Analysis of Efficiency of Container Operations with Automated System:
A Case study of Laemchabang Port

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ณิชกานต์ ภีมเดชาชัย : การวิเคราะห์ประสิทธิภาพการปฏิบัติงานขนถ่ายตู้สินค้าด้วยระบบอัตโนมัติ:กรณีศึกษาท่าเรือแหลมฉบัง. (Analysis of Efficiency of Container Operations with Automated System:A Case study of Laemchabang Port) อ.ที่ปรึกษาหลัก : รศ. ดร.จิตติชัย รุจนกนกนาฏ, อ.ที่ปรึกษาร่วม : รศ. ดร.คูนิฮีโระ คิชิ

การศึกษานี้วิเคราะห์ถึงการทำงานของระบบอัตโนมัติในกระบวนการขนถ่ายตู้สินค้าที่ท่าเรือแหลมฉบัง ประเทศไทย เนื่องจากท่าเรือมีการเติบโตอย่างรวดเร็ว ระดับการแข่งขันที่สูงขึ้นและปริมาณตู้สินค้าที่ผ่านท่าเรือที่เพิ่มขึ้น แต่ยังไม่สามารถบรรลุขีดจำกัดของท่าเรือได้ตลอด 20 ปีที่ผ่านมา ยังมีปัญหาเกี่ยวกับความล่าช้าจากการจัดการตู้สินค้า การจราจรติดขัดทั้งภายในและภายนอกท่าเรือ ปัญหาในการจัดการคนงาน ค่าแรงที่เพิ่มขึ้น ชั่วโมงการทำงานที่จำกัด รวมถึงพื้นที่ที่จำกัดต่อการขยายท่าเรืออีกด้วย ดังนั้นการประยุกต์ใช้ระบบอัตโนมัติในเครื่องมือจัดการตู้สินค้าจึงเป็นทางเลือกที่ดี เพื่อทดแทนการทำงานในระบบเดิม นอกจากนี้ยังเป็นการสนับสนุนและสอดคล้องกับนโยบายของการท่าเรือแห่งประเทศไทยในด้านการใช้เทคโนโลยีอัตโนมัติ ควบคู่ไปกับการเพิ่มประสิทธิภาพเพื่อการพัฒนาให้ท่าเรือแหลมฉบังให้มีความสามารถในการแข่งขันและขึ้นอยู่ในระดับที่ 15 ของโลก ด้วยการพัฒนาโครงสร้างพื้นบ้านและยกระดับสิ่งอำนวยความสะดวกให้ได้มาตรฐานระดับโลก การศึกษานี้ได้ประยุกต์ใช้ระบบอัตโนมัติในเครื่องจักรโดยการศึกษาผ่านแบบจำลองด้วยโปรแกรม ARENA ซึ่งได้ประยุกต์ 3 เครื่องจักรได้แก่ ปั้นจั่นหน้าท่ากึ่งอัตโนมัติ ปั้นจั่นในลานกองตู้อัตโนมัติและรถขนถ่ายตู้สินค้าอัตโนมัติ สำหรับกระบวนการขนถ่ายตู้สินค้าภายในท่าเรือตู้สินค้าเทอมินัล C1 และ C2 สำหรับข้อมูลตัวแปรต้นในแบบจำลองมาจากประสิทธิภาพของท่าเรือที่ทำได้ในปีที่ผ่านมา ผลของการศึกษาพบว่าเครื่องจักรในระบบอัตโนมัติสามารถเพิ่มประสิทธิภาพในการดำเนินงานในหลายๆด้าน เช่น ลดเวลาดำเนินการภายในท่าเรือ ลดเวลารอคอยของเรือตู้สินค้า เพิ่มประสิทธิภาพการใช้งานเครื่องจักร สุดท้ายนี้ การศึกษานี้ได้สรุปว่าระบบอัตโนมัติสามารถประยุกต์ใช้กับท่าเรือตู้สินค้าในแหลมฉบังเพื่อเพิ่มประสิทธิภาพและประสิทธิผลในด้านต่างๆ

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This study analyzed an automated system of container operations at Laem Chabang Port, Thailand. Due to the rapid growth in demand at the port, the throughput volume cannot reach the requirement, has difficulty in unskilled worker recruitment, working hours are limited, and has limitation on the terminal area. Therefore, an automated system is planned to replace the conventional container operations; this will also support the Port Authority of Thailand's encouragement of using automation technology. Along with the increasing the level of port development and enhancement of the container terminal port to be competitive in the world trade arena by developing and managing infrastructure and facilities to meet world-class standards. This study assumes an automatic system for container handling through the combination of machines, i.e., a semi-automated ship-to-shore gantry crane, an automated rubber-tired gantry crane, and an automated guided vehicle for the container movement. The specification of machines was obtained from the existing available technology in the marketplace. The data collected from the literature performance evaluation of container port outputs is simulated using ARENA software. The analysis showed that the automated system could improve operations in many aspects such as berth occupancy, ship waiting time, ship turnaround time, machine utilization, and resulting in much better container throughputs. Lastly, this paper summarizes the port's main advantages and challenges if the automated system is implemented.

Field of Study:	Civil Engineering	Student's Signature ....
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Nichkan Peemdechachai

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Introduction

1.1 Background

For decades, the development of deep seaport operations and container port industries in Thailand began with state-owned mechanisms. However, due to the expansion of the world economy and market trends in the increasing volume of containers, the Port Authority of Thailand could not support this expansion immediately. Therefore, the private sectors were pushed to build their ports to address modern technology.

The competition has been rising in the port industries-and-marine time at the regional and global levels. The technology is leading the way and opening new opportunities for advances in the marine time industry. Many large ports can see its benefits then they start investigating this kind of system and improving all benefits. Nowadays, there are many operating automation container terminals around the world. The primary purpose of bringing an automation system to ports and terminals is to introduce a whole new level of consistency when handling cargo and reduce operation time and the issue with human labor.

The impacts of automation may be more significant on the activities that effort port volumes, such as manufacturing, than on port operations- The degree of automation differs from port to port, depending on the capacity of the port, location, the annual amount of container, the ability of expansion even the current issue and the economic value.

Thailand is the essential deep seaport with a dominant share of 70 percent of the country's sea transport volume. Laem Chabang Port brims with the potential to be a genuinely world-class port. Under the Port Authority of Thailand (PAT) supervision, the port's development has been fast-tracked to serve the fast-growing industries in Chonburi Province as part of the Eastern Seaboard Development Project. Since its inaugural operations in January 1991, the port has provided services to meet its government mandate of sustaining economic growth by facilitating maritime transport and international trade. Also, the geographically advantaged to be situated in the crossroads of one of the fastest-growing economic clusters globally, Thailand’s Ministry of Transport has adopted a policy to promote the port as the main trading gateway of Indochina. As a principal port of Thailand, it can support largescale transportation of commodities in the region once some international mega-projects are completed in the near future, such as interconnecting routes to China and India, and trading routes in the Greater Mekong Subregion and the North-South Economic Corridor.

For more than 10 years, competition has been fierce in the port-and-marine transportation sector at the regional and global levels. Port technologies have become increasingly advanced and ships have become bigger for economy-of-scale reasons. The Thai market has expanded to a greater demand for goods and services partly because Thailand has engaged in many other nations' economic cooperation. Due to all of these factors, the number of ships and container vessels arriving and exiting Laem Chabang Port has climbed every year. It is forecast that from 2010 onwards, the container traffic at Laem Chabang Port will rise at the rate of 12% per annum or above 10 million TEUs (twenty-foot equivalent units) by 2016, which exceeds the port’s capacity in its first and second phases of development. Therefore, the PAT has started third phase development for the port to accommodate the rising need for sea transportation and boost Thailand’s competitiveness in the sector compared with other Asian ports. The goal is to establish Laem Chabang Port as the region’s hub port, as the Greater Mekong Sub-region’s gateway port, and as a port mirroring international standards. The PAT hopes development in Phase 3 will attract more cargo ships to Laem Chabang Port, which will boost job opportunities, income distribution to locals, and the country’s overall economy. The PAT is determined to boost the capacity of Laem Chabang Port to keep abreast with the country’s growing economy.

In a bid to establish Laem Chabang Port as an authentic eco-friendly facility with minimum negative environmental impacts and constructive co-existence with local communities on a sustainable basis, the PAT has executed the following measures: Using modern and environmentally-friendly technologies including efficient machinery for offering greater convenience and faster services to users, as well as pollution mitigation, Proactive and Eco-friendly Port promoting comprehensive environmental protection for enhanced quality of life, and support for a sustainable environment.

To ensure that the third-phase development of Laem Chabang Port responds to the goal of making the port a cosmopolitan facility, the PAT has commissioned a consultants’ consortium to conduct a feasibility study on economics and engineering as well as environmental impact assessment and detailed design of Laem Chabang Port – Phase 3. The PAT hopes the study results will deliver maximum benefits to communities, society and the country.

1.2 Problem statement

The Laem Chabang port problem statement refer to the study problem statement. The problems can be defined as follows.

1. Since Laem Chabang container terminal port start operating year by year, and the annual throughput still cannot reach the maximum capacity even they were increasing every year due to the cause factors involving around major processes operation that affect the volume of the container will be handled through the terminal.

2. Most of the operational problems in container terminals are strongly interconnected between human workers and machines. They currently have manned operations in the container terminal using less technology to cause a high risk for human safety working with the machine. Concerning human labor in port, a hundred people employed working day shift and night shift, which means the wage is a very large number with a steady result.

3. Currently, 60,000 container trucks access Laem Chabang Port per day, leading to traffic congestion. This from the expanding capacity to 11 million TEU in the last few years. The customers complained that the congestion wasted time waiting to get to the terminal, disturbing other road users, and spreading air pollution by diesel trucks. Moreover, the congestion caused to the bottleneck arises from limited space at the terminal gate and the existing gate. This problem can be caused by handling machine

operation in the traditional way of handling containers and taking much time until the truck gets the target container.

4. Delays and congestion in the area at several critical ports disrupt shipping service and competitiveness, with berthing delays of at least a week as ships are forced to wait at anchor also getting effect to the following processes in shipping service. The container terminal is reported to be most affected, with increased container volumes, inadequate infrastructure, and in some cases, bad weather all contributing to the problem.

5. The administration's policy formulation lacks the integration between government and private sectors, resulting in various and contrast operations directions. Besides, the inability to promptly manage and solve problems may cause to be less efficient and reduce potentials. As the PAT's strategies intend to push Laem Chabang port to be top 15th of world ranking after Phase 3 start operating and effort the marine time market to raise the volume of the container through the terminal port.

6. Concerning Phase 1 and Phase 2 of Laem Chabang port, considering as brown field container terminal, it is more difficult to applied new technology than green field terminal port or new construction port in Phase 3 but still strongly encourage the private sector who investing in the Laem Chabang Port Phase 3 develop to using the technology that is one of the crucial infrastructure projects listed in the EEC's phase. Some shipping lines company invest or operate in the terminal ports as well as providing a complete range of additional services, which may affect the operations of PAT in the future.

Laem Chabang Port is the main port of Thailand with a growth rate 10 percent per year. The number of container throughput is the 21^{st} of the world ranking in 2017 and up to 8 million TEU in 2018 (American Journal of Transportation, 2019). The operating system remains in the traditional method by using machinery with human labor which has limitations in working hours and may cause accidents. Labor causes and traffic in the port area both inside and outside the terminal occurs delays and congestion. The restrictions in the area, cost, and competitiveness of service providers are the main reason. Currently, the existing operation cannot support the terminal reach high efficiency to maximum volume. Therefore, the automation system will help to solve this problem which are prevalent in container ports in foreign countries around the world that have already been applied.

This study will be considered at Laem Chabang Port in C1 & C2 terminal in actual area of terminal including the total number of machineries to determine if an automated system is replacing in terminal by using ARENA Simulation software. The model would be set-up by combining the essential function and the same activity. The expected benefit will be helping to consider investing in automation technology in the future and the ability to compete with any ports in foreign countries.

1.3 The study purpose

1) Analyze the performance of the handling machine in container operation if the automated system is applied.

2) Examination of the productivity between the current system and the automation system.

3) Suggestions for the automation port system for an application at Laem Chabang Port.

1.4 Scope of the study

1) Using terminal C1&C2 in Laem Chabang port as a case study.

2) Considering both of import and export container operation only in the terminal.

3) Study on the productivity performance of container terminal port in terms of time.

4) In this study using the given machine combination which are Semi-automated quay crane as Ship to shore gantry crane, automated yard crane as Rubber-tired gantry crane and automated transporter as Automated guided vehicle.

5) Comparing the productivity performance by global performance index which are Ship turnaround time, Berth occupancy, Throughput per year, Throughput per berth length, Machine utilization, Idle time, and Container handling rate.

Chapter 2

Related research

2.1 Overview of the automatic container terminal

Automatic container terminal means port with convenient machinery and transportation equipment work in automation which can reduce time using. The primary operations are loading and unloading, arranging, positioning, and transferring to other modes of transportation. This operation is more complicated and requires a connection between the devices.

The development of port to be the one of modern container terminal that uses automated technology as a part of many components that need to be considered such as the capacity of the yard, Container stacking, Port expansion, Existing machinery and equipment. The integration between automation and manual control systems must cooperate. The automated port can be considered as separate parts which can be divided from activities that take place including:

- Automation at Gate
- Automation at Container Yard
- Automation at Quay crane

Gate Automation is not considered in this study due to the complexity of activity which involving with the customer truck cannot consider the specific time to pick up container and the container can be stored in yard does not release in a short while also comparing about investing cost in automation in this area. Regarding the previous study, it will not benefit investigation therefore, operations in this area still require human work. In this study, automation will not be mentioned in the port entrance area.

Currently, Quayside and Container yard or transportation in the terminal are considered for automation. In a high volume of container port terminal, this area will be high density to handle and take much time to release all of the containers. Automation technology is a new benchmark for Thai port development. Laem Chabang phase 3 has a policy that supports and guides the container movement that starts from arriving container ship at quayside. An automatic system container terminal port can be explained as following the inbound container is moved by remote-controlled gantry cranes to the shore, pending collection by AGVs. AGVs move the containers discharged from the gantry cranes to the container yard meanwhile, Automated RTGs pick up containers from the AGVs, which then return to the gantry cranes to collect more containers. For inland transport, the external trucks (customer trucks) are scanned when passing through the electronic truck gate (e-Gate), which matches them to specific locations of their target containers. The automated RTGs identified and move containers from the container yard onto the backs of external trucks. In the part of another transportation mode, rail freight, RTGs move the containers from the prime mover and stack them onto the rail to easy retrieval. All the automation system benefits can say that increased operational efficiency in terms of time and time cost. Around to clock operation enhances cargo handling capacity and allows for larger volumes of container throughput. Also, reduce risk and enhances safety which are lowered risk from human-induced accidents. The environment has been issued, Environment vigilance the battery-fueled equipment is noiseless, Batteries recharge automatically and continue operations without interruption.

The rapid development of automation container terminals, the first one came into being about 25 years ago, forces to reflect on the optimal models of their work and spatial organization, their effectiveness, and the appropriate application to the local conditions. According to the previous study conclude the automation process benefits in container terminals are improve productivity, Reduced wage and operating costs, increasing safety, Predictable, continuous operation almost completely independent of the weather, Maximum use of space, Maximum utilization of resources-and saving operation.

2.1.1 Automation equipment

Mostly, Automated machinery developed by computer system technology also can be run as programmed to focus on the highest efficiency. Handling systems of the automated container terminals base on automation in equipment are STS (Automated ship to shore cranes), RTGs (Automated stacking crane), and AGVs (Automated guided vehicle) will be introduced in this study the machine characteristics shown in Table 2-1.

Table 2-1: Information of automation equipment

No.	**Machines**		**Characteristics**
1	Automated Guided Vehicle	AGVs	Transport container from the quayside to the storage yard
2	Rubber tired gantry crane (Automated Stacking crane)	RTGs (ASC)	Arrange containers to the position and move the container to other modes of transportation
3	Ship-to-Shore Gantry crane	STS	Quay crane load/unload container from vessel

Source: Rademaker,2017

For the first time, a semi-automated quay crane was implemented in Europe on container terminal as a role model in the marine time in Hamburg. A few years later, it becomes a fully automated quay crane. This gantry crane breaks down the unlading process into two-phases – grabbing the container from the ship and leaving it on the platform of the gantry and moving the container from the platform. The first phase, due to un-probabilistic movements of the sea surface is done partially manually. The second part of the process is automatic. These gantry cranes, being equipped with two trolleys, can handle up to 4 TEU simultaneously and have very high productivity.

RTGs is the essential equipment in almost all automated terminals. It is an un-manned rubber-tired gantry crane, working individually, or in co-operations with the other RTGs on a container row. The space of RTGs operations must be accessible for vehicles of horizontal transportation. The following are the automated container terminal role, which has many automated handling container machines from the previous study.

AGVs are the electric vehicle and load carriers that travel autonomously throughout along set up lines or wires with un-manned moving platforms, built to carry containers, which may be for instance characterized by the following features: its wheels are rotating independently, move forward and backward at the same speed, carrying the maximum 2 TEUs 60 tons weight.

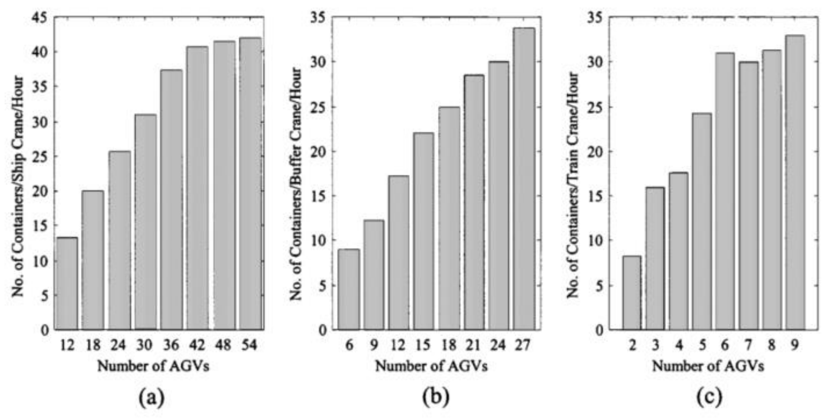
Different types of AGVs could be distinguished of example according to the type of their drive and Diesel-hydraulic, Diesel-electric, and Battery-powered (tested from 2009 in CTA in Hamburg), now use in worldwide.

In the previous study has been group of the automation handling machine. Automated machines at terminals collaborate with each other, as well as with other terminal equipment, creating a specific handling system. Automated or semi-automated handling systems in modern container terminals are as follows:

- STS – AGVs – RTGs.
- STS – manned shuttle carriers– RTGs.
- STS – AShC – RTGs so far theoretical system.
- ASTS – AutoStrads (fully automated straddle carrier terminal) – the first terminal was implemented in Patrick Container Terminal in Brisbane, Australia, where the fleet of 27 Kalmar’s AutoStrads serve both landside and waterside. With each STS there are 3 AutoStrads, which accelerates the process of handling.
- Hybrid system (extension of terminal TRA-PACK, Port of Los Angeles, which will be in operation in 2015. The terminal consists of 3 different automation concepts: ASC working on stacks both parallel and perpendicular to the quay, And Autostrads serving the area located diagonally to the quay.

An automation container terminal that uses AGVs is a conventional container except for using AGVs for container transport equipment. The previous study found that the literature discussing about using the AGV in container terminals is effective. Currently they are enable to perform all tasks that currently require a significant workforce in the terminal. AGVs are becoming more popular in manufacturing, distribution, transshipment, and transportation system. Moreover, the previous study also found that the developed and agent-based simulator for evaluating the cassette-based system and compared it with a traditional AGVs system based on operating cost. The characteristics of the equipment used by the AGVs automation container terminal system is considered to be the system which associated with the storage yard.

The number of AGVs, the minimum number of AGVs required to meet the container terminal system's demand, is determined by exercising the terminal's simulation model for different combinations of AGVs. The previous study has been studied about this. The result found that the objective is to have a sufficient number of AGVs to feed the quay cranes fast enough so that the cranes operate close to their maximum capacity. This turn will guarantee that the ship turnaround time is minimized. Assuming the system is loaded, finish the process, and ready to be loaded by the AGVs. While this scenario is not true all the time, the system should have a sufficient number of AGVs to deal with such possible extreme situations. Liu and et al,. has been investigating about this and found the number of AGVs for each task is calculated by choosing the combination with the minimum total number of AGVs that meet the expected maximum expected average throughput of the cranes at the gate and train buffers is 34 and 28.3 moves/hour/crane, a total of 80 AGVs will meet the demand for the AGVs automation container terminal system.



(a) Throughput of quay crane. (b) Throughput of buffer crane. (c) Throughput of train crane versus the number of AGVs used.

Figure 2-1: Number of AGVs
Source: Rademaker (2017)

Container movement in the terminal in general, the performance of a container handling crane is dependent on the crane driver’s skill. This machine's first development introduced an automated stacking crane known in this study as Rubber tired gantry crane (RTGs) that made cycle times deterministic. The main driver of automation is to reduce the time of handled containers while ensuring a consistent productivity level. It thus becomes relevant to measure crane performance in terms of cycle times. The interest of all parties that performance figures are clearly understood and result comparable. An automated stacking crane nowadays is become the current yard automation landscape, becoming a standard product. Its layout shows that end-loaded of automatic stacking crane with blocks perpendicular to the quay, the machine's side-loaded with blocks laid out parallel to the quay. The previous study said the efficient with high trans-shipment ratios. The machine also serves both sides to move containers from quay cranes to the stacking area and vice versa. Regarding the machine's performance, the automatic stacking crane reaches top speeds significantly when moving distances long. In overall, the machine can minimize-time of cycle time.

Regarding the system layout, the number of quay crane is determined based on the actual number which they installed at the Laem Chabang container port. For an arrival ship been used for 4 quay cranes the consideration of two different number 2 and 4 cranes will be introduced in this study. As for the container storage area, one work path is established at each location. Additionally, based on the literature suggestion that two or three RTGs should be inputted at one location, this study will use two different number of RTGs cranes in each slot of the container storage yard. The quay cranes can equally give a container transportation order to the AGVs. Besides, the destination location of the container is also randomly assigned to container storage yard. The container storage orders in the location (row, bay) are generated randomly in an initial state.

2.1.2 Port operation

General operations can be displayed in a picture as shown in Figure 2-2. The details on the machine are slightly different.

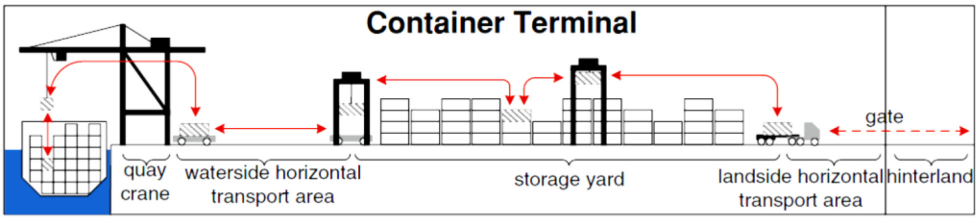


Figure 2-2: Basis container activities flow.
Source: Kemma and Spectrum (2011)

Regarding Figure 2-3, the automation operation can be explained. From the container ships (1) arrived at berth, the containers (3) are unloading by quay cranes (2) and also are loaded with containers on AGVs Transporter (4). The transit capacity through container terminal depends on the quay cranes number and handling capacity. The quay cranes provide direct transshipment between ship and landside transporter and from marine stacks on the landside transporter. On the berth, there are operative container stacks. In storage yard (5), containers wait before departure with another ship or for rail or truck transshipment. This is served by Rubber tired gantry cranes (6). These cranes are also useful for loading/unloading trucks. A container may be stored in one or more successive storage areas. Between marine stacks and landside stacks, containers are handled with AGVs Transporter (7).

When a ship arrives, a berth at quayside is assigned to the ship and unloading the container into the ship starts immediately. Henesey (2004) describes for main steps that each container has to follow from the moment it arrives on a ship until it exists a port either on a truck, train, or in another ship. The first step is the ship-to-shore movement where a Quay crane lifts a container from a ship and moves it to shore, where carriers known in this study AGVs are waiting to transport it to a stacking area. This study will explain the Quay cranes unloading a ship and AGVs transporting the containers to the storage yard. The second step is the transportation of the container to a storage yard. In addition to AGVs, there are other vehicles. AGVs do not need the driver, but they require a crane's assistance to load or unload a container. A straddle carrier, unlike AGVs, in some of the studies is very advantageous. They can pick a container from the ground or unload it without a crane but not considered in this study. The storage yard includes several blocks, where an AGVs unloads each container to its assigned block. The third step is when the automation machine replaces all of the manned-handling machines by operating in the same process and the same situation. Each block has a specified number of bays, rows, and tiers containers stored in stacks in the storage yard. RTGs Cranes in each block are responsible for storing and transporting the container into and out of the block.

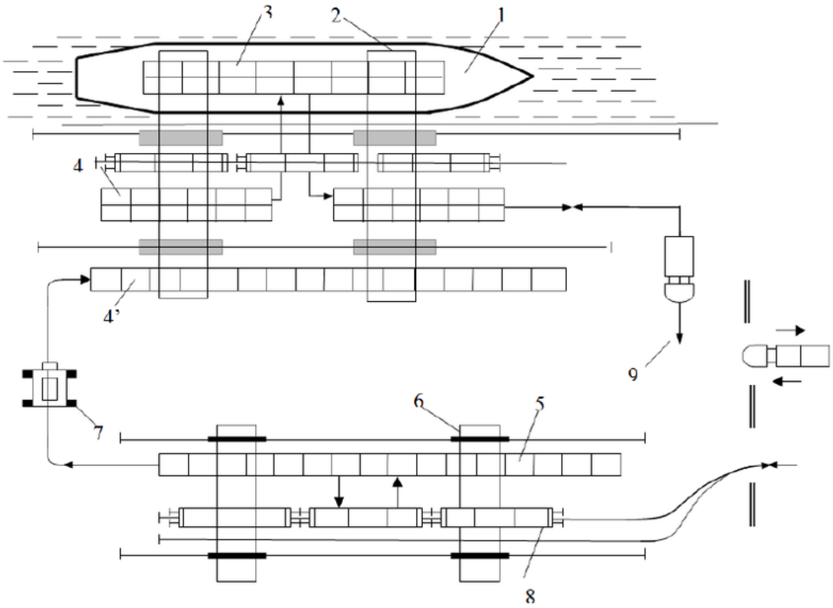


Figure 2-3: The process of container unloading
Source: Rusca and et al. (2013)

The container yard operations enhancement, from the previous study, has many ports with a high density of containers that are using not over five cranes in each block slot. They are the same size and type and cannot crossover also work in the same block, giving more flexibility in the movements.

The block slot of the container in the storage yard is either parallel or perpendicular to the shoreline. Blocks slot parallel to the shoreline are the most common at ports that are using RTGs.

Blocks perpendicular to the shoreline is common when RTGs stacks the containers due to the relative position between the container blocks slot and the shoreline.

The most adequate position to stack a container depends on the container's ordering and its characteristic regarding the current system. The terminal does not select the same stacking policy, mostly because of the differences in the available storage yards area and the types of cranes.

2.1.3 Port automation

According to Martín-Soberón and et al. (2014) the automation container terminal is commonly associated with a container port terminal with automatic cargo movement in the yard and the quayside interchanges. This automated system is usually designed with equipment such as Automated Stacking Cranes and Automated Guided Vehicles which enable driverless system operation.

The container terminal also indicates to an intermodal facility that facilitates the flow of arriving container cargo from ships or departing goods delivered to the port by land (Montfort et al.,2001). Automation of container terminals reduces costs associated with humans' involvement in cargo operation to achieve standards, efficiency, and service level from Martín-Soberón and et al. (2014). The container terminal automation can be followed back to the 1990s when the Delta Terminal in Port of Rotterdam introduced the automated container terminal concept, providing Automated Guided Vehicles (AGVs) to facilitate unmanned operations in the yard area (Evers and Koppers, 1996). After the success of Rotterdam, automated terminal gained global popularity. In Europe and Southeast Asia, policies made by authorities supported the development of automation (European Commission, 2007). The Singapore maritime industry recently received a budget approval of 100 million SGD (76.12 Million USD) from the Maritime Port Authority to further develop its automation for the future.

2.1.4 Fully and semi-automation container terminal

In Martín-Soberón and et al. (2014) the categorization is made the automation into only two levels namely, Fully Automation terminal and Semi-automation terminal. An automated terminal refers to the automatic movement of container in the terminal. Such a terminal is the Pasir Panjang terminal in Port of Singapore. Semi-automated terminal refers to the use of remote-controlled equipment within a terminal or only some of the operations in a terminal are automated.

As the previous study, the greenfield and Brownfield Automation Project was introduced. Automation of port terminal projects can be categorized into Greenfield and Brownfield projects. While Greenfield projects refer to developing new automated terminal, brownfield projects are converting existing terminals to automated terminals with partial or fully automated equipment. The current trend and common implications of port automation are three common areas in a terminal where automation usually are the gate; yard and quay.

2.2 Port performance & measurements

The container port industry measures its performance, Performance assessment is a requirement for the development of business activity and the literature offers different definitions of performance as Marlow and Casaca (2003) and Mentzer and Konrad (1991) define performance as an inquiry of effectiveness and efficiency in achieving a given activity and where the assessment is carried out concerning how well the objectives have been met.

There are many studies and views on determining factors measuring the performance in ports. Based on interviews and previous theories, Feng and et al. (2012) summarized 15 factors of evaluating port performance. Under the many factors presented which are the availability of shipping services, terminal handling, prices, feeder connections, the shipping service, the speed of port cargo handling, congestion, risk, port safety and i.e.

2.3 Laem Chabang port

Laem Chabang port is the leading deep seaport for international shipping in Thailand. Located in the eastern part of Thailand with 10,144,000 m^2, Laem Chabang port can support the Super Post Panamax. The Port Authority is acting as an overall port management organization while the operator privately owns the operations section.

Laem Chabang port is operating under the Port Authority of Thailand (PAT), where under the Ministry of Transport of Thailand's supervision. The port uses the landlord model, so PAT supervises the overall infrastructure, including channel maintenance dredging, water supply, electricity supply, access to the port (roads and lighting), port entrance gates, and navigational aids tugboats, and mooring line handling. On the other hand, the port has given concession agreements to private operators to handle the operation, such as constructing the superstructure, purchasing the handling equipment, cargo operation, maintenance of the terminal area, and personnel recruitment. The terminal operators that provide the maritime transport services are the container terminals (8 terminals), the multipurpose terminals (2 terminals) the RORO terminals (1 terminal), the passenger terminals (1 terminal), the general cargo terminals (1 terminal) and the shipyard (1 yard).

Laem Chabang deep seaport is the main shipping port of Thailand. At present, Thailand must support the larger vessels and all port applications which require to offer. Upgrading the machinery should consider it is more efficient due to the limited area in order to develop tools to progress with the growth of production volume through the port.

Currently, there is a government policy, a 20-year transportation system development strategy. The 5th strategy is using technology and innovation in transportation to support all application development. The Transport Infrastructure Development Report says that the proportion of water transportation volume increases by 19 percent from Wilairat Sirisoponsilp (2018) and can push the Laem Chabang port and become 15th world ranking. Moreover, to increasing the port limit up to 18 million containers by 2025 (overall number conclude Laem

Chabang Port Phase 3) with a policy focusing on technology and innovation using automatic systems. The expected of using the automation system below:

- Automation can increase workplace safety by 65%
- Automation can increase the stability of the work consistency by 62%.
- Reduce port administration expenses by up to 58%
- Increased overall efficiency by up to 53%

Currently, Top of ports in world-ranked has started to develop container ports to be automated ports and get many benefits of them and reduce errors and accidents in operation. The installation of the automated systems within the terminal also allows for 24-hour operations.

The current problems encountered at Laem Chabang Port in terms of efficiency and the ability to handle containers cannot be reached to the maximum limit. The main reason is due to human labor with limitations on working hours and the increased wage. Besides, one of the problems is terms of transportation that the traffic congestion in the port has an impact resulting in long waiting times and cost-effective to the chance of competitiveness.

Table 2-2: Volume of containers through Laem Chabang Port in 2018.

Import			**Export**			**Total (box)**			Overall and %
20'	40'	45'	20'	40'	45'	20'	40'	45'	
932,268	994,467	11,594	958,896	1,026,169	5,094	1,891,164	2,020,636	16,688	3,928,488
						48.14%	51.44%	0.42%	100%

Source: Laem Chabang port (2018)

The volume of containers increased up to 5 million TEU in 2018, shown in Figure 2-4, Affecting traffic congestion, especially in C1, C2, and B5 dock. Therefore, automation technology is the best option to choose for investment in the long term, even though automated systems can be applied but still need humans to control work, developing skills.

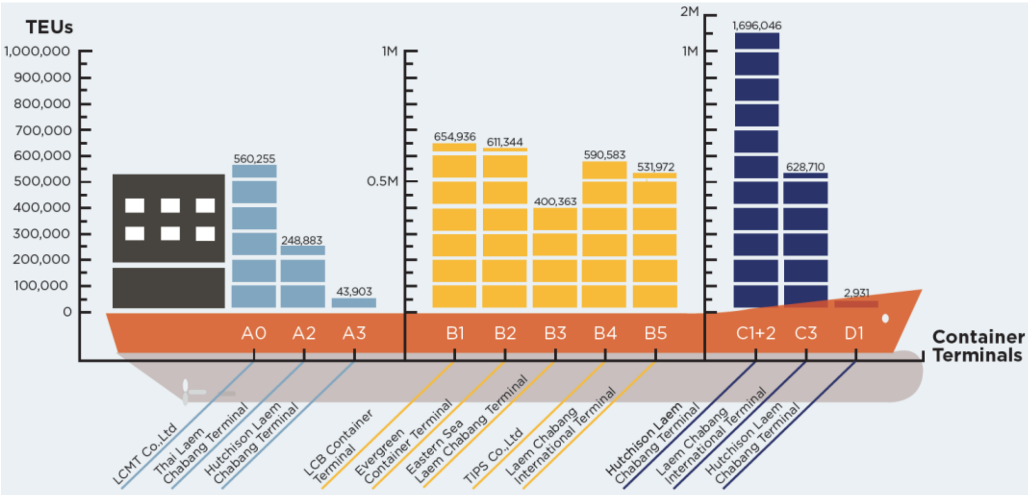


Figure 2-4: Overall volume through Laem Chabang port in 2018 period 3
Source: Laem Chabang port (2018)

2.3.1 Issue in Laem Chabang port

Since the beginning, PAT monopolizes all the port business in Thailand. There is no competition because the government itself supports the port of the state (Sumalee (2011)). PAT is considered the causes as the operation to be slow, such as the organizational structure adjustment or investing in various port businesses. At present, the government has encouraged the private sector to invest more in the port business, resulting in competition in the market.

Laem Chabang port must challenge in improving the organization administration able to compete with private sectors. Figure 2-5 shows the number of throughputs that pass through Laem Chabang port from 2012 to 2018.

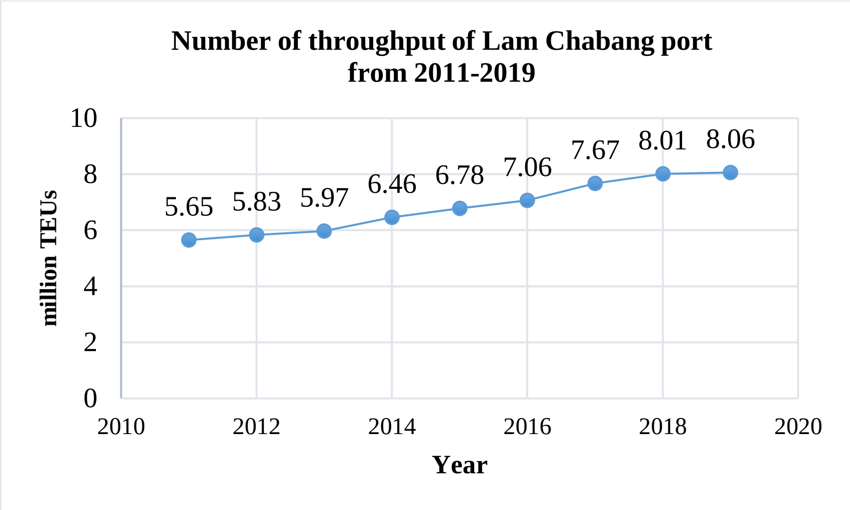


Figure 2-5: The container throughput from 2011-2019
Source: Laem Chabang port (2018)

While the Port Authority of Thailand has encouraged private sectors to invest more to support the expansion, the potential development is still delayed and unable to respond to current changes, affecting the many container port in Laem Chabang port. The increasing growth rate of container throughput has caused concern. In general, the reputation of PAT affects the attractiveness of investors. Reputation is often associated with the scope of the mechanism to build confidence in fair competition between various agencies competing in the port (Bennett & Gabriel 2001).

Since Laem Chabang container terminal port start operating year by year, and the annual throughput still cannot reach the maximum capacity even they were increasing every year due to the cause factors involving around major processes operation that affect the volume of the container will be handled through the terminal. Most of the operational problems in container terminals are strongly interconnected between human workers and machines. They currently have manned operation in the container terminal using less technology to cause a high risk for human safety working with the machine. Concerning human labor in port, a hundred people employed working day shift and night shift, which means the wage is a very large number with a steady result. Currently, 60,000 container trucks access Laem Chabang Port per day, leading to traffic congestion. This from the expanding capacity to 11 million TEU in the last few years. The customers complained that the congestion wasted time waiting to get to the terminal, disturbing other road users, and spreading air pollution by diesel truck. Moreover, the congestion caused to the bottleneck arises from limited space at the terminal gate both of entrance gate and exist gate. This problem can be caused by handling machine operation in the traditional way of handling containers and taking much time until the truck gets the target container.

The delays and congestion in the area at several critical ports disrupt shipping service and competitiveness, with berthing delays of at least a week as ships are forced to wait at anchor, also affecting the following processes in shipping service. The container terminal is reported to be most affected, with increased container volumes, inadequate infrastructure, and in some cases, bad weather all contributing to the problem. The administration's policy formulation also lacks the integration between government and private sectors, resulting in various and contrast operations directions. Besides, the inability to promptly manage and solve problems may cause to be less efficient and reduce potentials as the PAT’s strategies intend to push Laem Chabang port to be top 15th of world ranking after Phase 3 start operating and effort the marine time market to raise the volume of the container through the terminal port.

Concerning Phase 1 and Phase 2 of Laem Chabang port, considering as brown field container terminal, it is more difficult to applied new technology than green field terminal port or new construction port in Phase 3 but still strongly encourage the private sector who investing in the Laem Chabang Port Phase 3 develop to using the technology that is one of the crucial infrastructure projects listed in the EEC’s phase. Some shipping lines companies invest or operate in the terminal ports as well as providing a complete range of additional services, which may affect the operations of PAT in the future.

2.4 Related research

2.4.1 Performance of automation operation system

Rintanen (2018) have studied the efficiency of automatic stacking crane by measuring the machine's cycle time. Determine by using the Shortest path method with full speed machine operation. The results show that the automatic loading and unloading crane has more work cycles than the existing system. It was found that the results of the study did not measure the performance of working in combination with other machines and the delay in responding to commands.

Bahnes and et al. (2016) have studied the automation system by considering whether automation facilities can work well together or reduce collisions in the buffer area connecting loading and unloading in the container yard. The study using a software model called "Omnet ++ / Veins Simulation" in terms of the connection between vehicles is essential for operations and data transfer. Automatic machines and equipment can make decisions by themselves and respond to orders. Therefore, the operation of this system will respond in code while showing the working situation. The results from two situations are one-way data transmission and command loop has found that it can significantly reduce collisions and delays from work in terms of time and management but the tested determine only 50 container loops.

Y. Saanen and et al. (2015) have studied the optimization of the container terminal in the Netherlands. The researcher found that the automation systems increase production capacity and improve port efficiency by using Dual RTGs and AGVs to compare Twin-RTGs and Lift-AGVs have been replacing and measure the efficiency in the model. Performance tests show that Twin RTGs can move and store more than 19% of containers (82 TEUs: 70 TEUs). Efficiency increase by using AGVs up to 4% because Twin-RTGs are faster than Dual RTGs for replacement lift AGVs. There is an additional feature of lifting the container up and down by itself because of the same lifting mechanism as RTGs with the same working factor. Performance measurement results show that Lift-AGVs have faster cycle speed from 5 minutes / TUEs to 6.5 minutes / TUEs and reduce moving time to RTGs by 0.3 minutes per container. This moving speed can increase overall transport up to 3-3.5 TUEs per hour. In this study found that the machines are still unable to work consistently, resulting in the unemployment of Twin-RTGs' machines and terminal cranes, which may cost a waste of time.

Phan-Thi and et al. (2013) have studied the comparison of the working times. There are 2 types of quay crane, Double trolley QCs and Supertainer QCs, compared with conventional hand cranes. (Conventional QCs) using models and statistical analysis to estimate expected values and standard deviations of the container handling. This research requires transportation from trucks to ships assume in the random variable with normal distribution and divides the time variable into 3 phases called "Three Stages model". The results show that the statistical model has an average cycle error is 7.7% and the average standard deviation error is 0.95 for DQCs. SQCs results are 1.6% and 0.99, respectively which is less than DQCs. Therefore, concluded the average running time of the crane which takes less time than a conventional crane. The SQCs crane takes only 63.7% of the work cycle of CQCs and 72% for DQCs. The statistical experiment results also found this method can only be done in short time intervals and not analyze in details of the container position on the lifted vessel.

Mooney (2018) studied changes in container volumes in Hong Kong ports when automatic system is operated. The machine is running with a camera and sensors to control the machinery with remote control. The system combines the necessary information of container movement. The results show that the average effectiveness can be increased by 20% or reduce the cost by approximately $ 4.5 million in 1 year, or $ 575,284 per 1 of 29 Rail mount gantry crane. By the way, the researcher also found labor problems but did not conclude any matter, Including changes in labor costs.

MAREX (2017) reported the performance of Qingdao port in China after developing a fully automated system such as using remote control technology and Artificial Intelligence by scanning the position. Therefore, able to work precisely along 660 meters length with gantry crane, Automatic 7 Ship-to-shore with remote control systems, 38 automatic stacking cranes and 38 fully automated battery-powered transporter (AGVs). Currently, they have the capability to support 5.2 million TUE containers. The result shows that it can reduce labor costs by 70% and increase the efficiency by 30% due to 24 hours of operation and 60 human working control machines. This study does not elaborate on which part of the work efficiency it will increase and what the problems of applying technology in 3 years.

Vis and et al. (2004) has compared the models between AGVs system and ALVs system for loading and unloading containers from vessel to storage yard in a linear movement pattern. The results show that the ALVs system is better than AGVs in terms of efficiency as the ALVs system can reduce the waiting time in the work area together with other machines. In addition, the ALVs system uses less machinery than the AGVs system.

Y. Saanen and et al. (2003) studied and modeled between AGVs and ALVs. They were also considered in conjunction with the operation of Straddle carriers. However, the AGVs automation system is considered with less investment and adjustment risk than other automation. As well as Vis and et al. (2004) have been modeled to examines the effects of using AGVs and ALVs on the efficiency of loading and unloading vessels. The study concluded that AGVs is 38% more effective than ALVs in the same manner but also found that ALVs have a better cost than AGVs. Different studies by Yang and et al. (2004) and Vis and et al. (2004) considered the automation system's appropriate product at the lowest possible cost. It has been argued that ALVs, including ASCs, are extremely effective and can reduce costs substantially.

2.4.2 Simulation in research

The main and most important factors of computer-based simulation experimentation are possibility to controlling and/or observing a real system. As Chang and Makatsoris (2001) confirm, the use of simulation models in experimental designs is an appropriate alternative to understanding the system's behavior in the difficulty of experimenting with logistics and supply chain systems. It is possible to do some modifications or changes in the process or system that can be made through simulation, in addition to the possibility of observing these changes to the system (Manuj et al., 2009). Chang and Makatsoris (2001) point to the examination of processes or s\dynamic systems becomes easier through simulations, the possibility of real-time compression, since running simulations presses time so that what needs years of operation can be achieved within hours. That helps to get some conclusions about the system's behavior in a time period and making decisions opportunely. Law (2006) states that the results presented by simulation models may not be ideal but better compared to other alternatives, also believes that because most of the input and outputs of the simulation are random variables, it is difficult to interpret the simulation results. In addition, it is difficult to know whether the results of the observation are due to interrelationship or randomization. Regarding simulation in port, the logistics, especially the large container terminals, have reached a high degree of complexity, which led to the need for any improvement of scientific methods (Steenken and et al.(2004)). One of the main drivers for developing the simulation model or using any other modeling method is “it is an inexpensive way to gain important insights when the costs, risks or logistics of manipulating the real system of interest are prohibitive” (Kellner and et al. (1999)) and allows testing of many strategies and scenarios (Smew and et al. (2013)). The complexity of the observed system can be one of the reasons for the use of modeling and simulation in logistics and Disney and et al. (1997) explained that “to enable a model of simulation of supply chains in the real world completely, we must build a large and complex model in our minds, and this exceeds the capacity of most people, but the use of computers can help to a large extent. Steenken et al. (2004) conclude that “different logistics concepts, decision rules and optimization algorithms must be compared to simulations before they are applied in real systems.”

Many researches have been carried out to perform post safety measures by creating simulation models to predict the current situation to prevent delays, save time, and reduce costs. Studied ware carried out on schedule loadings at container terminals to integrate optimization algorithms and performance of dynamic and complex systems such as terminal ports. Simulation helps to mimic port operations and provide current and future predictions of performance and outcomes. Different scenarios can also be tested in a simulation model and results can be studied and analyzed (Kulak and et al. (2013)).

Simulation methods are the most common theory and operations management tools in enterprises and industrial organizations management. This indicated that they could provide sufficient support for the operating institutions' analysis to improve production and management processes through coordinated action and supervision of all subsystems (Muravev and et al. (2016)). Many literature researchers used different simulation programs to model port operations such as ARENA, AnyLogix, Flexsim, GPSS, and ProModel. All these programs allow users to analyze the behavior of a discrete event or system quickly without any financial investment. They have different logic to build different models or tools to analyze input and output data.

In addition, the effectiveness of a simulation modeling of a software process simulation model is used to study certain software activities, such as development, maintenance, or evaluation (Kellner (1999)). The development of simulation models is believed to have an impact on the quality of the models produced (Ericksson (2003)).

Ahmed and et al. (2014) found a lack of material to guide the software process simulation model in producing a software process simulation model, which is why he developed a framework and a guideline for the simulation modeling process. Ahmed and et al. (2014) focused on simulation quality and model maintainability and through various interviews, evaluations, and experiments, the maintainable simulation model is more effective, and results are more credible and closer to the real system.

Florin and et al. (2018) studied the marine time container terminal's simulation model by using ARENA version 14 simulation software. The authors found that this software as a simulation instrument because the model is a platform that reflect to the logical algorithm of discrete event simulation. The model was developed based on the topology of real terminal. The study set scenarios by the arrival time of trucks are assumed to be constant and the arrival time between vessels in a normal distribution and exponential distribution. The unloading time for quay cranes follows a triangular distribution. The result found this simulation validated the actual situation in Romania's container terminal, but the study was not developed to connect with inland transportation. The authors also said the importance of terminal administration depends on commercial restriction and port policy.

Eugen and et.al. (2013) have studied transshipment modeling and simulation of container port terminals. The authors create the simulation by using ARENA 11. The simulation model's main goal is to analyze the influence of ships' arrival flow to the berths system and to use of equipment in the terminal. The model was set-up by combining three primary functions: transport, transfer and stacking. The transport activity was assumed by the flows of the container vessel and trucks. Different characteristics of the arrival flows are assumed. The major simulation input variables are shown in Figure 2-6. The model was carried out under the assumption for the time between arrivals of vessels with exponential distribution and the waiting time for entering vessels to berth following a normal distribution. The simulation develops model for 90 days, daily operating time in terminal 24 hours and run for 20 statistically independent replications. The result found the simulation can be achieved the berth high occupancy and minimization of vessels waiting time at the port if the vessels inflows follow a distribution with small variance around the ideal value.

Variable	Distribution	Specific values	
Time between arrivals of vessels	Normal, Constant, Exponential	N (m_v, σ) C(m_v) Expo(m_v)	$m_v \in \{18,19,20,30\}$ hours $\sigma_v \in \{3,6\}$ hours
Number of containers per vessel	Normal, Constant	N(m_c , σ) Constant(m_c)	m_c = 400 containers σ_c = 80 containers
Time between arrivals of truck	Constant	C(m_t)	m_t = 3 minutes
Unloading/ Loading time for QC1, QC2	Triangular		TRIA(3,4,5) minutes

where indices represent v-vesels; c-containers; t-trucks

Figure 2-6: The distribution of data
Source: Eugen and et.al. (2013)

Kotachi and et.al., 2013 have studied the simulation modeling and analysis of complex port operations with multimodal transportation. A generic discrete-event simulation that models port operations with different resource types. The study has entailed various scenarios motivated by changes in different input to measure their impact on outputs, including throughput, resource, utilization and waiting times. The simulation created by ARENA 14 software due to transportation in the software are resource types that realistically represent a vehicle movement, including its speed and distances between pick-up and drop off locations and validated by the real system from 5 different containers seaport. The simulation was run for 10 replications each of 100 days to conduct face validation for the model. This study also set up the assumption that including the container yard is infinity, resources are personnel and staff running the port, and some of the machines are considered embedded whenever needed to reduce complexity and the container yard storage level is 5000 containers at the initiation. After the model was entirely run, the container yard reflected a container count of 12,486. This increase resulted from the incoming container arriving through the ship, train to truck to the container yard.

Container terminal comprises a vital part of the transport infrastructure and have evolved from cargo handling points to distribution centers serving as transport hubs in container supply chains. The most common types of yard cranes in traditional container terminal or the existing system consist of RMG cranes, RTG cranes, Straddle Carriers, reach stackers, and chassis-based transporters. Of these cranes, only RMG cranes are suitable for fully automated container handling. A container yard serves as a buffer for loading, unloading, and transshipping containers, and is typically divided into blocks: Each container block is served by one or more-yard cranes, which can be RTG or RMG cranes, or Straddle Carriers, automatic guided vehicles, and trucks are commonly used to transport containers between quayside and yard, between yard and gates, and to relocate containers within the yard. For example, there are 26 container terminals at the Ports from the previous study, and 10 container terminal operators manage these terminals. The container terminals have four types of cargo handling facilities. The result found that in terms of Mobility, Safety, Operating system, Integration method, Stability og signal, Breakdown ratio, energy source, maintenance cost ,and air pollution the chosen is AGVs transporter.

2.5 Summary

The complexity, the number of operations, the multi-flows interaction and the non-uniform arrivals of vessels and in-land vehicles lead to the need for a discrete event simulation model. Thus, it is necessary to have access to a software platform dedicated to a discrete simulation model. In my study ARENA Rockwell Software, which is not dedicated to studying maritime terminals like in the case of Microport, but with a high degree of adaptability. We find in the literature a set of papers with a discrete-event simulation model developed in ARENA. For this reason, this study uses ARENA version 14.00.00 software as a simulation instrument because the structure of the simulation model in the software platform reflects the logical algorithm of discrete event simulation. It is expected that this study will contribute to making up for the deficiency in the literature and could present a logical model for discrete simulation developed for the maritime container terminal.

The investment in technology should be within the scope of the policy and purpose of the port. To operate in the direction that is laid down for maximum benefit and found that some performance measurements are in different control situations or situations. Therefore, comparing each port's efficiency is often done as Which depends on the factors of the area Number of machinery Port size Amount of container that flows through the port And importantly the policy and objectives of the port.

Therefore, this study would like to measure the efficiency if the automation system was introduced at Laem Chabang Port for international development and can support more container volumes. Currently, the Laem Chabang deep seaport is still in continuous development.

Chapter 3

Methodology of the study

3.1 Overview of the chapter

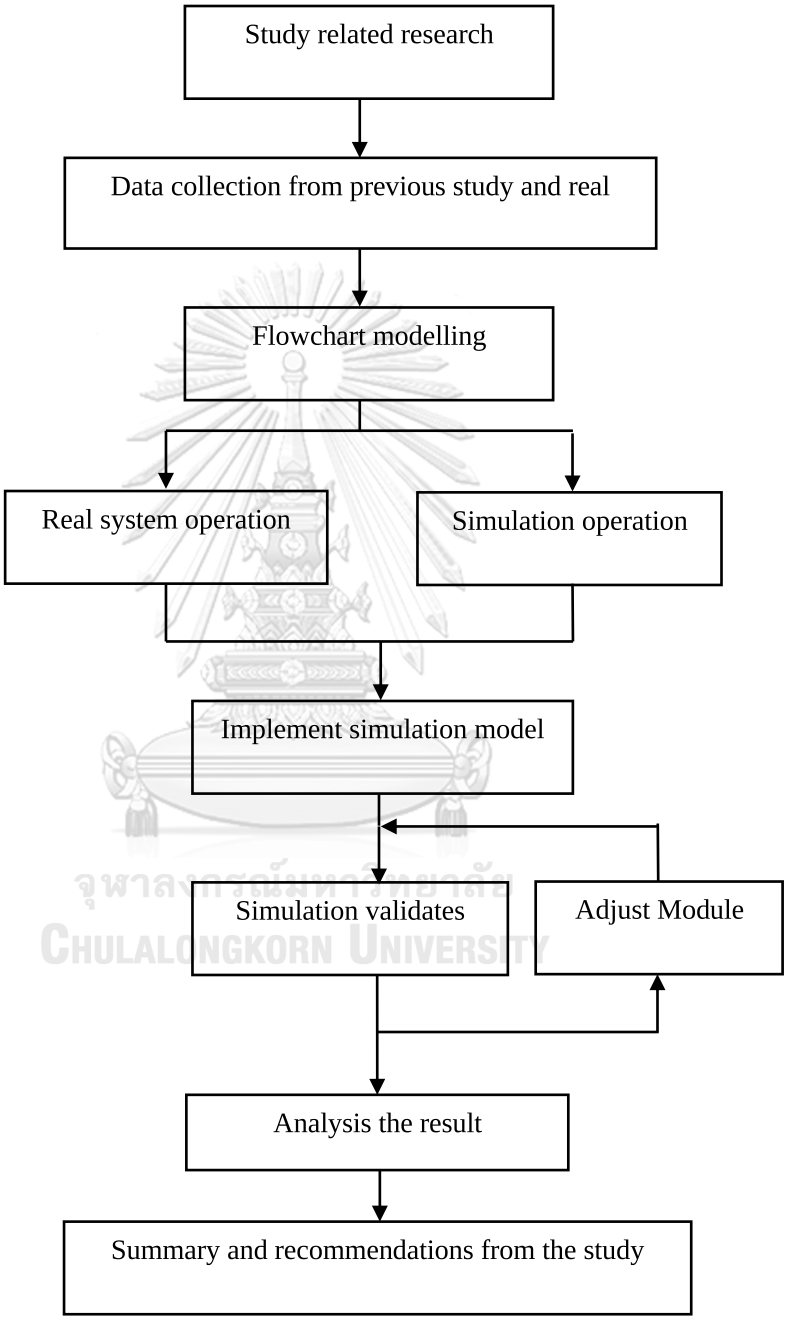


Figure 3-1: Process diagram

The case study port operation which is called "The currently system" in this study, has built a conceptual model and the system is to be thoroughly explored. The currently system consists mainly of ships and vehicles. Besides, container-handling equipment, including quay cranes, yard cranes, and transporter, is used to move containers at the terminals.

3.2 ARENA simulation

The software implements in this study, precisely ARENA version 14.00.00, is a discrete event simulation software developed by System Modeling and acquired by Rockwell Automation in 2000.

Figure 3-2: ARENA simulation software version 14

This simulation software uses the SIMAN processor and simulation language. It is not necessary to create a code program because ARENA allows to choose the closest representation possible and fill in modules with stochastic data to consider, analyze, and interpret how a dynamic system, changing at discrete points evolves over time. In ARENA, the modeler builds an experiment model, with the logic drag and drop, by placing the so-called modules, essentially boxes of different shapes and usefulness, that represent processes or logic the explanation provided in the next chapter. Connector lines are used to join these modules together and specify the flow of entities, which can be customers, vehicles, pallets, workers or machines. While modules have specific actions relative to entities, flow, and timing, each module's precise representation and entity relative to real-life objects is up to the modeler. Modules work in predefined conditions, among which the modeler has to choose to recreate the model as close as possible to the real system.

The modules are the Basic Process, Create, Assign, Decide, Process, Batch, Separate, Record, and Dispose; they are fundamental because they allow crating small models that can be enlarged, but without them no simulations can be done.

In this simulation software, it is also possible to create some sort of Sub-Models that can simplify the graphic visualization, in a complex model, or simulate the inner processes of a specific area or even model complicated conditions in the real behavior of a company. This is possible thanks to more available templates and can be added in the Project Bar of the ARENA. Some external tools can help the ARENA to improve the simulation. These accessories are the Input Analysis, Output Analyzer, and Process Analyzer. The input analyzer grant to find the distribution from some random value, choosing from the most common distribution like Normal, Beta, Triangular, Erlang, Uniform, Exponential, Weibull, Gamma, Empirical, Lognormal or Poisson. Once the analysis is ultimate, the program automatically makes a histogram of the data and performs a basic statistical summary of the data, which can be later used in the simulation with ARENA. The fitting process depends on the chosen intervals for the data histogram, because changing the number of intervals the most proper distribution can change, so it is recommended to verify the fitting process's sensitivity to the number of intervals in the histogram.

In this study, the logic of the simulation model is designed to be adopted to different scenarios or expended to handle more processes (Eriksson (2003)). The study is done by programming and has a standardized way of how the logic operates. When looking at the process flow in Figure 3-3, will see the standard procedure of today's processes at the port for the personal machine. But some parts are excluded from the simulation such as a dangerous goods container, train transportation and external truck to pick up the container in port.

The ARENA is a general-purpose simulation package by System Modeling. The reason chose ARENA will be discussed as following:

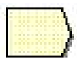
- It combines the ease of using high-level simulators with the flexibility of general-purpose programming languages. The enables convenient modeling and a more efficient implementation using ARENA's object Model and writing out the outputs for later analysis.

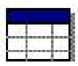
- It includes dynamic animation in the same work environment, which was very helpful in model verification and validation.

- It provides integrated support for statistical design and analysis. Most of the input probability distributions were identified with the help of ARENA Input Analyzer.

- The result of simulation provides as many terms as possible.

Creating models with ARENA, modeling shapes called "Modules" are used. These modules are grouped into several panels (Templates). There are two types of modules on a panel: Flowchart modules and Data modules.

 - Flowchart module shapes are placed in the model window and connected to form a flowchart, describing the logic of the process.

 - Data modules are not placed in the model window. Instead, they are edited via a spreadsheet interface.

The ARENA model-building panels are:

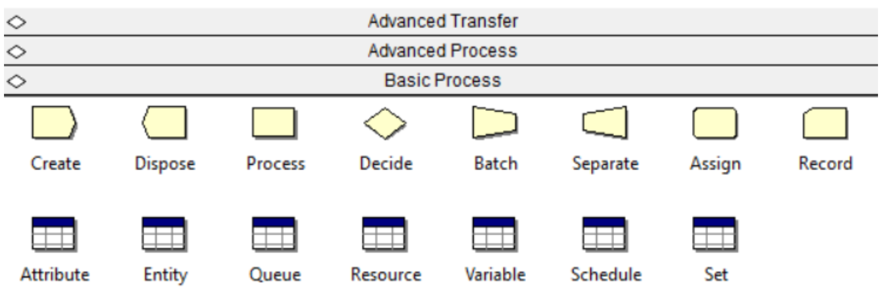


Figure 3-3: Basic process modules in ARENA

Basic Process in the panel is used most commonly and as the basis for most models. It includes such flowchart modules as Create (to entities like vessels or weather entity, Dispose (to dispose entity from the model), Assign (to assign different characteristics to the entity or variables, like the route to the ship, ship type etc.), Process (to describe the characteristics of the process like Loading operations) and others. There are also some basic data modules, like Variables, Entities, etc.

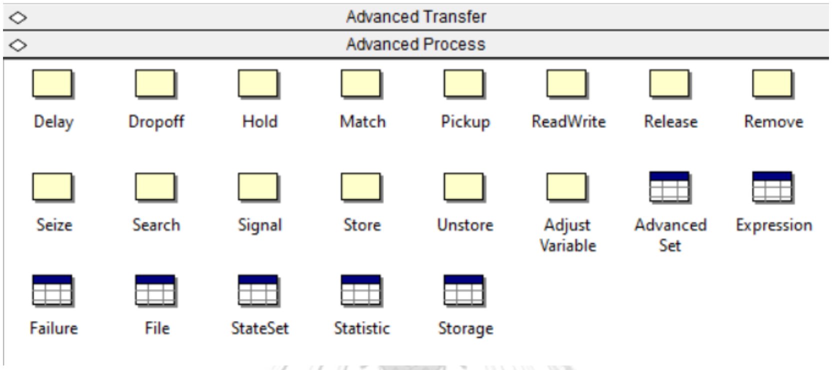


Figure 3-4: Advance process modules in ARENA

The Advanced Process is the most important flowchart modules in this template for our model are: Delay (delays the entity for specified time) and Hold (holds the entity until specified condition or signal). Data modules that will be used in the model are: Advanced Set (defines set of objects of the same type, e.g., routes) and Expression.

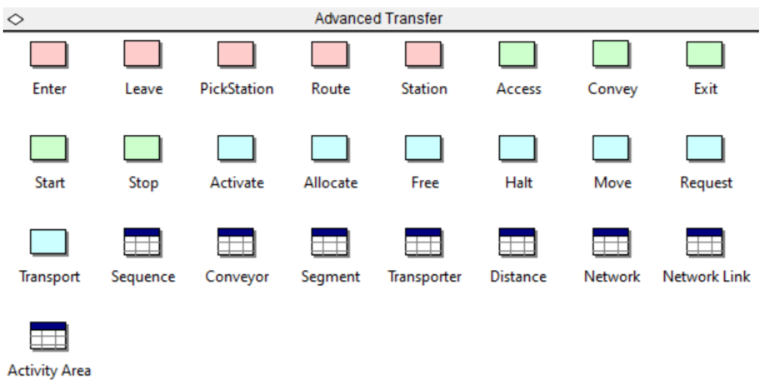


Figure 3-5: Advance transfer modules in ARENA

The Advanced Transfer is different kinds of transfer. From this template we will use Station and Route flowchart modules, and Sequence and Distance data modules. A model is constructed by dragging and dropping modules into the model window, connecting them to indicate the flow of entities through simulated system, and then detailing the modules using dialog boxes or ARENA's built-in spreadsheet. The results of the simulation run can be viewed through an automatically generated report. By default, the report contains the following information:

- Entities: times, number in, number out, work-in-process

- Queues: Waiting times and Number waiting

- Resource: usage

- User-specified parameters

Other information can be requested to be present in the report. A short summary on ARENA software can be found in Law and Kelton (2000).

3.3 Number of Replications

Starks (2017) has concluded the issue to be considered is the start-up bias by the start-up or warm-up period for the model. The warm-up period is the time necessary for the model to reach a steady state and, therefore, mimic the actual system.

1. The system designers or experts should have some idea of how long it would take to reach a steady state if they started their system empty and idle. This would be a good starting point for determining the length.

2. Make some plots of performance measures and eyeballs when they appear to stabilize.

In order for the results obtained by processing the scenario model to have an acceptable error value or not exceed a certain value (Half-width), the number of replications must have corresponded with the condition, for example, set 1 replication, and then run the model if the result show Half-width value not exceeding the acceptable value indicates that the number of repetitions is enough. However, if the result is more than that acceptable value, the number of repetitions must be increased to get the appropriate number of replications. There is the equation which is related to the Half-width value It can be calculated from equations follows:

$$n \cong {z^2}_{1-(\frac{\alpha}{2})} \frac{S^2}{h^2} \qquad \text{Equation (1)}$$

$$n \cong n_0 \frac{{h_0}^2}{h^2} \qquad \text{Equation (2)}$$

Where n = Number of replications

n_0 = Number of replications at the first time

S = The standard deviation in each replication at the first time

h = The error acceptance value

h_0 = The error value at the first time

3.4 Data available

Regarding to the simulation software used for this study, the quantitative data is mainly needed. The quantitative data will be an input data in the simulation model to provide a statistical overview for the working machine in many categories, follow by the index of performance.

According to simulation, there is the condition to be follow such as the distribution of data, the input data must be collected from the actual number weather data from the schedule, the input analyzer in ARENA can improve and use them as input data to simulation.

Table 3-1: Distribution of data available

Name (Distribution of process)	Distribution	Detail
Ship arrival time	Exponential	Mean 21 hours
Ship arrival rate	Mean	35 Ships/month
Process berthing	Triangular	15,20 and 30 minutes
Container volume on ship	Uniform	800-2000 containers
Process by quay crane	Uniform	90 – 150 second/container
Process by yard crane	Uniform	80 – 90 second/container
AGVs velocity	-	19.6 ft/s

Source: Hutchison Port Thailand (2018)

The using technique of the simulation experiments were conducted to evaluate the performance of the developed models using real data collected from the report of result of Port Authority of Thailand. The review of existing data, such as from terminal operating systems, a variety of performance index. The discussion potential data sources and provide an overview of input data. Thus, the simulation commitment all process to be input to the model, the importance of data is the category of them to be used. The analysis of data in order to make it in term of distribution, the several statistics were used as a comparison between simulation output and real data in 2018 for 12 months since October 2017 to October 2018.

Ship arrival time is from the count of the ship arriving until ship leaving the port in average. The 12 months of data collection as the raw data has been using the Input analyzer one of ARENA tools and the result report that this sample data is the Exponential distribution with mean 21 hours, every 21 hours a ship will arrive at the port.

The data of berthing process time is from the Transportation institute Chulalongkorn university, the result of data survey from the officer who is operating at the quayside that it is depends on the ship size and the availability of pilot ship then found that it mostly takes around 20 minutes, minimum 15 minute and maximum 30 minutes. Even a few sample data but also conclude it as the triangular (15,20 and 30 minutes).

Container volume is difficult to analyze the actual number because the result report covers all of Laem Chabang port results, which means every container terminal is included. The consideration of terminal C1 and C2 can be found that the average as the whole year is combined between small ships and large ships in the range of 800 – 2000 container per ship as the same every month. It can say that the container volume has uniform distribution also can prove by the Input analyzer tool in simulation programs.

For the handling container time, the time using can be found in the final report of Transportation institute Chulalongkorn university by calculation from the handling rate in an hour, the performance report that the average handling crane rate at 15 containers (30 TEU) per hour, means the handling time around 4 minutes per container. In the simulation model, the input data of the automation system are from the previous study, the benchmarking of each machine, and the information from the industrial enterprises.

The velocity of transporter, it is the benchmarking of the vehicle set by its standard easy operation with entire fleet. The characteristic of 4 wheels AGV has a maximum velocity at 19.6 ft/s, positioning to +/- 25 mm accuracy, maximum carry 2 TEU and travel forwards, backward and sideways along the set route in terminal. As the simulation model uses only the velocity and the set route for transferring in the terminal layout also related with the distances in the terminal.

Table 3-2: The characteristics of the C1 and C2 terminal

Characteristics	C1 terminal	C2 terminal
Quay length (Meter)	700	500
Water depth (Meter)	16	16
Maximum capacity	1.4 million TEU/year	1.0 million TEU/year
Container ship size	Post Panamax	Post Panamax
Quay	1	1

Source: Hutchison Port Thailand (2018)

Table 3-3: Number of facilities in the terminal

Facilities	Quantity
Quay crane	12
RTGs	33
Tractors	52
Forklift	12

Source: Hutchison Port Thailand (2018)

Table 3-4: The performance result in many categories

Indication	Performance of terminal port
Ship waiting Time	Delay 10% of ship turn-around time
Ship Turn-around time	30 minutes to berth
Ship Service time	24 Hours
Berth Occupancy	45%
Equipment Available	90%
Equipment Utilization	100%
Truck Turnaround time	30 minutes
Net Crane Rate	30 TEU/Crane/Hour
Annual Terminal,	834 TUE/Meter Throughput per Berth Meter
Storage Utilization	60%

Source: Chulalongkorn University Transportation Institute (2017)

3.5 Assumption and limitation

3.5.1 Assumption in the study

In the simulation model, some assumptions are made in order to reduce some unnecessary details. These assumptions can in future expansions, be relaxed when considering other aspects and details of a port. The conducting studies and data from the result of previous studies. It is necessary to have a condition that will control the model.

- The terminal operation are 24 hours, not affected the holidays, any downtime delays.

- No transportation congestion in the buffet area and in the terminal.

- The handling machine is no breakdown.

- The initial container storage yard is empty.

- The transporter will set to ready and travels by setting up route in terminal port.

- The terminal layout is set as Figure 3-6

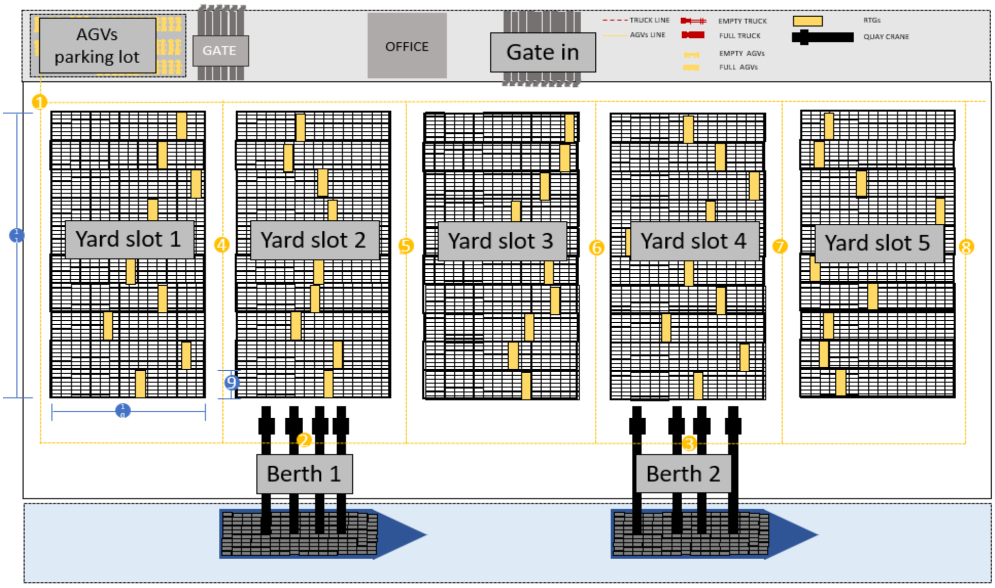


Figure3-6: Terminal layout of C1 and C2 terminal port

3.5.2 Limitation in the study

Price, James H. and Judy Murnan (2004) described the limitations in the study are those characteristics of design or methodology that impacted or influenced the interpretation of the findings in the study. They are the constraints on generalizability, applications to practice, and/or utility of findings that result from the ways in which initially chose to design the study, or the method used to establish internal and external validity or the result of unanticipated challenges that emerged during the study. A simulation model is a simplified representation mostly of real operation can be possible, but not all situations can be evaluated using simulation. Only situations involving uncertainty are candidates, and without a random component, all simulated experiments would produce the same answer. There is some limitation in the study concerning the scope of the study as following:

- This study considers only the actual container handling.
- Not consideration of the human working time due to lack of available information.
- Limitation on transporter routing base on the current use, it was setting as one-way.
- The limitation of operations management refers to the processes only in the terminal.
- As part of scope, the problem area is limited to unloading or loading of the container from/to the ship, to its handling and storage but does not include the gate.
- The limitation on container volume due to the statistical data collection, the container capacity will be considered only the result of terminal C1 and C2.
- The limitation on the number of machines, the way of "increase or decrease" of the number of machines according to the capacity limitation of the transfer platform in terminal which virtually to the current use, to minimize the number of finding the appropriate number using in the operations.
- The limitation in-vehicle type is also based on the current use and recommended from the previous study that applies to the container terminal size.
- The simulation techniques are object-oriented. Its ability to reflect the various operating environment of the container terminal is limited.

3.6 Simulation scenarios

There is one significant scenario for defining the performance analysis to the given combination in various numbers of the machine as the purpose of this study: number of STS, number of RTG and number of AGVs. Regarding the previous study, the selected machine was the result and proved that they are the best combination and now used in world-wide.

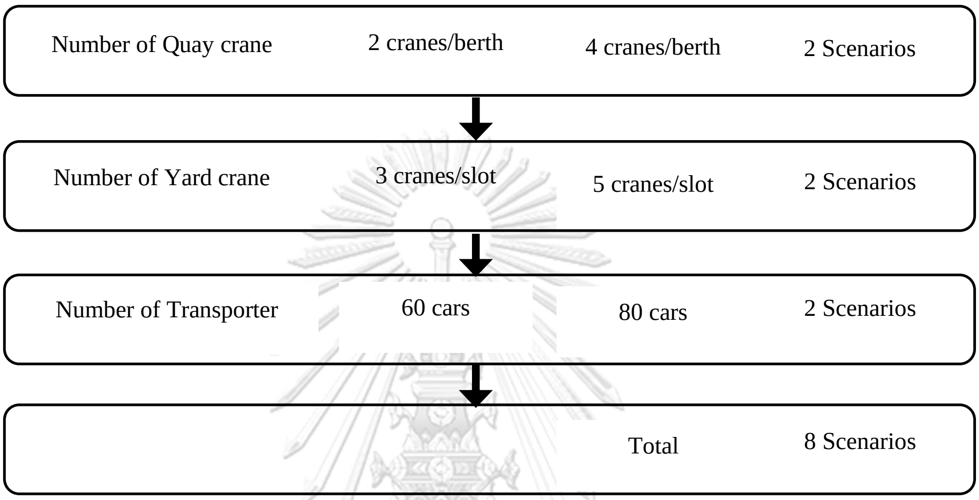


Figure3-7: Simulation scenarios

Each scenario is based on the number of STS start from 2 and 4 which is the maximum number of quay cranes at the existing system operated then followed by the number of RTG starts from 3 and 5 and the last follow is the number of AGVs 60 and 80 cars in the terminal and each scenario can be shown in Table 3-5.

Table 3-5: The machine number in scenario

Scenario	**Number of STS Cranes**	**Number of RTG Cranes**	**Number of AGV Cars**
Scenario 1	2	3	60
Scenario 2	2	3	80
Scenario 3	2	5	60
Scenario 4	2	5	80
Scenario 5	4	3	60
Scenario 6	4	3	80
Scenario 7	4	5	60
Scenario 8	4	5	80

3.7 Study procedures

Five tasks are proposed with detailed methodology descriptions to achieve the objectives.

1) Summarization of currently automation container terminal. A literature review will conduct to summarize the currently container terminal simulation models for a container movement infrastructure. The review will specifically focus on data available as input data in this study.

2) Study on ARENA simulation program by a manual, previous study, development of the simulation framework, and selecting the simulation platform. A framework for the automation container terminal simulation will be developed, including all significant machine component, the connections of the components, the embedded relationship in each component can be divided into 3 sub-models, the variability that will be included in the model, input data, output data from the program result. The simulation model will conclude data from the source of the port.

3) Adjust, improve, and development of the simulation model. Following the framework, input the previous study and data available. This task will program a simulation model for containers' movement in the terminal by an automation handling machine. The model is expected to allow users to change the setting, input data, and define scenarios.

4) Validation of the simulation model. The simulation model will be validated based on historical and the current system working in the port.

5) Analysis of various components on the simulation model, result, and sensitivity of input data that affected output to compare with the real result. A selected number of handling machines will be identified based on suggestions and results from the previous study in the same situation and run on the simulation model.

3.8 Methods and simulation process

This study aims to operation of containers starting from arrival and ending with their departure container. A conceptual model can be inferred and constructed after studying the real system and building an overall understanding of the on-going operations. The processes in the model are constructed based on the operations that take place.

The software has been widely used to analyze the business process in many sections, namely manufacturing system, port, and terminal operation. The software makes it possible to understand certain situations. The potential changes in the process or the system can be trialed and observed without many physical actual experiments. The software is a vital tool for decision making in planning. In the operation efficiency analysis, this technique helps a lot in adjusting the system without empirical modifications. Figure 3-7 shows the typical process of simulations.

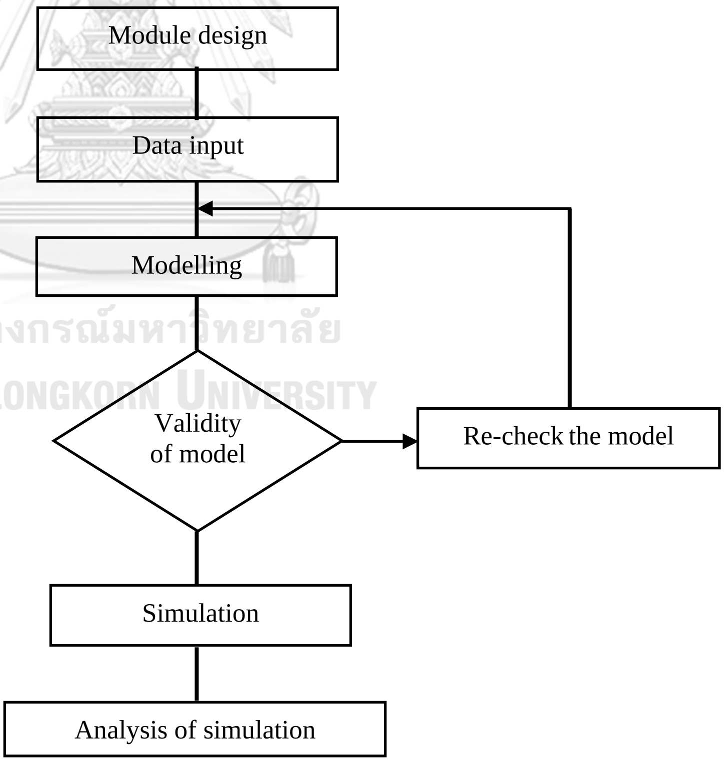


Figure 3-8: Process flowchart of simulations

3.8.1 Sensitivity analysis

This study addresses terminal operation simulation in general. However, it mainly focuses on modeling an automation port with modern resources. The overall objective behind this work is to reflect the real system's overall interactions in a simulated environment, create a platform that would allow sensitivity analysis, and develop a tool that would give numeric outcomes of the current system and opportunities of improvement. The proposed simulation model analyzes some simpler measures, like average resource utilization, the total number of containers throughput the port, average waiting time in queues, and handling machine utilization.

Sensitivity analysis shows how uncertainty in the output of a mathematical model. A related practice is an uncertain analysis that focuses on uncertainty quantification and propagation of uncertainty due to the difficult measurement of numerical or otherwise.

Table 3-6: Uncertain variables

Uncertainty variables	Unit
1. Machine speed	Second
2. Increasing container volume	TEU
3. Number of machines	Cranes/cars

Chapter 4

Simulation models

This chapter will implement the simulation on ARENA software. The simulation was chosen because it allows a logic model development using logical blocks with specific functions and analyzes it with the existing system. The management operations to realize the problem, strength and weakness of the operation and service systems.

4.1 Model implemented in the simulations

The models are run, analyzed, and compared, in order to find out the best solution, according to the performance measures recorded. All the models are connected since the entities of the container created into the simulation. The simulation starts with creating ship to berthing process. There are 2 parts: the ship creation and attributes assignment, the second part, and the berthing process when berth is available. the container created and handling by 4 quay cranes each berth. The discrete quay methodology is often applied by previous study recommendation, to assign quay crane of time operating due to its easiness and approximation, the input of operation time will be applied as the same of previous study and real-time of video recording. The transportation mode will begin, the request of AGVs to loading container start, at first all AGVs will be parked at their parking lot and travel following the request to carrying container after that AGVs will heading to the storage yard. In the simulation will be shown the mentioned process in the station module of transportation. RTGs will take over the arriving container from AGVs to unloading them and stacking them to the position. All the resource used in simulation has set up in fixed position, so container movement will be run on. After AGVs unloading containers to RTGs, they will be free for the next request. The STS, RTGs and AGVs cycle will be repeated again. Also, the condition and assumption in simulation which using base on the current port have been set up. The implement mentioned before can be explained in the flow chart Figure 4-1.

4.1.1 Simulation replications number

In general, The Confidence Interval (with Specified Precision) Method is the one chosen both statistics wise as well as its capability to be adapted into an algorithm for automation for testing using artificial and real models. This method runs increasing numbers of replications until the confidence intervals constructed around the chosen output variable using the t-statistic are within a (user) specified precision. This allows the user to tailor the accuracy of output results to their particular requirement or purpose for that model and result. This method assumes that the cumulative mean has a normal distribution (which is proper under the Central Limit Theorem when the number of replications is large).

To determine the appropriate number of replications and whether the simulation model can represent a current system result. By comparing the consistency of the data obtained from the model with the data from the current system result which is the ship turnaround time using raw data for 12 months from PAT (2018) and the statistical result found that the average 24.49 hours, 2.638 standard deviations and Half-width 1.2245 hours at 95% confidence interval. In order to determine, set the 10 replications to get the result and calculated in the equation (1)

$$n \cong {z^2}_{1-(\frac{\alpha}{2})} \frac{S^2}{h^2} = (1.96^2)\frac{(2.638^2)}{(1.2245^2)} = 17.829 \text{ replications}$$

The result of 18 replications found that the half-width is 0.84, it is less than 1.2245 then this number of replications can be concluded and confirm of use in the simulation development to get the result which can be represented and compare with the current system result. The simulation will use 10 replications for the warm-up period, which will not affect the result and 18 replications for simulation development to reach the steady-state of simulation results.

4.1.2 Simulation model development

The explanation of each created flowchart goes along with the actual process. The flowchart modeling will be the guidance of the simulation model.

No	Flowchart name	Module	Operation explanation
1	Ship arriving	Create	Simulation creates the entities as the container ship to the model
2	Berth available	Decision	There are 2 berths to decide to stop at dock
3	Ship berthing	Process	Ship assign to berth at this module a
4	Quay crane	Resource	The quay crane set-as the resource in this module and set as the quayside station
5	Request transporter	Request	The quay cranes request transferring container by the transporter
6	Container unloading (Import)	Hold	The process of unloading container from ship to load on the transporter
7	Container to yard	Transport	The transferring container to the container yard. This process take time from transporter traveling from the request model
8	Transporter arrived at yard	Station	The yard station for transporter
9	Yard crane	Resource	The yard crane set-as the resource in this module
10	Yard slot	Station	The yard station for positioning the resource
11	Stacking container in yard (Import)	Process	Yard crane received the container from the transporter and proceed the stacking process
12	Free Yard crane	Free	The yard crane was assigned for the task after finishing the task. The module set it free for the next task.
13	Free transporter	Free	The transporter was assigned for the task after finishing the task. The module set it free for the next task.
14	Yard crane request transporter	Request	This module proceeds the export container cycle, start with request the transporter
15	Yard crane load container (Export)	Process	While the transporter arrived, the yard crane loads the container to the transporter
16	Transfer container to quay	Transport	The transferring container from yard to quay as the vice versa of the beginning process
17	Quay crane	Resource	The station of quayside
18	Load container to ship (Export)	Process	While the transporter delivered container at quay crane, the process of load on ship start in this module
19	Finish load to ship	Release	The cycle of import and export container proceed until its finish
20	Ship leaves the port	Dispose	The ship will leave the port in this module. After developed simulation from the ship, the result will go to “Dispose module” to be collected and end the cycle process of a ship.

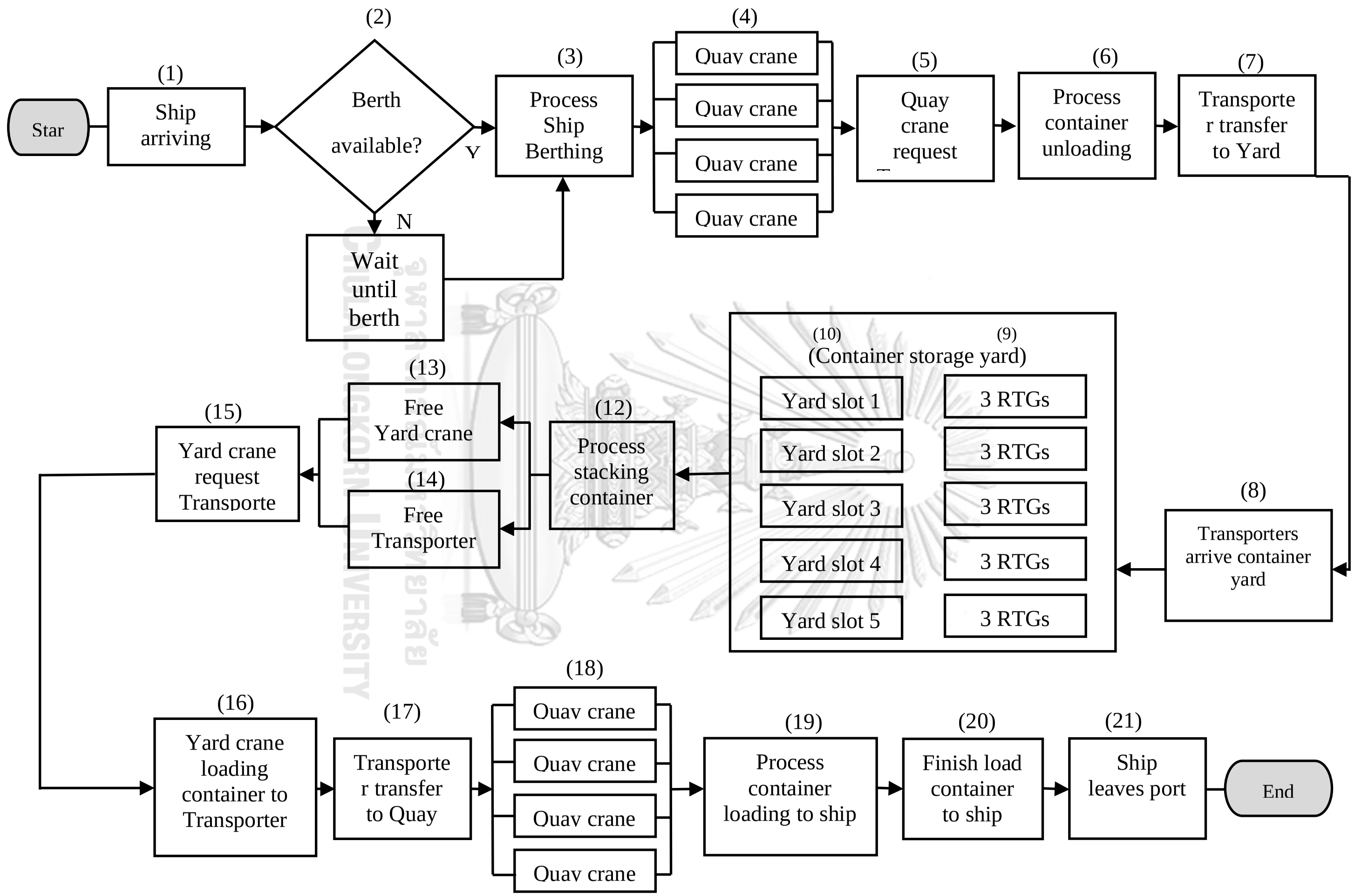


Figure: 4-1 The logic process of simulation creation

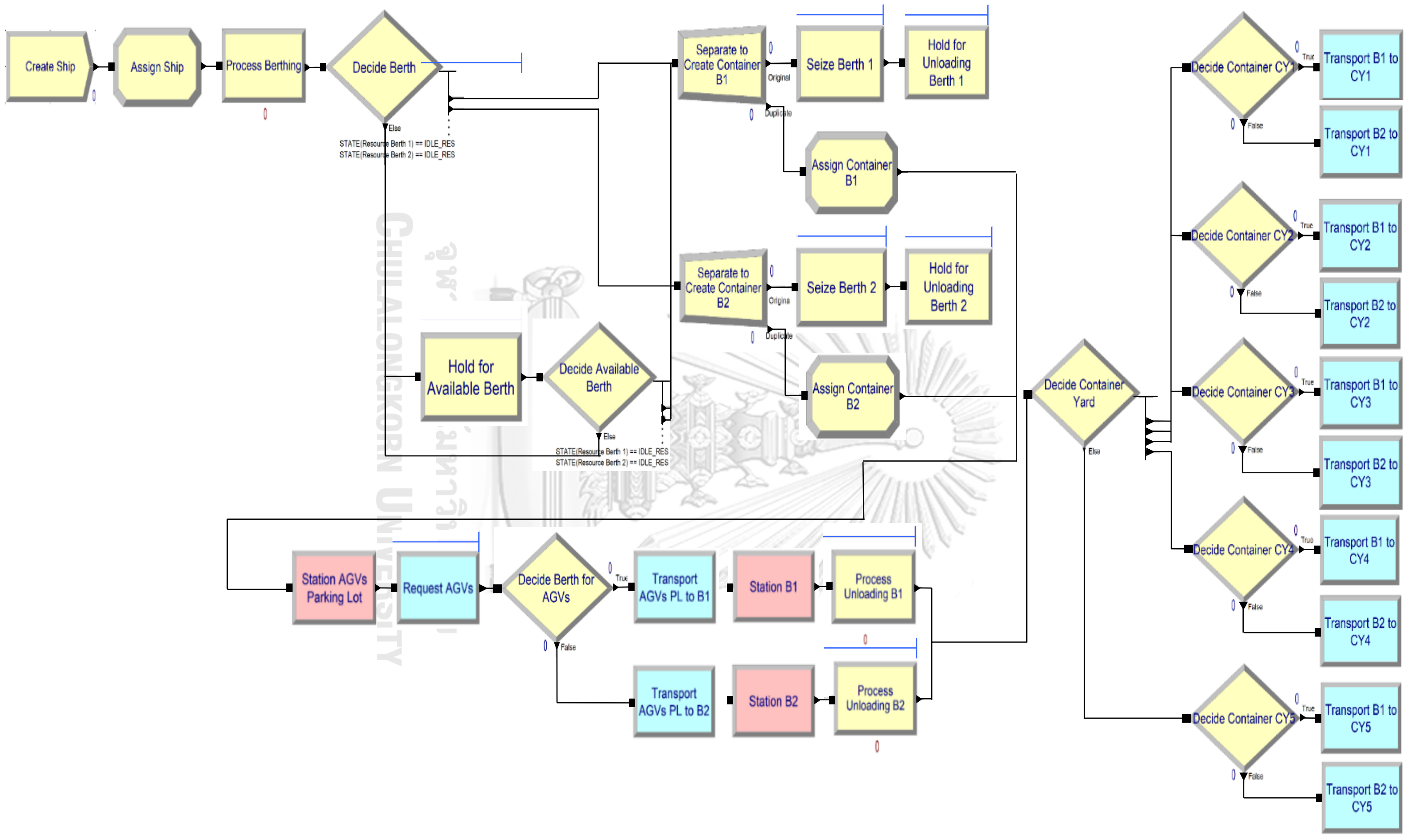


Figure 4-2: The first sub-model in the simulation

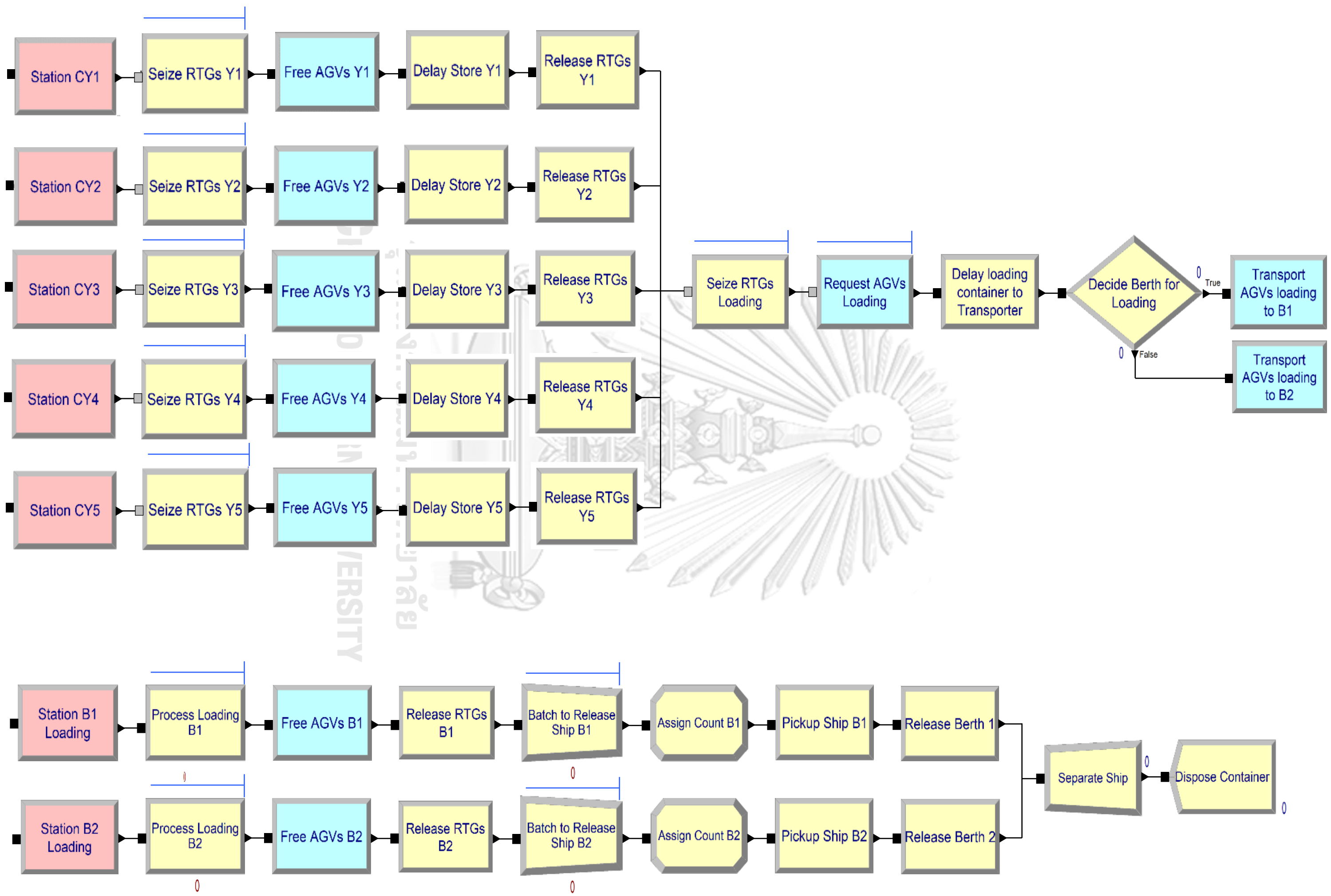


Figure 4-3: The second and third sub-model in the simulation

4.2 Resource unit simulation models

The first sub-model in Figure 4-4 describes ship arrival to port: waiting in the queue or free berth, occupancy the berth, waiting for containers unloading, and in the end, leaving the terminal by the statistical probability. The resource unit control structure is presented in Figure 4-4 below:

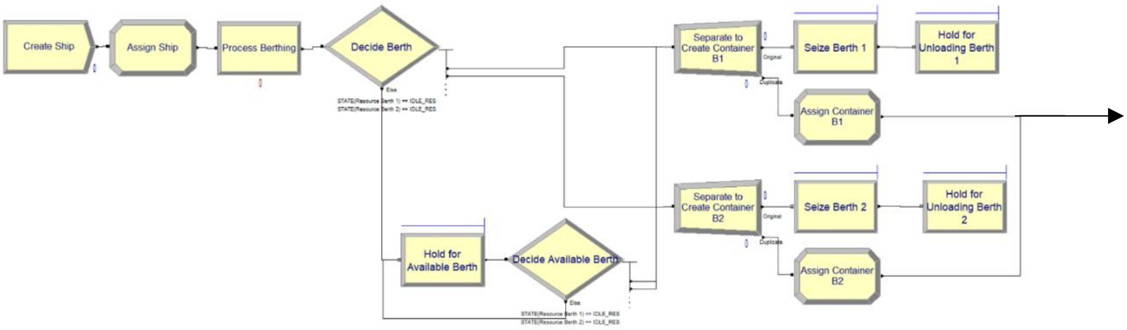
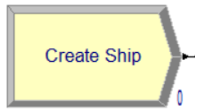
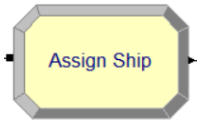
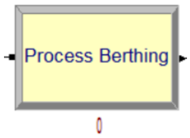
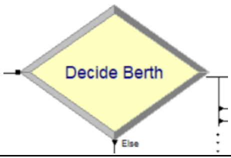
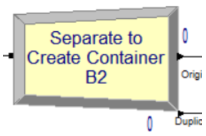
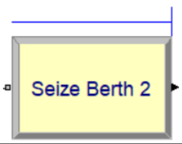
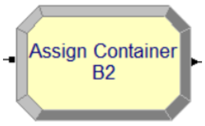
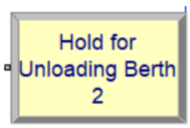


Figure 4-4: The first part of the first sub-model

The represent of handling activities of quayside of the terminal are ship berthing and container unloading process. Ship and Quay crane will be handling processes in the simulation model. The identification part of the model is quite difficult because it is a condition and simulation decide by chance.

First of all, The part of the model starts with creating a ship in simulation by inputting the ship arrival rate into the module and assigning a ship to berth at free berth and there will be the first condition since creating to choose for berthing. Secondly, the Berth process will sometimes take berth when the simulation will create the container in the ship and run to the next process. In the case of more than 2 ships at berth the queue will occur. The processing flow chart means the ship is at berth and quay crane will handle unload containers from ship to the internal terminal by AGVs as a transporter. All statistics and numbers in simulation records are statistical, average, and overall, by replicating the final report after finish running model. Lastly, of this model part, the entities called container will run into the next model part instead of the ship.

Table 4-1: The module of simulation explanation of first sub-model in first part

Module	Name	Type	Explanation
	Create Ship	Create	Create arriving ship to simulation
	Assign Ship	Assign	Set up the assignment, value and picture attached to ship while running in simulation
	Process Berthing	Process	Set up the operation to the incoming entities including logic, time using or statistical equation
	Decide Berth	Decide	The decision of choosing for berthing of ship given by first come first serve
	Hold for Available Berth	Hold	When the berth is full, the ship will be held in a queue and wait until the berth free
	Create Container	Separate	Creating a container which carried on ship and set it as entities which run in simulation
	Seize Berth 2	Seize	Seize the berth (Berth 1 and Berth 2) for container unloading
	Assign Container	Assign	Set up the assignment of container to be remarkable to count in simulation
	Hold for Unloading Berth	Hold	This module set as a process of unloading container handling by Quay crane to

			AGVs

There is a different process next to the quayside process after the ship completely berth the transporter's request in the terminal will occur. In common, the terminal used the chassis or truck to hand containers moving around the port. However, The AGVs will be considered in this study. The resource unit control structure is presented in Figure 4-5 below:

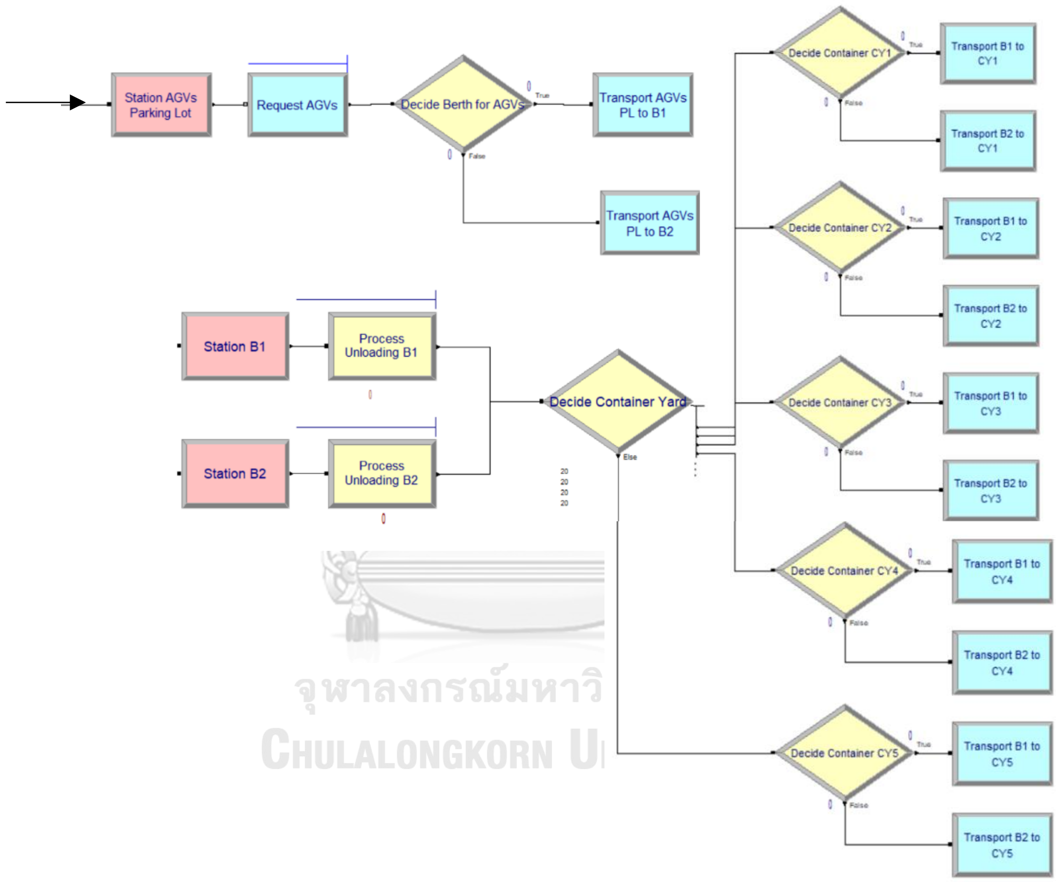
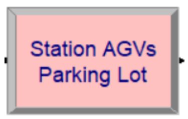
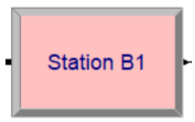
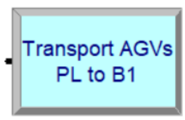
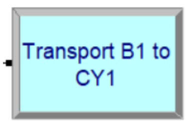
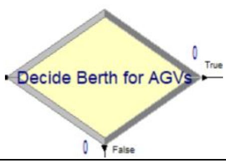


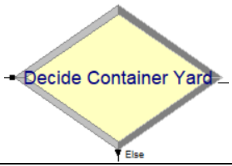
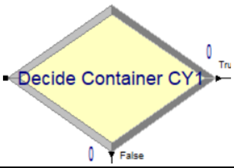
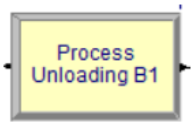
Figure 4-5: The second part of the first sub-model

The represent of handling activities of buffet zone between quayside and inland terminal side. It can be called the transportation process from quay to storage yard which handling by AGVs transporter. In simulation and ARENA program, the module of transportation is basically set as "Station and Transport" to assign entities move where to where without connection link between modules. The sub-model above shows the red and the blue module in simulation which means location and assignment of the transporter respectively.

This part will start by set the location as a station in simulation. The incoming of entities known as "containers" from previous process come through the station to set the location of container for AGVs after that process makes a request for AGVs to pick up from Berth 1 and Berth 2 following the module in simulation, In the beginning, AGVs located at its parking lot show in Chapter 3, AGVs travels with set up empty velocity and full load velocity (Maximum 2 TEUs container carrying). Consequently, Station to Station means AGVs travel from Quayside to Storage yard to follow the link or routing set up before. Regarding to its routing reference by Truck's routing in real system use to worked and improved it to prevent the congestion by running in one-way routing in shortest routing. There is a decision to choose which yard slot to be delivered by randomly and repeat the cycle after that RTGs will handle the container and show in the next sub-model.

Table 4-2: The module and method of simulation explanation of first sub-model

Module	Name	Type	Explanation
	AGVs parking Lot	Station	To set the original location of AGVs and start the process
	Station Berth 1 (Also Berth 2)	Station	Location of Berth 1 and Berth 2
	Request of AGVs	Request	To request the transportation in simulation
	AGVs to Berth1	Transport	Transport order to AGVs travels from the parking lot to Berth 1 (Also Berth2)
	Berth 1 to Container Yard	Transport	Transport order to AGVs travels from berth to container yard
	AGVs chooses Berth	Decision	The decision of choosing Berth to load container

	AGVs chooses Container yard	Decision	The decision of choosing yard slot to deliver container
	AGVs chooses Container yard	Decision	In the case of this module is to choose between transport from Berth 1 or 2
	Process Unloading	Process	Quay crane unload container to AGVs in this process

The second sub-model in Figure 4-6 describes the container yard process after AGVs delivery container which handling by RTGs. The layout of the terminal has been set up nearly to the original container storage yard. The simulation provides 5 module process to duplicate each slot in the same process in the simulation model. Therefore, AGVs finish their work and repeat to the request cycle again, all container stacks in a random storage yard position.

The resource unit control structure is presented in Figure 4-6 below:

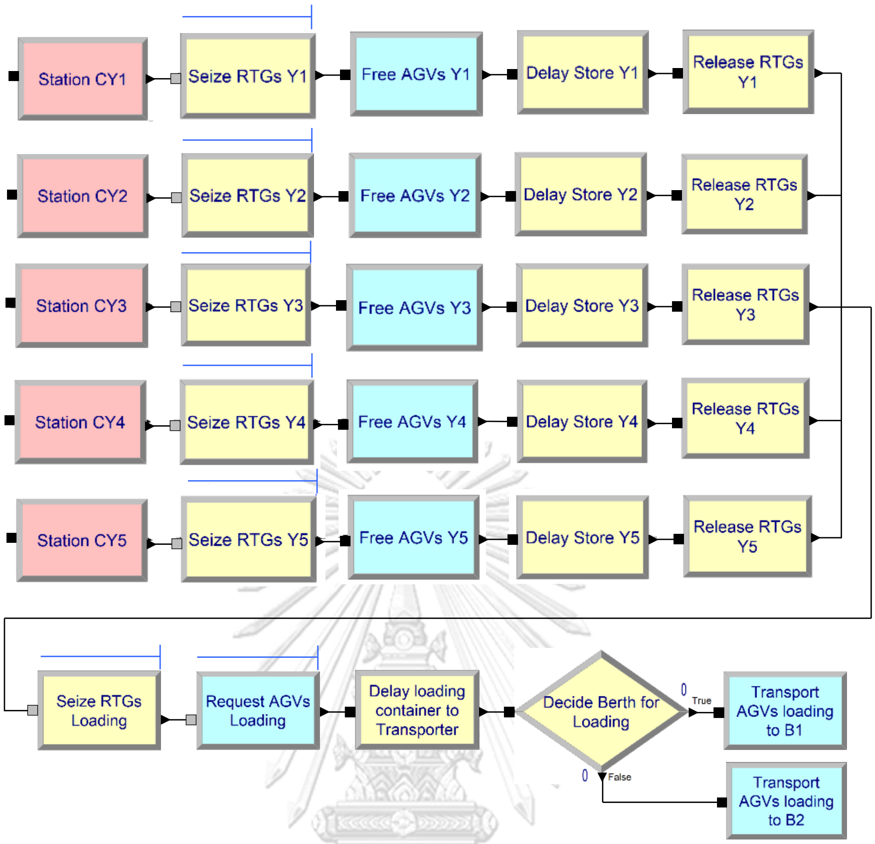
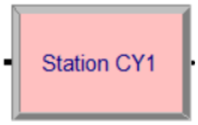
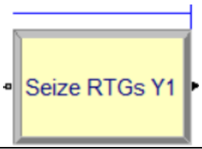
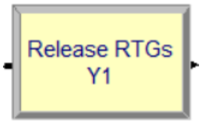
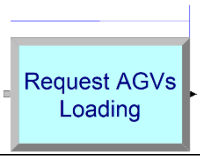
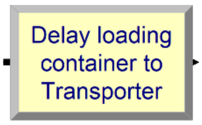
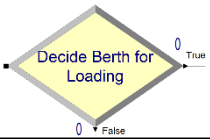
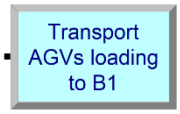


Figure 4-6: The second sub-model

This part starts with the container yard station set up in simulation after AGVs transport containers to RTGs. The process needs to seize the resource for manage the container process. The simulation in this part set as first come, first serve by seizing order. Hence, RTGs lift the container from AGVs, the AGVs will set to free of assign to get a request again follow its cycle in “Free AGVs” in simulation. After finish stacking container to a random position in yard slot, the RTGs will be seized again by the loading container process to ship in vice versa. Even though the RTGs seem to be busy all the time, but there is a time gap that affects the RTGs idle time.

Table 4-3: The module simulation explanation of the second sub-model.

Module	Name	Type	Explanation
	Station Container yard 1	Station	To set the original location of Container Yard slot 1
	Seize RTGs at Yard 1	Seize	Seize RTGs to process container to be stored at Yard 1
	Free AGVs at Yard 1	Free	After AGVs finish its work and free to repeat the cycle again. If not set them free, the AGVs will stay at RTGs
	Process of storing	Delay	Due to the previous use “Seize” order and to complete the process, it must be “Delay” order
	Release RTGs at Yard 1	Release	Similar to “Free AGVs” but RTGs set at the resource in simulation to free them to repeat their cycle of work again
	Seizing RTGs	Seize	Seize RTGs for loading container process to ship
	Request of AGVs	Request	RTG requests transporter for transfer container
	Delay loading container to transporter	Delay	RTG load container to transporter

	Transporters choose berth	Decision	Transporters make a decision to transfer container to quay crane
	Transporter travels to berth 1	Transport	Transporter travels to berth 1 and berth 2

The exporting container operation or loading process in simulation model has been explain in the following. This sub-model design unloading and loading operation process can simulate at the same time. In the meaning, that while quay crane unload container from ship (import), some of them chang to loading container (export) back to ship if the unloading container number is less. This can be reduce the ship turnaround time to finish early than usaul. The resource unit control structure is presented in Figure 4-7 below:

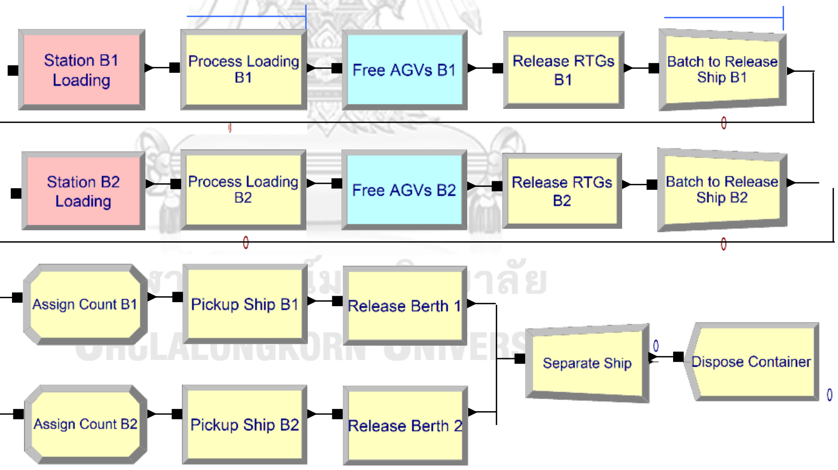
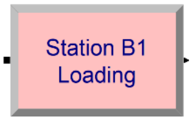
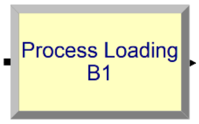
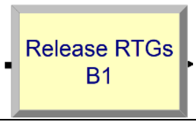
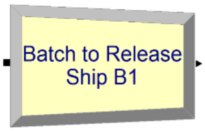
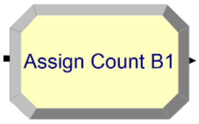
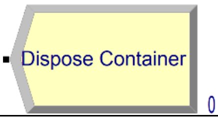


Figure 4-7: The third sub-model

Moreover, this part also includes the process until ship leaves the port with carried container. There is the set-up station in model for transporter to stop by then the loading process handling by quay crane begins. After the transporter delivered container to berth the machine resource will set to free again, the AGVs transporter set to free and the RTGs is release its assign. These two processes can simulate at the same time. Accordingly, after finish export or loading process in the same number of import container volume. It is the condition has been made by to count the number of containers and conditions to release the ship from the berth. The first condition is counting the entities to be the same of original, this process is for validation. Furthermore, the complete counting container will disappear in simulation, means the export container carried on the ship, ready to leave the terminal then the berth will be free again. The completely unloading and loading ship's destination goes to “Dispose Ship” to finish the process in this part.

Table 4-4: The third sub-model explanation

Module	Name	Type	Explanation
	Station berth 1	Station	The set-up station for transporter
	Process container loading by quay crane	Process	After container has arrived at berth, quay crane lift container to the ship
	Free transporter	Free	After finish tranfer container to quay crane, the transporter is free to next request
	Release RTGs	Release	Release the order of Yard crane
	Batch to release ship berth 1	Batch	Prepare to release berth 1
	Assign container count at berth 1	Assign	Set the order to count number of container loading in ship
	Pickup Ship	Pickup	Recall Ship to get ready to release. It means recalling full ship to leave the port

	Release Ship	Release	To release the ship at berth 1
	Separate Ship	Separate	The separate ship before go to dispose of them to get a count as how many ships to come and finish work
	Dispose ship	Dispose	Ending process of ship work

Regarding to distribution of data which input to the simulation model can be concluded in the table showing below:

Table 4-5: The distribution of data in the model

Name (Distribution of process)	Distribution	Detail
Ship arrival time	Exponential	Mean 21 hours
Ship arrival rate	Mean	35 Ships/month
Process Berthing	Triangular	15,20 and 30 minutes
Container on ship	Uniform	800-2000 containers
Process unloading container by Quay crane	Uniform	90 – 100 second/container
AGVs velocity	-	19.6 ft/s
Process storage container by RTGs	Uniform	60 – 80 second/container

4.3 Modelling resource operation cycle

The process of modeling an essential and challenging task is choosing a reasonable level of details abstraction of the logistic model so that the model remains comprehensible for the end-user without losing its explanatory power. While choosing an appropriate depth for detailing, an important factor to consider is not to overcomplicate the model, the end-user should be capable of verifying the model's logical structure. To facilitate model comprehensible and calibration, there were introduced resource operational cycles, i.e. aggregated elementary resource operations in cyclical repetition. The paragraphs that follow introduction to the three resource cycles featured in the model: Quay crane cycle, Yard card cycle, and AGVs cycle.

4.3.1 Quay crane operational cycle

The necessary conditions for the quay crane to start working are the following events:

- Test for current working time is positive
- Test for container availability in the loading queue is also positive

The first condition allows taking regard in the model for lunch breaks, shift change breaks, and work stops due to equipment malfunction. Testing for loading container availability is applied for the quay crane not to make an unnecessary move and not to remain in meaningless waiting for the container if the container queue is empty.

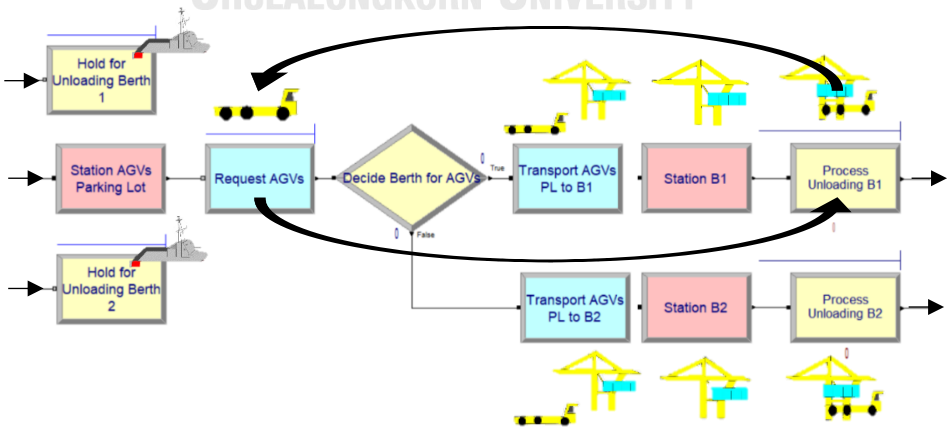


Figure 4-8: Quay crane operation cycle

4.3.2 Yard crane operation cycle

The modeling principle is certainly the same as for the quay crane described in the previous paragraph. The significant difference is the object to be served: RTGs or Yard crane that actually performs loading container on the AGVs. The RTGs modeled operational cycle is displayed in Figure 4-9.

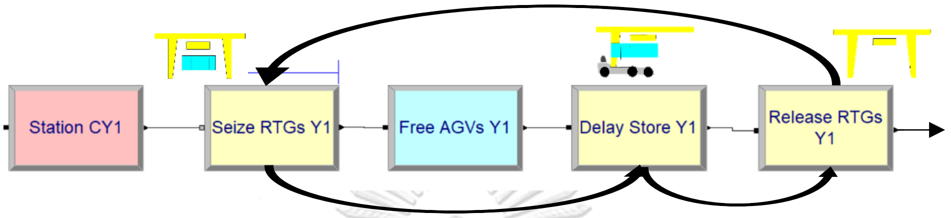


Figure 4-9: Yard crane operation cycle

4.3.3 AGVs operation cycle

Modeling the AGVs operational cycle's logic is more complicated than that of the crane operation cycle. In case of leave time losses in queues for lading at quay crane and respective time losses at discharge queues at the yard crane, the routing of AGVs transporter in the model will be linked as the "Blue Module" and "Red Module" in simulation. The cycle of AGVs modeled operational cycle is displayed in Figure 4-10.

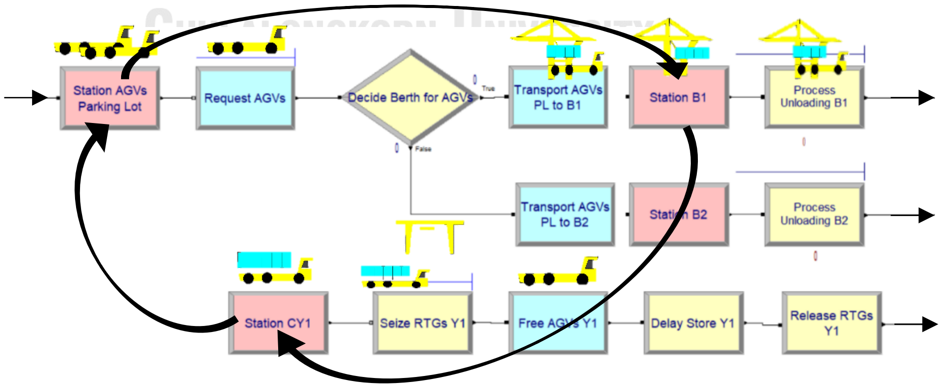


Figure 4-10: AGVs operation cycle

4.4 Verification and validation

4.4.1 Verification of the model

For validation of simulation model and verification of simulation computer program, the results of the simulation model were compared with the actual measurement.

Sargent (2011) defines model verification as "ensuring that the computer program of the computerized model and its implementation are correct. Computerized model verification ensures that the computer programming and implementation of the conceptual model are correct." Sargent (2011) also defines two basic testing simulation software approaches static testing and dynamic testing. In statistic testing, the computer program is analyzed to determine if it is correct by using such techniques as structured walkthroughs, correctness proofs, and examining the program's structure properties. In dynamic testing, the computer program is executed under different conditions and the value obtained (including those generated during the execution) are used to determine if the computer program and its implementations are correct. Both, dynamic and static testing is a part of the simulation model development. However, we rely more on the dynamic verification of our model.

Design of verification is a review of results of input compared to output due to in the simulation has set up the condition to count a number of initial incoming container and the lasted number of the container when it goes to "Dispose Module" and confirming that the model operates the way the analyst intended (debugging) and that the output of the model is believable and representative of the output of the real system.

To understand whether the model behaves the way it was meant and verify that it can entirely run. This study will compare between input of entities equal to output entities which is the container can run through the model without debugging and errors. Also, use animation by date and time that can confirm the verification. It illustrates the behaviors of the created ship in the most transparent way. The current data and time are displayed on Figure 4-11. The module assignment set the animation picture in animation, but some of them are not assigned, such as the created ship its picture will show up while model running, date and time also start. The box is representing of the container at any process it stops by. As Figure 4-11 demonstrates, there are final day of replication (24 hours, 7 days and 1 Replication running) the date and time shown complete round. Through the animation, it is easy to verify the model after any changes. Through the animation run, container movement in model while running and the result of input and output can be observed in Figure 4-12. The simulation clock shows what time ship creation starts to model and it was evident that the timing is consistent with one of a weekly plans. All mentioned above allows the study to conclude that the implementation of the model is correct.

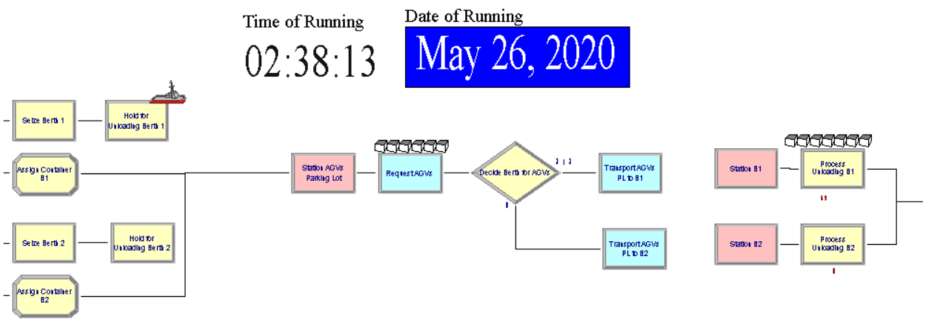


Figure 4-11: Time verification in simulation model

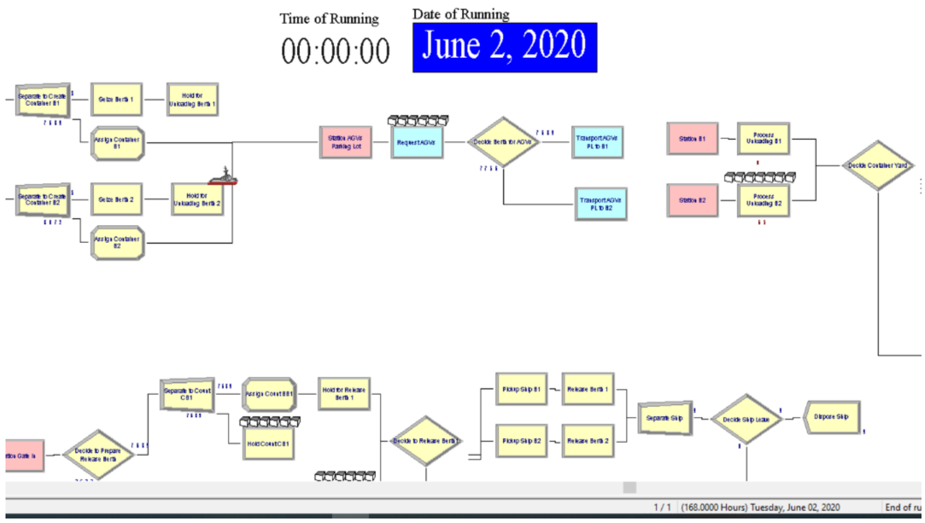


Figure 4-12: The ending time of simulation model

4.4.2 Validation of model

For model validation, the famous method to validate will again use the techniques of Sargent (2011) Model validation is defined as “substantiation that a computerized model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model”. It is often difficult to separate verification and validation, as these two processes are closely related, and often the same techniques are used both. Various validation techniques are described by Sargent (2011). Those used for validating our model are listed below:

- The result of entities run through the simulation compare with the real system.
- Process Validity: The “Process” of the simulation model occurrences are compared to those of the real system to determine if they are similar. This technique was used to validate the fulfillment of the weekly ship plan. It was determined that the simulated process as ship creation and container movement are consistent with providing data. Here it should be noticed that Data validity is of great importance for successful model development. We assume that the data provided on the Week ship schedule is the system's exact behavior, excluding uncertainty factors and can be used for validation of the model.
- Operation Graphics: Values of various performance measured, e.g., percentage of serves busy, handling machine utility, are shown graphically as the model moves through time: i.e., the dynamic behaviors of performance indicators are visually displayed as the simulation model running through time.
- This study will be using the Validation Simulation model method by statistical analysis of Input-Output Transformations between the real system and simulation model in the SPSS statistics program. The simulation model was implemented and set the input as the real system work to get the result to compare that the model can be validated. Simulations that occur in the form of predicted presentations of some data may require slight changes to the model's input. Also, the operation may have to adapt to the simulation of real work system in real condition. The change of data input to model consisting modification of

variable values but does not change the distribution of rate and changing of result unit as the same unit using in simulation also, the important changes which are caused by the implementation of the model.

The T-Testing is applied to proving the reliability experiment uses the Null Hypothesis's statistical testing methods for 4 variables: throughput (Number out of container, Quay crane rate, Ship turnaround time and Berth Utilization. Simulation is set 12 replications of running which has 7 days and 24 hours operation. Comparing between Real system and Simulation model the testing use Paired sample statistics testing in SPSS software. and the result show below:

Likewise, the first pair sample testing is throughput, and another result variable is quay crane rate, the crane's handling rate in hour in a unit of the container (2 TEU). Regarding to the report of port operation, this unit of result can be compared. Similar to Ship turnaround time to validate the delay that affects operation in port, the delay testing is more reliable, means the total time port can handle all of the container unloading from the arrival ship. On the other hand, Port Utilization is one of the vital performances. This unit of the result may be taking into consideration and validate that simulation can get the result as utilization. The hypothesis of 4 variables in the same assumption can be formed as follows:

H_0 = The throughput in a week of simulation result is different from the real system.

H_1 = The throughput in a week of simulation result is not different from the real system.

The result from SPSS software testing at 95% confidence interval showing that 3 of 4 variables has $t_{exp} > t_{\alpha/2,\ n-1}$ (α=0.05, $t_{critical}$= 2.201, n = 12) which is Throughput, Crane rate and Ship turnaround time. The Two-side test have proven that H_0 can be rejected means the 3 tested result is not different from real system significantly.   Otherwise, Berth occupancy testing has to accept H0 means simulation is different from the existing system. There is reason to prove the simulation can be validated and close enough to simulate new port operations to get a reliable result. The statistical analysis of the result can be shown in the following table:

Table 4-6: The statistical result of the existing system and simulation system

Paired Samples Statistics		Mean	N	Std. Deviation	Std.Error Mean
Pair 1 - Container throughput	The current.SYSTEM	8634.210	24	542.929	156.730
	The simulation.SYSTEM	8596.417	24	261.979	75.623
Pair 2 - Container handling rate	The current.SYSTEM	25.000	10	4.123	1.844
	The simulation.SYSTEM	25.310	10	2.039	0.912
Pair 3 - Ship turnaround time	The current.SYSTEM	24.499	24	2.638	0.762
	The simulation.SYSTEM	24.708	24	5.017	1.448
Pair 4 - Berth occupancy	The current.SYSTEM	0.450	8	0.062	0.031
	The simulation.SYSTEM	0.683	8	0.070	0.035

Table 4-7: The correlations of paired sample statistics

Paired Samples Correlations		N	Correlation	Sig
Pair 1 - Container throughput	The current & simulation system	24	-0.229	0.475
Pair 2 - Container handling rate	The current & simulation system	10	0.080	0.898
Pair 3 - Ship turnaround time	The current & simulation system	24	0.419	0.176
Pair 4 - Berth occupancy	The current & simulation system	8	-0.453	0.547

Table 4-8: T-Testing of paired sample statistics

Paired Samples Statistics		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std.Error Mean	of the Difference				
					Lower	Upper			
Pair 1 - Container throughput	The current & simulation system	37.793	654.607	188.909	-378.124	453.710	0.200	23	0.845
Pair 2 - Container handling rate	The current & simulation system	-0.310	4.451	1.991	-5.837	5.217	-0.156	9	0.884
Pair 3 - Ship turnaround time	The current & simulation system	-0.209	4.588	1.324	-3.124	2.708	-0.158	23	0.877
Pair 4 - Berth occupancy	The current & simulation system	-0.235	0.113	0.057	-0.415	-0.054	-4.144	7	0.026

Chapter 5

Output analysis

In this chapter the result of the simulation run is presented and analyzed. The performance measure for the model can be explained. The experimental design result factors are basic criteria.

The criteria of the result can be shown in Table 5-1. Regarding the selection of key performance indices for ports under the Port Authority of Thailand from Transportation Institute Chulalongkorn University (2017), it has been explained the suitable performance index.

Table 5-1: Performance criteria in the study

Type	**Criteria**	**Unit**
Throughput	Throughput/Year	TEU
	Throughput per Berth Meter	TEU/Meter
Berth Occupancy	Berth Occupancy	%
Utilization	STS Utilization rate	%
	RTG Utilization rate	%
	AGV Utilization rate	%
Container handling rate	STS Container rate	TEU/hour
	RTG Container rate	TEU/hour
	AGV Container rate	TEU/hour
Idle Time	STS Idle time	%
	RTG Idle time	%
	AGV Idle time	%
Cycle time	Container time cycle	Minute
	AGVs time cycle	Minute
Ship	Ship turnaround time	Hour

5.1 The ideal container throughput

Recognizing the importance of measuring container port performance by the predictable state of container throughput for reacting the application of automation system in the terminal. The same demand of container volume in the current situation results from container handling will be the same number. The discussion of this topic will show the result beforehand by having the combination machine applied. A future situation with this greater handling machine capable of providing more efficiency on transporter service and predictable container throughput can be expected. The ideal container throughput will be show as the result of simulation model in the following.

The container throughput expresses the amount of cargo a terminal handle over the time, without specifying the resources utilized. When the output is expressed in monetary units. The simulation output overview shows the effect of the system of a different number of handling machines. The simulation model was run for 28 replications 7 days and 24 hours of operation to conduct output validation for the model and check whether it realistically models the current system. Container throughput of the automation handling machine operate in software can perform the result shown in Figure 5-1.

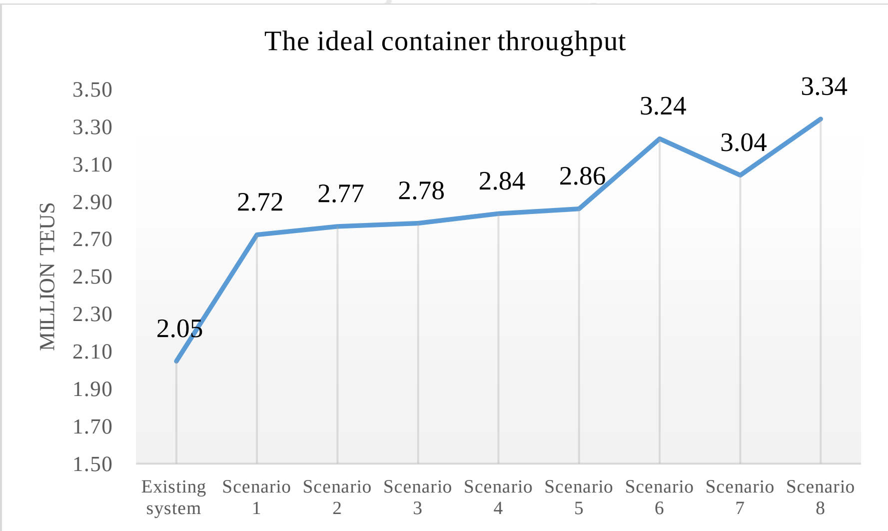


Figure 5-1: The ideal annual container throughput

The minimum throughput that can be performed is 2.72 million TEU per year perform by scenario 1 and the maximum is up to 3.37 million TEU per year. There are increasing throughput, scenario 1 can perform at least 32% and the maximum performance is about more than 70% of the existing system. This category of the result indicates that all machines can be seamless cooperation and produce products more than usual means the combination of handling machine replacement can perform high throughput.

The total volume of containers handled by the automation system has increased steadily in each scenario, which varies by the number of machine usage. Scenario 8 has the maximum throughput but compared to scenario 6, which has less throughput but not much different and cannot take significance from scenario 6.

Another category of the result can be shown as throughput per berth length, which is the container port terminal benchmarking of the resource usage. Laem Chabang port terminal C1 and C2 has 1,2000 meters then the number of throughputs per meter show in Figure 5-2.

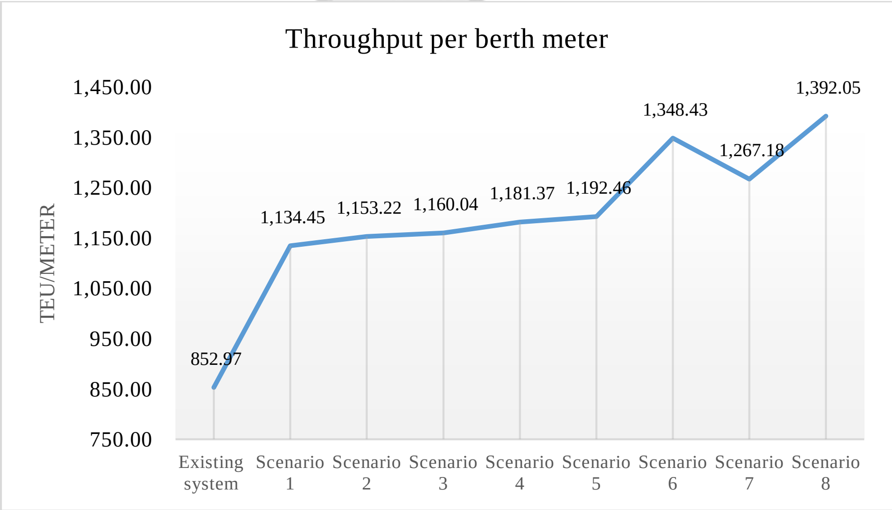


Figure 5-2: Annual terminal throughput per berth meter

5.2 Machine utilization

Base on the throughput and the available land and crane capacities, it is possible to plot land and crane capacity utilization as a graph depicted. The overall machine series plots for the its utilization are provided in Figure 5-3. Regarding the resources operating the terminal port, the utilization varied from one process to another. The Quay crane, RTGs crane and AGVs transporter if count AGVs as the resource in port its reflected the highest utilization due to the high number of seizing while simulating AGVs service for transporting a container from quayside to storage yard as well as loading and unloading process which handling by another automatic machine.

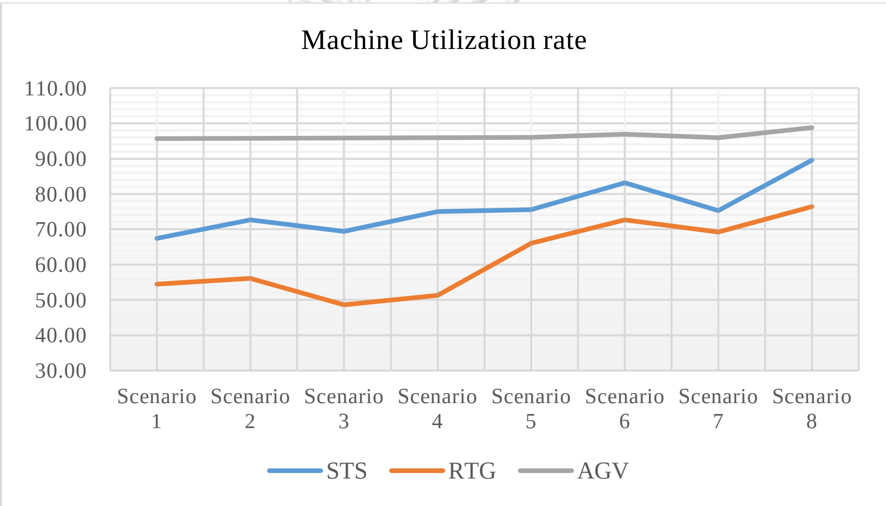


Figure 5-3: Comparison of three machines utilization

5.2.1 Quay crane utilization

Quay crane utilization means the percentage of time that the quay crane is active also means that complementary to the time that the quay crane is waiting for AGVs. The developed quay crane assignment mostly concentrates on minimizing the completion times of the tasks or cranes. Quay crane utilization rate and traveling times are also considered as performance measures. From the simulation results, Ship to shore gantry crane as the quay crane show that there are 5 scenarios meet the expectation result (over 75% utilization) which are scenario 4-6. As Figure 5-4 indicates, scenario 2,4,6,8 which is 80 cars of AGVs effect to quay crane has higher utilization than 60 cars scenario.

In the supportive machine, additional AGVs may be deployed because they can increase the cooperate machine utilization. However, the added benefit of additional units reduces as more AGVs are assigned per quay crane.

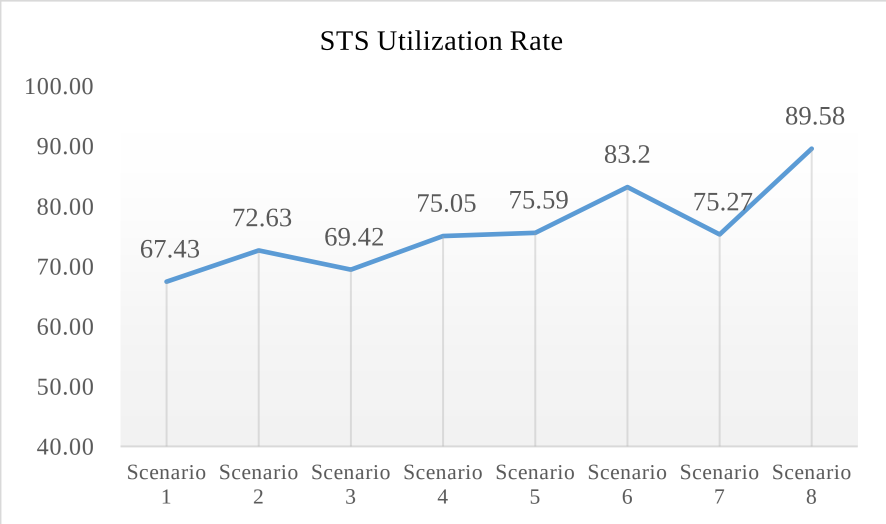


Figure 5-4 : Ship to shore crane utilization rate

Multiplying each quay crane utilization by the simulation replication length, 168 hours, the number of hours worked for each quay crane in the simulation on average 136.2 hours. The result shows that the semi-automation quay crane utilization can improve productivity as its utilization reaches 75% and can be further by following the number of incoming containers.

Thus, by optimizing the utilization of those quay cranes can be calculated to reach the maximum utilization, there is an alternative method to solve. The number of semi-automation quay crane can be reduced it is basically and commonly in real work operating depends on the number of containers on ships and manage the number of cranes that can handle unloading containers. Also, its high efficiency of automation crane can be handling containers in very high density. The result is the first transshipment speed in the container terminal is the significant factor participating in the overall transport time and affects another machine in the terminal, then to support and make the workflow in fit and fine the level of automation of quay crane and another must take into consideration.

5.2.2 Yard crane utilization

The Rubber-tired gantry crane as yard crane operates in the storage yard, this category related with the yard operation. The efficiency of yard operation heavily depends on the productivity of these RTGs. As the workload distribution in the yard changes over time, dynamic deployment of RTGs among storage blocks is an essential issue of terminal operating. The storage strategies applied in the yard depends on the type of containers. Generally speaking, the storage strategy is chosen best to utilize the relative fixed information of incoming containers to store them in the proper location to facilitate container retrievals.

The simulation result shows that the utilization of RTG yard crane mostly does not reach the expectation (more than 75%) regarding the reason mentioned in quay crane utilization. There is an effect since the number of containers and density is very low and not enough the supportive transporter. There is the minimum result scenario 1 with 54.45% and the maximum is on scenario 8 with 76.42%.

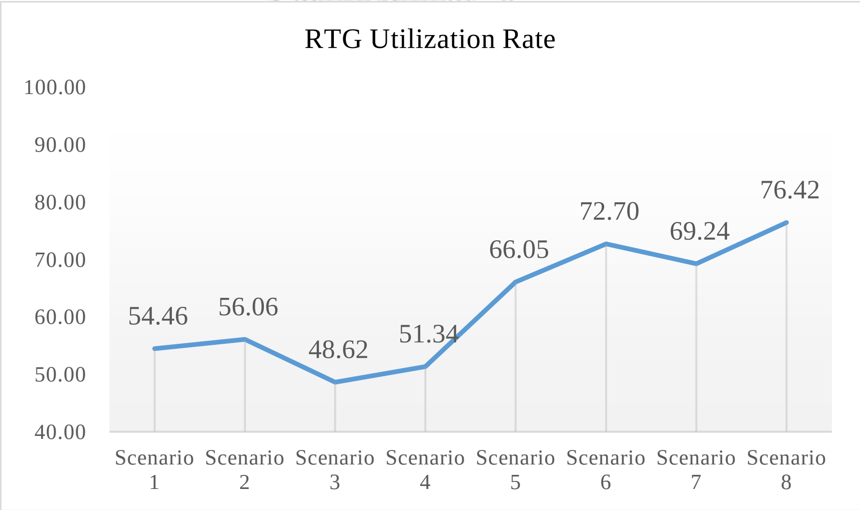


Figure 5-5: Rubber tired gantry crane utilization rate

5.2.3 Transporter utilization

This performance category means how the transporter is responsible for optimizing the vehicle utilization, transporting orders like dispatching and travel of routing information and keeping the tracks of materials for transferring containers around the terminal both of waterside and landside.

In this study, the assumption has been applied and set up in the simulation, the transporter AGVs are served by FCFS (first come, first serve), then there will be no conflict with the crane scheduling problem. A container terminal's efficiency is directly related to the amount of time each ship spends in the port. Hence to maintain competitive advantage and increasing efficiency, it is necessary to determine the appropriate number of AGVs to deploy and formulate right dispatching strategies for these AGVs. Regarding the previous study, the researcher recommended that the situation in terminals entails a greater network complexity and suggest a fleet of 80 or at least 10 cars per quay crane for the middle-sized container terminal.

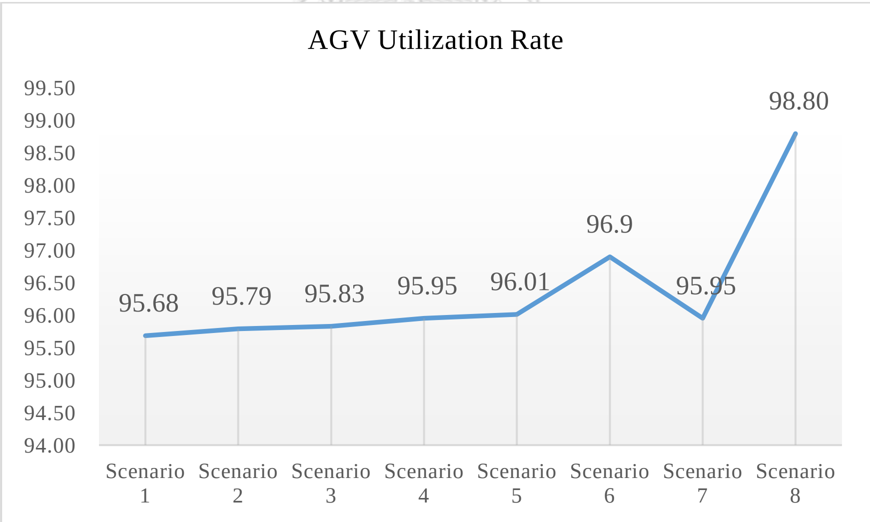


Figure 5-6: Automated guide vehicle utilization rate

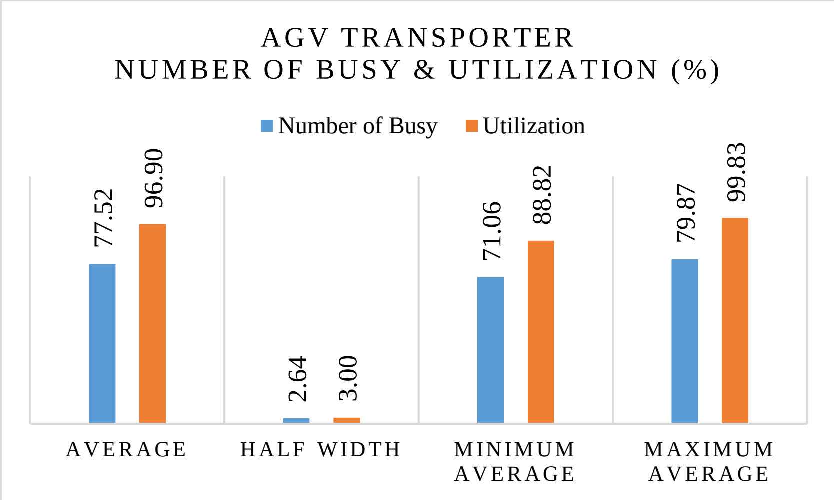


Figure 5-7: Utilization of AGVs transporter

From the simulation result, 80 AGVs with 19.6 ft/s are applied. The result shows that the AGVs transporter is an excellent supportive transport machine to support and increase the productivity that its utilization is average 96.9% due to the request from quay crane seizing to transfer container in the terminal all the time. The AGVs routing based on a network flow from the original used in the existing system assumed that the transporter would travel in one-way and stop by the station set in the simulation. Upon running, the simulation model was initial with zero containers in the yard, then after the ship finishes unloading and left the port, AGVs will start travel by seizing order and traveling in the set-up link-network.

5.3 Machine container handling rate

The container port productivity is the container handling rate: quay crane container rate, yard crane container rate, and AGVs transporter handling rate. This performance category explains how many containers a crane lifts on/off a container ship in an hour. The comparison of three machines cooperates in the simulation shown in Figure 5-8.

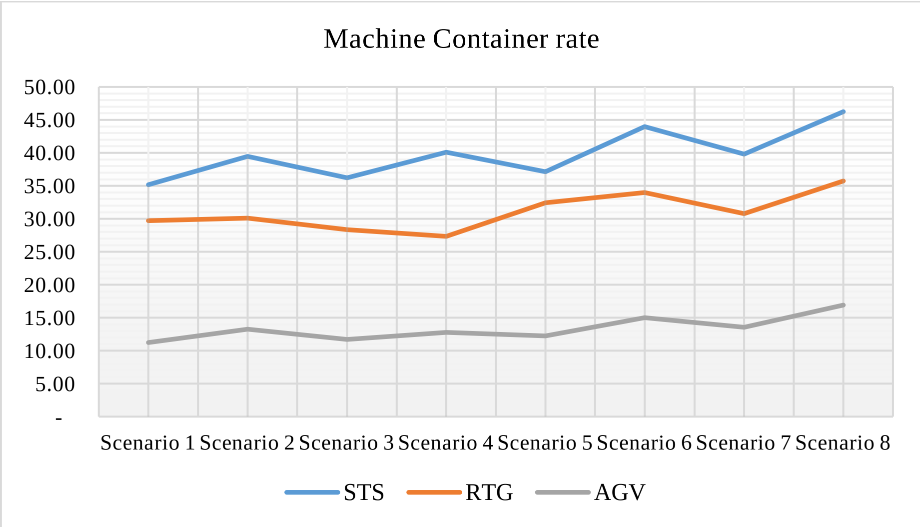


Figure 5-8: Comparison of three machine container rate

5.3.1 Quay crane container handling rate

Quay crane productivity in terms of the number of moves per hour measures by container rate which is a performance indicator of overall terminal productivity. One move equals a transshipment of containers between ship and transporter. Almost all terminals are able to achieve maximum productivity as low as 70 % and as high as 80 % of the computed number. The technological can indicate as the improvements are increasing Quay crane productivity. The overall time load/unload of ship is generated from the total sum of loading/unloading containers.

The simulation result shows that scenarios 1 to 8 can be performed more than 35 TUE/hr. As Figure 5-9 shows the container's apparent volume from the scenario with 80 AGVs transporter. The result can be indicated that 2 machines cooperate well during the simulation. The minimum container rate is 36 TEU/hr. from scenario 1 and the maximum container rate is 47 TEU/hr. from scenario 8. Notice that the scenario 6 and scenario 8 are not different significantly mean that in term of the number of machines, scenario 6 can replace scenario 8.

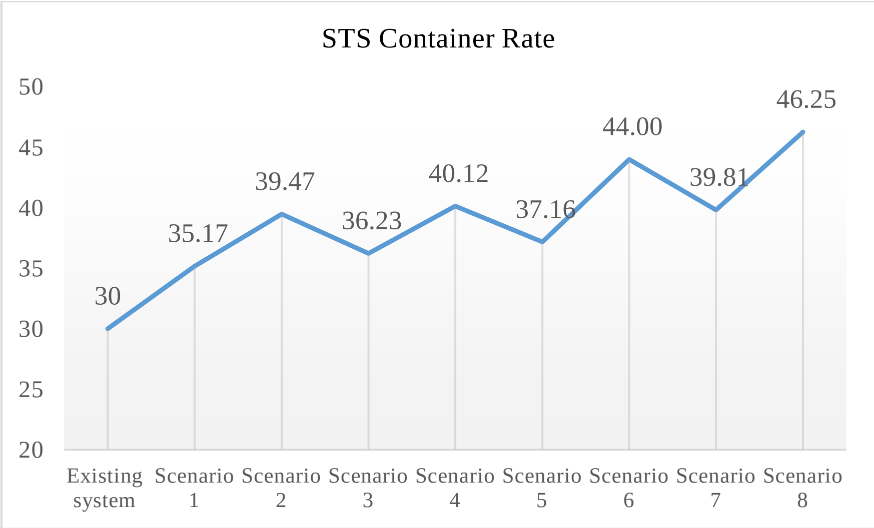


Figure 5-9: Ship to shore crane container rate

In terms of time using, to reduce waiting times for quay cranes, additional AGVs may be deployed. However, the added benefit of additional units reduces as more AGVs are assigned per quay crane. To evaluate this reduction, the simulation is run several times with varying numbers of AGVs assigned to each quay crane. From the simulation result, it becomes visible that the added benefit of additional AGVs per crane reduces less quickly for the system operating. The simulation running only a single AGVs per quay crane indicates the productivity of a single AGVs, indicating a minimum cycle time per AGVs larger than the determined 120 s.

5.3.2 Yard crane container handling rate

Rubber-tired gantry cranes (RTGs) as yard cranes are the one equipment choice for container stacking at terminals, especially where high-capacity stacking and good maneuverability are key requirements. Automated RTGs are suitable for the same types of terminals as manually operated rubber-tired gantry cranes. The main reasons to choose an RTG setup compared to other terminal concepts include simplicity and relatively low capital expenditures and infrastructure costs for deployment. The rubber-tired cranes can be moved to a different terminal area if, for example, additional handling capacity is needed at another stack.

The RTG was served for AGVs transporter, they can perform up to 30 TEU/hr. in average. It is the impact of low density of import and export container. The RTG in simulation can perform as a minimum 30 TEU/hr. and a maximum 36 TEU/hr. There are 3 and 5 RTGs in different scenarios and operate in the assigned slots in the terminal container yard.

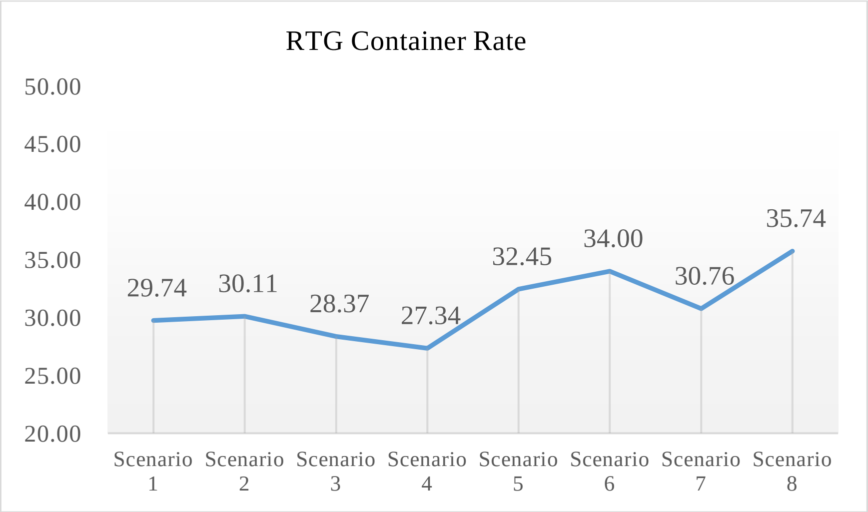


Figure 5-10: Rubber tired gantry crane container rate

5.3.3 Transporter container handling rate

The AGVs system's characteristics are used as inputs to the simulation model together with the arrival patterns of containers brought in and taken out by ships. Assuming that the patterns of container arrivals and departures to the terminal by ship are repeated every 21 hours so that a 21-hour simulation was sufficient to make projections about annual productivity. This assumption may not be valid today due to the randomness that exists in the system. However, the use of automation and information technologies, coupled with optimum dispatching and scheduling techniques, will lead to very close scenarios to the assumed one. The results of the simulation are shown in Figure 5-11.

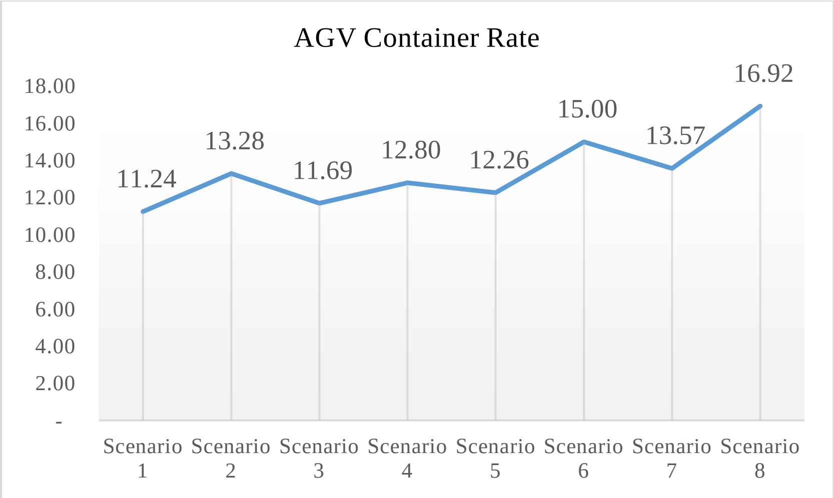


Figure 5-11: Automated guide vehicle container rate

The container rates of AGVs with different configuration principles with 80 cars will be the lower container rate but still need the larger number of AGVs assigned to each single quay crane. The result shows that it can indicate a large number of AGVs can increase productivity and result in a high utilization for each AGVs.

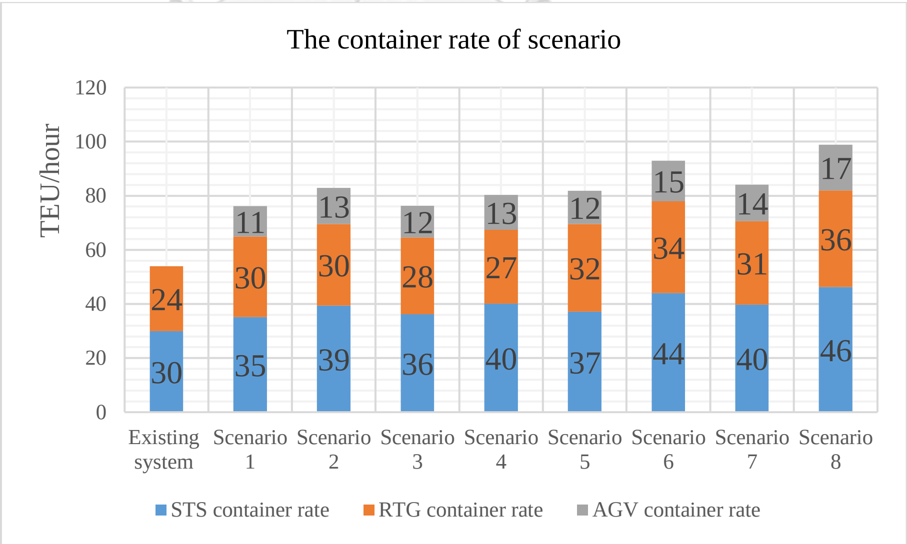


Figure 5-12: The combination machine container rate

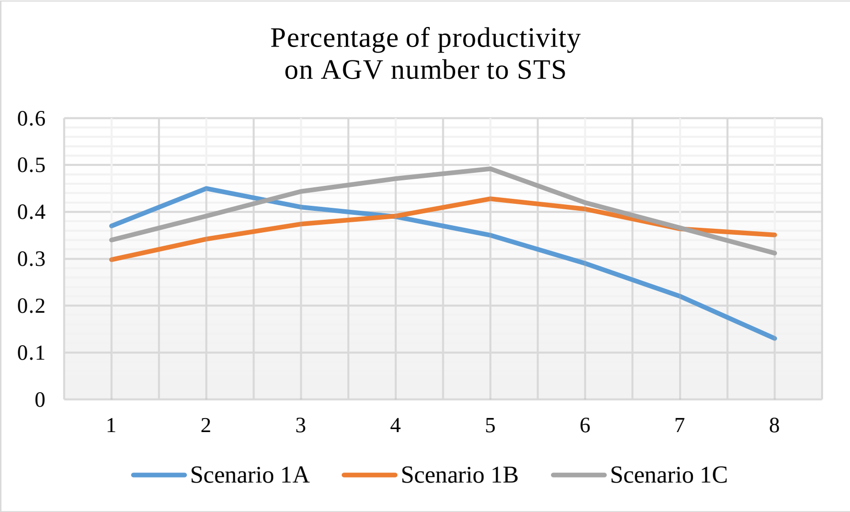


Figure 5-13: The percentage of productivity on AGVs to STS

This study also finds out that productivity-related between STS and AGVs inappropriate number by trying the different number of AGV to serve the different number of STS and the result found that 12 AGVs serve 4 STS in also 50% increasing for cooperation supporting. at the same time, the horizontal transport is performed by AGVs which continuously cycle between the STS cranes on one side and the RTG stacks on the other side.

5.4 Times operation

Time efficiency of ports is considered to be the average time of ship spend in port and also considered the idle time of machine which mean the machines waste time or waiting for another request of handling. In this paper, the indicators (total, average, maximum capacity of the ship, number of the ship, number and frequency of ship calls, total container throughput) and network indicators. In terms of the relationship between traffic size and time efficiency was set-up by schedule in statistic number.

The shipping plan is often delayed because the late arrival of the container ship does not take into account because there is the set-up of arriving ship by distribution the ship will be come on time but the queue for berth or waiting time still occur. On the other hand, if the terminal supplies are late, the ship must wait for the delayed container ship and be late on the assigned schedule. There are also other reasons for delayed time can take into consideration. These delays have been implemented in the simulation model but not enough by adding the Delay module in the model, after assigning specific time to the relating machine. Historical data about ship delays on the ship's schedule will become available, it can be analyzed using ARENA Input Analyzer, and the probability distribution for the duration of such delays must be entered as the delay time.

As we know, the engineering simulation model is an effective method for the analysis of the terminal system containing a stochastic process. From here it is a simulation model is created with the purpose of analyzing of several options to reduce the idle time on the equipment which increased terminal performance.

The simulation results in Figure 5-14 show that the comparison of three machines, The RTG has the highest of idle time, about to 9% of operation time following by STS's and AGVs the lowest. The idle time is mostly caused by waiting time or queue time sometimes means the machine waits on the queue list for the task. These wastes time still on the count for idle time. The category of the performance shows that even the automation machine has the time which not productivity.

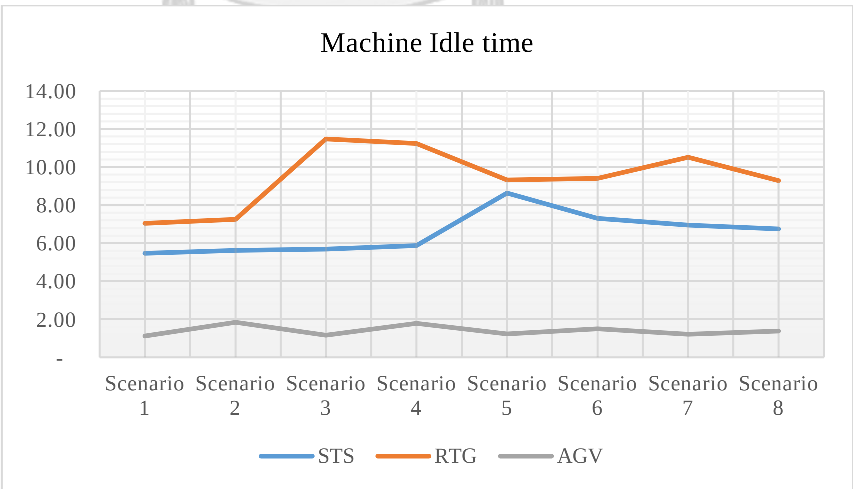


Figure 5-14: Comparison of three machine idle time

Figure 5-15 show the ship to shore idle time. The simulation result performs the minimum idle time of 5.47% in scenario 1 and at most 8.63% in scenario 5. Many processes cause the idle time since the formulation of the berthing time is the total sufficient time coupled with idle time and time does not operate. The idle time is many components such as the waiting container and waiting for the transporter. In the other hand, the time does not operate such as an over shift, break time and praying time are not considered in this study.

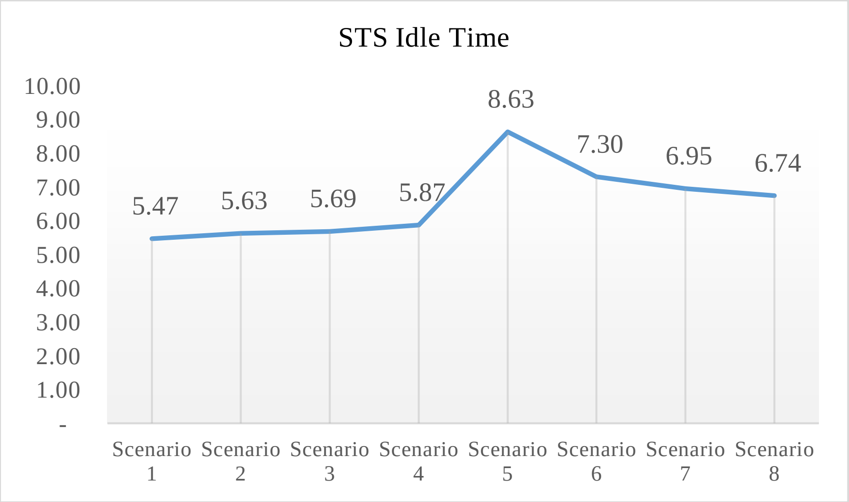


Figure 5-15: Ship to shore crane idle time

The rubber-tired gantry crane work in the storage yard also cause idle time. It is a common practice in container terminals and consists of executing additional automated stacking crane movements to improve the quality of the block piles. The goal is to relocate containers as close as possible to the transfer areas to enhance faster retrieval movements, especially for vessel loading. As these operations have no priority over regular stacking or retrieval of containers, they can only occur only when an automated stacking crane is idle.

As the cranes operate without drivers, and operator idle time is reduced by handling multiple RTGs from one remote control desk in the sequence of work orders, they are available to execute container moves at any time. Loading and unloading by RTGs, at the container storage yard, this simulation result cannot be compared with the existing system, but the overall result must be involved with handling machine operation. Therefore, the operation time would also be reduced cycle time.

AGVs, and themselves can cause the idle time of rubber-tired gantry crane. The yard crane mostly serves the kind of transporter and stacking container. There will be the wasted time as a stoppage-time while serving load and unload container also they can travel along with the slot between row and row.

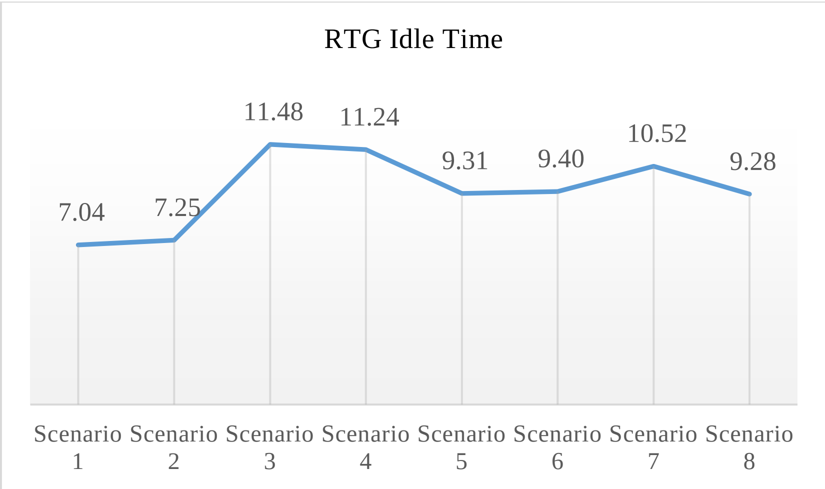


Figure 5-16: Rubber tired gantry crane idle time

From the simulation results, The lowest idle time is 7.04% of operation time in scenario 1 and the highest is 11.5% in scenario 3 due to in 5 cranes scenario has a more significant number of idle time compare to 3 cranes in the scenario. The result can improve that fewer yard cranes can be performed, not significantly different based on the current container volume.

As the transporter, automatic transport vehicles, AGVs are start travel since receiving the request from quay crane and always pooled while operated equipment commonly operates at one crane (fixed allocation). The AGVs operation if the loading capacity exceeds one container, a multiple load mode is possible. Multiple loads for AGVs contain the potential for optimization, but it rarely occurs in simulation because it is hard to organize. However, the request of AGVs occurred all the time if the ship keeps coming to the port terminal. Their main task is to stand ready synchronize the equipment so that the containers arrive 'in-time' at the interfaces. This may cause that all AGVs was busy and its idle times are minimized.

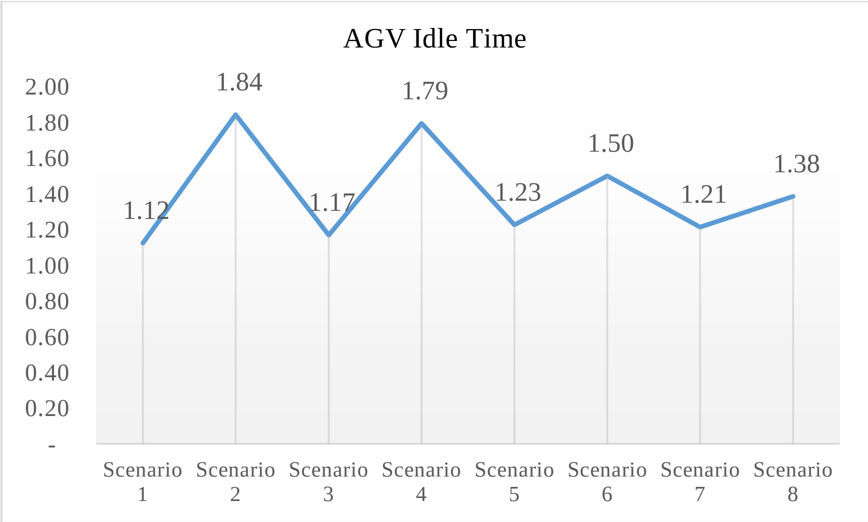


Figure 5-17: Automated guide vehicle idle time

From the simulation result, the minimum idle time is 1.12% in scenario 1 means they are on the run all the time and the maximum is 1.84% in scenario 2. The result shows that 80 cars scenario has larger idle time than 60 cars due to the minimum number of AGVs required all the time while terminal operating. As mention AGVs in the quay crane discussion section, they are the most significant supportive transporter means the number of the transporter has an essential role in port. The increasing number of container shipments causes higher demands on the seaport container terminals, container logistics, management, and technical equipment. Increased competition between seaports, especially between geographically close ones, is a result of this development.

The increase in the number of arrivals of ships and containers in the handling requires an pattern of loading and unloading equipment operating settings that provide the terminal's best performance. Increased utilization will reduce the idle time of equipment and increase the number of ships serviced and terminal throughput.

The container cycle time is the container's total time since the quay crane unloads from ship til stack in storage yard. This kind of category can simulate in simulation and will not appear in the realistic, but it can be one of the indexes that indicate the performance of the automation operating system that they can prove and handle containers quickly. The simulation's result is the maximum container time cycle is 19.16 minutes and 8.08 minutes in scenario 8, respectively.

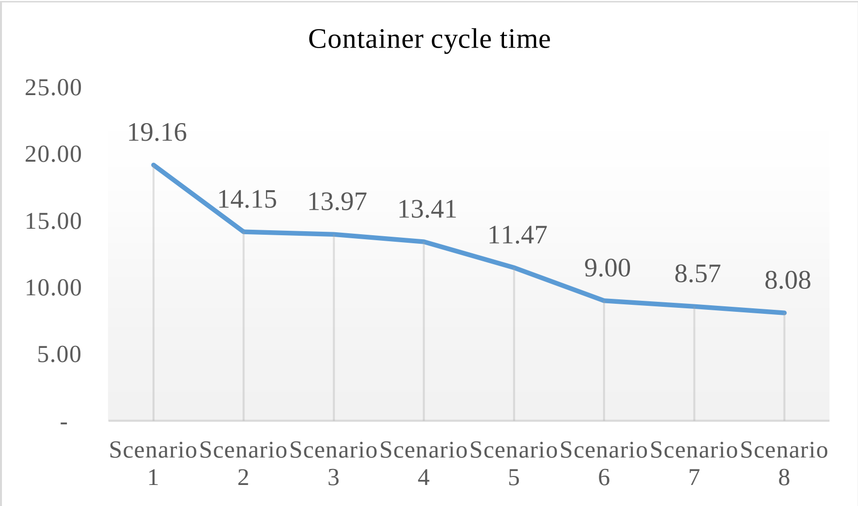


Figure 5-18: The cycle time of the container

The examination of two different AGVs number was dispatching in combination with the cyclic selection of three machines. This study has varied the number of AGVs from 60 and 80 cars, which corresponds to 7 to 10 AGVs per quay crane. These numbers are quite realistic in practice. Fig 5-19 represents each of the AGVs scenarios in the total cycle times per TEU or container 1 round in minutes for various AGVs.

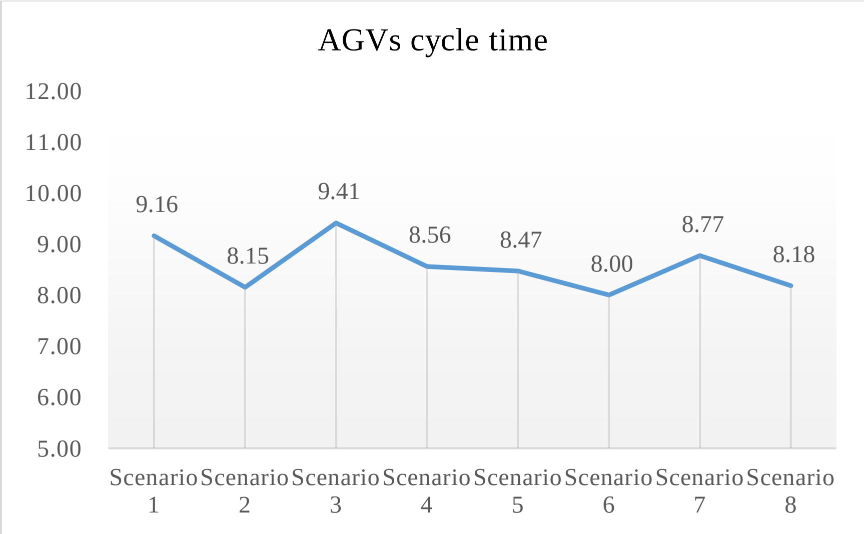


Figure 5-19: The cycle time of AGVs

The simulation results, the transporter cycle time has the maximum is 9.41 minutes in scenario 3 with 60 cars and the minimum is 8 minutes in scenario 6 with 80 cars. The result is not much different in each scenario, but they can reduce time of the container transferring. The cycle time start when loaded container from quay crane and finish when delivered container to RTGs. The performance is related with the optimum vehicles number which make the shortest ship for unloading, and the assumption of continuity of the quay crane working cycle. of the AGVs were tested. The study used an approximation method to calculate the minimum number of simulations runs required in order to obtain results from a simulator with small enough statistical errors.

5.5 Operations of ships measurement

From the simulation result, at the quayside, part of the ship and quay crane operation found that there are more than 23 ships arrived and the ship stays at the port on average at most 9 hours only for unloading container from the ship and waiting time for a free berth on less than 3 hours. The reduction of ship turn-around time is 30% from existing system work and concerning the current system result found that ship waiting time is about 10% of ship turn-around time. The result of simulation can improve the ship time operation in port can be reduced and since they stay in port less than usual means, the berth will be available for incoming ship all the time. Furthermore, the on-time operation delays could not indicate there are the only ship cause all the delay.

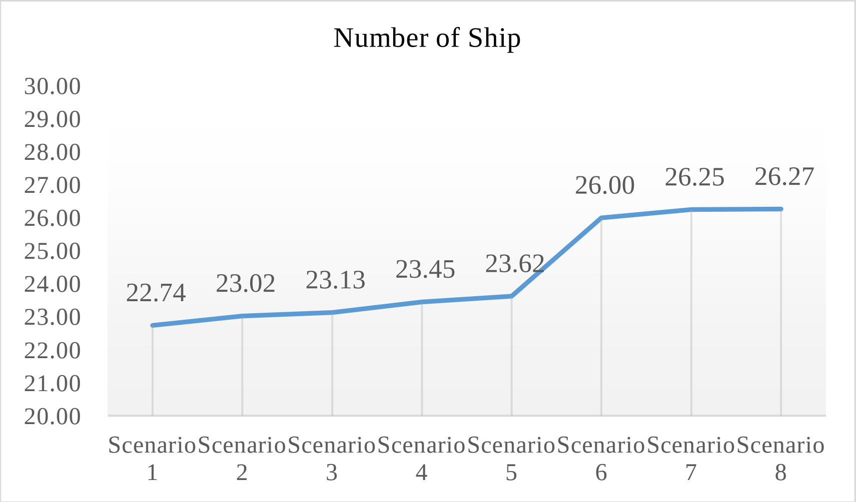


Figure 5-20: The number of arriving ship

One of the most important factors that have affected customer satisfaction is related to ship waiting time at port container terminals. Ship waiting time is an essential contributor to the competitive advantage of a port terminal. Port terminals with low average waiting times can attract more ships than port terminals with a high average waiting time. Waiting and queuing times at the berthing area of port container terminals is the most significant problem port managers encounter. Long wait times negatively impact port terminal efficiency, and ship managers prefer to berth at a port terminal with short waiting time and high efficiency.

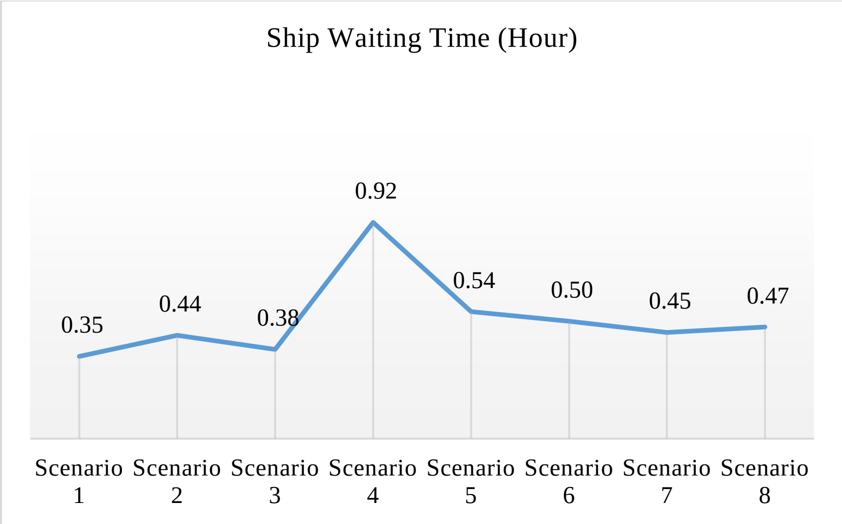


Figure 5-21: The ship waiting time

After running the simulation model in Figure 5-23. It can be seen that the waiting time is not much. The new incoming ship can be wait in queue berthing operations. There is a maximum waiting time 55 minute, and the minimum is only or 21 minutes. On the other hand, this study does not consider since the Tug/Pilots operation will take times and create bottlenecks for port terminals. The long queue at the roadstead waiting for a free Tug/Pilot machine and long ship waiting times generates expensive ships and customers' expensive costs. High waiting time impacts the ships management decision to choose this port terminal for berthing operation.

For this reason, all port container terminal managers try to solve the queuing problem at the berthing area. The big issue can because of many processes following. However, the automation system show that they need only a few times for the berthing process (since the ship arrived) and reduce the total turnaround time (since finish unloading and leave the terminal port)

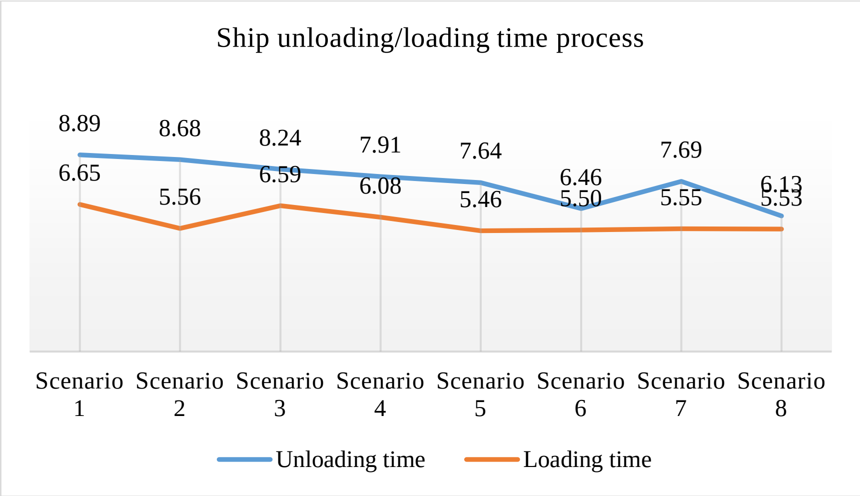


Figure 5-22: The ship service time

The existing system has the ship turnaround port for 24 hours in average. The automation system can significantly reduce ship turnaround time. The maximum is 16 hours at scenario 1 and 12 hours in scenario 8 but unquestionable that many factors related must be considered likes the container volume and the time spent in the port terminal. In a general scenario, the higher the productivity – the lesser the turnaround time where the ship turnaround time is defined as a summation of all waiting times, idle times, and container handling times at ports.

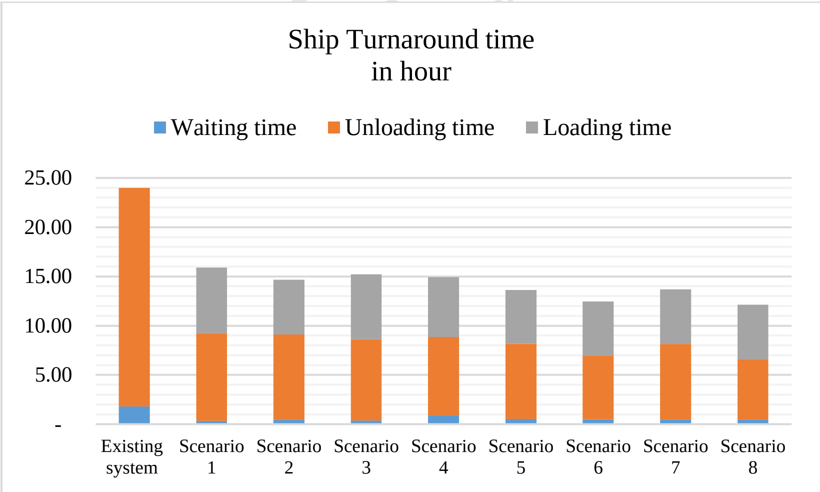


Figure 5-23: The ship turnaround time

Chapter 6

Study conclusion

From the result, it can be concluded that the increase of performance which the handling machine can do is directly related the results in many aspects. It has been proven that the simulation model developed is robust since it contemplates situations that can prove to increase the productivity of container operation.

6.1 Results from the simulation study

The simulation model was run for 28 replications, 7 days, and 24 hours operation to conduct face validation for the model and check whether it realistically models the real system.

Through the study and the practical simulation results were conducted in the terminal port, including the link and reference with the previous studies, this study contributes to knowing that by using simulation to represent the existing system as a virtual interface will allow testing current and future situations in logistics flow and operations without having experimented with the purchase of real equipment and take high risk in the cost. Besides, using simulation as an analyzing tool and documentation (increase reliability and quality) as a key performance indicator may enable logistics management to make the right decision in determining future strategies. The simulation model approach is also developed based on the theoretical knowledge that is adapted by considering empirical findings; such a model can structure other academic studies aimed at specific purposes.

In terms of optimization, the simulation model results in this chapter are compared with a number of simulations for assessing the required equipment units in each scenario as determined by performance measurement. The simulation is run with the same combinations and different equipment numbers. The table below is an overview of the output of this simulation runs.

According to scenario in Table 6-1.

Table 6-1: The machine number in scenario

Scenario	Number of STS Cranes	Number of RTG Cranes	Number of AGV Cars
Scenario 1	2	3	60
Scenario 2	2	3	80
Scenario 3	2	5	60
Scenario 4	2	5	80
Scenario 5	4	3	60
Scenario 6	4	3	80
Scenario 7	4	5	60
Scenario 8	4	5	80

The simulation results shown in Table 6-2

Table 6-2: The overall result in various categories

Scenario	Unit	S1	S2	S3	S4	S5	S6	S7	S8
Throughput/Year	m TEU	2.72	2.77	2.78	2.84	2.86	3.24	3.04	3.34
Throughput/Meter	TEU/m.	1,134	1,153	1,160	1,181	1,192	1,348	1,267	1,392
Waiting time	Hours	0.35	0.44	0.38	0.92	0.54	0.50	0.45	0.47
unloading process	Hours	8.89	8.68	8.24	7.91	7.64	6.46	7.69	6.13
turnaround time	Hours	15.54	14.24	14.83	13.99	13.1	11.96	13.24	11.66
Utilization rate	%	67.43	72.63	69.42	75.05	75.59	83.20	75.27	89.58
Container rate	TEU/hr.	35.17	39.47	36.23	40.12	37.16	44.00	39.81	46.25
Idle time	%	5.47	5.63	5.69	5.87	8.63	7.30	6.95	6.74
Utilization rate	%	54.46	56.06	48.62	51.34	66.05	72.70	69.24	76.42
Container rate	TEU/hr.	29.74	30.11	28.37	27.34	32.45	34.00	30.76	35.74
Idle time	%	7.04	7.25	11.48	11.24	9.31	9.40	10.52	9.28
Utilization rate	%	95.68	95.79	95.83	95.95	96.01	96.90	95.95	98.80
Container rate	TEU/hr.	11.24	13.28	11.69	12.80	12.26	15.00	13.57	16.92
Idle time	%	1.12	1.84	1.17	1.79	1.23	1.50	1.21	1.38
Cycle time	Min.	9.16	8.15	9.41	8.56	8.47	8.00	8.77	8.18
Container Cycle time	Min.	19.16	14.15	13.97	13.41	11.47	9.00	8.57	8.08

Regarding the study purpose, this study accomplishes the analyze the performance of container yard, quay crane and new transporter if an automated system is applied. In the conclusion part would be discussed and given the suggestions for the automation port system for an application at under construction of Laem Chabang port Phase 3.

The consequence from the simulation result on the variations in equipment numbers each scenario has the following effect on the container operation:

- Quay cranes: in a different scenario, they have 40 container rates, 76% of machine utilization in average, and idle time 6.5% of 168-hour operation. The most effective of reducing operation time in the number of quay cranes can be noticed when comparing 2 and 4 cranes.

- Yard cranes: in a difference scenario, they have 31 container rates, 62% of machine utilization in average, and idle time 9.4% of 168-hour operation the impact of varying the number of yard cranes is rising when cooperate with larger number of other machines. This can be seen when comparing scenario 1-4 and 5-8.

- AGVs transporter: they have 14 container rates, 96% of machine utilization in average, idle time 1.4% of 168-hour operation, and overall 6 minute per container. The effect is visible when comparing the cooperation support of quay crane and yard crane.

In terms of operation, the efficiency is essential for port development. Port Authority of Thailand has the policy to improve port efficiency to be as efficient as possible with a set of performance quality indicators. According to this study, the author chose performance indicators in comparing the operations of both systems, as follows:

1) Crane productivity

Crane productivity is the crane movement per hour used to measure the ability to handle the container cargo from the ship to the shore. Cranes with higher capacity will help to increase the speed of ship turnaround time. Therefore, port operators tend to consider the optimal number of cranes to shorten ship response times for shipping lines when cranes work for the ship.

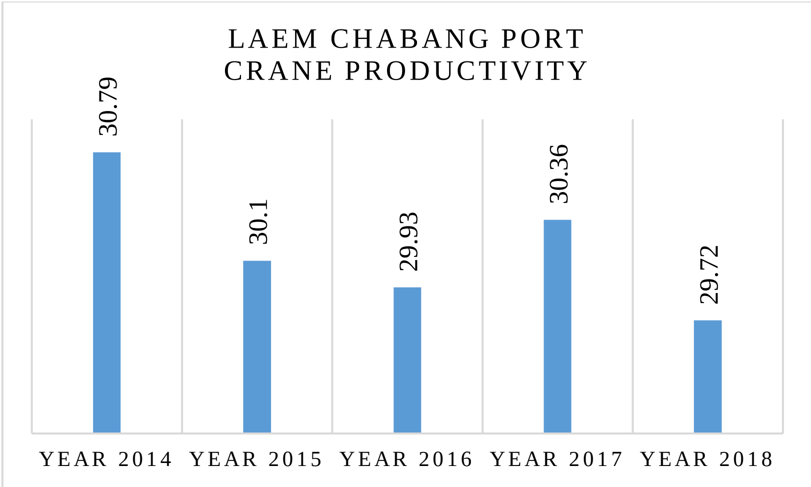


Figure 6-1: Laem Chabang port crane productivity

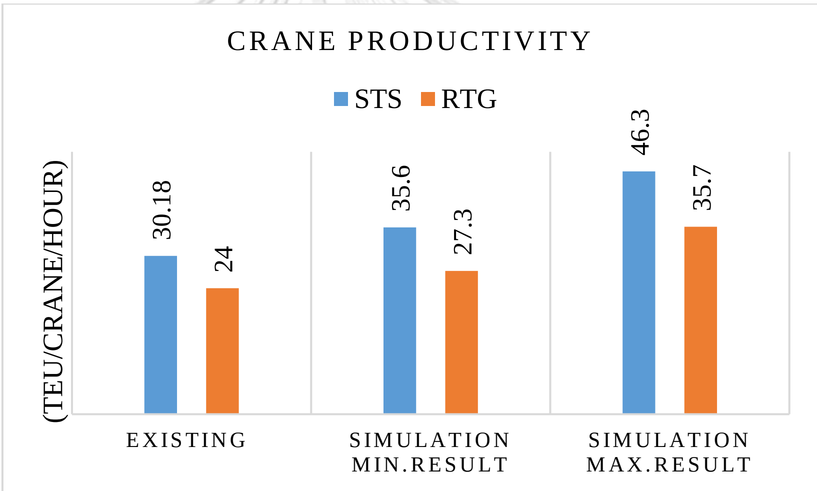


Figure 6-2: Comparison of crane productivity

The quay crane productivity of existing system is around 30.18 TEU per hour while crane productivity from automation system in simulation is 35.6 and 46.3 TEU per hour in minimum and maximum respectively there is at least 18% increasing. Besides, The yard crane productivity is around 24 TEU per hour while crane productivity from automation system is 27.3 and 35.7 TEU per hour and it is at least 14% increasing as shown in Figure 6-1. The data above indicates the automation system can improve the productivity although the current situation will let the result in the small percentage.

2) Container per meter of quay

Container port throughput per meter of the quay in terminal C1 and C2 decreasing due to the affect from the terminal expansion in D1 – D3. There is 853 TEU/meter while the container throughput of the automation system in simulation is 1228.6 in average. Figure 6-3 shows the comparison of throughput per berth meter.

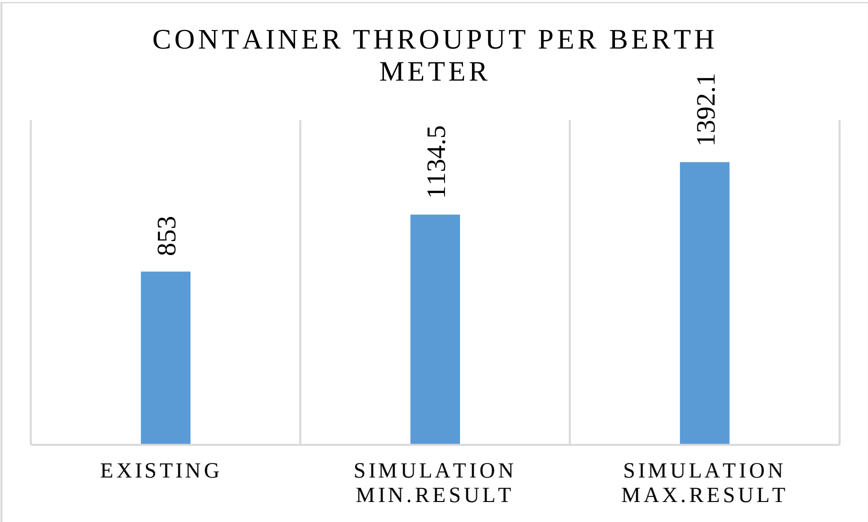


Figure 6-3: Comparison of container throughput per berth meter

As indicated by the simulation model, the automated system's performance fails to meet service requirements on berth productivity. The additional stacks/yard crane improve waterside productivity as more cranes can be assigned to handle the container transferred by the transporter AGVs. However, the more significant number cannot perform to meet the expectation yard crane utilization, the result can be discuss that they are improving overall terminal performance. During peaks in service demand on the landside of the terminal, waterside handling capacity decreases. From the simulation result, the maximum productivity is scenario 8 as STS 4 cranes, RTG 5 cranes and AGVs 80 cars, and the optimal number of machines which suitability for the port terminal's current situation is scenario 6 as STS 4 cranes, RTG 3 cranes and AGVs 80 cars.

Furthermore, it is recommended that operations will with better 4 STS gantry cranes. The simulation study has brought to light that with four cranes berth productivity, two cranes are not enough and not reduce the time significantly then a third and a fourth crane may require if at most 10 AGVs are assigned per crane. For the yard crane if assigned 5 cranes in each slot, the container rate and idle time are higher than those assigned 3 cranes. However, the RTGs reflected the low utilization due to the queue demand on the RTGs service for stacking containers in the container yard and loading and unloading to AGVs. The transporter AGVs travels around the terminal to support both of the landside and waterside machine operations without errors, breakdown, and less idle time.

The result is suggesting that the current system has the capacity it needs to be able to function internally as it is today, with a replacement of an automation handling machine at the facility and different stuffing terminals. Nevertheless, as a result show, the replacement of all of the handling machine might have some more significant issues, like it is not appropriate enough, the result did not meet the expectation. As mentioned before, simulation models are usually random variables to simulate arrivals. This can have an impact on the system. For example, the number of RTGs its utilization depends on the density of inbound containers, the next study might be considered about this, then after this change, the logistic flow seems better and does not affect the internal process. Overall, the waiting time was slightly reduced. But the study still needs to make some changes to make the process run more smoothly and step forward to being the same as in-detailed of the real system operated. This can also have some future implications of environmental sustainability, increase more container and go along with terminal policy, and the market trend.

6.2 Conclusion and future study

This thesis offers a simulation model for the methodical study of container terminal operations at the Laem Chabang container port (C1&C2 terminal) in Thailand. It is a predictive tool, capable of isolating and exploring the contributions of the individual and shared components within the port authority. The simulation model is designed with high engineering maintainability that allows interested people to easily modify, upgrade, and extend the future development port model. The developed model can potentially serve as a good supporting tool in decision-making on container terminal port management.

This study is concerned with designing a generic discrete event simulation to model the flow of entities in automation handling machines but the standard port in the world. The port's process starts by the arrival of ship refer to ship schedule, all handling machine in the terminal. Many assumptions have been assuming in this study also some situation has not taken into consideration. This study's main purpose was to study if the existing handling machine replaces by automation like worldwide. The complex operations involved as well as the utilization of resources.

This studied has analyzed the performance of handling machine of container operation if automated applied in system, the result shows that the automation system improves productivity in terms of time factor at least 27% from overall. From the simulation result, the examination on productivity between the current system and automation system found that the machine productivity has increased at least 18%, throughput per berth length has increased at least 33%, and ship turnaround time has decreased least 48%. Also found that the STS and AGV have high efficiency when cooperation, the number of AGVs assigned to each quay crane must be sufficient. The result also found the optimal fleet to serve quay crane should be 12 AGVs per quay crane.

As the given combination of handling machine, the different number in each scenario has a different result. The simulation result found that scenario 8 is the best, perform the highest result in each index. Furthermore, also found the result of scenario 6 is not much different from scenario 8, the different number of RTGs is not impacted to the productivity in the current situation. As a result of scenario 6, if considered about the cost investment number of machines in scenario 6 is more appropriate than scenario 8. The study result recommends the number of automation handling machines which is using 4 quay cranes/berth, 3 RTGs in each slot and 80 AGVs. This combination will increase the terminal productivity. The study of automation application can be confirming the increasing of performance productivity if the system will be replaced in brownfield. This can encourage and ensure the private sector who operation the container terminal to make a decision on automation system investment. The automation system concludes that it can be applied in greenfield or new construction easier than the existing terminal, but it is also possible to partially or wholly apply as automated to achieve the benefits of automation.

Furthermore, the output of the simulation is studied. This study is just the initial work for a larger scope in which the influence of other port functions such as economic cost, human labor impact, and another situation to consider will be studied and simulated furthermore. First of all, studying and simulating the berth with quay crane assignment and scheduling is the possibility. The approximation that quay cranes are always available for any berthing position can be modeled and analyzed to find the most suitable number of cranes to assign to the ship according to the incoming ship's schedule. Thus, all the terminal activities can be simulated with all handling machine processes to find the best combination of the machine, enhancing cooperation to improve and maximize the efficiency and productivity of ports. The following step stands in optimizing the best simulation scenario, finding the optimal case that can cut down costs and improve the current situation or after this study, keeping in mind that it is necessary to increase benefits and productivity. As far as the speed to assignment is concerned, due to all machines being replaced in this study, it is possible to modify the current simulation and find a better scenario that can allow a more precise and accurate assessment of the right speed assign ship.

World trade has shown a stable increase over the previous years and this trend continues. With a growing container throughput, increasing container terminal performance is a critical issue for the container terminals. Simultaneously, high operation costs should take into account and container terminals also high capitalization of ships, containers and port equipment demand a reduction of unproductive times at port. Therefore, the potential for handling machines and the importance of performance analysis tools is becoming more acute with increasing contain flows.

In the future study, required data is to be collected and statistically analyzed to provide input distributions for arrival and service times as well as parameters for the different stations and scenarios. Further detailed modeling will also include market trends and train transportation and another container or variable. Also, focus on the port's internal policies and processes to make it more comprehensive and accurate. Furthermore, output analysis will be conducted on the results and sensitivity analysis will be used to determine each parameter's impact on the overall container flow and statistical testing.

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