Average number of customers in the system
L_q	:	Average number of customers in the queue
W	:	Average time a customer spends in the system
W_q	:	Average time a customer spends in the queue

Since port facilities are a high capital investment, port operator tends to fully utilize their terminal facilities. Consequently, as the ship call and cargo volume increase the terminal gets congested and ships and cargo have to wait for service which in turn lowering the level of service. For the customer side (ship owner) this occurrence is a lost because of ship waiting cost. On the other hand, providing the terminal facilities which enable the ships never have to wait for service is also an uneconomic and inefficient policy due to the waste of costly terminal facilities. Therefore, both interests from ship owner and terminal operator should be considered to calculate a

PCTC. To compromise these two opposing interests, a cost model which applying queuing theory would be a very useful approach. According to UNCTAD (1985) the total costs incurred by ships in terminal is found by adding together port costs for service and the cost of ship's time in terminal. Port service related costs consist of fixed component which is independent to the throughput such as investment costs of facilities and variable component such as including labor costs, fuel and maintenance costs. Meanwhile, ship's time in port related costs which occurred due to the time the ship spends at the berth and waiting for a berth. Alderton (2005) describe the relationship between level of service and total cost in a port queuing system. As shown in figure 2.4 the minimum total cost will be achieved when service cost and cost of ship's time reach a breakeven point.

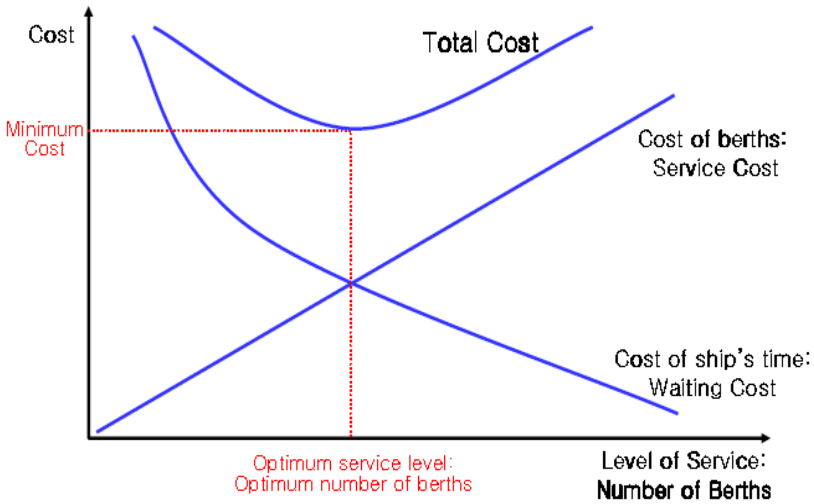


Figure 2.4 - Port Queuing System-related Costs

Source: Alderton, P. (2005). Port Management and Operations, Lloyd's Practical Shipping Guides, LLP (as cited in Moon, 2010b)

Noritake and Kimura (1990) employed queuing theory to estimate the optimum size of a seaport by considering the cost of the service facilities and the cost of ship staying in a port as formulated as follow,

$$TC = U_s \cdot \lambda \cdot (W_q + 1/\mu) + U_b \cdot N \quad (2.9)$$

Where U_s is the unit time cost of a ship's in port, λ is the average arrival rate of ships in port (ship/hour), W_q is the average waiting time of the ships, 1/μ is the average service time in the required period (hour/ship), U_b is the unit time cost of berths, and N is the number of berths at port, while the average berth occupancy ratio of the port system is notated as ρ.

2.4. Conceptual framework

According to the literature review, most of the studies pertaining to container terminal capacity focusing on one subsystem such as berth operation, transfer operation or stacking yard operation. Since the terminal consists of several sub system which is interrelated, this study try to analyze the proper capacity for all sub system in the terminal with the conceptual framework as shown in figure 2.5.

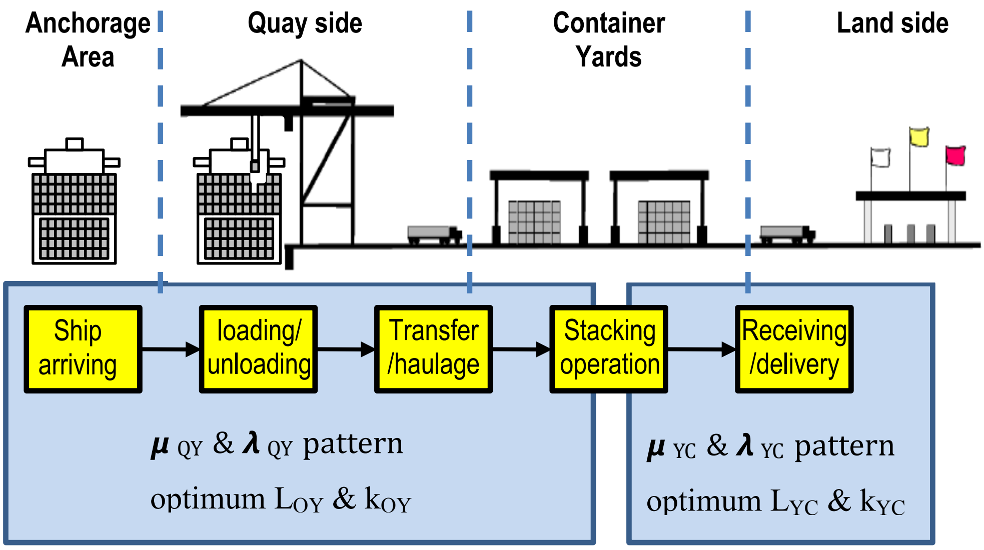


Figure 2.5 - Conceptual Framework of Port Queuing System

Source: author

In order to consider comprehensively all activities in the terminal, the analysis will be divided into two queuing subs system. The first sub system is the queuing model for container handling operation between the quay and the container yards. This sub system is started from the incoming container ships at the port anchorage area which then be berthed and the containers are unloaded at the quay. From the quay the container which has been put on the trailer then will be transferred to the stacking yard for temporary stacked and vice versa. Second sub system is the queuing model for receiving containers from the customer and delivery containers to the customer.

First, a queuing model for ship service at the berth will be studied in order to estimate the optimal number of berths (k_{QY}) should be provided in the terminal. This estimation is made by analyzing the ships arrival rate at the port in unit of ships per unit time (λ_{QY}) and ships service rate at a berth (μ_{QY}). Service time of ship at a berth consist of preparation time for loading/unloading operation after ship berthing, time for loading/unloading operation and preparation time before ship un-berthing. Time required for unloading and loading the ship depends on set of equipment used in operation between the quay and stacking yard i.e. ship operation (loading/unloading) by using Container Crane, haulage (Quay Transfer Operation) by using trailer and stacking yard operation by using Rubber Tire Gantry and the balance amongst these equipment. Due to this reason, in this sub system we need also to analyze the proper number of equipment set should be deployed. By using a queuing model, the number of ships in the port (L_{QY}) will be calculated for several numbers of berths (k_{QY}) and several number of equipment sets. At last, a minimization cost model will be applied for several estimated L_{QY} to determine the optimal number of the berth (k_{QY}).

Secondly, a queuing model for container handling activities between the yard and the customer (receiving/delivery) will be analyzed to estimate the optimal number of handling equipment for receiving/delivery activities (k_{YC}). This estimation is made by analyzing the arrival rate of export container received from the customer and import container delivered to the customer (λ_{YC}) and service rate for receiving/delivery activities (μ_{YC}). Then, by using a queuing model, the number of containers in receiving/delivery operation sub system (L_{YC}) will be calculated for several number of handling equipment (k_{YC}). Finally, a minimization cost model will be applied for several estimated L_{YC} to determine the optimal number of handling equipment for receiving/delivery activities (k_{YC}).

This conceptual framework is developed in order to answer the following question,

1) What is the arrival pattern and service rate of the ships and the containers?
2) What is the effect of several numbers of facilities and equipment to the number of ship and container queuing in the port?
3) What is the proper utilization of facilities and equipment in the terminal?
4) What is the optimal requirement of terminal facilities and handling equipment to provide a certain level of service?
5) What is the proper terminal capacity?

Chapter 3 RESEARCH METHODOLOGY

The methodology of this study is basically divided into several stages. First is a test of arrival pattern and service pattern at the container terminal to determine the type of queuing model will be used. Then, by using the queuing model can be calculated the number of units waiting in the system which will function as input variable to calculate total waiting cost. Analyzing of an appropriate composition of the number of equipment is also conducted in order to ensure the balance amongst container handling operation. Based on the calculation of waiting cost and the cost of port services which is the input of the minimum total cost model, can be determined number of optimal facilities and equipment. Generally, description of the stages of problem solving can be seen in the figure 3.1.

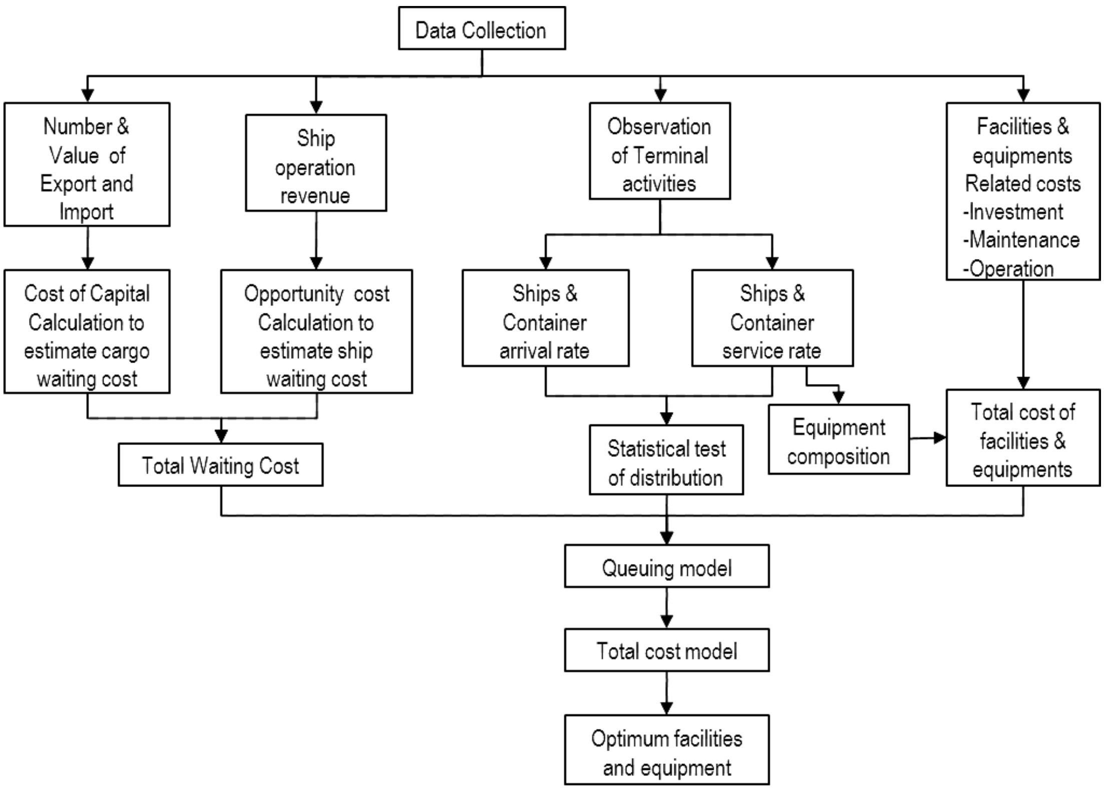


Figure 3.1 - Research Methodology

Source: author

3.1. Arrival Pattern and Service Time Pattern

The first step in this study is to analyze arrival pattern and service time pattern in the container terminal. The analysis will be conducted using several statistic tools as explained in the following section.

3.1.1. Histogram

After the data of time between arrival and service time is collected, it is then presented into a histogram. The Histogram will show a frequency distribution of these set of data as a bar chart. The width of each bar is constant and represents a fixed range of data (called a cell, bin or class). The height of each bar is proportional to the number of data within that bin.

The histogram is formed with the following steps (Calyampudi *et al.*, 2005, p.231):

a. Determine the number of bins (k) which can be calculated using the *Sturgess Rule* with the formula:

   $$k = 1 + \log_2 n \qquad (3.1)$$

   Where n is the number of data observations.

b. Determine the bin width (h) by dividing the difference between maximum and minimum value by number of bins, with the formula:

   $$h = \frac{x_{max} - x_{min}}{k} \qquad (3.2)$$

c. Tabulate the frequency of data in each bin.

3.1.2. Kolmogorov Smirnov Goodness of Fit Test (K-S test)

Determination of the appropriate queue model depends on the arrival pattern and service time patterns. Therefore, before determining the queuing model, firstly conducted testing on frequency distribution of arrival and time of service.

The test of frequency distribution is conducted by using Kolmogorov Smirnov Goodness of fit test (K-S test) which can be explained as follow (Rajagopalan, 2006, p.197):

a. Aim

To test the population distribution F(x) be regarded as $F_0(x)$, based on a random sample.

b. Source

Let X_i, (i = 1,2,…,n) a random sample of n observations be drawn from a population. Let $F_0(x)$ be the cumulative distribution function (CDF) of a specified (given) population.

c. Hypothesis

H_0: the population distribution F(x) is $F_0(x)$, $F(x) = F_0(x)$

H_1: the population distribution F(x) is not $F_0(x)$, $F(x) \neq F_0(x)$

d. Level of significance (α) and critical value (D_α)

The critical value D_α for the level of significance α and the sample size n more than 35 is obtained from the table 3.1.

Table 3.1 - Critical values of the Kolmogorov-Smirnov Test Statistic

Sample Size (n)	Level of Significance α for $D = \max \mid F_0(X) - F_n(X) \mid$				
	.20	.15	.10	.05	.01
Over 35	$\frac{1.07}{\sqrt{n}}$	$\frac{1.14}{\sqrt{n}}$	$\frac{1.22}{\sqrt{n}}$	$\frac{1.36}{\sqrt{n}}$	$\frac{1.63}{\sqrt{n}}$

Source : Rajagopalan, V. (2006). Selected Statistical Tests

e. Method

1) Calculate the cumulative distribution $F_0(x)$ base on the sample observations and the specified (given) population distribution.
2) Obtain the cumulative distribution of the sample, $F_n(x)$ be the empirical distribution function, $F_n(x)$ = (Number of observations $X_i \leq x$)/n.
3) Find the absolute difference $\mid F_0(x) - F_n(x) \mid$

f. Test Statistic

$D = \text{maximum} \mid F_0(x) - F_n(x) \mid$ (3.3)

g. Conclusion

If $D \le D_\alpha$, accept H_0 and If $D > D_\alpha$, reject H_0 or accept H_1

3.1.3. Frequency Distribution

Frequency distribution which is tested to determine the queuing model is poisson and exponential distribution. The arrival of ships and containers is assumed to follow the poisson distribution or exponential distribution for their time between arrival while the service time follows exponential distribution.

The probability density function (pdf) for poisson distribution is obtained by using the formula:

$$f(x) = \frac{\lambda^x . e^{-\lambda}}{x!} \quad (3.4)$$

Where,

f(x) : probability density function of ships or containers arrival

x : 0,1,2,3, …

$\boldsymbol{\lambda}$: average arrival of ships or containers per unit time ($\boldsymbol{\lambda}>0$)

While the probability density function (pdf) for exponential distribution is obtained by using the formula:

$$f(t < x \le T) = \left| e^{-(\frac{t}{m})} - e^{-(\frac{T}{m})} \right| \quad (3.5)$$

Where,

$f(t<x\le T)$: probability density function for service time or time between arrival from t to T.

m : average service time or time between arrival

3.2. Queuing Model

If the hypothesis that the arrival pattern follows a poisson distribution dan the service time follows an exponential distribution is accepted, it can be known that the queuing model that fits in this study is a queuing model with poisson distributed arrival rate and exponentially distributed service time (M/M/s). To apply this queuing model it is necessary to make assumptions as follows:

1) Service is performed with First Come First Serve (FCFS) discipline.
2) Queuing system in steady state (stable), meaning that the distribution of arrival and service time does not change with a change in time.
3) Input resources and queuing size is not limited.
4) There are k units service facility, for k = 1 or k > 1.
5) Arrival rate $\boldsymbol{\lambda}$ < sevice rate $\boldsymbol{\mu}$ for number of service facility k = 1 and $\boldsymbol{\lambda} < k.\boldsymbol{\mu}$ for number of service facility k > 1.

There are three queuing systems will be analyzed in this research. Firstly, ship service at the berth. In the queuing model of ship service at the berth will be analyzed the container handling operation between the quay and container yard which consists of loading/unloading, haulage and lift on/off at the container yard since these three sub systems are inter-related and determine the length of time a ship will be served at the berth. Second is delivery operation i.e. arrival of trailer from the customer that will pick up import container from the stacking yard. Thirdly, receiving operation i.e. arrival of export container from the customer that will be grounded in the container yard.

3.2.1. Ships service at the berth

To describe queuing system of ships service at the berth can be used an illustration as shown in figure 3.2.

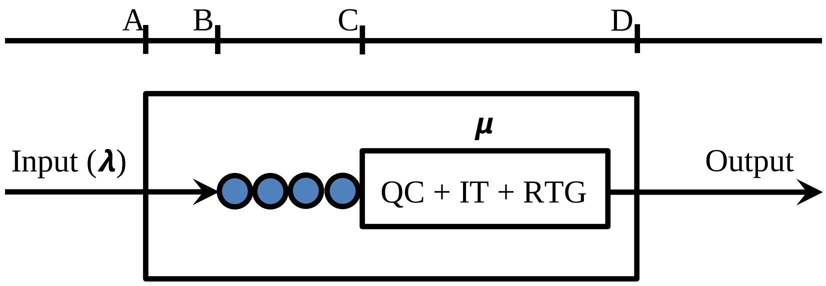


Figure 3.2 – Queuing system of ship service at a berth

Source: author

The element of ships arrival queuing system is explained as follow:

1) Point A is point where a container ship has arrived at the port anchorage area.
2) Arrival rate of ships (**λ**) is number of ships arrive at the port per unit time.
3) Point B is point where the ships are queuing to be served at a berth.
4) Ships time between arrivals is hypothesized to follow an exponential distribution or poisson distribution for their arrival rate.
5) Point C is the starting point of berth service which is recorded when the ship has been berthed.
6) Point D is the output when ship service at a berth has been completed which recorded when the ship has been un-berthed.
7) Service time of ship at a berth consist of preparation time for loading/unloading operation after ship berthing, time for loading/unloading operation and preparation time before ship un-berthing. Time required for unloading and loading the ship depends on set of equipment used in operation between the quay and stacking yard i.e. ship operation by using Container Crane (QC), haulage (Quay Transfer Operation) by using internal trailer (IT) and yard operation by using Rubber Tire Gantry (RTG) and the balance amongst these equipment.
8) Service time of ship at a berth is hypothesized to follow an exponential distribution.

3.2.2. Delivery Operation

To describe queuing system in delivery operation where external trailer (XT) arrives at the terminal to pick up the import container to the customer can be used an illustration as shown in figure 3.3.

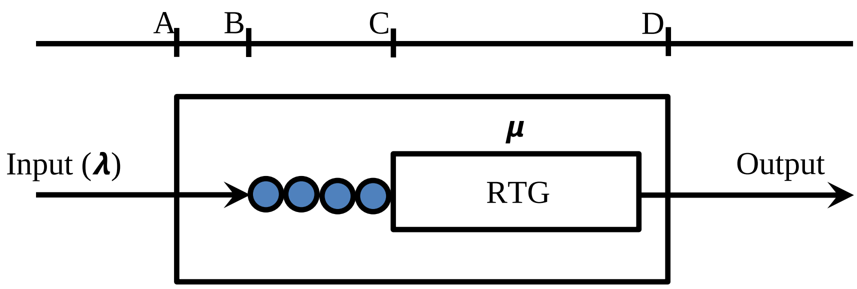


Figure 3.3 – Queuing system in delivery operation

Source: author

The element of queuing system in delivery operation is explained as follow:

1) Point A is point where container has already in the container yard.
2) Arrival of trailer (λ) is number of external trailers arrive in the terminal which will pick up the containers to the customer.
3) Point B is point where external trailers are queuing in the yard to be loaded with the container which will be delivered to the customer. From this point will be counted number of arrival trailers.
4) Time between arrivals of external trailers hypothesized to follow an exponential distribution or poisson distribution for their arrival rate.
5) Point C is the starting point of *service* when the import container is un-stacked from the yard then will be lifted on to the external trailer by using RTG.
6) Point D is the output when an import container has been lifted on to the external trailer and ready to be delivered outside the terminal to the customer premises.

7) Service time of picking up import container is counted from the time when the import container starts to be lifted from yard to the time when the container has been loaded to the external trailer or time between point C and D.
8) Service time of picking up import container is hypothesized to follow an exponential distribution.

3.2.3. Receiving operation

To describe queuing system in receiving operation where external trailer (XT) arrives at the terminal to deliver the export container which will be grounded in the yard can be used an illustration as shown in figure 3.4.

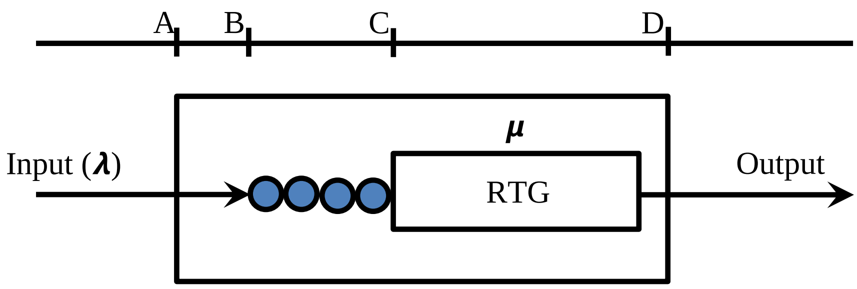


Figure 3.4 – Queuing system in receiving operation

Source: author

The element of queuing system in receiving operation is explained as follow:

1) Point A is point where external trailer which load an export container from the customer has already inside the container terminal gate.
2) Arrival of trailers (**λ**) is number of arrival of external trailers which load an export container from the customer.
3) Point B is point where externals trailer with their container are queuing in the yard before then the container will be lifted off from the trailer. From this point will be counted number of arrival trailers.
4) Time between arrivals of external trailer is hypothesized to follow an exponential distribution or poisson distribution for their arrival rate.

5) Point C is the starting point of *service* when the export container starts to be lifted off from the trailer then will be grounded in the yard by using RTG.

6) Point D is the output when an export container has been grounded in the container yard.

7) Service time of receiving export container is counted from the time when the export container starts to be lifted off from trailer to the time when the container has been grounded in the yard or time between point C and D.

8) Service time of receiving export container is hypothesized to follow an exponential distribution.

3.3. Total Cost Model

Minimum total cost model is one of the tools used in queuing model to determine the optimum level of service. Total cost is the resultant of the service costs provided by the container terminal and cost of losses suffered by port service user due to waiting for service. Improving service means less waiting time, or vice versa. The optimum level of service achieved under conditions where the total cost is obtained at a minimal point. Total cost of service and waiting costs as a function of the level of service is shown in Figure 3.5.

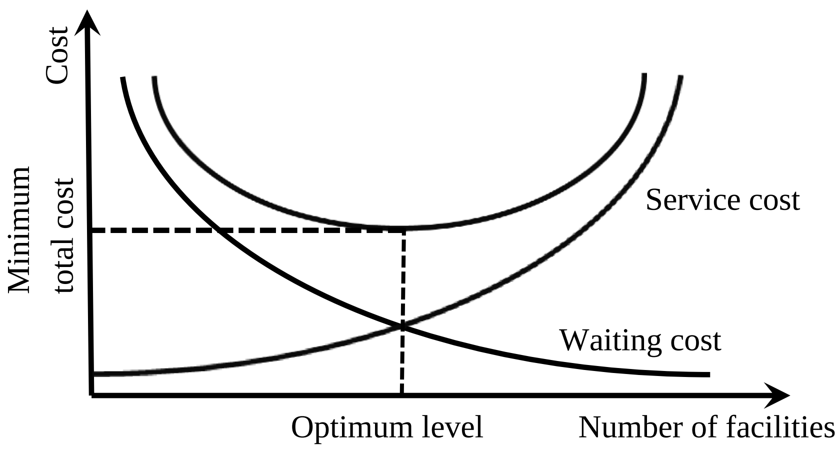


Figure 3.5 – Total Cost Model

Source: Author

3.3.1. Cost of waiting

The calculation of waiting cost is approached with the cost of cargo and ship.

3.3.1.1. Cargo Cost

The cargo congestion cost consisting of goods opportunity costs and economic depreciation which is calculated by the formula:

$$CC = \frac{GV.(OC+ED)}{365} \tag{3.6}$$

Where:

CC : cargo congestion costs

GV : goods value which is the price of goods for import and export

OC : opportunity cost, typically 3%-4% per year (Notteboom, 2006, p.19-39).

ED : economic depreciation, typically 20%-30% per year (Notteboom, 2006, p.19-39).

3.3.1.2. Ship Cost

Approach used in this research to calculate the cost of the ship is the opportunity cost of the ship. Opportunity cost of the ship is revenue that would be obtained if the ship sailed, calculated by the formula:

SOP = R / SD (3.7)

Where:

S : ship opportunity cost

R : ship revenue

SD : number of sailing days in a year

3.3.2. Cost of Service

Cost of service is cost incurred by the container terminal to provide services to the ships and containers. The amount of service costs depend on the number of facilities and equipment provided to handle the ships and containers in the terminal.

3.3.2.1. Number of Facilities and Equipment Required

Inventory of existing facilities and equipment is first conducted then the number of facilities and equipment required is determined by the following steps.

3.3.2.1.1. Berth

Number of berth required is determined by using the queuing model of ships arrival in the terminal which considers the number of ship waiting. Length of a berth is determined by the longest ship size served in the terminal.

3.3.2.1.2. Container yard

The size of container yard which is represented by the total number of container in TEUs which can be stack in the ground (Total Ground Slot) is calculated by Dally (1983) formula as follow:

$$TGS = \frac{CC.DT.PF}{H.U.K} \tag{3.8}$$

Where:

TGS : total ground slot

CC : yard throughput in a year

DT : dwell time of containers

PF : peaking factor

H : average stacking height

U : land utilization ratio

K : service days of the yard, usually 365 days

3.3.2.1.3. Container handling equipment

A set of container handling equipment used in the container terminal consists of quay crane (QC) for loading/unloading operation, trailer (TR) for haulage /quay transfer operation and rubber tire gantry crane (RTG) for stacking/un-stacking in the yard. Concept of man and machine process chart will be adopted to analyze a proper composition of this equipment in order to minimize idle time and as consequence gives a high utilization of the equipment. Manek (2003, p.56) explains man and machine process chart as a special type of multiple activity chart in which the activities of the different operatives and machines are recorded in terms of working time and idle time. However, in this research instead of man and machines, the author will analyze the activities amongst handling equipment. The step is to define activities involved during the operation and to indicate it on chart. The activities are classified in three categories:

1) Independent activities when equipment is working independently such as in haulage activity by internal truck/trailer.
2) Combined activities when both equipment are involved in working on a job such as in loading/unloading both quay crane and trailer are involved and in lift of/on both yard crane and trailer are involved.
3) Idle when equipment is waiting for other equipment to complete their work..

The activities are shown by following symbols on chart:

Independent activities

Combined activities

Idle time

3.3.3. Total Cost

Total cost model used in this study is formula proposed by Noritake and Kimura (1990) which employed queuing theory to estimate the optimum size of a seaport by considering the cost of the service facilities and the cost of ship staying in a port as formulated as follow,

$$TC = U_s \cdot \lambda \cdot (W_q + 1/\mu) + U_b \cdot N \tag{3.9}$$

Since $L = \lambda \cdot (W_q + 1/\mu)$ the formula can be simplified as

$$TC = U_s \cdot L + U_b \cdot N \tag{3.10}$$

Where :

U_s : the unit time cost of a ship's in port

λ : the average arrival rate of ships or containers

W_q : the average waiting time of the ships or container

$1/\mu$: the average service time in the required period

U_b : the unit time cost of facilities or equipment

N : the number of facilities or equipment

L : the average number of ships or container in the terminal

Chapter 4 DATA COLLECTION

Data collected in this research consists of both quantitative and qualitative data. All of these data is collected by conducting field observation and collecting sample data from Jakarta International Container Terminal to study the process of container handling activity, and collect the data of ships arrival pattern, service time rate, facilities and equipment used in the terminal. Furthermore, data collection is also conducted from several companies/institutions such as Indonesia Central Bureau of Statistics to collect the export and import value, shipping companies to collect the data of ship revenue and trucking company to collect the cost of trucking. The result of data collection will be presented in detail this chapter.

4.1. Company Overview

Jakarta International Container Terminal (JICT) is located in Tanjung Priok, Indonesia's largest sea port. It is jointly owned by state-owned port operator, Indonesia Port Corporation II (PT Pelindo II) and Hong Kong-based leading port operator Hutchinson Port Holdings. JICT is the largest container terminal in Indonesia which serves as national hub port and a gateway to Jakarta and industrial heartland of West Java.

JICT is committed to providing fast, efficient and reliable services 24 hours a day, all year round. It has served more than 20 shipping lines with direct routes to more than 25 countries. To ensure the quality of its services, JICT is also accredited to ISO 9002 standards. Through the dedication of its workforce and the application of the latest cutting edge technology and equipment, in May 2001 JICT received an Asian Freight and Supply Chain Award (AFSCA) as the best container terminal with less than four million twenty-foot equivalent units handling capacity.

4.1.1. Terminal Facilities and Equipment

As the largest container terminal in Indonesia, JICT covers a total of 100 hectares which consists of 2 terminals T1 and T2 as shown in figure 4.1.

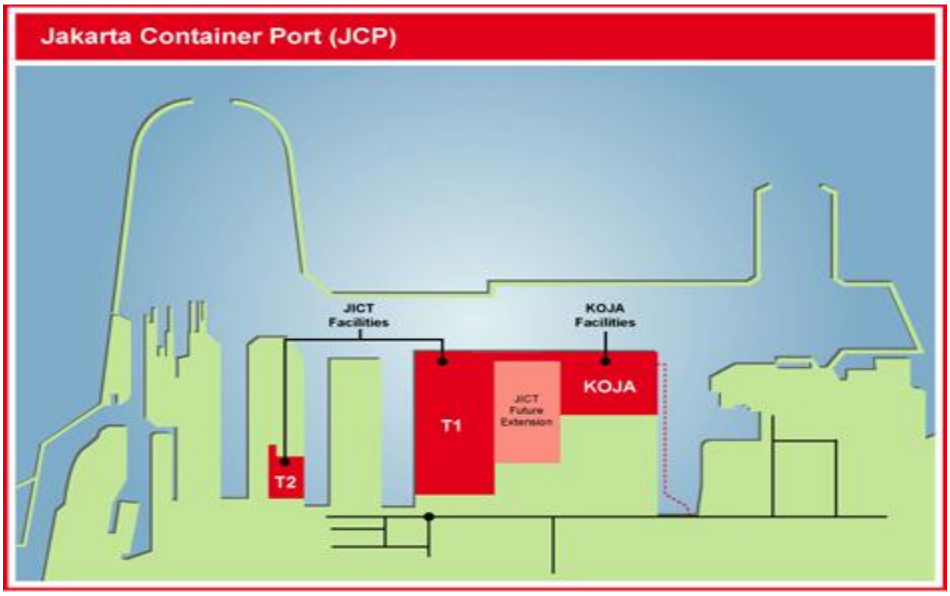


Figure 4.1 – JICT Terminal Layout

Source: http://www.jict.co.id/en/content/terminal-layout

JICT provides container terminal handling facilities and equipment to handle more than 1.7 million TEUs (Twenty foot Equivalent Units) with the list as presented in table 4.1.

Table 4.1 – Terminal Facilities and Equipment

Description	Terminal I	Terminal II	Total
I. Berth			
- Length	1690 m	510 m	2150 m
- Width	26.5 - 34.9 m	16 m	
- Draught	11 - 14 m	8.6 m	
II. Container Yard			
- Area	36.90 Ha	9.24 Ha	46.14 Ha

Description	Terminal I	Terminal II	Total
III. Equipment			
- Quay Crane Container	14 Unit	4 Unit	18 Unit
- Rubber Tire Gantry Crane	45 Unit	11 Unit	56 Unit
- Head Truck	111 Unit	18 Unit	129 Unit
- Chassis / Trailers	128 Unit	19 Unit	147 Unit
- Spreader for QCC	20 Unit	5 Unit	25 Unit
- Spreader for RTGC	40 Unit	11 Unit	51 Unit
- Over High Frame	2 Unit	1 Unit	3 Unit

Source: http://www.jict.co.id/en/content/terminal-facilities

4.1.2. Operational Data

Operational data comprises containers traffic flow and ship call, container handling processes, ships and external trailer time between arrival at the terminal, container service time and other supporting data.

4.1.2.1. Container Traffic Flow

Container traffic flow at JICT has grown continuously with the average growth of 4% per year as presented in Figure 4.2. World economic downturn in 2009 has also a serious impact on container traffic at JICT. Loading and unloading volume dropped significantly from 1.050 million TEUs and 946 thousand TEUs in 2008 to 917 thousand TEUs and 758 thousand TEUs in 2009 or in overall there was a decrease by16%. Un-loading volume in JICT is bigger than loading volume with the average proportion of 53% and 47% respectively.

In term of ship calls, there was a little fluctuation in the number of calls annually as shown in Figure 4.3. The growth was smaller than container traffic growth with the average growth of 2% per year. In line with the decrease in containers volume in 2009, the numbers of ship calls were also dropped significantly from 1,852 ship calls in 2009 to 1,680 ship calls in 2008 or there is a decrease by 9%.

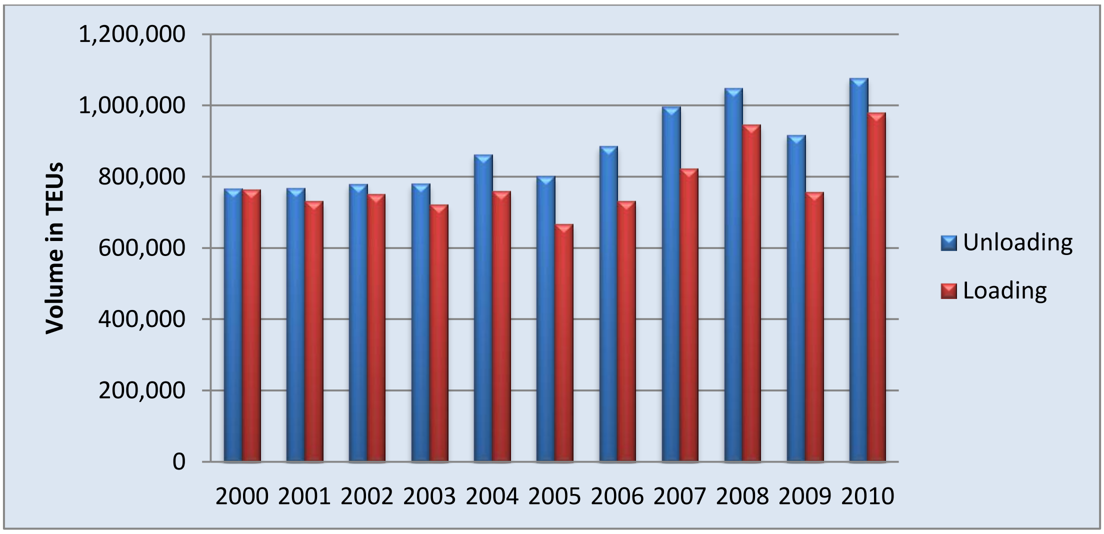


Figure 4.2 – Container Traffic in JICT from the year 2000 to 2010

Source: JICT

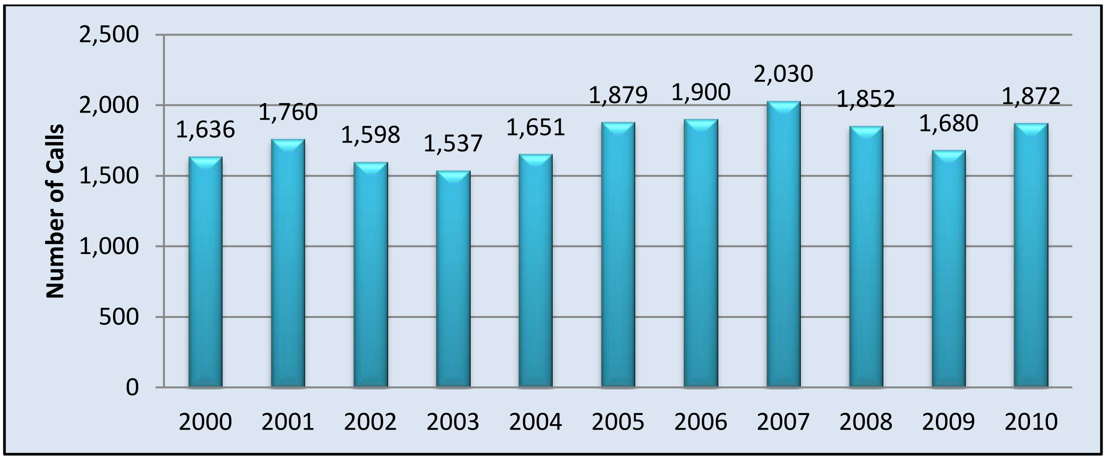


Figure 4.3 – Ship Calls in JICT from the year 2000 to 2010

Source: JICT

4.1.2.2. Container Handling Process

Container handling at the terminal consists of loading and unloading operation.
The process of unloading container from the ship to the terminal can be explained as follows:

a. Quay crane (QC) is prepared while waiting for the container ships that will be berthed at a berth and ready to be discharged.
b. Using quay crane container is unloaded from the ship and put onto the internal trailer (IT) which has lined up at the quay. This operation is commonly known as stevedoring.
c. Then, the container that has been on the trailer will be transferred to the stacking yard, which is commonly known as haulage or quay transfer operation.
d. Upon arrival at the stacking yard, the container is lifted off from trailer using rubber tire gantry crane (RTG) and then be grounded at the stacking yard for temporary storage.
e. After storage for a temporary period, the container will be lifted on onto the external trailer (XT) using rubber tire gantry crane (RTG) and then be delivered to the customer. This process is known as delivery operation.

While the process of loading container from the terminal to the ship in principle is the same as the process of unloading container but it is done in reverse order.

4.1.2.3. Ships and Containers Time between arrivals

Ships and containers time between arrival is collected from the data of terminal daily report during the year 2010 which then be processed using a spreadsheet.

4.1.2.3.1 Ship time between arrivals

Data ship time between arrivals is data of time interval between the arrivals of two ships. The following is a calculation example of ship time between arrivals:

a. Determine the number of bins (k) which calculated using the *Sturgess Rule* $k = 1 + \log_2 n$. Since the number of data observations is the number of ship calls in the year 2010 i.e 1,872 calls, thus the number of bins is
$k = 1 + \log_2 (1{,}872) = 11.8$.

b. Determine the bin width (h) by dividing the difference between maximum and minimum value by number of bins. From the data known that the minimum ship time between arrival is 0 minute and the maximum ship time between arrival is 31 minutes, thus the bin width is

$$h = \frac{31-0}{11.8} = 2.63$$

c. Having known the number of bins k and the bin width h then we tabulate the frequency of data in each bin interval with result as shown in table 4.2.

Table 4.2 - Distribution of Ship time between arrivals

Bin	Interval (hours)			Frequency
1	0.00	-	2.63	757
2	2.63	-	5.25	512
3	5.25	-	7.88	223
4	7.88	-	10.51	190
5	10.51	-	13.14	105
6	13.14	-	15.76	38
7	15.76	-	18.39	23
8	18.39	-	21.02	11
9	21.02	-	23.65	6
10	23.65	-	26.27	4
11	26.27	-	28.90	2
12	28.90	-	31.53	1
Average	4.68 hours			Σ 1872

Source: Author calculation base on terminal daily report during the year 2010

Base on the table then the histogram is made as presented in the figure 4.4.

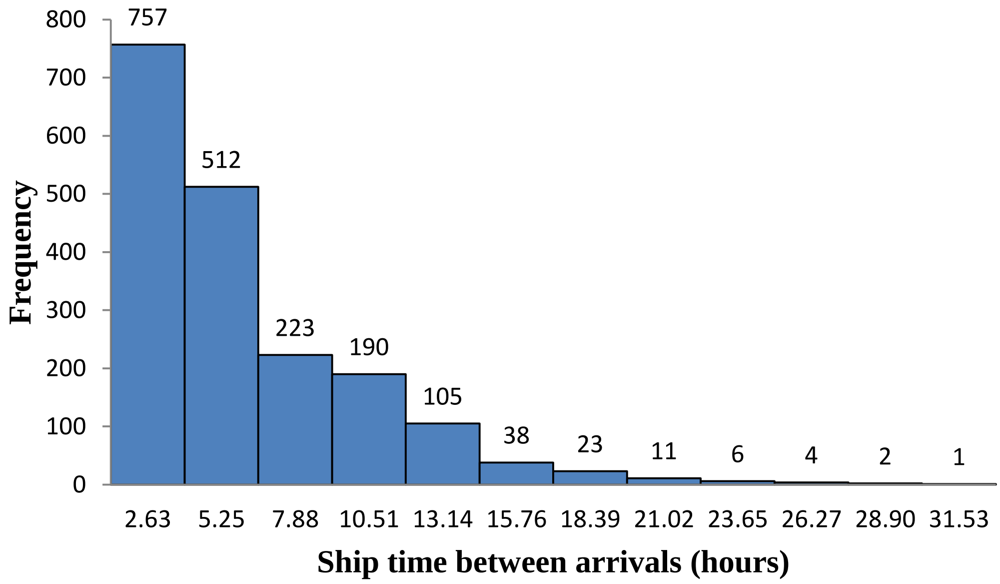


Figure 4.4 - Histogram of Ship Time between arrivals

Source: Author calculation base on terminal daily report during the year 2010

4.1.2.3.2. Time between arrivals of Trailer in Receiving Activities

The data of time between arrival of external trailer (XT) to deliver the export container which will be grounded in the stacking yard is taken from the daily report of average time between arrival of external trailers from the customer at the stacking yard. Using the same method as explained in the ship time between arrival calculations, the data of time between arrivals of external trailer in receiving activities is presented in table 4.3 and the histogram is shown in the figure 4.5.

Table 4.3 - Distribution of Time between arrivals of Trailers in Receiving Activities

Bin	Interval (minutes)			Frequency
1	0.00	-	0.66	179
2	0.66	-	1.31	103
3	1.31	-	1.97	34
4	1.97	-	2.62	22
5	2.62	-	3.28	11
6	3.28	-	3.93	6
7	3.93	-	4.59	4
8	4.59	-	5.25	2
9	5.25	-	5.90	3
10	5.90	-	6.56	1
Average	0.85 minutes			Σ 365

Source: Author calculation base on terminal daily report during the year 2010

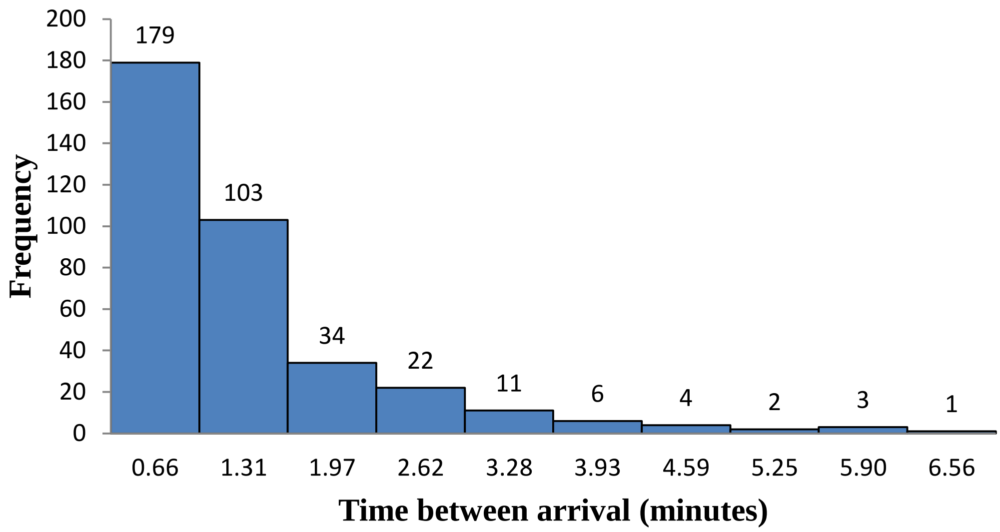


Figure 4.5 - Histogram of time between arrivals of trailer in receiving activities

Source: Author calculation base on terminal daily report during the year 2010

4.1.2.3.3. Time between arrivals of Trailers in Delivery Activities

The data of time between arrivals of external trailers (XT) in delivery activities is taken from the daily report of average time between arrivals of external trailers from the customer to pick up the import container at the stacking yard. The data of time between arrivals of trailers in delivery activities is presented in table 4.4 and the histogram is shown in the figure 4.6.

Table 4.4 - Distribution of Time between arrivals of Trailers in Delivery Activities

Bin	Interval (minutes)			Frequency
1	0.00	-	0.66	189
2	0.66	-	1.32	92
3	1.32	-	1.98	36
4	1.98	-	2.64	17
5	2.64	-	3.30	12
6	3.30	-	3.96	9
7	3.96	-	4.62	5
8	4.62	-	5.28	2
9	5.28	-	5.94	2
10	5.94	-	6.60	1
Average	0.75 minutes			Σ 365

Source: Author calculation base on terminal daily report during the year 2010

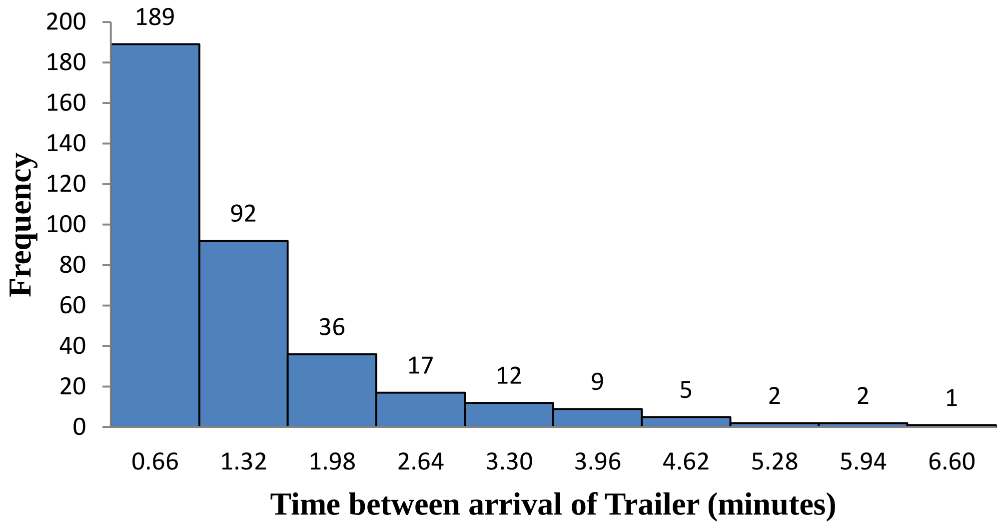


Figure 4.6 - Histogram of time between arrivals of trailers in delivery activities

Source: Author calculation base on terminal daily report during the year 2010

4.1.2.4. Container Service Time

Container service time consists of data of service time for loading/unloading operation by Quay Crane (QC), haulage operation by internal trailer (IT) and lift on/off in the stacking yard by Rubber Tire Gantry Crane (RTG). Unloading/loading service time is the time required by QC to lift a container from the ship and put onto the trailer or vice versa. Haulage service time is the time required by the trailer to transfer a container from the quay to the yard or vice versa. Lift off/on is the time required by RTG to lift a container off from the trailer and grounded at the stacking yard or vice versa. All of these data is collected from the average performance of equipment which is recorded in the terminal daily report. The service time of loading/unloading operation, haulage and lift on/off is shown in table 4.5, 4.6, 4.7, respectively and the histogram is presented in figure 4.7, 4.8, 4.9, respectively.

Table 4.5 - Distribution of Loading/unloading Service Time

Bin	Interval (minutes)			Frequency
1	0.77	-	1.28	166
2	1.28	-	1.79	67
3	1.79	-	2.30	42
4	2.30	-	2.81	27
5	2.81	-	3.33	15
6	3.33	-	3.84	20
7	3.84	-	4.35	12
8	4.35	-	4.86	10
9	4.86	-	5.37	4
10	5.37	-	5.88	2
Average	1.98 minutes			Σ 365

Source: Author calculation base on terminal daily report during the year 2010

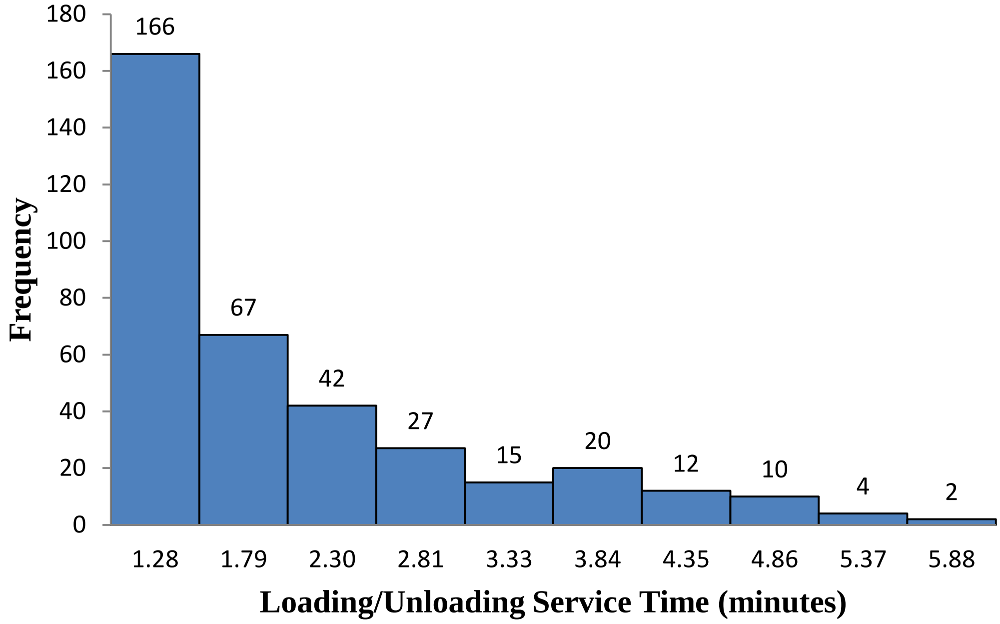


Figure 4.7 - Histogram of Loading/unloading Service Time

Source: Author calculation base on terminal daily report during the year 2010

Table 4.6 - Distribution of Haulage Service Time

Bin	Interval (minutes)			Frequency
1	4.90	-	6.33	208
2	6.33	-	7.76	62
3	7.76	-	9.18	22
4	9.18	-	10.61	17
5	10.61	-	12.04	18
6	12.04	-	13.47	12
7	13.47	-	14.89	9
8	14.89	-	16.32	6
9	16.32	-	17.75	6
10	17.75	-	19.18	5
Average	6.90 minutes			Σ 365

Source: Author calculation base on terminal daily report during the year 2010

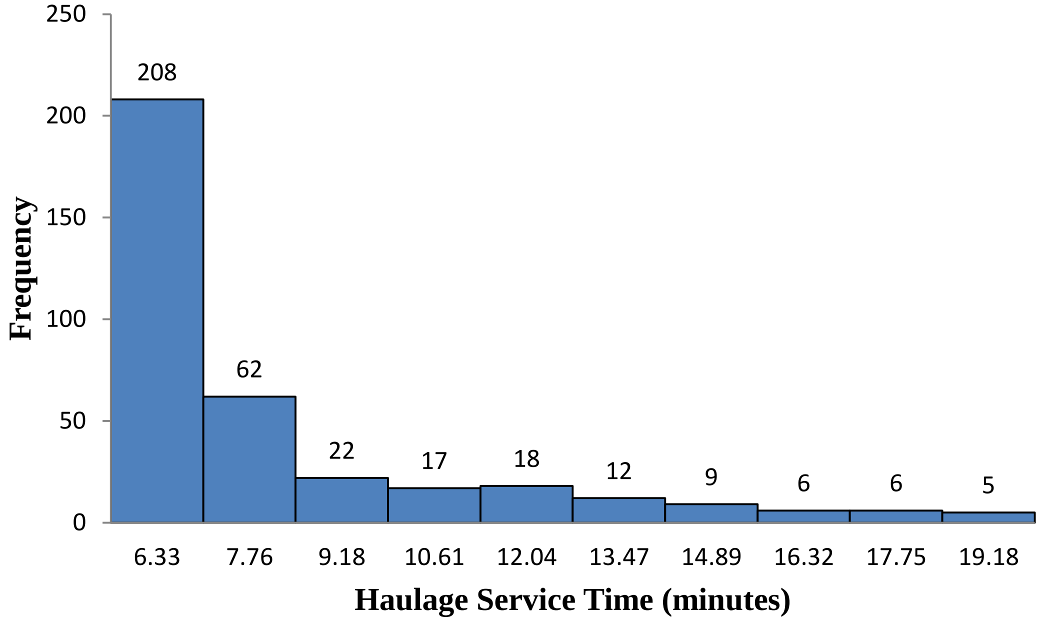


Figure 4.8 - Histogram of Haulage Service Time

Source: Author calculation base on terminal daily report during the year 2010

Table 4.7 - Distribution of Lift on/off Service Time

Bin	Interval (minutes)			Frequency
1	2.80	-	3.67	208
2	3.67	-	4.54	62
3	4.54	-	5.40	28
4	5.40	-	6.27	19
5	6.27	-	7.14	13
6	7.14	-	8.01	12
7	8.01	-	8.88	6
8	8.88	-	9.75	8
9	9.75	-	10.61	6
10	10.61	-	11.48	2
Average	3.89 minutes			Σ 365

Source: Author calculation base on terminal daily report during the year 2010

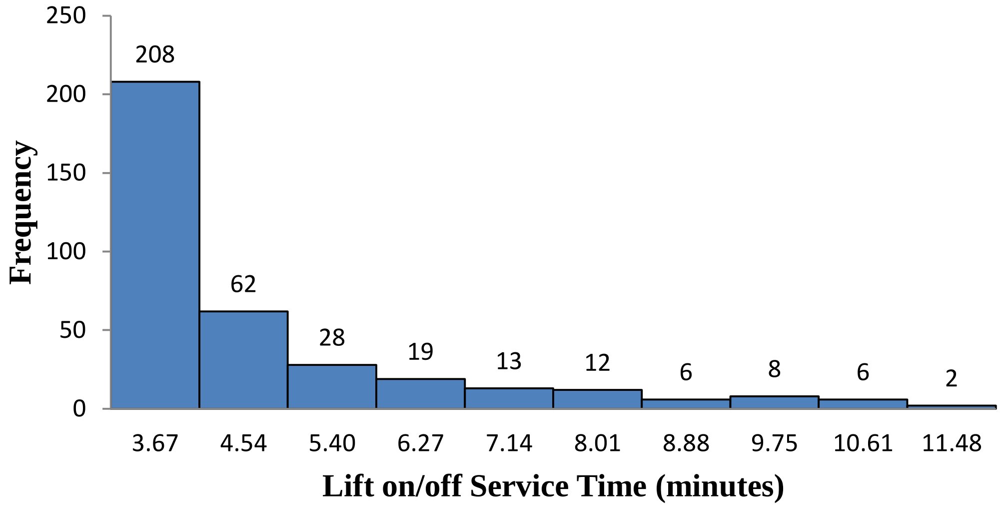


Figure 4.9 - Histogram of Lift on/off Service Time

Source: Author calculation base on terminal daily report during the year 2010

4.1.2.5. Other Operational Data

Other data required in this study are QC deployment, lift per call (LPC), vessel size in GT and Length Overall (LOA) of the vessel. Lift per call is the number of container loaded and unloaded in each ship while QC deployment is the number of QC deployed in each vessel. Data distribution of QC deployment, LPC, GT and LOA of the vessel is presented in table 4.8, 4.9, 4.10, and 4.11, respectively.

Table 4.8 - Distribution of OC Deployment

Number of QC	Frequency
1	455
2	455
3	661
4	215
5	55
6	24
7	9
8	4
	1,878

Source: Author calculation base on terminal daily report during the year 2010

Table 4.9 - Distribution of LPC

Bin	Interval (containers)			Frequency
1	10	-	415	669
2	415	-	820	399
3	820	-	1,225	444
4	1,225	-	1,631	174
5	1,631	-	2,036	98
6	2,036	-	2,441	39
7	2,441	-	2,846	33
8	2,846	-	3,251	15
9	3,251	-	3,656	0
10	3,656	-	4,061	0
11	4,061	-	4,467	0
12	4,467	-	4,872	1
Average	774 containers			Σ 1,872

Source: Author calculation base on terminal daily report during the year 2010

Table 4.10 - Distribution of Vessel Size in GT

Bin	Interval (GT)			Frequency
1	1,503	-	5,701	279
2	5,701	-	9,899	198
3	9,899	-	14,097	163
4	14,097	-	18,294	375
5	18,294	-	22,492	250
6	22,492	-	26,690	142
7	26,690	-	30,888	238
8	30,888	-	35,086	102
9	35,086	-	39,284	98
10	39,284	-	43,482	5
11	43,482	-	47,680	8
12	47,680	-	51,877	14
Average	16,833 GT			Σ 1,872

Source: Author calculation base on terminal daily report during the year 2010

Table 4.11 - Distribution of LOA

Bin	Interval (GT)			Frequency
1	69	-	87	123
2	87	-	105	189
3	105	-	123	199
4	123	-	141	140
5	141	-	159	224
6	159	-	177	434
7	177	-	195	251
8	195	-	213	206
9	213	-	231	91
10	231	-	249	1
11	249	-	267	0
12	267	-	285	14
Average	167 m			Σ 1,872

Source: Author calculation base on terminal daily report during the year 2010

4.2. Costs incurred in the terminal

Data of costs in the terminal consists of costs incurred by terminal operator and costs incurred by the customer. The costs related to the terminal operator are the expenses for providing terminal facilities and equipment (service costs). While the costs that must be borne by the customer related to waiting cost.

4.2.1. Service costs

Costs of facilities consist of costs required for investment and maintenance of terminal facilities such as berth and stacking yard. While costs of equipment comprise costs required for investment, maintenance and operation of container handling equipment such as quay crane, trailer and rubber tire gantry crane. In term of investment cost the data collected is the unit price of facilities and equipment.

Whereas maintenance cost is assumed as the proportion of investment cost. In detail the costs of facilities and equipment is presented in the table 4.12.

Table 4.12 - Cost of Facilities and Equipment

Type	Economic Usage	Investment /unit price	Maintenance /year	Operator /unit
Berth	30 years	US$ 3,114 /m^2	5%	-
Stacking yard	30 years	US$ 155 /m^2	5%	-
QC	20 years	US$ 13 million	8%	US$ 14,000
RTG	20 years	US$ 2.5 million	8%	US$ 14,000
Trailer	5 years	US$ 125 thousand	8%	US$ 14,000

Source: Indonesia Port Corporation II

4.2.2. Waiting Costs

Waiting cost is the cost that incurred due to wait for service in the terminal. Waiting costs can be suffered by ships, goods and external trailers that will pick up/deliver the container from/to the terminal.

4.2.2.1. Ship Waiting Cost

In this study, an approach of ship opportunity cost is used to represent the ship waiting cost. Opportunity cost of the ship is the revenue that would be obtained if the ship sailed. In other word, when the ship cannot sail due to she has to wait at the port, the ship owner suffer the cost of loss the opportunity to get revenue. Data required is collected at six shipping company that their ships call at JICT i.e Djakarta Lloyd, Indonesia Fortune Lloyd, Meratus, Pelayaran Indx Lines, Samudera Indonesia and Tempuran Mas. The revenue and number of sailing days in the year 2010 with the sample number 40 vessels are presented in table 4.13.

Table 4.13 - Ship Revenue in the year 2010

No	Ship Name	GT	Revenue (US$)	Sailing Day	Cost /GT /day
Djakarta Lloyd					
1	Caraka JN III-07	3,258	810,136	263	0.95
2	Palembang CJN III-37	3,401	844,607	254	0.98
3	Panjang CIN III-41	3,401	834,172	248	0.99
4	Cirebon CJN III-36	3,401	848,820	252	0.99
5	Lhoksumawe CJN III	3,401	849,730	260	0.96
6	Belawan CJN III-8	3,508	868,148	255	0.97
7	Manado CJN III-42	3,508	866,161	252	0.98
Indonesia Fortune Lloyd					
8	Cinta Bahari	1,727	426,376	258	0.96
9	Jakarta Fortune	4,324	1,072,554	245	1.01
10	Lintas Nusantara	5,075	1,258,837	258	0.96
Meratus					
11	Mataram Express	3,790	942,973	254	0.98
12	Meratus Express	4,098	1,008,372	252	0.98
13	Martapura River	4,152	1,029,890	256	0.97
14	Meratus Progress 1	4,476	1,110,257	250	0.99
15	Meratus Tangguh 1	6,251	2,146,901	286	1.20
16	Meratus Banjar 1	6,349	2,180,559	290	1.18
17	Magnolia Star	6,998	2,403,457	292	1.18
18	Mayapada	8,639	2,988,208	288	1.20
19	Mitra Ocean	8,639	2,967,057	286	1.20
20	Meratus Balikpapan	9,440	3,242,160	285	1.21
21	Meratus Manado	9,440	3,325,572	288	1.22
22	Meratus Spirit 1	9,909	3,403,238	294	1.17
23	Meratus Spirit 2	9,943	3,414,915	286	1.20
24	Meratus Medan 1	13,281	5,011,760	318	1.19
Pelayaran Indx Lines					
25	Kota Rancak	9,678	3,469,680	292	1.23
26	Kota Hadiah	13,272	8,315,563	316	1.98
27	Kota Harta	13,272	8,307,917	312	2.01
28	Kota Hasil	13,272	9,612,720	320	2.26
Samudera Indonesia					
29	Sinar Jambi	2,656	958,851	242	1.49
30	Sinar Demak	2,668	968,197	252	1.44
31	Sinar Padang	2,705	974,596	250	1.44
32	Sinar Sabang	18,321	13,146,405	323	2.22

33	Sinar Sumba	18,321	10,927,280	330	1.81
34	Anthea	18,335	10,927,280	325	1.83
Tempuran Mas					
35	Estuari Mas	7,032	2,901,410	288	1.43
36	Jales Mas	7,032	2,887,985	284	1.45
37	Mare Mas	7,032	3,100,182	295	1.49
38	Hilir Mas	9,279	3,970,155	280	1.53
39	Umbul Mas	9,279	4,059,919	286	1.53
40	Lautan Mas	17,156	10,842,592	312	2.03
	Average				1.32

Source: Author calculation base on the data from six shipping companies

4.2.2.2. Cargo Waiting Cost

To calculate cargo waiting cost which is represented by goods opportunity costs and depreciation, we have to know the cargo value. Data of cargo value through port of Tanjung Priok in the year 2010 is collected from Indonesia Central Bureau of Statistics and presented in table 4.14.

Table 4.14 - Cargo Value and Volume through Port of Tanjung Priok in 2010

	Cargo Value (US $)	**Volume (Tonnes)**	**Value per Tonne (US $ /Tonne)**
Export	34,237,761,516	12,545,525	2,729
Import	60,039,435,358	28,649,357	2,096
Total	94,277,196,874	41,194,882	2,289

Source: Indonesia Central Bureau of Statistics

4.2.2.3. External Trailer Waiting Cost

External trailer waiting cost is represented by the cost of surcharge due to the trailer is exceeding the agreed time for pick up/deliver the container from and to the terminal. Base on the survey on several trucking company, the average surcharge imposed to the customer is US$ 30 per hour.

Chapter 5 ANALYSIS

This chapter is core subject of the study where the data that is presented in the chapter 4 will be further analyzed using the steps that has been explained in chapter 3. The analysis that will be presented in this chapter consists of the following subject:

a. The distribution test of arrival pattern and service time pattern.
b. Analysis of facilities and equipment composition required in the terminal.
c. Calculation of service costs and waiting costs.
d. Analysis of queuing model for loading/unloading operation, receiving and delivery.
e. Analysis of total cost model in order to determine the optimal number of facilities and equipment required to provide a proper container terminal capacity.
f. Proper terminal capacity analysis.

5.1. Distribution Test

In this study the arrival pattern (time between arrivals) and service time pattern are assumed to follow the exponential distribution. The test of frequency distribution is conducted by using Kolmogorov Smirnov Goodness of fit test (K-S test). The following is an example of the steps conducted to test ship time between arrivals distribution.

a. The first step is to propose a hypothesis that will be tested, i.e.

   H_0: the population distribution of ship time between arrivals F(x) is the same as $F_0(x)$ which follows the exponential distribution.

   H_1: the population distribution of ship time between arrivals F(x) is not the same as $F_0(x)$ which follows the exponential distribution.

b. Calculate the critical value D_α for level of significance (α) 95% and the sample size 1,872 data.

$$D_{0.95} = \frac{1.36}{\sqrt{1{,}872}} = 0.0314$$

c. Calculate the cumulative distribution of the sample $F_n(x)$ with calculate the cumulative frequency probability for each time interval. The following are examples of the calculation.

   For interval between 0 and 2.63: $F(0<x\leq 2.63) = 757 / 1872 = 0.4044$

   For interval between 2.63 and 5.25: $F(2.63<x\leq 5.25) = (757+512)/1872 = 0.6779$

   With the same way the cumulative distribution of the sample $F_n(x)$ for other intervals are then calculated.

d. Calculate the probability density function (pdf) for specified distribution, in this case is assumed to follow exponential distribution with the formula:

   $$f(t < x \leq T) = \left| e^{-(\frac{t}{m})} - e^{-(\frac{T}{m})} \right|$$

   Where,

   $f(t<x\leq T)$: probability density function for time interval between t and T.

   m : average time

   With the average ship time between arrivals 4.68 hours the probability density function for each interval is calculate as the following:

   $$f(0 < x \leq 2.63) = \left| e^{-(\frac{0}{4.68})} - e^{-(\frac{2.63}{4.68})} \right| = 0.4298$$

   $$f(2.63 < x \leq 5.25) = \left| e^{-(\frac{2.63}{4.68})} - e^{-(\frac{5.25}{4.68})} \right| = 0.2451$$

   With the same way the probability density function (pdf) for other intervals are then calculated.

e. Calculate the cumulative distribution $F_0(x)$ of specified (given) population distribution which is the cumulative of probability density function (pdf).

g. Calculate the absolute difference between $F_0(x)$ and $F_n(x)$, $| F_0(x) - F_n(x) |$

   The complete calculation result for all time intervals is shown in table 5.1.

Table 5.1 - Cumulative distribution function of ship time between arrivals

Interval			Empirical Distribution			Specified Distribution		Different
			Frequency	Probability	Cum Prob. $F_n(X)$	Probability	Cum Prob. $F_0(X)$	D
0.00	-	2.63	757	0.4044	0.4044	0.4298	0.4298	0.0254
2.63	-	5.25	512	0.2735	0.6779	0.2451	0.6749	0.0030
5.25	-	7.88	223	0.1191	0.7970	0.1397	0.8146	0.0176
7.88	-	10.51	190	0.1015	0.8985	0.0797	0.8943	0.0042
10.51	-	13.14	105	0.0561	0.9546	0.0454	0.9397	0.0149
13.14	-	15.76	38	0.0203	0.9749	0.0259	0.9656	0.0093
15.76	-	18.39	23	0.0123	0.9872	0.0148	0.9804	0.0068
18.39	-	21.02	11	0.0059	0.9931	0.0084	0.9888	0.0042
21.02	-	23.65	6	0.0032	0.9963	0.0048	0.9936	0.0026
23.65	-	26.27	4	0.0021	0.9984	0.0027	0.9964	0.0020
26.27	-	28.90	2	0.0011	0.9995	0.0016	0.9979	0.0015
28.90	-	31.53	1	0.0005	1.0000	0.0009	0.9988	0.0012
			1,872	1.0000				

Source: Author calculation

h. The next step is to find the maximum different (D) between $F_0(x)$ and $F_n(x)$. Base on the calculation shown in table 4.13 D = maximum l $F_0(x)$ - $F_n(x)$ l is 0.0254.

i. Finally is to draw a conclusion with the criteria if the value of D is smaller than or the same as Dα then the hypothesis H_0 regarding the distributional form is accepted. Base on the calculation D = 0.0254 and $D_{0.95}$ = 0.0314, thus $D \leq D_\alpha$, and H_0 is accepted. It means that statistically the ship time between arrivals follow an exponential distribution. Figure 5.1 shows that cumulative distribution function of ship time between arrivals is almost identical with theoretical cumulative distribution function of exponential distribution.

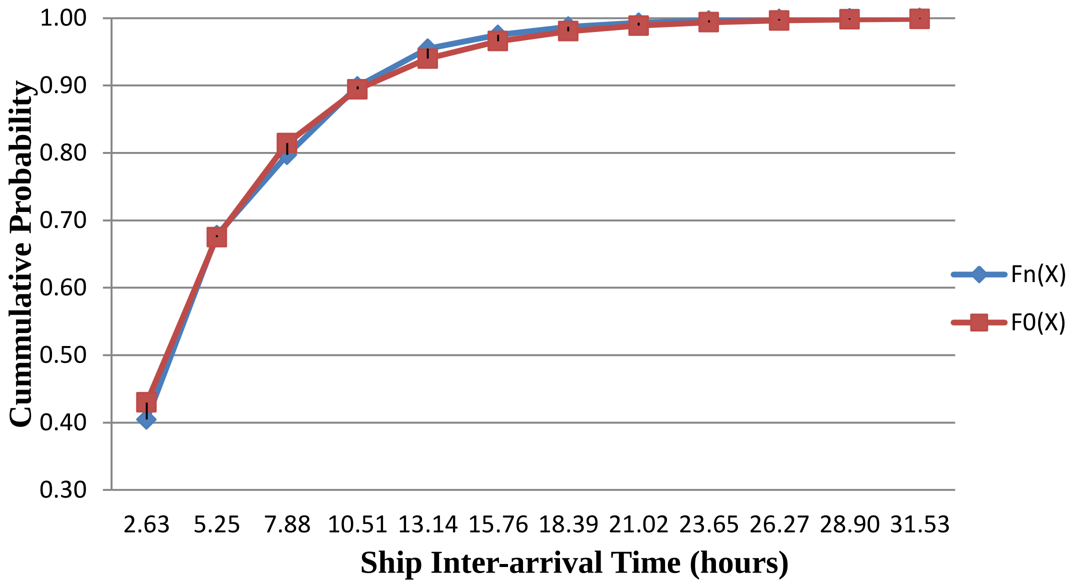


Figure 5.1 - Cumulative distribution function of ship time between arrivals

Source: Author calculation

With the same method the test of frequency distribution using Kolmogorov Smirnov Goodness of fit test (K-S test) is conducted for the distribution of time between arrival of external trailer (XT) to pick up and grounding the containers, service time of loading/un-loading by using QC, service time of haulage by using IT, and service time of lift on/off by using RTG. The test result of overall distribution is presented in table 5.2.

Table 5.2 - K-S Test on Distribution of Time between Arrivals and Service Time

Description	Unit	Sample	Average	D	$D_{0.95}$	Distribution
Ship arrival	hour	1,872	4.68	0.0254	0.0314	Exponential
XT arrival in delivery	minute	365	0.85	0.0472	0.0712	Exponential
XT arrival in receiving	minute	365	0.75	0.0674	0.0712	Exponential
QC service time	Minute	365	1.98	0.0695	0.0712	Exponential
IT service time	Minute	365	6.90	0.0706	0.0712	Exponential
RTG service time	minute	365	3.89	0.0679	0.0712	Exponential

Source: Author calculation

It is shown in table 5.2 that all of distributions tested both time between arrival and service time follow the exponential distribution. Since distribution of time between arrivals is exponential means that arrival distribution of ships and external trailers is poisson.

5.2. Analysis of facilities and equipment required in the terminal.

Facilities and equipment required for handling containers in the terminal that will be analyzed are berth, stacking yard, and the composition of equipment number for one set container handling equipment for the operation between the quay and yard which consists of container quay crane, trailer and rubber tire gantry crane.

5.2.1. Berth

Length of a unit berth required is determined by considering the longest vessel which often calls at the terminal and allowance for the secure distance. Base on LOA distribution of vessels as shown in table 4.11 the longest vessels which often call is 231 m. By adding the secure distance allowance of 10 m, the length of a unit berth is 241 m. While the size for berth width is the same as the existing condition i.e. 35 m. Thus, the area required for one unit berth is 241 m x 35 m = 8,435 m^2. Whereas, for the vessel with LOA more than 231 m which has call frequency only a little she can be berthed with over stake.

5.2.2. Stacking yard

To calculate the area required for stacking yard (lay out of a block stacking yard is shown in figure 5.2) we need to make several assumptions as explained as follows:

- The equipment used at the stacking yard is RTG with capability of stacking one over four and spanning 7 rows.
- Distance between containers in a block is 0.25 meter.
- TEU conversion factor is 1.47 per containers.

- Dimension of a TEU container is 6.1 m x 2.4 m.
- There are 3 roadways for trailer in a block with the width 3.75 meter each.
- There are 2 sides of roadways for RTG in a block with the width 1.5 m each.
- Width of roadway between blocks is 25 meter.
- A block is consists of 66 slots with 7 row in each slot.
- The proportion of export and import containers is 43% and 57%.
- Dwelling Time (DT) for export and import is 2.3 days and 5.2 days, by multiplying the proportion of export and import, we can get the average dwelling time of 3.8 days.
- Peaking factor (PF) is 1.30.
- Stacking height (H) for export and import is 3.5 and 3 container high, by multiplying the proportion of export and import, we can get the average stacking height of 3.2 containers high.
- Land utilization (U) ratio is 80%.
- Number of working days in a year (K) is 365 days.

Based on these assumptions the TEU Ground Slot (TGS) required is calculated but before that we need to calculate the annual throughput first. With the average ship time between arrivals of 4.68 hours per ship thus the ships arrival rate is 1,872 ships in a year. By multiplying the average LPC of 774 containers per ship, we obtain the annual throughput of 1,448,137 containers or 2,128,762 TEUs.

TGS is calculated using Dally formula as follow,

$$TGS = \frac{Capacity.DT.PF}{H.U.K} = \frac{(2{,}128{,}762).(3.8).(1.30)}{(3.2).(0.80).(365)} = 11{,}222\ TEUs$$

Then we calculate the stacking yard area required with the following steps,

(1) Number of slots required = 11,222 TEUs / 7 rows = 1,603 slots.

(2) Number of blocks required = 1,603 slots / 66 slots = 24 blocks

(3) Total area of overall slots = 1,603 slots x (6.1 m x 2.4 m) = 164,291 m^2.

(4) Total area for distance between containers =

0.25 m x (2.4 m x 7 rows) x (66 slots – 1) x 24 blocks = 6,631 m^2.

(5) Effective area = 164,291 m^2 + 6,631 m^2 = 170.922 m^2.

(6) Total area for trailer roadways =

3 ways x 3.75 m x 418.85 m x 24 blocks = 114,457 m^2.

(7) Total area for RTG roadways =

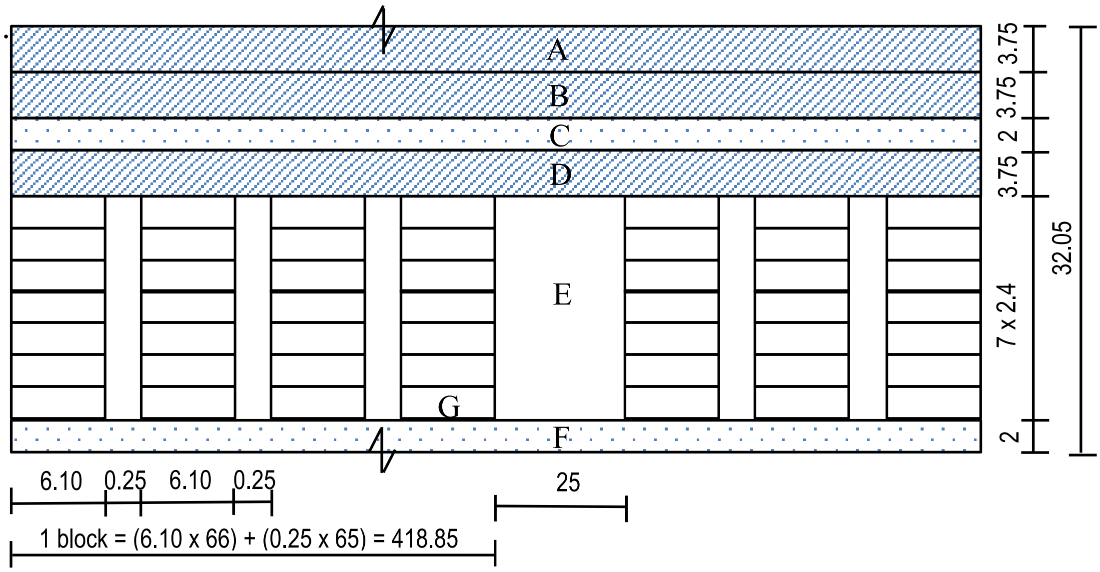
2 ways x 2 m x 418.85 m x 24 blocks = 40,696 m^2.

(8) Total area for roadways between the blocks =

25 m x 32.05 m x (24 blocks - 1) = 18,661 m^2.

(9) Total stacking yard area required =

170.922 m^2 + 114,457 m^2 + 40,696 m^2 + 18,661 m^2 = 344,736 m^2 = 34.47 Ha or 30.72 m^2 /TEUs.



Note :

A, B, D : roadway for trailer
C, F : roadway for RTG
E : roadway between blocks
G : a slot row for a TEU container

Figure 5.2 - Lay out of stacking yard block

Source: Author

5.2.3. Composition of one set container handling equipment

Composition analysis of one set container handling equipment is conducted for container handling operation between quay and stacking yard which consists of loading/unloading operation by using QC, haulage by using trailer and lift on/off by using RTG. Purpose of the analysis is to determine the proper number of trailer and RTG should be deployed for each QC in order to obtain a balance operation amongst these three types of equipment. By providing a balance operation all equipment can fully utilized with a minimum idle time.

To analyze a proper composition of container handling equipment set will be used a man & machine chart. By using this chart all activities involved during the operation will be defined and indicated on chart. Figure 5.3 and 5.4 show the chart analysis for the first cycle and the next cycle of container handling operation between quay and stacking yard. The first cycle of operation is a cycle where all equipment has just started to do its task. One cycle of operation is the service to 10 containers. Since in the first cycle not all IT and RTG can start its task at the same time and have to wait until the previous processes completed, utilization for this equipment is low as seen in table 5.3. However after all of equipment can do its task simultaneously in the next cycle, utilization in every cycle (10 containers) is high as seen in table 5.4 with the utilization for QC, IT and RTG is 100%, 99% and 98% respectively.

With loading /unloading service time by using QC 1.98 minutes, haulage service time by using internal tractor-trailer service time 6.90 minutes and lift on/off service time by using RTG 3.89 minutes, we obtain that the proper composition of one set equipment is 1 unit QC, 10 units tractor-trailer (IT) and 2 units RTG with the cycle time of service 19.8 minutes per 10 container or 1.98 minutes per containers.

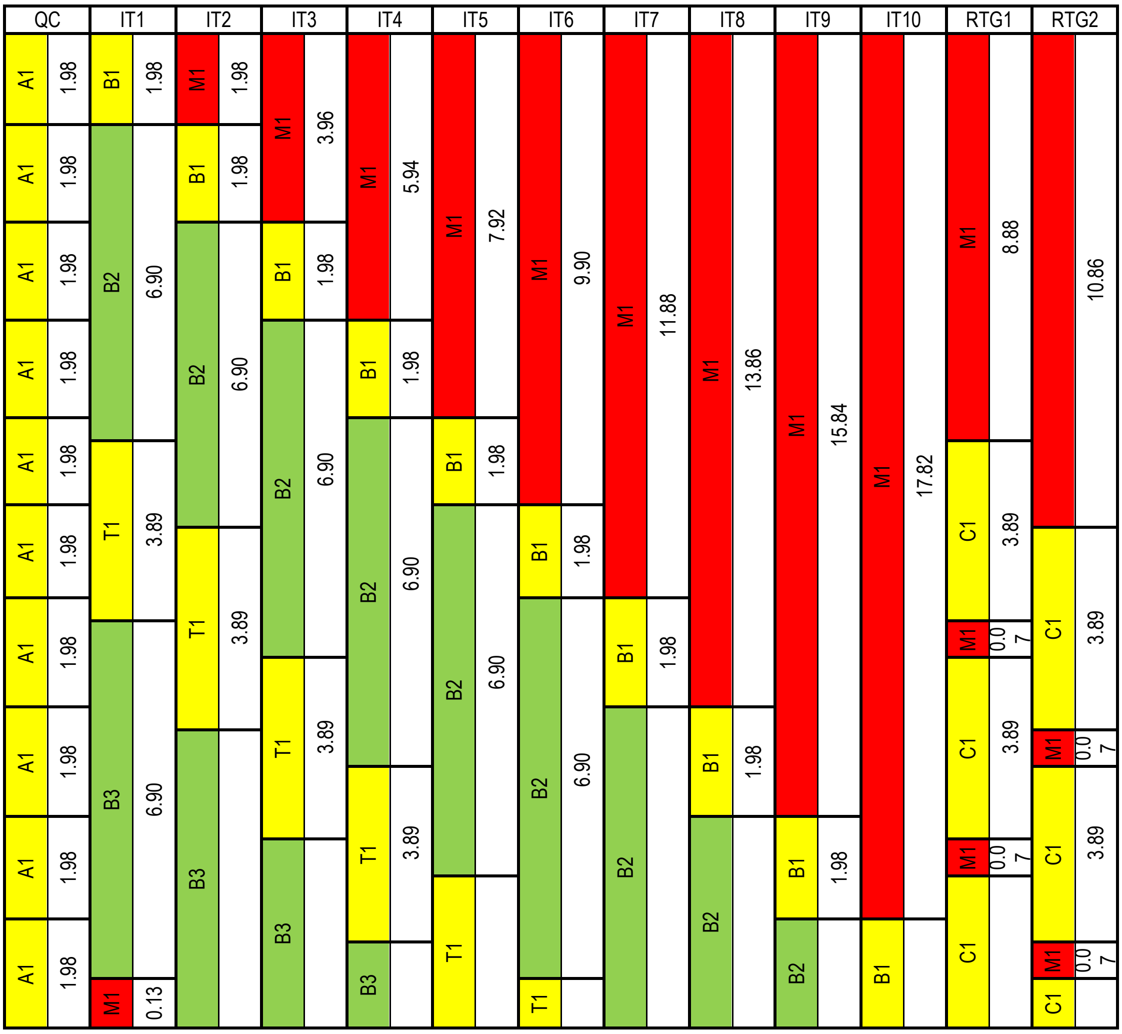


Figure 5.3 - Man & Machine Chart for the first cycle

Source: Author calculation

Table 5.3 - Equipment utilization in the first cycle

Description	QC	IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10	RTG1	RTG2
Operating	19.80	19.67	17.82	15.84	13.86	11.88	9.90	7.92	5.94	3.96	1.98	10.78	8.80
Idle	0.00	0.13	1.98	3.96	5.94	7.92	9.90	11.88	13.86	15.84	17.82	9.02	11.00
Total	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80
Utilization	100%	99%	90%	80%	70%	60%	50%	40%	30%	20%	10%	54%	44%

Source: Author calculation

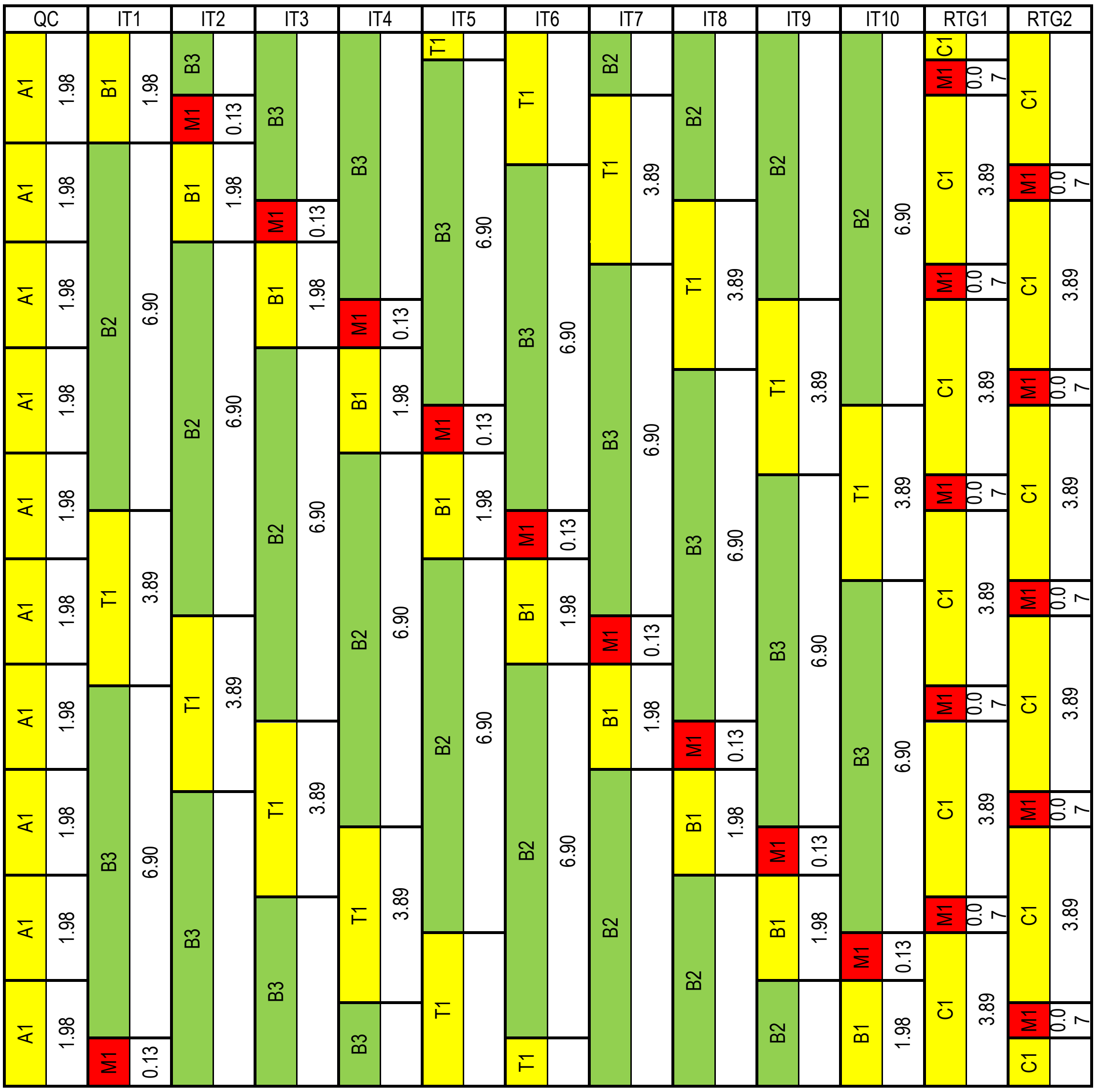


Figure 5.4 - Man & Machine Chart in every cycle after the first cycle

Source: Author calculation

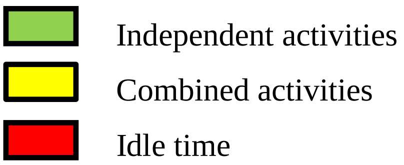
Table 5.4 – Equipment utilization in every cycle after the first cycle

Description	QC	IT1	IT2	IT3	IT4	IT5	IT6	IT7	IT8	IT9	IT10	RTG1	RTG2
Operating	19.80	19.67	19.67	19.67	19.67	19.67	19.67	19.67	19.67	19.67	19.67	19.45	19.45
Idle	0.00	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.13	0.35	0.35
Total	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80	19.80
Utilization	100%	99%	99%	99%	99%	99%	99%	99%	99%	99%	99%	98%	98%

Source: Author calculation

The symbols used in the chart as seen in figure 5.3 and 5.4 is explained as follows:

- QC : Quay Container Crane
- IT1 : Internal Trailer 1
- IT2 : Internal Trailer 2
- IT3 : Internal Trailer 3
- IT4 : Internal Trailer 4
- IT5 : Internal Trailer 5
- IT6 : Internal Trailer 6
- IT7 : Internal Trailer 7
- IT8 : Internal Trailer 8
- IT9 : Internal Trailer 9
- IT10 : Internal Trailer 10
- RTG1 : Rubber Tire Gantry Crane 1
- RTG2 : Rubber Tire Gantry Crane 2
- A1 : QC unload import container from the ship and put on the trailer
- B1 : Trailer wait until import container is put on
- B2 : Trailer transfer import container to the stacking yard
- B3 : Trailer back to the quay to pick up the next import container
- T1 : Trailer wait until import container is lifted off and grounded at the yard
- C1 : RTG lift off import container from trailer and ground it at the yard
- M1 : Wait without any activities (idle)
- Unit time is minutes
- The color represented an activity as follows,



5.3. Calculation of service costs and waiting costs

Calculation of service costs and waiting costs is required to analyze the total costs in the terminal. Based on data presented in chapter 4 all costs will be converted to the same time unit that is US$ per day.

5.3.1. Service costs

Service costs is the costs for providing facilities which consist of berth and stacking yard and equipment which consists of QC, trailer and RTG.

5.3.1.1. Costs of facilities

Service costs are calculated based on the data as presented in table 4.12 and analysis of area required in meter square for berth and stacking yard. Calculation of the facility costs consist of the cost for investment and maintenance.

5.3.1.1.1. Berth cost

Investment of 1 unit berth = 241 m x 35 m x US$ 3,114 /m^2 = US$ 26,269,937

By assuming economic usage 30 years and interest (r) 13% the investment cost is converted to equivalent uniform annual cost with the formula

$$\text{Annual Cost} = \text{Investment}\,\frac{r.(1+r)^n}{(1+r)^n-1} = 26{,}269{,}937\,\frac{0.13.(1+0.13)^{30}}{(1+0.13)^{30}-1}$$

= US$ 3,504,689 /year

Maintenance cost = 5% x US$ 3,504,689 /year = US$ 175,234 /year

Total cost = US$ 3,679,924 /year = US$ 10,082 /day

5.3.1.1.2. Stacking yard cost

Investment of 1 unit berth = 344,756 m^2 x US$ 155 /m^2 = US$ 53,575,743 /year

By assuming economic usage 30 years and interest (r) 13% the investment cost is converted to equivalent uniform annual cost with the formula

$$\text{Annual Cost} = 53{,}575{,}743\,\frac{0.13.(1+0.13)^{30}}{(1+0.13)^{30}-1} = \text{US\$ } 7{,}147{,}575 \text{ /year}$$

Maintenance cost = 5% x US$ 7,147,575 /year = US$ 357,379 /year

Total cost = US$ 7,504,954 /year = US$ 20,562 /day

5.3.1.2. Costs of Equipment

Calculation of the equipment costs consist of the cost for investment, maintenance and operator. With the same method as facility cost calculation the investment cost for equipment is converted to equivalent uniform annual cost.

5.3.1.2.1. Quay Container Crane Cost

By assuming economic usage 20 years and interest (r) 13% the investment cost for QC is converted to equivalent uniform annual cost with the formula

$$\text{Annual Cost} = 13{,}000{,}000\,\frac{0.13.(1+0.13)^{20}}{(1+0.13)^{20}-1} = = \text{US\$ } 1{,}850{,}599 \text{ /year}$$

Maintenance cost = 8% x US$ 1,850,599 /year = US$ 148,048 /year

Operator cost = US$ 14,000 /year

Total cost = US$ 2,012,647 /unit /year = US$ 5,514 /unit /day

5.3.1.2.2. Rubber Tire Gantry Crane Cost

By assuming economic usage 20 years and interest (r) 13% the investment cost for RTG is converted to equivalent uniform annual cost with the formula

Annual Cost $= 2{,}500{,}000 \frac{0.13.(1+0.13)^{20}}{(1+0.13)^{20}-1}$ = US$ 355,884 /year

Maintenance cost = 8% x US$ 355,884 /year = US$ 28,471 /year

Operator cost = US$ 14,000 /year

Total cost = US$ 398,355 /unit /year = US$ 1,091 /unit /day

5.3.1.2.3. Trailer

By assuming economic usage 5 years and interest (r) 13% the investment cost for trailer is converted to equivalent uniform annual cost with the formula

Annual Cost $= 125{,}000 \frac{0.13.(1+0.13)^{5}}{(1+0.13)^{5}-1}$ = US$ 35,539 /year

Maintenance cost = 8% x US$ 35,539/year = US$ 2,843 /year

Operator cost = US$ 14,000 /year

Total cost = US$ 52,382 /unit /year = US$ 144 /unit /day

5.3.2. Waiting costs

Waiting cost is the cost that incurred due to wait for service in the terminal and can be suffered by ships, cargo (container) and external trailers that will pick up/deliver the container from/to the terminal.

5.3.2.1. Ship waiting cost

As explained in chapter 4 ship waiting cost is represent by ship opportunity that is the revenue that would be obtained if the ship sailed. From table 4.10 known that the average size of vessels which call at JICT is 16,833 GT and in table 4.13 presented that the average revenue of the vessels is US$ 1.32 per day per GT. Thus, the ship opportunity cost is 16,833 GT x US$ 1.32 = US$ 22,212 per ship per day.

5.3.2.2. Cargo waiting cost

In this study cargo waiting cost is represented by cargo congestion cost which consists of goods opportunity costs and economic depreciation. By assuming opportunity cost 3% and depreciation 40%, congestion cost for the average value of cargo US$ 2,289 /ton as shown in table 4.14 is calculated by using the formula presented in chapter 4 as follow:

$$\text{Congestion cost} = \frac{\text{US\$ } 2{,}289.\ (0.03 + 0.40)}{365} = \text{US\$ } 2.70 \text{ /ton /day}$$

With the average weight of cargo 14 tons per containers thus the cargo congestion cost is US$ 37.75 per container per day. By multiplying the average lift per call 774 containers per ship, we obtain that the cargo congestion cost is US$ 29,202 per ship per day.

5.4. Analysis of queuing model

The queuing models that will be analyzed in this study are queuing model of ship service at a berth, queuing model for receiving operation and queuing model for receiving operation. Based on the frequency distribution test, the inter-arrival time of ship and external trailer (which also represent the arrival of containers) and service time of equipment follow an exponential distribution. Since inter arrivals time is exponentially distributed which means that the number of arrival has a poisson distribution, and service time also follows exponential distribution, a queuing model of M/M/k can be applied to analyze the queuing behavior in the terminal.

5.4.1. Queuing model of ship service at a berth

As explained in chapter 4, queuing model of ship service at a berth will analyze three types of container handling operations between the quay and container yard since these three operations are inter-related for determining the length of ship service time at a berth. Therefore, the analysis will be conducted for three alternatives number of equipment sets deployed per berth for operation between the quay and container i.e. 2 sets, 3 sets and 4 sets that in one set consists of 1 QC, 10 trailers and 2 RTGs.

5.4.1.1. Queuing model for 2 sets equipment

Data input required to analyze the queuing model for 2 sets of equipment are explained in the following.

a. Ship arrival rate ($\boldsymbol{\lambda}$) calculation is based on the average ship time between arrivals. With the average ship time between arrivals 4.68 hours thus the ship arrival rate is 1,872 ships per year.
b. Ship service time consists of time required for container handling preparation which is assumed 30 minutes, time for loading/unloading which depends on the number of equipment set deployed per berth and time required for ship un-berthing preparation which is assumed 30 minutes. The cycle time of service is 19.8 minutes per 10 containers per equipment set (1.98 minutes per container) thus berth productivity is 30 moves per equipment set. With lift per call per ship 774 moves (as shown in table 4.8) and by using 2 sets of equipment thus the time required for loading/unloading is 774 / (30 x 2) = 12.77. By adding the time for preparation before and after loading/unloading operation thus the the ship service time at a berth is 13.77 hours or the ship service rate ($\boldsymbol{\mu}$) is 636 ships per year.
a. Since ship service rate ($\boldsymbol{\mu}$) 636 ships per year is less than ship arrival rate ($\boldsymbol{\lambda}$) 1,872 ships per year we should have more than one server (in this case is berth). Using the minimum number of server k = 3 the requirement of the queuing model that is $\boldsymbol{\lambda} < k.\boldsymbol{\mu}$ has been met.

By using the queuing model M/M/3 we calculate the average number of ships in the terminal which is one of variables which will be used in the total cost model. The average number of ships in terminal can be obtained by calculating several operational characteristics in the queuing model as follow:

a. Utilization rate for each berth

$$\rho = \frac{\lambda}{k\mu} = \frac{1872}{3(636)} = 0.9804$$

b. Probability that there is no ship in the system

$$P_0 = \frac{1}{\sum_{n=0}^{k-1} \frac{1}{n!}\left(\frac{\lambda}{\mu}\right)^n + \frac{1}{k!}\left(\frac{\lambda}{\mu}\right)^k \left(\frac{k\mu}{k\mu-\lambda}\right)}$$

$$P_0 = \frac{1}{\frac{\left(\frac{1872}{636}\right)^0}{0!} + \frac{\left(\frac{1872}{636}\right)^1}{1!} + \frac{\left(\frac{1872}{636}\right)^2}{2!} + \frac{\left(\frac{1872}{636}\right)^3}{3!}\left(\frac{3(636)}{3(636)-1872}\right)} = 0.0044$$

c. Average time a ship spends in the queue

$$W_q = \frac{\left(\frac{\lambda}{\mu}\right)^k \mu}{(k-1)!(k\mu-\lambda)^2} P_0 + \frac{1}{\mu}$$

$$W_q = \frac{\left(\frac{1872}{636}\right)^3 .636}{(3-1)!\,(3(636)-1872)^2}(0.0044) + \frac{1}{636} = 0.0258\ year$$

d. Average number of ships in the queue

$$L_q = P_0 \frac{\left(\frac{\lambda}{\mu}\right)^k}{k!} \frac{\rho}{(1-\rho)^2}$$

$$L_q = 0.0044 \frac{\left(\frac{1872}{636}\right)^3}{3!} . \frac{0.9804}{(1-0.9804)^2} = 48.29 \text{ ships}$$

e. Average time a ship spends in the terminal

$$W = W_q + \frac{1}{\mu} = 0.0258 + \frac{1}{636} = 0.0274\ year = 240\ hours$$

f. The average number of ships in the terminal

$$L = L_q + \frac{\lambda}{\mu} = 48.29 + \frac{1872}{636} = 51.23\ ships$$

Since the existing number of berth in JICT is 7 berths, this study also analyzes all those queuing operational characteristics for the number of server k = 3 berths to k = 7. The calculation result is shown in table 5.5.

Table 5.5 - Operational Characteristics of queuing model for 2 sets equipment

Operational Characteristic	Unit	Number of Berth (k)				
		3	4	5	6	7
λ	Ships/year	1,872	1,872	1,872	1,872	1,872
µ	Ships/year	636	636	636	636	636
ρ	%	98.04%	73.53%	58.83%	49.02%	42.02%
Po		0.0044	0.0412	0.0498	0.0520	0.0526
W	Years	0.0274	0.0023	0.0017	0.0016	0.0016
	Hours	239.7789	20.0727	15.2490	14.1784	13.8817
Wq	Years	0.0258	0.0007	0.0002	0.0000	0.0000
	Hours	226.0135	6.3073	1.4836	0.4130	0.1163
L	Ships	51.2348	4.2890	3.2583	3.0296	2.9662
Lq	Ships	48.2935	1.3477	0.3170	0.0882	0.0248

Source: Author calculation

Table 5.5 shows that the more berth deployed the lower utilization and as consequence the less ship have to wait for berth services.

5.4.1.2. Queuing model for 3 sets equipment

By using the same step as the calculation example in queuing model for 2 sets equipment we obtained data input as explained in the following:

b. Ship arrival rate (***λ***) is 1,872 ships per year.
c. Ship service rate (***µ***) is 921 ships per year.
d. Since service rate (***µ***) 921 ships per year is less than ship arrival rate (***λ***) 1,872 ships per year we should have more than one server. Using the minimum number of server k = 3 the requirement of the queuing model that is ***λ*** < k.***µ*** has been met.

Having obtained the data input then all queuing operational characteristics with 3 sets of equipment is calculated for the number of server k = 3 berths to k = 7 berth as shown in table 5.6.

Table 5.6 - Operational Characteristics of queuing model for 3 sets equipment

Operational Characteristic	Unit	Number of Berth (k)				
		3	4	5	6	7
λ	Ships/year	1,872	1,872	1,872	1,872	1,872
μ	Ships/year	921	921	921	921	921
ρ	%	67.74%	50.80%	40.64%	33.87%	29.03%
Po		0.1060	0.1259	0.1300	0.1308	0.1310
W	Years	0.0016	0.0012	0.0011	0.0011	0.0011
	Hours	14.0264	10.3894	9.7129	9.5567	9.5203
Wq	Years	0.0005	0.0001	0.0000	0.0000	0.0000
	Hours	4.5161	0.8791	0.2027	0.0464	0.0100
L	Ships	2.9971	2.2200	2.0754	2.0420	2.0343
Lq	Ships	0.9650	0.1878	0.0433	0.0099	0.0021

Source: Author calculation

5.4.1.3. Queuing model for 4 sets equipment

By using the same step as the calculation example in queuing model for 2 sets equipment we obtained data input as explained in the following:

a. Ship arrival rate (**λ**) is 1,872 ships per year.
b. Ship service rate (**μ**) is 1,187 ships per year.
c. Since service rate (**μ**) 1,187 ships per year is less than ship arrival rate (**λ**) 1,872 ships per year we should have more than one server. Using the minimum number of server k = 2 the requirement of the queuing model that is $\lambda < k.\mu$ has been met.

Having obtained the data input then all queuing operational characteristics with 4 sets of equipment is calculated for the number of server k = 2 berths to k = 7 berth as shown in table 5.7.

Table 5.7 - Operational Characteristics of queuing model for 4 sets equipment

Operational Characteristic	Unit	Number of Berth (k)					
		2	3	4	5	6	7
l	Ships/year	1,872	1,872	1,872	1,872	1,872	1,872
m	Ships/year	1,187	1,187	1,187	1,187	1,187	1,187
r	%	78.88%	52.58%	39.44%	31.55%	26.29%	22.54%
Po		0.1181	0.1922	0.2040	0.2061	0.2064	0.2065
W	Years	0.0022	0.0010	0.0009	0.0008	0.0008	0.0008
	Hours	19.5377	8.7595	7.6476	7.4356	7.3927	7.3845
Wq	Years	0.0014	0.0002	0.0000	0.0000	0.0000	0.0000
	Hours	12.1549	1.3768	0.2649	0.0529	0.0100	0.0018
L	Ships	4.1747	1.8717	1.6341	1.5888	1.5796	1.5779
Lq	Ships	2.5972	0.2942	0.0566	0.0113	0.0021	0.0004

Source: Author calculation

5.4.2. Queuing model of Delivery Operation

Queuing model in delivery operation describes the activities of arrival of external trailer to the terminal to pick up import container from container yard and deliver it to the customer.

Data input required to analyze the queuing model in delivery operation are explained in the following.

a. Container arrival rate (**λ**) is assumed the same as external trailer arrival rate. With the average trailer time between arrivals 0.75 minute thus the container arrival rate is 80 containers per hour.
b. Container service time is the time required by RTG to lift the import container from the stacking yard onto the trailer. With the average service time 3.89 minutes per containers thus the service rate is 15 containers per hour.
e. Since service rate (**μ**) 15 containers per hour is less than arrival rate (**λ**) 80 containers per hour we should have more than one server (in this case is RTG).

Using the minimum number of server k = 6 the requirement of the queuing model that is $\boldsymbol{\lambda} < k.\boldsymbol{\mu}$ has been met.

Having obtained the data input then all queuing operational characteristics in delivery operation with several number of RTG is calculated as shown in table 5.8.

Table 5.8 - Operational Characteristics of queuing model in delivery operation

Operational Characteristic	Unit	Number of RTG (k)		
		6	7	8
λ	Containers/hour	80.0000	80.0000	80.0000
μ	Containers/hour	15.4242	15.4242	15.4242
ρ	%	86.44%	74.10%	64.83%
Po		0.0033	0.0048	0.0053
W	Hours	0.1172	0.0781	0.0694
	Minutes	7.0303	4.6850	4.1612
Wq	Hours	0.0523	0.0132	0.0045
	Minutes	3.1403	0.7950	0.2712
L	Containers	9.3738	6.2466	5.5482
Lq	Containers	4.1871	1.0599	0.3616

Source: Author calculation

Table 5.8 shows that the more RTG deployed in the yard for delivery operation the lower their utilization and as consequence the less trailer/containers have to wait for service.

5.4.3. Queuing model of Receiving Operation

Queuing model in receiving operation describes the activities of arrival of external trailer to the terminal to deliver export container from the customer which will be grounded at stacking yard by using RTG.

Data input required to analyze the queuing model in receiving operation are explained in the following.

a. Container arrival rate (**λ**) is assumed the same as external trailer arrival rate. With the average trailer time between arrivals 0.85 minute thus the container arrival rate is 71 containers per hour.
b. Container service time is the time required by RTG to lift the export container off from the trailer. With the average service time 3.89 minutes per containers thus the service rate is 15 containers per hour.
c. Since service rate (**μ**) 15 containers per hour is less than arrival rate (**λ**) 71 containers per hour we should have more than one server (in this case is RTG). Using the minimum number of server k = 5 the requirement of the queuing model that is **λ** < k.**μ** has been met.

Having obtained the data input then all queuing operational characteristics in receiving operation with several number of RTG is calculated as shown in table 5.9.

Table 5.9 - Operational Characteristics of queuing model in receiving operation

Operational Characteristic	Unit	Number of RTG (k)		
		5	6	7
λ	Containers/hour	70.5882	70.5882	70.5882
μ	Containers/hour	15.4242	15.4242	15.4242
ρ	%	91.53%	76.27%	65.38%
Po		0.0040	0.0083	0.0096
W	Hours	0.1868	0.0851	0.0710
	Minutes	11.2103	5.1065	4.2623
Wq	Hours	0.1220	0.0203	0.0062
	Minutes	7.3203	1.2165	0.3723
L	Containers	13.1886	6.0076	5.0145
Lq	Containers	8.6121	1.4312	0.4380

Source: Author calculation

Table 5.9 shows that the more RTG deployed in the yard for receiving operation the lower their utilization and as consequence the less trailer/containers have to wait for service.

5.5. Analysis of total cost model

The purpose of total cost analysis is to determine the optimal number of facilities and equipment required to provide a proper container terminal capacity. As discussed in chapter 3 total cost model used in this study is formula proposed by Noritake and Kimura (1990) which employed queuing theory to estimate the optimum size of a seaport by considering the cost of the service facilities and the cost of ship staying in a port as formulated as $TC = U_s.L + U_b.k$.

According to the formula there are four variables that will be used to calculate the total cost in the terminal with the explanation as follow,

a. For the queuing model of ship service at berth which analyzes the container handling operation between quay and stacking yard, k is the number of berth and L is the average number of ships at the terminal which is obtained from the queuing model analysis as discussed before. U_s is waiting cost of ship and cargo per ship per day. U_b is total cost of service which consists of cost for providing container yard, one unit berth, and the number of equipment set deployed per berth which is simulated by 2 sets, 3 sets and 4 set of equipment (one equipment set consists of 1 unit QC, 2 units RTG and 10 units trailer).

b. For the queuing model in receiving/delivery operation, k is the number of RTG and L is the average number of container in receiving/delivery operation which is obtained from the queuing model as discussed before. U_s is waiting cost of cargo and trailer per container per hour. U_b is total cost of service which consists of cost for providing container yard and one unit RTG. The cost of container yard for receiving and delivery operation is calculated proportionally according to the proportion of export and import container in the terminal.

5.5.1. Total cost for ship service at berth

Total cost for ship service at berth is analyzed to determine the number of berth should be used in the terminal to achieve a minimum total cost. The analysis will be conducted for several equipment sets deployed at a berth i.e. 2 sets, 3 sets and 4 sets of equipment which will affect the waiting cost due to the length of service time at a berth and the service cost due to the more equipment deployed the higher the cost will be. The total cost calculation result for each equipment set deployed at a berth is shown in table 5.10, 5.11 and 5.12, which is also presented in a line chart as shown in figure 5.5, 5.6 and 5.7.

Table 5.10 - Total Cost in US$ per day for Ship Service at Berth with 2 sets of equipment

Number of berths (k)	3	4	5	6	7
Costs of Service	105,600	133,945	162,291	190,637	218,983
a. Stacking yard	20,562	20,562	20,562	20,562	20,562
b. Berth	30,246	40,328	50,410	60,492	70,574
c. Equipment					
- QC	33,085	44,113	55,141	66,169	77,197
- Trailer	8,611	11,481	14,351	17,222	20,092
- RTG	13,097	17,462	21,828	26,193	30,559
Average number of Ships (L)	51.23	4.29	3.26	3.03	2.97
Costs of waiting	2,634,203	220,518	167,525	155,763	152,504
a. Ship Cost	1,138,023	95,268	72,374	67,293	65,884
b. Cargo cost	1,496,180	125,250	95,151	88,471	86,619
Total cost (TC)	2,739,802	354,463	329,816	346,401	371,487

Source: Author calculation

As seen in table 5.10 and figure 5.5 by deployment of 2 sets of equipment per berth the minimum total cost is achieved by using 5 units berth with the total cost US$ 329,816 per day.

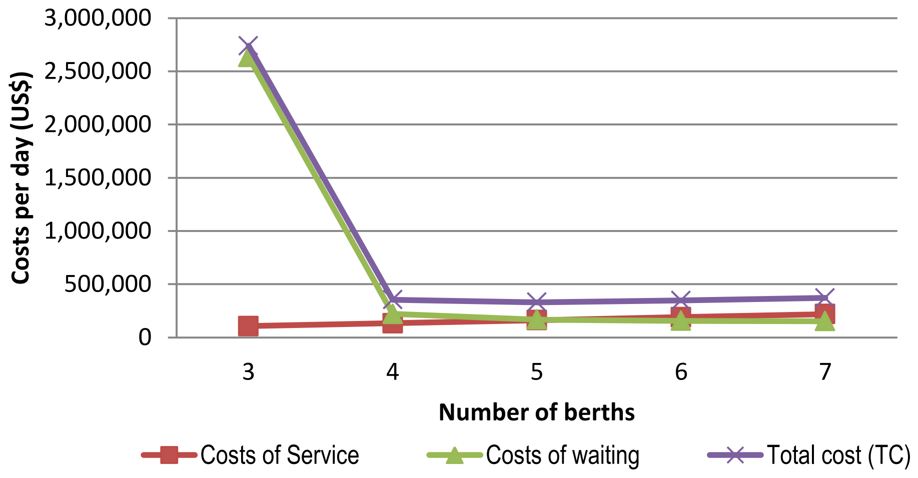


Figure 5.5 - Total Cost for Ship Service at Berth with 2 sets of equipment

Source: Author calculation

As seen in table 5.11. and figure 5.6. by deployment of 3 sets of equipment per berth the minimum total cost is achieved by using 4 units berth with the total cost US$ 284,611 per day.

Table 5.11 - Total Cost in US$ per day for Ship Service at Berth with 3 sets of equipment

Number of berths (k)	3	4	5	6	7
Costs of Service	132,996	170,474	207,952	245,430	282,908
a. Stacking yard	20,562	20,562	20,562	20,562	20,562
b. Berth	30,246	40,328	50,410	60,492	70,574
c. Equipment					
- QC	49,627	66,169	82,712	99,254	115,796
- Trailer	12,916	17,222	21,527	25,832	30,138
- RTG	19,645	26,193	32,742	39,290	45,838
Average number of Ships (L)	3.00	2.22	2.08	2.04	2.03
Costs of waiting	154,093	114,137	106,706	104,989	104,590
a. Ship Cost	66,571	49,309	46,099	45,357	45,185
b. Cargo cost	87,522	64,828	60,607	59,632	59,405
Total cost (TC)	287,089	284,611	314,658	350,419	387,497

Source: Author calculation

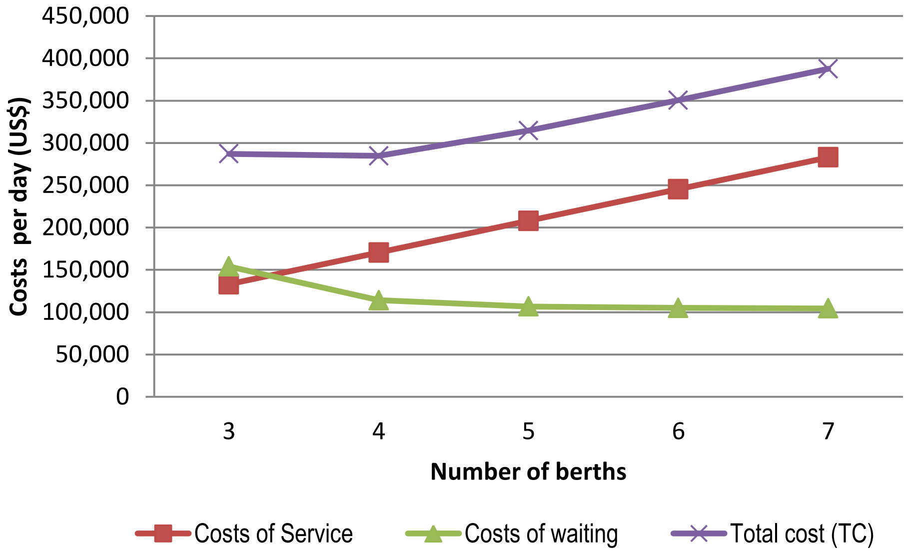


Figure 5.6 - Total Cost for Ship Service at Berth with 3 sets of equipment

Source: Author calculation

As seen in table 5.12 and figure 5.7 by deployment of 4 sets of equipment per berth the minimum total cost is achieved by using 3 units berth with the total cost US$ 284,611 per day.

Table 5.12 - Total Cost in US$ per day for Ship Service at Berth with 4 sets of equipment

Number of berths (k)	2	3	4	5	6	7
Costs of Service	113,782	160,392	207,002	253,612	300,222	346,832
a. Stacking yard	20,562	20,562	20,562	20,562	20,562	20,562
b. Berth	20,164	30,246	40,328	50,410	60,492	70,574
c. Equipment						
- QC	44,113	66,169	88,226	110,282	132,338	154,395
- Trailer	11,481	17,222	22,962	28,703	34,443	40,184
- RTG	17,462	26,193	34,924	43,655	52,386	61,118
Average number of Ships (L)	4.17	1.87	1.63	1.59	1.58	1.58
Costs of waiting	214,640	96,231	84,016	81,687	81,216	81,125
a. Ship Cost	92,728	41,574	36,296	35,290	35,087	35,048
b. Cargo cost	121,912	54,658	47,720	46,397	46,129	46,078
Total cost (TC)	328,422	256,623	291,018	335,299	381,438	427,957

Source: Author calculation

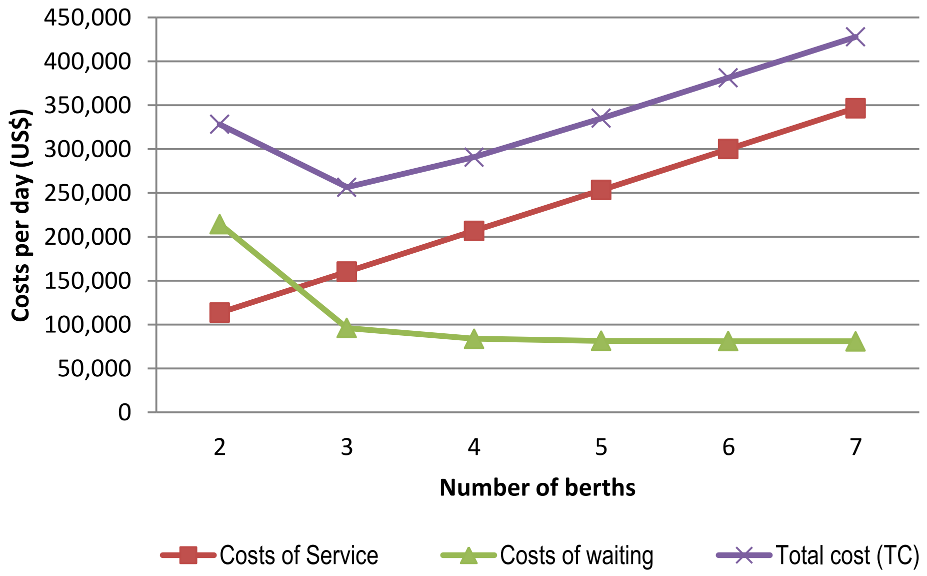


Figure 5.7 - Total Cost for Ship Service at Berth with 4 sets of equipment

Source: Author calculation

Having analyzed the total cost of ship service at berth for each set of equipment deployment, it is obtained that the minimum total cost will be achieved by using 3 units berth with the deployment of 4 equipment sets in each berth. However, based on data of the vessel size in table 4.10 and 4.11 which shows that the size of vessels which often call at JICT are feeder and small size and in table 4.8 shows that the most often QC deployment for a vessel is 3 units thus regarding the average vessel size the author proposes that the best alternative is using 3 equipment sets per berth with the optimal number of berth is 4 units berth.

5.5.2. Total cost in Receiving and Delivery Operation

Total cost in receiving and delivery is analyzed to determine the number of RTG should be used for receiving and delivery operation at the container yard to achieve a minimum total cost. The total cost calculation result for receiving and delivery operation is shown in table 5.13 and 5.14, which is also presented in a line chart as shown in figure 5.8 and 5.9.

Table 5.13 - Total cost in Receiving Operation (US$ per hour)

Number of RTG (k)	5	6	7
Costs of Service	632	677	723
a. Stacking yard	404	404	404
b. RTG	227	273	318
Average number of Containers (L)	13.19	6.01	5.01
Costs of waiting	416	190	158
a. Trailer Cost	396	180	150
b. Cargo cost	21	9	8
Total cost (TC)	1,048	867	881

Source: Author calculation

As seen in table 5.13 and figure 5.8 the minimum total cost in receiving operation is achieved by using 6 units RTG with the total cost US$ 867 per hour.

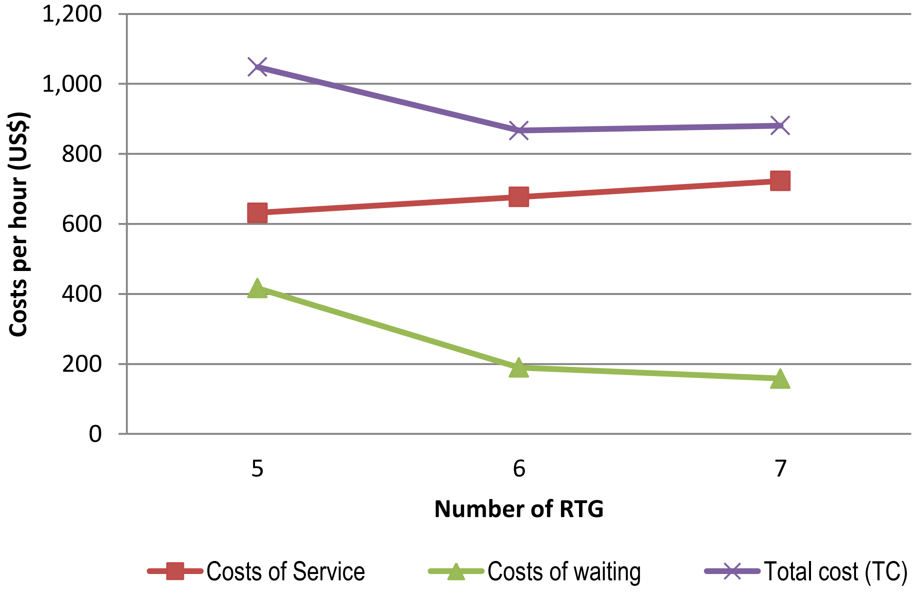


Figure 5.8 - Total cost in Receiving Operation (US$ per hour)

Source: Author calculation

Table 5.14 - Total cost in Delivery Operation (US$ per hour)

Number of RTG (k)	6	7	8
Costs of Service	725	771	816
a. Stacking yard	452	452	452
b. RTG	273	318	364
Average number of Containers (L)	9.37	6.25	5.55
Costs of waiting	296	197	175
a. Trailer Cost	281	187	166
b. Cargo cost	15	10	9
Total cost (TC)	1,021	968	991

Source: Author calculation

As seen in table 5.14 and figure 5.9 the minimum total cost in delivery operation is achieved by using 7 units RTG with the total cost US$ 968 per hour.

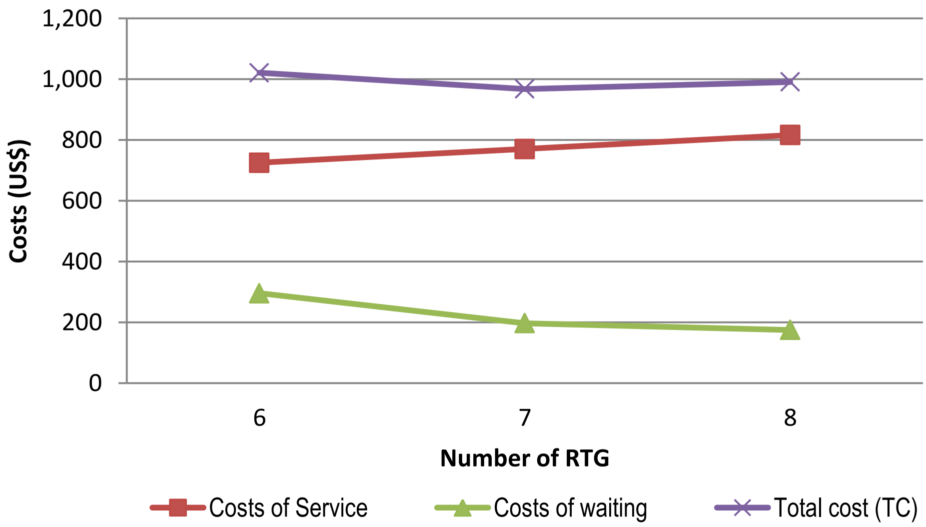


Figure 5.9 - Total cost in Delivery Operation (US$ per hour)

Source: Author calculation

5.6. Proper Terminal Capacity Analysis

Proper terminal capacity is achieved when the containers can be handled with a minimum waiting time and an optimum the utilization of facilities and equipment. By applying queuing theory to analyze total cost model we obtain a proper number and proper utilization of facilities and equipment which will determine the terminal capacity. The following are several variables that will be used to calculate proper terminal capacity in each container handling operation:

a. Equipment service time.
   As collected from the daily report of the terminal the average service time of QC and RTG is 1.89 minutes and 3.98 minutes. While for trailer, service time is counted from the activities of waiting container unloaded from the ship, transfer to the yard, waiting container lifted off from the trailer and back to the quay as explained in the man & machine analysis with the total service time 19.67 minutes
b. Annual terminal working hour that is 365 days x 24 hours.
c. Number of equipment deployed in each container handling operation.
   Based on previous analysis the optimum number of berth in the terminal is 4 units berth with 3 equipment sets (consists of 1 unit QC, 10 units trailer and 2 units RTG per set) per berth. Thus, the number equipment deployed for the operation between quay and yard is 12 units QC, 120 units trailer and 24 units RTG. Whereas, the equipment deployed for receiving and delivery operation is 6 and 7 units RTG respectively.
d. Utilization of equipment which is obtained from queuing model analysis and man & machine chart analysis. Based on queuing analysis the optimum utilization of berth by using 3 sets of equipment is 50.80%. From man & machine chart analysis is shown that the utilization of equipment in each cycle of operation for QC, Trailer and RTG are 100%, 99% and 98% respectively. By multiplying the berth utilization and equipment utilization in each operation cycle thus the optimum utilization of QC, Trailer and RTG in yard operation is 50.80%,

50.29%, and 49.29% respectively. While the optimum utilization for receiving and delivery operation is 76.27% and 74.10% respectively.

By multiplying annual terminal working hours, number of equipment and utilization then divided by equipment service we obtain the proper capacity as shown in table 5.15.

Table 5.15 - Proper Terminal Capacity Calculation

Type of Operation	Service Time (minutes)	Type of Equipment	Number of Equipment	Utilization	Proper Capacity	
					Containers	TEUs
Loading /Unloading	1.98	QC	12	50.80%	1,618,300	2,378,902
Haulage	19.67	Trailer	120	50.29%	1,612,706	2,370,678
Yard Operation	3.89	RTG	24	49.29%	1,598,328	2,349,543
Receiving	3.89	RTG	6	76.27%	618,353	908,979
Delivery	3.89	RTG	7	74.10%	700,800	1,030,176

Source: Author calculation

As far as proper terminal capacity is concerned we should have a balance capacity amongst the container terminal facilities. From table 5.15 we figure out that berth capacity (loading/unloading), haulage and yard operation (lift on/lift off) is more and less the same of about 2.3 million TEUs and the total capacity of receiving/delivery operation is around 1.3 million TEUs. Whereas, for the stacking yard with the existing area of 36.90 Ha and area requirement per TGS is 29.26 m^2/TEUs (based on the previous calculation in section 5.2.2), the total yard capacity is 2,278,596 TEUs. In order to achieve proper terminal capacity it is required to add more capacity in receiving/delivery operation by 1 million TEUs and in container yard by around 0.1 million TEUs. Using the same method and assumption as previous calculation we obtained that for receiving and delivery we need the addition of 4 units RTG in each operation, while for container yard the terminal operator should provide additional area of 1.5 Ha. Regarding the existing number of RTG available in the terminal is 45 units, while the total requirement of RTG is also 45 units thus the terminal operator do not need to provide more unit RTG. The evaluation of overall facilities & equipment is presented in table 5.16.

Table 5.16 - Evaluation of Overall Terminal Facilities & Equipment

Types	Existing	Required	Shortage/Surplus
Berth	7 units x 241 m	4 units x 241 m	3 units x 241 m
Yard	36.90 Ha	38.43 Ha	(1.5) Ha
QC	14	12	2
RTG	45	45	0
Trailer	128	120	8

Source: Author calculation

Chapter 6 CONCLUSION AND RECOMMENDATION

Proper terminal capacity is maximum throughput that can be handled by the terminal with a minimum waiting time and an optimum utilization of facilities and equipment. In other word, the proper terminal capacity should consider the interest of the two parties that is customer and terminal operator. For terminal operator, it is important to maximize the utilization of terminal facilities and equipment due to its high investment cost. As consequence, it will cause ship and cargo waiting time which is unexpected by the customer due to the waiting cost that should be borne by them. Regarding this reason, the study applies a queuing theory to analyze the total cost in the terminal to find a minimum total cost of waiting which represent the customer interest and cost of service which represent the terminal operator interest. After conducting frequency distribution test by using Kolmogorov Smirnov Goodness of fit test (K-S test) we figure out that time between arrivals and time of service pattern follows an exponential distribution so that in this study we use M/M/k queuing model.

The analysis shows that the optimum number of berth is 4 units berth with the average utilization 50.80%. The equipment should be deployed for container handling operation between quay and stacking yard is 12 units QC, 120 units trailer and 24 units RTG with the average utilization of 50.80%, 50.29%, and 49.29% respectively. By using this optimum number of berth and equipment would be achieved the minimum total cost of US$ 284,611 per day with the proper capacity of around 2.3 million TEUs. Meanwhile in receiving and delivery operation, analysis shows that the optimum number of RTG should be deployed is 6 units for receiving and 7 units for delivery with the average utilization of 76.27% and 74.10% respectively. By using this optimum number of equipment would be achieved the minimum total cost of US$ 968 per hour for receiving with the proper capacity of around 0.9 million TEUs and US$ 867 per hour for delivery operation with the proper capacity of about 1 million TEUs.

As far as proper terminal capacity is concerned we should have a balance capacity amongst the container terminal facilities. After evaluating the capacity of facilities and equipment in each container handling operation we find that there is a shortage in stacking yard capacity by around 0.1 million TEUs and in receiving/delivery operation by 1 million TEUs. In order to achieved a proper terminal capacity of 2.3 million TEUs we recommend to have additional investment in container yard area of 1.5 Ha.

Furthermore, based on this study we also recommend that the usage of 4 berths instead of the existing 7 berths in the terminal is more efficient regarding the cost of service, although from the customer point of views it is more than satisfying them due to almost no waiting time suffered. However, a recommendation to operate 4 berth with 3 set equipment per berth is not always correct since the container traffic flow and the size of vessels call in the terminal is continue to grow. A further analysis should be carried out considering the future container traffic flow and the development of vessel call in JICT. As container traffic flow is growth and size of the vessel call is bigger the terminal may need to use more berths and more equipment set deployed per berth, certainly with additional investment in terminal facilities and equipment. In other word, when the arrival rate and service rate in the terminal has been change we have to conduct further study.

REFERENCES

1) Alderton, P. M. (2005). Port Management and Operations, 2nd Edition, London.

2) Bierwirth, C. and Meisel, F. (2010). A survey of berth allocation and quay crane scheduling problems in container terminals, *European Journal of Operational Research,* 202 (3), 615–627.

3) Bish, E. K., Leong, T. Y., Li, C. L., Ng, W. C. and Simchi-Levi, D. (2001). Analysis of a new vehicle scheduling and location problem, *Naval Research Logistics,* 48, 363–385.

4) Branislav, D. and Nam, K.P. (2006). Modeling of ship-Berth-Yard Link Performance and Throughput Optimization, IAME 2006 Conference, Melbourne, Australia.

5) Calyampudi, R. R., Edward, J. W. and Jeffrey, L. S. (2005). Handbook of Statistics: Data Mining and Data Visualization, 1st Edition, Elsevier B. V., Netherland.

6) Canonaco, P., Legato, P., Mazza, R. M. and Musmanno, R. (2007). A queuing network model for the management of berth crane operations, *Computers and Operations Research,* doi:10.1016/j.cor.2006.12.001.

7) Chen, L., Bostel, N., Dejax, P., Cai, J. and Xi, L. (2007). A tabu search algorithm for the integrated scheduling problem of container handling systems in a maritime terminal, *European Journal of Operational Research,* 181, 40–58.

8) Cheng, Y. L., Sen H. C., Natarajan, K., Teo, C. P. and Tan, K. C. (2005) Dispatching automated guided vehicles in a container terminal, in J. Geunes and P. M. Pardalos (eds.) *Supply Chain Optimization*, Applied Optimization, Springer.

9) Cordeau, J. F., Laporte, G., Legato, P. and Moccia, L. (2005). Models and tabu search heuristics for the berth-allocation problem, *Transportation Science,* 39 (4), 526–538.

10) Dai, J., Lin, W., Moorthy, R. and Teo, C. P. (2008). Berth allocation planning optimization in container terminals, in C. S. Tang, C. P. Teo and K. K. Wei (eds.) *Supply Chain Analysis, International Series in Operations Research & Management Science,* 119, 69–104, Springer.

11) Daganzo, C. F. (1989). The crane scheduling problem, *Transportation Research Part B,* 23, 159–175.

12) Ding, Y. Z. (2010). Throughput capacity of a container terminal considering the combination patterns of the types of arriving vessels, *Journal of Shanghai Jiaotong Univ,* 15(1), 124-128, doi: 10.1007/s12204-010-8174-y.

13) Gambardella, L. M., Rizzoli, A. E. and Zaffalon, M. (1998). Simulation and planning of an intermodal container terminal, *Simulation*, 71, 107–116.

14) Giallombardo, G., Moccia, L., Salani, M. and Vacca, I. (2010). Modeling and solving the tactical berth allocation problem, *Transportation Research Part B,* 44 (2), 232–245.

15) Goodchild, A. V. and Daganzo, C. F. (2006). Double-cycling strategies for container ships and their effect on ship loading and unloading operations, *Transportation Science,* 40, 473–483.

16) Goodchild, A. V. and Daganzo, C. F. (2007). Crane double cycling in container ports: planning methods and evaluation, *Transportation Research Part B,* 41, 875–891.

17) Henesey, L. (2006). *Multi-agent Container Terminal Management*, PhD thesis, Karlshamn, Blekinge Institute of Technology.

18) Huang, S. Y., Hsu, W. J., Chen, C., Ye, R. and Nautiyal, S. (2008). Capacity Analysis of Container Terminals Using Simulation Techniques, *International Journal of Computer Applications in Technology*, doi: 10.1504/IJCAT.2008.021379.

19) Imai, A., Nagaiwa, K. and Tat, C. W. (1997). Efficient planning of berth allocation for container terminals in Asia, Journal *of Advanced Transportation*, 31(1), 75-94.

20) Imai, A., Nishimura, E. and Papadimitriou, S. (2001). The dynamic berth allocation problem for a container port, *Transportation Research Part B,* 35 (4), 401–417.

21) Imai, A., Nishimura, E. and Papadimitriou, S. (2003). Berth allocation with service priority, *Transportation Research Part B,* 37, 437–457.

22) Imai, A., Chen, H. C., Nishimura, E. and Papadimitriou, S. (2008). The simultaneous berth and quay crane allocation problem, *Transportation Research Part E*, 44 (5), 900–920.

23) Imai, A., Nishimura, E., Hattori, M. and Papadimitriou, S. (2007). Berth allocation at indented berths for mega-containerships, *European Journal of Operational Research*, 179, 579–593.

24) Imai, A., Nishimura, E. and Papadimitriou, S. (2008). Berthing ships at a multi-user container terminal with a limited quay capacity, *Transportation Research Part E,* 44, 136–151.

25) Imai, A., Sun, X., Nishimura, E. and Papadimitriou, S. (2005). Berth allocation in a container port: using a continuous location space approach, *Transportation Research Part B,* 39, 199–221.

26) Kang, J., Ryu, K. R. and Kim, K. H. (2006). Deriving stacking strategies for export containers with uncertain weight information, *Journal of Intelligent Manufacturing,* 17, 399–410.

27) Kim, K. H. and Bae, J. W. (1998). Re-marshaling export containers in port container terminals, *Computers and Industrial Engineering,* 35, 655–658.

28) Kim, K. H. and Kim, H. B. (1998). The optimal determination of the space requirement and the number of transfer cranes for import containers, *Journal of Computers and Industrial Engineering*, 35(3-4), 427-430

29) Kim, K. H. and Kim, H. B. (1999). Segregating space allocation models for container inventories in port container terminals, *International Journal of Production Economics,* 59, 415–423.

30) Kim, K. H. and Hong, G. P. (2006). A heuristic rule for relocating blocks, *Computers and Operations Research,* 33, 940–954.

31) Kim, K. H., Park, Y. M. and Ryu, K. R. (2000). Deriving decision rules to locate export containers in container yards, *European Journal of Operational Research,* 124, 89–101.

32) Kim, K. H. and Kim, H. B. (2002). The optimal sizing of the storage space and handling facilities for import containers, *Transportation Research Part B,* 36, 821–835.

33) Kim, K. H. and Lee, J. S. (2006). Satisfying constraints for locating export containers in port container terminals, *Lecture Notes in Computer Science,* 3982, 564–573.

34) Kim, K. H. and Park, Y. M. (2003). A note on a dynamic space-allocation method for outbound containers, *European Journal of Operational Research,* 148, 92–101.

35) Kim, K. H. and Moon, K. C. (2003). Berth scheduling by simulated annealing, *Transportation Research Part B*, 37 (6), 541–560.

36) Kim, K. H., Lee, K. M. and Hwang, H. (2003). Sequencing delivery and receiving operations for yard cranes in port container terminals, *International Journal of Production Economics*, 84, 283–292.

37) Kim, K. H. and Park, Y. M. (2004). A crane scheduling method for port container terminals, *European Journal of Operational Research,* 156 (3), 752–768.

38) Kozan, E (1997). Increasing the operational efficiency of container terminals in Australia, *The Journal of the Operational Research Society*, 48 (2), 151-161.

39) Kozan, E. (2000). Optimizing container transfers at multimodal terminals, *Mathematical and Computer Modeling,* 31, 235–243.

40) Kozan, E. and Preston, P. (2006). Mathematical modelling of container transfers and storage locations at seaport terminals, *OR Spectrum,* 28, 519–537.

41) Lau, H. and Zhao, Y. (2007). Integrated scheduling of handling equipment at automated container terminals, *International Journal of Production Economics*, doi:10.1016/j.ijpe.2007.05.015.

42) Lee, D. H., Cao, Z. and Meng, Q. (2007). Scheduling of two-transtainer systems for loading outbound containers in port container terminals with

simulated annealing algorithm, *International Journal of Production Economics,* 107, 115–124.

43) Lee, D. H., Wang, H. Q. and Miao, L. (2008). Quay crane scheduling with non-interference constraints in port container terminals, *Transportation Research Part E,* 44, 124–135.

44) Lee, D. H., Cao, J. X., Shi, Q. and Chen, J. H. (2009). A heuristic algorithm for yard truck scheduling and storage allocation problems, *Transportation Research Part E,* 45 (5), 810–820.

45) Lim, A. (1998). The berth planning problem, *Operations Research Letters,* 22 (2-3), 105–110.

46) Lim, A., Rodrigues, B., Xiao, F. and Zhu, Y. (2004). Crane scheduling with spatial constraints, *Naval Research Logistics,* 51, 386–406.

47) Liu, C. I., Jula, H. and Ioannou, P. A. (2002). Design, simulation, and evaluation of automated container terminals, *Journal of IEEE Transactions on Intelligent Transportation Systems*, 3(1), 12-26.

48) Liu, C. I., Jula, H., Vukadinovic, K. and Ioannou, P. (2004). Automated guided vehicle system for two container yard layouts, *Transportation Research Part C,* 12, 349–368.

49) Legato, P. and Mazza, R. M. (2001). Berth planning and resources optimisation at a container terminal via simulation, *European Journal of Operational Research,* 133, 537–547.

50) Maione, G. and Ottomanelli, M. (2005). A petri net model for simulation of container terminals operations, *Advanced OR and AI methods in transportation*, Poznan University of Technology, 373–378.

51) Manek, N.J. (2003). Comprehensive Industrial Engineering, Laxmi Publications, New Delhi.

52) Meisel, F. and Bierwirth, C. (2006). Integration of berth allocation and crane assignment to improve the resource utilization at a seaport container terminal, *Operations Research Proceedings 2005,* Springer, 105–110.

53) Moccia, L., Cordeau, J. F., Gaudioso, M. and Laporte, G. (2006). A branch-and-cut algorithm for the quay crane scheduling problem in a container terminal, *Naval Research Logistics,* 53, 45–59.

54) Monaco, M. F. and Sammarra, M. (2007). The berth allocation problem: a strong formulation solved by a lagrangean approach, *Transportation Science,* 41 (2), 265–280.

55) Moon, S. H. (2010a). Port Logistics (Why 'Proper Container Throughput Capacity'?), Unpublished lecture handout, WMU, Malmo, Sweden.

56) Moon, S. H. (2010b). Port Logistics (Queuing Theory), Unpublished lecture handout, WMU, Malmo, Sweden.

57) Murty, K. G., Liu, J., Wan, Y. W., et al. (2005) A decision support system for operations in a container terminal, *Journal of Decision Support Systems,* 39(3), 309-332.

58) El-Naggar, M. E. (2010). Application of queuing theory to the container terminal at Alexandria seaport, *Journal of Soil Science and Environmental Management,* 1 (4), 77-85.

59) Ng, W. C. (2005). Crane scheduling in container yards with inter-crane interference, *European Journal of Operational Research,* 164, 64–78.

60) Ng, W. C. and Mak, K. L. (2005). Yard crane scheduling in port container terminals, *Applied Mathematical Modeling,* 29, 263–276.

61) Ng. W. C. and Wong, C. S. (2006). Evaluating the impact of vessel traffic interference on container terminal capacity, *Journal of Waterway, Port, Coastal, and Ocean Engineering,* 132(2), 76-82.

62) Nishimura, E., Imai, A. and Papadimitriou, S. (2001). Berth allocation in the public berth system by genetic algorithms, *Journal of European Journal of Operational Research*, 131(2), 282-292.

63) Noritake, M. and Kimura, S. (1990). Optimum allocation and size of seaports, *Journal of Waterway, Port Coastal, and Ocean Engineering*, 116, 287-299.

64) Notteboom, T. (2006). The time factor in liner shipping services, Maritime Economics & Logistics, 8, 19-39.

65) Park, Y. M. and Kim, K. H. (2003). A scheduling method for berth and quay cranes, *OR Spectrum,* 25, 1–23.

66) Rajagopalan, V. (2006). Selected Statistical Tests. New Age International Publishers.

67) Sammarra, M., Cordeau, J. F., Laporte, G. and Monaco, M. F. (2007). A tabu search heuristic for the quay crane scheduling problem, *Journal of Scheduling,* 10, 327–336.

68) Stahlbock, R. and Voß, S. (2007). Operations research at container terminals: a literature update, *OR Spectrum* 2008, 30, 1–52, doi: 10.1007/s00291-007-0100-9.

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

70) Tadashi, Y. (2003). Optimizing the handling Capacity in a Container Terminal for Investigating efficient Handling Systems, *Journal of Eastern Asia Society for Transportation Studies,* 5, 597–608.

71) UNCTAD. (1985). Port development: A handbook for Planners in Developing Countries, 2nd Edition, New York.

72) Vacca, I., Salani, M. and Bierlaire, M. (2010), Optimization of operations in container terminals: hierarchical vs integrated, Swiss Transport Research Conference 2010.

73) Vis, I. F. A. and de Koster, R. (2003). Transshipment of containers at a container terminal: An overview, *European Journal of Operational Research,* 147, 1–16.

74) Willig, A. (1999). A short introduction to queuing theory, Technical University Berlin, Telecommunication Network Group.

75) Yamada, T., Frazila, R. B., Yoshizawa, G. and Mori, K. (2003). Optimizing the handling capacity in a container terminal for investigating efficient handling system, *Journal of the Eastern Asia Society for Transportation Studies,* 5, 597-608.

76) Yang, J. H. and Kim, K. H. (2006). A grouped storage method for minimizing relocations in block stacking systems, *Journal of Intelligent Manufacturing,* 17, 453–463.

77) Zhang, C., Liu, J., Wan, Y. W., *et al*., (2003). Storage space allocation in container terminals, *Journal of Transportation Research Part B*, 37(10), 883-903.

Appendix 1 K-S test for ship time between arrivals

a. Hypothesis:

H_0: the population distribution of ship time between arrivals F(x) is the same as $F_0(x)$ which follows the exponential distribution.

H_1: the population distribution of ship time between arrivals F(x) is not the same as $F_0(x)$ which follows the exponential distribution.

b. Critical value D_α for level of significance (α) 95%: $D_{0.95} = \frac{1.36}{\sqrt{1,872}} = 0.0314$

c. Cumulative distribution function of ship time between arrivals

Interval	Empirical Distribution			Specified Distribution		Different
	Frequency	Probability	Cum Prob. $F_n(X)$	Probability	Cum Prob. $F_0(X)$	D
0.00 - 2.63	757	0.4044	0.4044	0.4298	0.4298	0.0254
2.63 - 5.25	512	0.2735	0.6779	0.2451	0.6749	0.0030
5.25 - 7.88	223	0.1191	0.7970	0.1397	0.8146	0.0176
7.88 - 10.51	190	0.1015	0.8985	0.0797	0.8943	0.0042
10.51 - 13.14	105	0.0561	0.9546	0.0454	0.9397	0.0149
13.14 - 15.76	38	0.0203	0.9749	0.0259	0.9656	0.0093
15.76 - 18.39	23	0.0123	0.9872	0.0148	0.9804	0.0068
18.39 - 21.02	11	0.0059	0.9931	0.0084	0.9888	0.0042
21.02 - 23.65	6	0.0032	0.9963	0.0048	0.9936	0.0026
23.65 - 26.27	4	0.0021	0.9984	0.0027	0.9964	0.0020
26.27 - 28.90	2	0.0011	0.9995	0.0016	0.9979	0.0015
28.90 - 31.53	1	0.0005	1.0000	0.0009	0.9988	0.0012
	1,872	1.0000				

d. Conclusion:

Base on the calculation D = 0.0254 and $D_{0.95}$ = 0.0314, thus $D \leq D_\alpha$, and H_0 is accepted. It means that statistically the ship time between arrivals follow an exponential distribution.

Appendix 2 K-S test for trailer time between arrivals in receiving

a. Hypothesis:

H_0: the population distribution of trailer time between arrivals F(x) is the same as $F_0(x)$ which follows the exponential distribution.

H_1: the population distribution of trailer time between arrivals F(x) is not the same as $F_0(x)$ which follows the exponential distribution.

b. Critical value D_α for level of significance (α) 95%: $D_{0.95} = \frac{1.36}{\sqrt{375}} = 0.0712$

c. Cumulative distribution function of tr trailer time between arrivals in receiving operation

Interval			Empirical Distribution			Specified Distribution		Different
			Frequency	Probability	Cum Prob. $F_n(X)$	Probability	Cum Prob. $F_0(X)$	D
0.00	-	0.66	179	0.4904	0.4904	0.5376	0.5376	0.0472
0.66	-	1.31	103	0.2822	0.7726	0.2486	0.7862	0.0136
1.31	-	1.97	34	0.0932	0.8658	0.1149	0.9012	0.0354
1.97	-	2.62	22	0.0603	0.9260	0.0531	0.9543	0.0283
2.62	-	3.28	11	0.0301	0.9562	0.0246	0.9789	0.0227
3.28	-	3.93	6	0.0164	0.9726	0.0114	0.9902	0.0176
3.93	-	4.59	4	0.0110	0.9836	0.0053	0.9955	0.0119
4.59	-	5.25	2	0.0055	0.9890	0.0024	0.9979	0.0089
5.25	-	5.90	3	0.0082	0.9973	0.0011	0.9990	0.0018
5.90	-	6.56	1	0.0027	1.0000	0.0005	0.9996	0.0004
			365	1.0000				

d. Conclusion:

Base on the calculation D = 0.0472 and $D_{0.95}$ = 0.0712, thus $D \leq D_\alpha$, and H_0 is accepted. It means that statistically trailer time between arrivals in receiving operations follow an exponential distribution.

Appendix 3 K-S test for trailer time between arrivals in delivery

a. Hypothesis:

H_0: the population distribution of trailer time between arrivals F(x) is the same as $F_0(x)$ which follows the exponential distribution.

H_1: the population distribution of trailer time between arrivals F(x) is not the same as $F_0(x)$ which follows the exponential distribution.

b. Critical value D_α for level of significance (α) 95%: $D_{0.95} = \frac{1.36}{\sqrt{375}} = 0.0712$

c. Cumulative distribution function of trailer time between arrivals in delivery operation

Interval			Empirical Distribution			Specified Distribution		Different
			Frequency	Probability	Cum Prob. $F_n(X)$	Probability	Cum Prob. $F_0(X)$	D
0.00	-	0.66	189	51.78%	0.5178	0.5852	0.5852	0.0674
0.66	-	1.32	92	25.21%	0.7699	0.2427	0.8280	0.0581
1.32	-	1.98	36	9.86%	0.8685	0.1007	0.9286	0.0602
1.98	-	2.64	17	4.66%	0.9151	0.0418	0.9704	0.0553
2.64	-	3.30	12	3.29%	0.9479	0.0173	0.9877	0.0398
3.30	-	3.96	9	2.47%	0.9726	0.0072	0.9949	0.0223
3.96	-	4.62	5	1.37%	0.9863	0.0030	0.9979	0.0116
4.62	-	5.28	2	0.55%	0.9918	0.0012	0.9991	0.0073
5.28	-	5.94	2	0.55%	0.9973	0.0005	0.9996	0.0024
5.94	-	6.60	1	0.27%	1.0000	0.0002	0.9998	0.0002
			365	1.0000				

d. Conclusion:

Base on the calculation D = 0.0674 and $D_{0.95}$ = 0.0712, thus $D \leq D_\alpha$, and H_0 is accepted. It means that statistically trailer time between arrivals in delivery operation follow an exponential distribution.

Appendix 4 K-S test for loading/unloading service time

a. Hypothesis:

H_0: the population distribution of loading/unloading service time F(x) is the same as $F_0(x)$ which follows the exponential distribution.

H_1: the population distribution of loading/unloading service time F(x) is not the same as $F_0(x)$ which follows the exponential distribution.

b. Critical value D_α for level of significance (α) 95%: $D_{0.95} = \frac{1.36}{\sqrt{375}} = 0.0712$

c. Cumulative distribution function of loading/unloading service time

Interval			Empirical Distribution			Specified Distribution		Different
			Frequency	Probability	Cum Prob. $F_n(X)$	Probability	Cum Prob. $F_0(X)$	D
0.77	-	1.28	166	0.4548	0.4548	0.4764	0.4764	0.0216
1.28	-	1.79	67	0.1836	0.6384	0.1191	0.5956	0.0428
1.79	-	2.30	42	0.1151	0.7534	0.0920	0.6876	0.0658
2.30	-	2.81	27	0.0740	0.8274	0.0711	0.7587	0.0687
2.81	-	3.33	15	0.0411	0.8685	0.0549	0.8136	0.0549
3.33	-	3.84	20	0.0548	0.9233	0.0424	0.8560	0.0673
3.84	-	4.35	12	0.0329	0.9562	0.0328	0.8888	0.0674
4.35	-	4.86	10	0.0274	0.9836	0.0253	0.9141	0.0695
4.86	-	5.37	4	0.0110	0.9945	0.0196	0.9336	0.0609
5.37	-	5.88	2	0.0055	1.0000	0.0151	0.9487	0.0513
			365	1.0000				

d. Conclusion:

Base on the calculation D = 0.0695 and $D_{0.95}$ = 0.0712, thus $D \leq D_\alpha$, and H_0 is accepted. It means that statistically loading/unloading service time follow an exponential distribution.

Appendix 5 K-S test for haulage service time

a. Hypothesis:

H_0: the population distribution of haulage service time F(x) is the same as $F_0(x)$ which follows the exponential distribution.

H_1: the population distribution of haulage service time F(x) is not the same as $F_0(x)$ which follows the exponential distribution.

b. Critical value D_α for level of significance (α) 95%: $D_{0.95} = \frac{1.36}{\sqrt{375}} = 0.0712$

c. Cumulative distribution function of haulage service time

Interval			Empirical Distribution			Specified Distribution		Different
			Frequency	Probability	Cum Prob. $F_n(X)$	Probability	Cum Prob. $F_0(X)$	D
4.90	-	6.33	208	0.5699	0.5699	0.6005	0.6005	0.0307
6.33	-	7.76	62	0.1699	0.7397	0.0747	0.6752	0.0645
7.76	-	9.18	22	0.0603	0.8000	0.0607	0.7360	0.0640
9.18	-	10.61	17	0.0466	0.8466	0.0494	0.7853	0.0612
10.61	-	12.04	18	0.0493	0.8959	0.0401	0.8255	0.0704
12.04	-	13.47	12	0.0329	0.9288	0.0326	0.8581	0.0706
13.47	-	14.89	9	0.0247	0.9534	0.0265	0.8847	0.0688
14.89	-	16.32	6	0.0164	0.9699	0.0216	0.9062	0.0636
16.32	-	17.75	6	0.0164	0.9863	0.0175	0.9238	0.0625
17.75	-	19.18	5	0.0137	1.0000	0.0143	0.9380	0.0620
			365	1.0000				

d. Conclusion:

Base on the calculation D = 0.0706 and $D_{0.95}$ = 0.0712, thus $D \leq D_\alpha$, and H_0 is accepted. It means that statistically haulage service time follow an exponential distribution.

Appendix 6 K-S test for lift on/off service time

a. Hypothesis:

H_0: the population distribution of lift on/off service time F(x) is the same as $F_0(x)$ which follows the exponential distribution.

H_1: the population distribution of lift on/off service time F(x) is not the same as $F_0(x)$ which follows the exponential distribution.

b. Critical value D_α for level of significance (α) 95%: $D_{0.95} = \frac{1.36}{\sqrt{375}} = 0.0712$

c. Cumulative distribution function of lift on/off service time

Interval			Empirical Distribution			Specified Distribution		Different
			Frequency	Probability	Cum Prob. $F_n(X)$	Probability	Cum Prob. $F_0(X)$	D
2.80	-	3.67	208	0.5699	0.5699	0.6105	0.6105	0.0407
3.67	-	4.54	62	0.1699	0.7397	0.0779	0.6885	0.0513
4.54	-	5.40	28	0.0767	0.8164	0.0623	0.7508	0.0657
5.40	-	6.27	19	0.0521	0.8685	0.0499	0.8006	0.0679
6.27	-	7.14	13	0.0356	0.9041	0.0399	0.8405	0.0636
7.14	-	8.01	12	0.0329	0.9370	0.0319	0.8724	0.0646
8.01	-	8.88	6	0.0164	0.9534	0.0255	0.8979	0.0555
8.88	-	9.75	8	0.0219	0.9753	0.0204	0.9184	0.0570
9.75	-	10.61	6	0.0164	0.9918	0.0163	0.9347	0.0571
10.61	-	11.48	2	0.0055	0.9973	0.0131	0.9478	0.0495
			365	1.0000				

d. Conclusion:

Base on the calculation D = 0.0679 and $D_{0.95}$ = 0.0712, thus $D \leq D_\alpha$, and H_0 is accepted. It means that statistically lift on/off service time follow an exponential distribution.

Appendix 7 Calculation of additional yard area

To calculate the area required for additional yard capacity of 0.1 million TEUs per year we use the same assumptions as explained in section 5.2.2 (p.54) as follows:

- The equipment used at the stacking yard is RTG with capability of stacking one over four and spanning 7 rows.
- Distance between containers in a block is 0.25 meter.
- TEU conversion factor is 1.47 per containers.
- Dimension of a TEU container is 6.1 m x 2.4 m.
- There are 3 roadways for trailer in a block with the width 3.75 meter each.
- There are 2 sides of roadways for RTG in a block with the width 1.5 m each.
- Width of roadway between blocks is 25 meter.
- A block is consists of 66 slots with 7 row in each slot.
- The proportion of export and import containers is 43% and 57%.
- Dwelling Time (DT) for export and import is 2.3 days and 5.2 days, by multiplying the proportion of export and import, we can get the average dwelling time of 3.8 days.
- Peaking factor (PF) is 1.30.
- Stacking height (H) for export and import is 3.5 and 3 container high, by multiplying the proportion of export and import, we can get the average stacking height of 3.2 containers high.
- Land utilization (U) ratio is 80%.
- Number of working days in a year (K) is 365 days.

TEU Ground Slot (TGS) is calculated by the following formula:

$$TGS = \frac{Capacity.DT.PF}{H.U.K} = \frac{(100{,}000).(3.8).(1.30)}{(3.2).(0.80).(365)} = 523\ TEUs$$

Then we calculate the stacking yard area required with the following steps,

(1) Number of slots required = 523 TEUs / 7 rows = 74.69 slots.

(2) Number of blocks required = 74.69 slots / 66 slots = 1.13 blocks

(3) Total area of overall slots = 74.69 slots x (6.1 m x 2.4 m) = 7,654 m^2.

(4) Total area for distance between containers =
0.25 m x (2.4 m x 7 rows) x (66 slots – 1) x 1.13 blocks = 309 m^2.

(5) Effective area = 7,654 m^2 + 309 m^2 = 7,963 m^2.

(6) Total area for trailer roadways =
3 ways x 3.75 m x 418.85 m x 1.13 blocks = 5,332 m^2.

(7) Total area for RTG roadways =
2 ways x 2 m x 418.85 m x 1.13 blocks = 1,896 m^2.

(8) Total area for roadways between the blocks =
25 m x 32.05 m x (1.13 blocks - 1) = 105 m^2.

(9) Total stacking yard area required =
7,963 m^2 + 5,332 m^2 + 1,896 m^2 + 105 m^2 = 15,297 m^2 = 1.53 Ha

Appendix 8 Calculation of additional unit RTG in receiving/delivery

- Additional capacity required: 1 million TEUs per year with the breakdown of 470,000 TEUs for receiving and 530,000 TEUs for delivery.
- By operating the RTG with the utilization of 76.27% for receiving and 74.10% for delivery, the number of RTG required are:

For receiving operation:

$$\frac{(470{,}000 \text{ TEUs} / 1.47) \times 3.89 \text{ minutes}}{365 \text{ days} \times 24 \text{ hours} \times 60 \text{ minutes} \times 76.27\%} = 3.1 \text{ units} \sim 4 \text{ units}$$

For delivery operation:

$$\frac{(530{,}000 \text{ TEUs} / 1.47) \times 3.89 \text{ minutes}}{365 \text{ days} \times 24 \text{ hours} \times 60 \text{ minutes} \times 74.10\%} = 3.6 \text{ units} \sim 4 \text{ units}$$