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A COMPUTER SIMULATION MODEL TO DETERMINE THE PRODUCTIVITY OF AN INVESTMENT ON A CONTAINER TERMINAL.

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by
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To the sailors who lost their lives at sea and the Heros who saved the sailors lives at Sea ….

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ABSTRACT

A Computer Simulation Model to Determine The Productivity of an Investment on a Container Terminal

Because of the dynamic nature of the maritime transportation environment, a large number of timely decisions have to be continuously reviewed in accordance with the changing conditions of the container terminal system. The development of a terminal to its optimum capacity with minimum infrastructure investment basically depends on the efficient loading and unloading of ships, trains and trucks using the terminal equipment's and the rapid movement of containers in and out of the terminal area.

In this thesis, it has been presented an approach that combines the advantages of simulation models and Data Envelopment Analysis optimization method in order to reach an optimum investment decision for the enhancement of a container terminal. For this purpose it was decided to approach the problem by a discrete event simulation model, in order to reproduce the activities carried out inside a container terminal, to estimate the monthly container throughput and average ship turnaround time for different investment scenarios. To be able to evaluate the optimum investment decision for the target container terminal, total of 16 simulation scenario were employed. For each scenario, different sets of terminal equipment were assigned to simulation model as input. These parameters are length of quay, number of quay cranes, yard trucks and yard cranes. The objective is, on the one side, to minimize average ship turnaround time and on the other side, to maximize container throughput generated by the terminal.

As a follow on step, Data Envelopment Analyses method is utilized as a tool to evaluate the relative efficiencies of these outputs gathered from container simulation scenarios. At the end, cost efficiency analysis is conducted to be able to decide best investment package for the enlargement of the target container terminal with minimum cost.

ÖZET

KONTEYNER TERMİNALİNE YAPILACAK OPTİMUM YATIRIMIN SEÇİMİNDE BİLGİSAYAR SİMÜLASYON MODELLEMESİNİN KULLANIMI

Limanlar, ulaştırma ve global ticari faaliyetlerde önemli rol oynamaktadırlar. Milyonlarca ton ticari mal küresel ekonominin işleyişi içinde limanlarda işlem görmektedirler. Limanların verimli ve etkin çalışmasının sağlanması ile altyapı yeteneklerinin geliştirilmesinde optimum yatırım seçeneklerinin seçimi maksadıyla, matematiksel yöntemlerin kullanımı gerekli olmaktadır.

Bu tezde; konteyner terminali altyapısının geliştirilmesi için en etkin yatırım alternatifi seçiminde, benzetim modellerinin ve Veri Zarflama Analizi optimizasyon yönteminin avantajlarını birleştiren bir yaklaşım kullanılmıştır. Bu amaçla, bir intermodal konteyner terminalinde yürütülen faaliyetlerin bezetimini yapan ayrık benzetim modeli kullanılarak, limanda aylık olarak elleçlenen toplam konteyner sayısının ve ortalama gemi servis süresinin farklı yatırım senaryoları için tahmin edilmesi yaklaşımı esas alınmıştır. Hedef olarak seçilen konteyner terminali için optimum yatırım kararının belirlenmesinde, 16 değişik benzetim senaryosu ve her bir senaryo için de terminal ekipmanlarının farklı bileşenleri modelde girdi olarak kullanılmıştır. Söz konusu ekipman parametreleri; rıhtım uzunluğu, rıhtımdaki vinç sayısı, konteyner taşıyan çekici/kamyon sayısı ve konteyner depolama alanında kullanılan vinç sayısıdır. Optimizasyonun amacı; gemilerin limanda kaldığı ortalama toplam süreyi en aza indirmek ve aynı zamanda elleçlenen konteyner miktarını azami sayıya çıkartmaktır.

Takip eden aşamada, konteyner benzetim senaryoları çıktılarının birbirlerine göre etkinliklerinin değerlendirilmesi için Veri Zarflama Analizi yöntemi kullanılmıştır. Tezin son bölümünde, Veri Zarflama Analizi sonuçlarını ve altyapı yatırım maliyetlerini girdi olarak kabul eden maliyet etkinlik analizi neticesinde, temel konteyner terminalinin geliştirilmesi için gerekli olan minimum maliyetli optimum yatırım paketi karar teklifi oluşturulmuştur .

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LIST OF ACRONYMS /ABBREVIATIONS

AAT	Time Required to Sail from Entrance (Arrival) to Anchoring Area
ABT	Time Required to Sail from Entrance to Berh
APT	Time Required to Sail from Anchoring Area to Berth
BBC	Banker, Charnes and Cooper DEA Model
BOT	Time Between Berthing and Commance of Operation
CCR	Charnes, Cooper, and Rhodes DEA Model
CT	Container Terminal
CY	Container Yard
DEA	Data Envelopment Analysis
DMU	Decision Making Unit
DRS	Decreasing Returns to Scale DEA Model
DWT	Deadweight Tonnage
GDP	Gross Domestic Product
IAT	Interarrival Time between Consequently Arriving Vessels
IMO	International Maritime Organisation
IRS	Increasing Returns to Scale DEA Model
LPC	Lift per Ship Call
MHC	Mobile Harbor Crane
ODT	Operation to Departure Time (ODT)
OPT	Time between Finish of Operation and Departure of Vessel
QC	Quay Crane
SBL	Ship-Berth Link
SM	Simulation Model
STS	Ship to Shore Gantry Crane
UNCTAD	United Nations Conference on Trade and Development
TEU	Twenty- Foot Equvalant Unit
TOT	Total Time in Port (From Entrance to Departure)
WAT	Waiting Time at Anchoring Area
VRS	Variable Returns to Scale DEA Model
YT	Yard Trucks
YC	Yard Cranes

1. INTRODUCTION

The shipping industry is one of the oldest industries and still plays an important role in the modern society. Approximetly 90 percent of all the world's cargo, transported by the international shipping industry(Lewis, 2013). The fleet is represented in over 150 countries, crewed with over 1.5 million sailors working around the world. The different types of cargo being transported are goods for consumers, food, raw material, cars and fuel, just to name a few (Grib, 2016). Figure 1.1 highlights the relationship between economic growth and industrial activity, industrial production index, merchandise trade and seaborne shipments. (UNCTAD, Review of Maritime Transport, 2015).

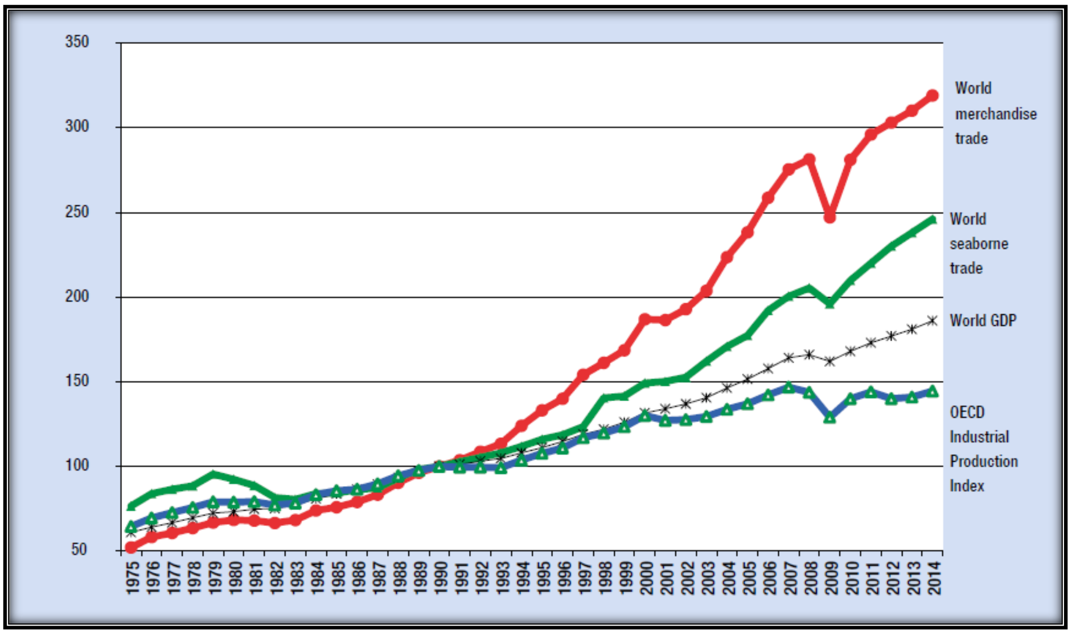


Figure 1.1. Indices for World GDP, Merchandise Trade and Seaborne Trade (1975-2014) (Source, UNCTAD, Reviev of Maritime Transport, 2015, Pg. 5).

The use of container systems in commercial maritime transportation, which is a standard box of length 20 or 40 ft, width 8 ft and height 8 ft 6 in., has drastically improved the efficiency of the global shipping industry, and will continue to provide a foundation for an efficient method of transport for future. Importing and exporting of goods necessary for the international community will not be possible without shipping containers. This makes them a vital part of the world economy. Without container shipping services, the world will not be as prosperous as it is today, and many countries will not be able to participate in world trade. In a globalizing economy, the container offers the advantage of freight movement in all modes of transport. Shipping containers are the first way to transport all goods worldwide, whether by air, land or sea; It is a necessary part of all trading operations (Lewis, 2013). With the recent enlargement of the Panama Canal and the predicted global economic outburst, there is still a worldwide requirement for maritime transport investments to meet the growing demand of the maritime industry and ongoing international growth (Lewis, 2013). Global container trade increased by 5.3 percent in 2014 and is expected to reach 171 million TEUs as seen in Figure 1.2 (UNCTAD, Review of Maritime Transport, 2015).

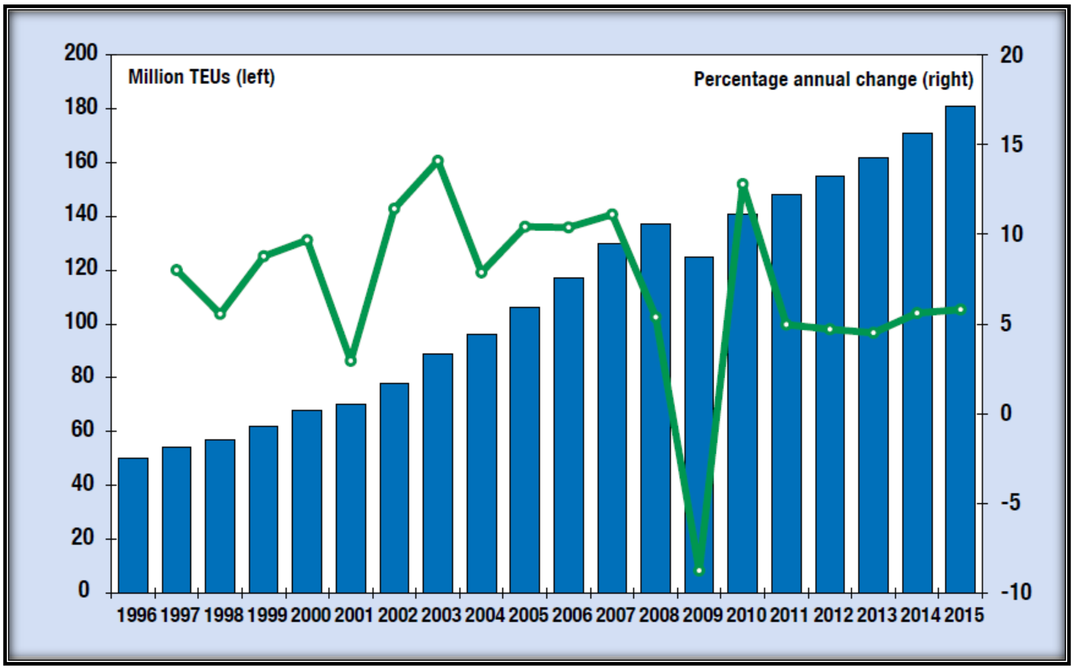


Figure 1.2. Global Containerized Trade, 1996–2015 (Million TEUs and % annual change) (Source, UNCTAD, Reviev of Maritime Transport, 2015, Pg. 19).

Within this context, container port owners may decide to make infrastructure investments to extend the capacity of terminals to be able to get more share from growing markets. The capital cost of such investments may require prior mathematical analyses to be made to select the most financially optimal one among the possible alternatives.

Simulation modeling and financial optimization techniques have been used extensively in container terminal (CT) planning processes including financial optimization of the investments on CTs. These models have become extremely valuable as decision support tools during the planning and modeling of CT operations as well as investment planning (Park at al, 2009) The simulation model in this thesis is expected to be useful for assessment of the effects of prospective new equipment on the performance of container terminals and, thereby, for decision-making on the implementation of such equipment investment plans (Carson and Maria, 1997).

Simulation of the logistics activities related to the arrival, loading/unloading and departure processes of ship-berth link (SBL) can be carried out for different purposes such as design of container yard (CY), increase productivity and efficiency of terminal equipment such as quay cranes (QCs), yard trucks (YTs), and yard cranes (YCs), analysis and planning of CT transfer operations from the quay to the CY (Park at al., 2009).

These logistics activities are particularly complex and very costly since they require the combined use of expensive infrastructure capacities especially berths and CY. CT operations are required to serve containers as quickly as possible. Thus, in order to successfully design and develop CY operations and utilize it as efficiently as possible, it is necessary to develop simulation models (SMs) that will support financial decision making processes of CT managers. The recommendations given in this thesis are intended to offer the best alternative investment option for CT enlargement project (Park et al., 2009).

1.1. Container Terminals

Container terminals generally have several berths, each served by one or more large cranes capable of lifting 40 tons. In an adjacent storage area the containers are stored to await collection. To carry the weight of the container crane it is generally necessary to strengthen the quay to support the container cranes. Several types of container terminal have been developed to meet differing requirements. One system is to lift the container off the ship on to a trailer chassis, which is then moved to a storage park to await collection. This has the advantage that the container is handled only once and it interfaces efficiently with the road haulage system. Its main drawback is that it uses a large amount of land and there is a significant investment in trailers. Where land is at a premium, containers could be stacked up to five high, using a system of gantry cranes which may also be used on the quayside, but the disadvantages of this system are the difficulty of obtaining random access to containers in the stack and the cost of multiple handling of individual units. The compromise is to stack containers two or three high, using ‘straddle carriers’, large fork-lift trucks or low loaders to move them from the quayside to the stack and retrieve them when required. In small ports an area of the quayside is often allocated for container storage(Stopford, 2009).

In the advanced industrial areas of Europe, North America and the Far East, containerization has channeled trade through a small number of ports that have invested in high-productivity container terminals of the type outlined above. In the developing countries the problem is more complex, since the inland infrastructure is often not sufficiently developed to handle a sophisticated container network(Stopford, 2009). In general, cargo is not exclusively containerized. In such cases, even small ports need to be equipped to handle containers. This generally involves developing an existing berth for container handling, undertaking any necessary strengthening of the quay, the purchase of a suitable crane, often a mobile unit, and straddle carriers or fork-lift trucks and the provision of a container-packing service for break-bulk cargo not delivered to the port in a container. The containers are then stacked in a suitable location (Stopford, 2009).

In this context, a container terminal (CT), as depicted in Figure 1.3, is a complex system with various interrelated components. There are many complicated decisions that operators or planners have to make.

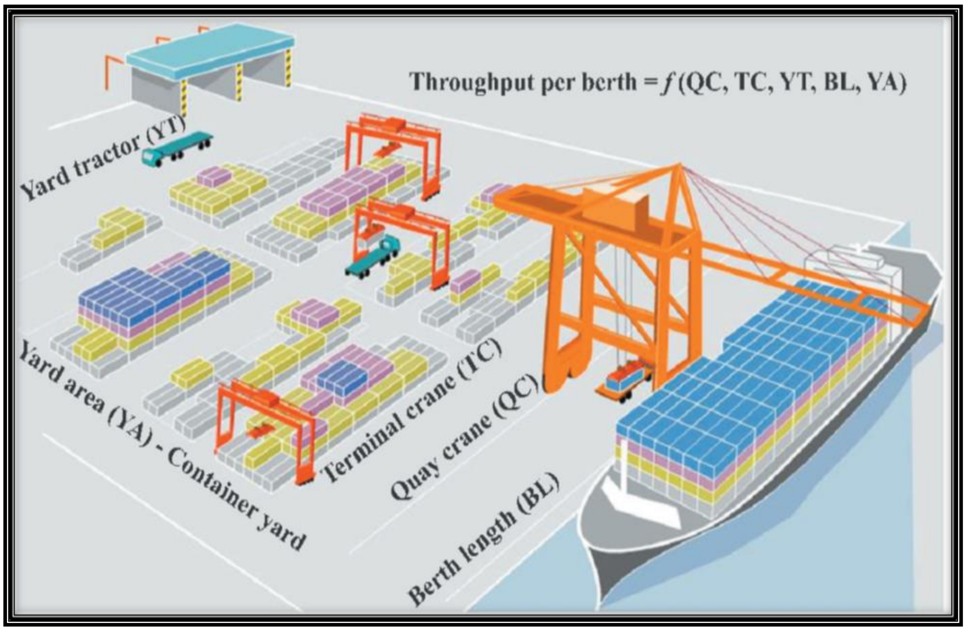


Figure 1.3. Container Terminal Operations (Source, Park at al, 2009).

The handling operations in CTs include three main types of operations:

- Container vessel operations related with SBL,
- Container handling and storage operations in a CY
- Receiving/delivery operations for external trucks, (Park at al, 2009).

Ships unload containers from ship to a YT with QC. The YT then delivers the inbound container to a YC which may be a rubber tired gantry crane (RTGC) or rail mounted gantry crane (RMGC). The YC picks it off the YT which moves back to the QC to receive the next unloaded container. For the loading operation, the process is carried out in the opposite direction. This is indirect transfer systems where a YT delivers a container between the apron and the CY. RTGCs or RMGCs transfer containers between YTs and yard stacks in the CY (Park at al., 2009).

Simulation Model(SM) and analysis with ARENA have been developed to CT performance evaluation of MARPORT CT in İstanbul. This model also addresses issues such as the Key Performance Criteria (KPI) and the model parameters to propose an operational method that reduces average time that ship spends in port and increases the CT throughput (Park at al, 2009).

1.2. Phases of the Thesis

The thesis is organized as follows; the first Phase of the thesis provides introduction, background, literature overview and methodology which presents a brief description of CT modeling procedure and evaluation of SMs. The second Phase includes definition of container port operations, data collection and analysis of MARPORT data, port infrastructure investment alternatives and ARENA simulation model. Phase 3 outlines the Data Envelopment Analysis (DEA) methodology and includes the application of DEA method which is designed to evaluate the relative efficiency scores of the output of 16 simulation scenarios. In this Phase, the cost and performance analysis is also explained as decision support tool to decide the optimum investment package for CT. And finally, conclusions and recommendations including further study proposals are presented in the last Phase. The flowchart of the Phases is displayed in Figure 1.4.

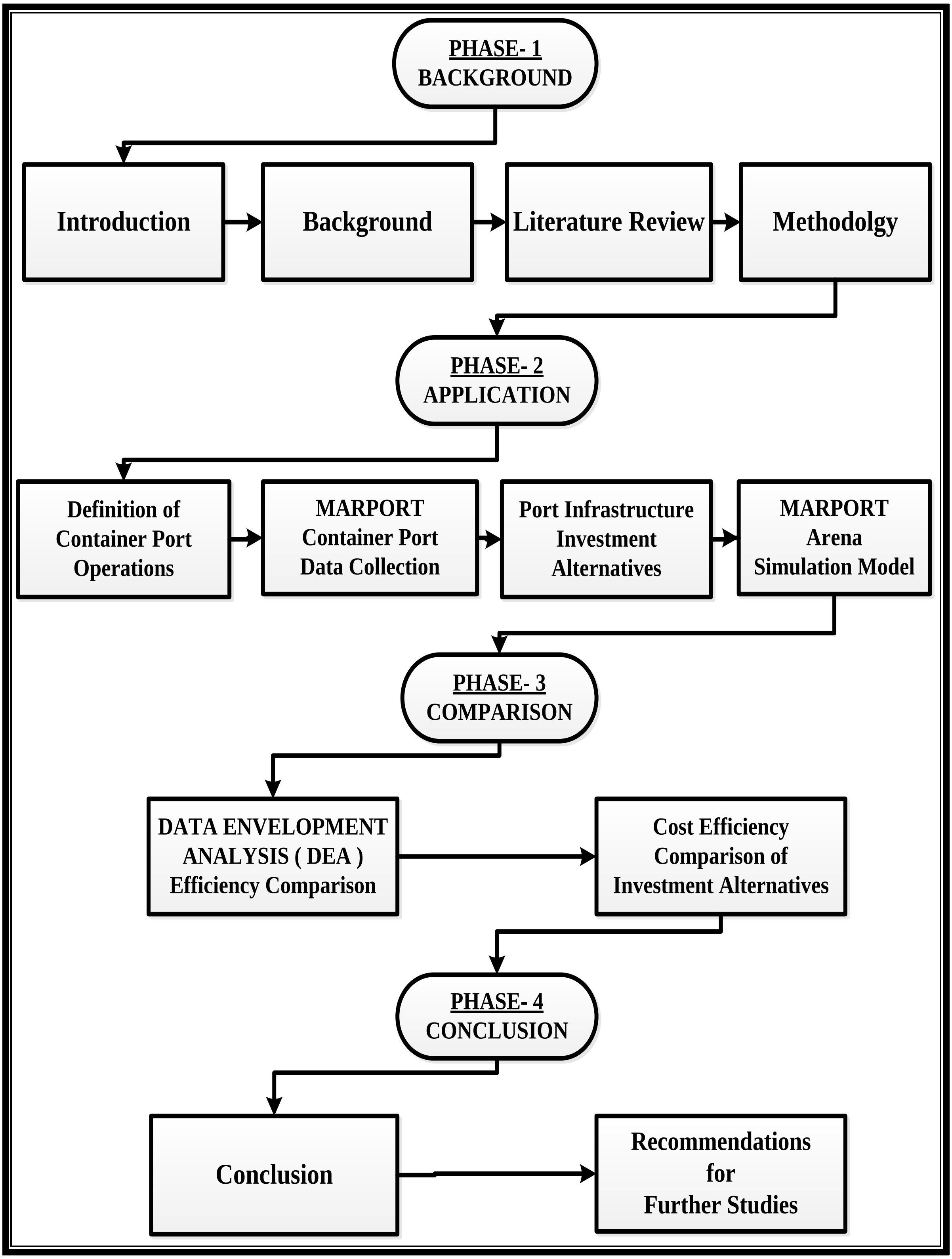


Figure 1.4. Flowchart of the Phases.

2. LITERATURE REVIEW

2.1. Simulation Modeling Studies

SMs have been used extensively in the modeling, planning and analysis of CTs. Many different SMs regarding port operation, especially CTs modeling, have been developed in journal papers (e.g. Borgman et al. (2010), Bruzzone and Signorile (1998), Ding (2010), and so on). These models are coded in different simulation languages that have been used including PORTSIM, Modsim II and III, PCModel, SIMPACK, SIMAN, SIMLIB, SIMPLE++, SLX, SLAM and Visual SLAM, ARENA, AweSim, Witness software, Taylor II, GPSS/H, TermSim, Extend-version 3.2.2, HARAP, MUST, Anylogic, Matlab, FORTRAN, Pascal, Visual BASIC, C, C++, Java etc. Therefore it is attempted to collect all the papers which include ARENA softer (Bruzzone and Signorile (1998), Guldogan (2010), Khatiashvili et al (2006), Kozan (2006), Legato et al. (2009) (Park at al, 2009).

Computer algorithms are described in most of the papers to give examples how the SMs are built from sequence of operational procedures which have been conducted to the determination of the CT performance in different environment within various points of view and in heterogeneous cases(Park at al, 2009).

More recently, excellent investigations of simulation modeling on CT operations have been done by Petering (2010 and 2011) where we have identified new research trends and significant increase of the knowledge using discrete-event SMs. It should also be pointed out, that there are a few concepts of integrating simulation and optimization to modeling CT operations in ports given by Bruzzone and Signorile (1998), Legato et al. (2009 and 2010), Sacone and Siri (2009), Zeng and Yang (2009), Longo and Mirabelli (2008) and Longo (2010). Efficient simulation-based optimizations for CT operations have been done by these authors. Simulation optimization models consider the stochastic factor in CT and can tackle the practical assigning and scheduling problem efficiently(Park at al, 2009).

Bruzzone and Signorile (1998) developed a collection of simulation tools and used genetic algorithms to make strategic decisions and scheduling for resource allocation and CT organization. Key issues of the application of modeling and simulation for the management of the Malaysian Kelang CT are discussed in paper by Tahar and Hussain (2000). Merkuryeva et al. (2000) considered simulation of containers processed at the Baltic CT in Riga as a basic simulation research. Vis and van Anholt (2010) studied the effect of different types of berth configurations on vessel operation times at container terminals and also created SMs for each type of berth in which all relevant logistics processes required for unloading and loading a vessel have been implemented. Guldogen (2010) investigated the effect of different storage policies on the overall performance of a CT(Park at al, 2009).

A simulation optimization method for scheduling loading operations in container terminals is developed by Zeng. The method integrates the intelligent decision mechanism of optimization algorithm and evaluation function of simulation model, its procedures are: initializing container sequence according to certain dispatching rule, then improving the sequence through genetic algorithm, using simulation model to evaluate objective function of a given scheduling scheme (Zeng and Yang, 2008).

Soner, in his study for optimization of logistics processes at container terminals used ARENA software package. The purpose of his research is to develop a logistical oriented decision supporting models as a decision support instrument for port managements aims to contribute to such basic topics as comprehending analyzing and evaluating the logistical structure of ports as well as port performance indicator, planning port capacity, increasing port efficiency, developing internal port logistical processes and predicting the needs of the port in the future (Soner, 2009).

2.2. Data Envelopment Analysis (DEA) Studies

Second mathematical model used in the thesis is Data Envelopment Analysis (DEA)which is a relatively new “data oriented” approach for evaluating the performance of a set of similar entities called Decision Making Units (DMUs) which convert multiple inputs into multiple outputs. The definition of a DMU is generic and flexible. There have been a great variety of applications of DEA for use in evaluating the performances of many different kinds of entities engaged in many different activities in many different contexts in many different countries. The concept "Data Envelopment Analysis" was introduced in the journal literature by the highly influential 1978 paper of Charnes, Cooper, and Rhodes.

Data Envelopment Analysis applications have used DMUs of various forms to evaluate the relative performance of entities, such as ports, hospitals, military units, universities, cities, courts, business firms and others. Because it requires very few assumptions, DEA has also opened up possibilities for use in cases which have been resistant to other approaches because of the complex (often unknown) nature of the relations between the multiple inputs and multiple outputs involved in DMUs (Cooper at al, 2003).

While there is extensive literature on bench marking applied to a diverse range of economic fields, the scarcity of studies regarding the Infrastructure investment alternatives for container ports bears testimony to the fact that this is a relatively under-researched topic. Therefore, the DEA articles related to sea or air ports and transportation have been focused on during literature survey.

The efficiency of 22 seaports in the Middle East and East African region were Evaluated in an article titled " *Efficiency of Middle Eastern and East African Seaports: Application of DEA Using Window Analysis"* . Two separate analyses were performed based on data collected for 6 years (2000–2005), Standard Data Envelopment Analysis method was used in the first analysis and DEA window analysis was used in second analysis. By using both methods, better insight into the efficiency situation at hand is gathered; the advantages and disadvantages of the methods are highlighted (Al- Eraqi at al, 2008).

Ateş and Esmer, in their study titled " *Calculation of Container Ports Efficiency in Turkey with Different Methods*" used Data Envelopment Analysis and Free Disposable Hull methodologies to determine the efficiency of container ports of Turkey, which has a developing economy for the 2012 period. The super efficiency method has been also used in this study to determine the efficiency levels of Turkish container ports (Ateş and Esmer, 2004).

In a similar study named "*Relative Efficiency Analysıs Of Black Sea Container Terminals*", the year performance, 2011 of nine container terminals (Novorossiysk, Odessa, Varna, Burgas, Batumi, Poti, Ilyichevsk, Constanta and Trabzon) belonging to a total of six countries with coastlines to the Black Sea, which is the largest inland sea, as five countries from the TRACECA (Transport Corridor Europe-Caucasus-Asia) program (Turkey, Georgia, Ukraine, Bulgaria and Romania) and Russia out of the program, have been determined through the application of data envelopment analysis (DEA), as a non-parametric method. According to the results of the study, it has been determined that the Poti and Novorossiysk container terminals have been the efficient terminals. On the other hand, Burgas container terminal has been found out to be the terminal with the lowest performances (Ateş at al, 2013).

Ateş and Esmer wrote another article about the effects of 2009 global economic crisis on Turkish container terminals. In this study, efficiency changes are analyzed for 13 Turkish container terminals by the period of before and after the global financial crisis in 2009. Relative efficiency values were calculated using Data Envelopment Analysis method. On the other hand, changes in efficiency value on the period were calculated by Malmquist Total Factor Productivity (TFP) index. According to results of the analysis, output-oriented DEA CCR included 13 terminals; Port of Izmir was the only port which was effective in during three years. Average efficiency values were 59,26 % for 2008, 52,68 % for 2009 and 65,05 % for 2010. Based on the total factor productivity index, the Turkish container terminals decreased 4.1 % averagely in 2008-2009, and 33.1% increase during the 2009-2010 periods (Ateş and Esmer, 2013).

In the article titled "*Measuring the economic efficiency of airports: A Simar–Wilson methodology analysis* ", DEA is used to estimate the efficiency determinants of Italian airports. The airports' relative technical efficiency is estimated with data envelopment analysis (DEA) to establish the airports that perform most efficiently. These airports could serve as peers to help improve performance of the least efficient airports. The paper ranks these airports according to their total productivity for the period 2001–2003 (Barros and Dieke, 2008).

George Kobina van Dyck made a resarch on Port Efficiency in West Africa Using Data Envelopment Analysis. The aim of his paper was to apply the DEA method in assessing efficiencies of major ports in West Africa. Six ports were selected based on their container throughput levels, and the DEA model was used to determine their relative efficiencies and their efficiencies over time through window analysis. The DEA model was applied to a number of inputs of port production and a single output (container throughput). It was determined that the Port of Tema in Ghana was the most efficient West African port under study. Although Tema exhibited some inefficiency in its operations, the port was found to make good use of its resources for production. On the other extreme, the Port of Cotonou in Benin was found to be the least efficient port obtaining the lowest average efficiency rating over a seven year period. It was determined that the port exhibited a substantial waste in production. Generally, ports in West Africa could be said to exhibit high levels of efficiency considering that four out of six ports had an average efficiency score of 76% or higher for the period under study (Van Dyck, 2015).

Güner and Coşkun, in their research named "*Efficiency Measurement of Passenger Ports with Data Envelopment Analysis and Utilizing Malmquist Productivity Index*", measure the efficiencies of four participating passenger ports comparatively and to evaluate the changes occurred in their efficiencies during the period of eight years from 2003 to 2010. To measure the time dependent efficiency levels of each port, Data Envelopment Analysis based Malmquist Productivity Index has been utilized in this research. By utilizing the Malmquist Productivity Index;

- Efficiency scores for each port for every year,
- Average efficiency scores for each year for all the ports, and
- Average efficiency scores for each port over the time period had been measured. The results show that average efficiency scores by years did not follow a stable trend and fluctuated (Güner and Coşkun, 2013).

Bazargan and Vasigh (2003) prepared a paper which presents a productivity analysis using data envelopment analysis (DEA) of 45 US commercial airports selected from the top 15 large, medium, and small hub airports. Financial and operational data, such as aircraft movements, number of airport gates, the annual number of enplaned passengers and runway capacity, is used. Initially, a DEA is deployed to analyze the efficiency and performance measures of airports within each group by comparing and cross-referencing them with each other. Then the analysis is extended to identify those airports that are not efficient and are thus dominated by other airports that are more efficient.

Data Envelopment Analysis has also been used as a tool for measuring and evaluating the operational efficiency of US Air Force organizations. This study involves the application of DEA to locate possible inefficiencies in the performance of US Air Force real-property maintenance activities. The testing was done in close coordination with Air Force officials, who reviewed the results for accuracy, validity and relevance. It is concluded that this type of efficiency analysis does have value for the Air Force, where it can serve as a guide to auditors, budget programmers, managers and others in measuring, evaluating and enhancing operational efficiency (Bowlin, 1987).

As a result of Literature Review, It has been observed that there have been several research on optimization of container terminal operations. On the other hand, this thesis which has three submodels, simulation, data envelopment analyses and cost efficiency analyses, is evaluated as an unique one with regard to assessment of container terminal infrastructure investment alternatives.

3. METHODOLOGY

3.1. Aim of the Thesis

The aim of this thesis is to establish a mathematical model as a decision support tool to find the optimum investment package for the enlargement of a container terminal. The objective of the model is, on the one side, to minimize average ship turnaround time and, on the other side, to maximize monthly container throughput generated by the terminal by an investment on terminal equipment with minimum financial expenditure

As depicted in Figure 3.1, the mathematical model consists of three sub-models; Discrete Event Simulation Model, Data Envelopment Analysis and Cost Efficiency Analysis.

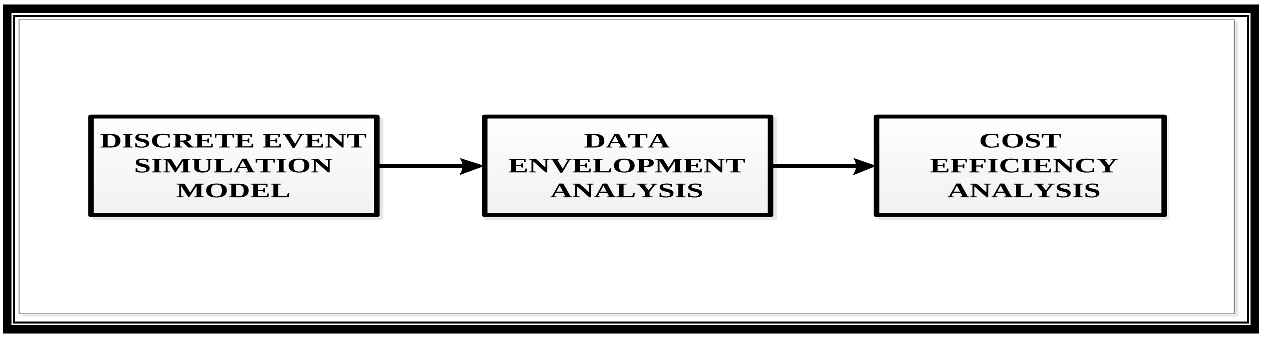


Figure 3.1. Mathematical Model and Its Sub-Models.

3.2. The Main Structure of the Thesis

In this thesis, a methodology has been employed to combine the advantages of simulation models and Data Envelopment Analysis optimization method in order to reach an optimum investment decision for the capability enhancement of a container terminal as indicated in Figure 3.2. For this purpose, it was decided to approach the problem by a discrete event simulation model, in order to reproduce the activities carried out inside a container terminal, to estimate the monthly container throughput and average ship turnaround time for different investment scenarios.

To be able to evaluate the optimum investment decision for the target container terminal, MARPOT; total of 16 simulation scenarios were employed. For each scenario, different sets of terminal equipment were assigned to the simulation model as input. These parameters are length of quay, number of quay cranes, yard trucks and yard cranes. The objective is, on the one side, to minimize average ship turnaround time and on the other side, to maximize container throughput generated by the terminal.

Several site surveys in MARPORT/İstanbul and Asia Port/Tekirdag were conducted to get the knowledge of container port operations and the historical data related with container ship movements in the Terminal. The data belonging to the container ships, visiting MARPORT, has been statistically analyzed to obtain distributions of time parameters to be used as input in simulation model. ARENA software package together with input and output analyzers has been deployed to create container port simulation model.

As a follow on step, Data Envelopment Analyses method is utilized as a tool to evaluate the relative efficiencies of these outputs gathered from container simulation scenarios. At the end, cost efficiency analysis is conducted to be able to decide the optimum investment package for the enlargement of the target container terminal with minimum cost.

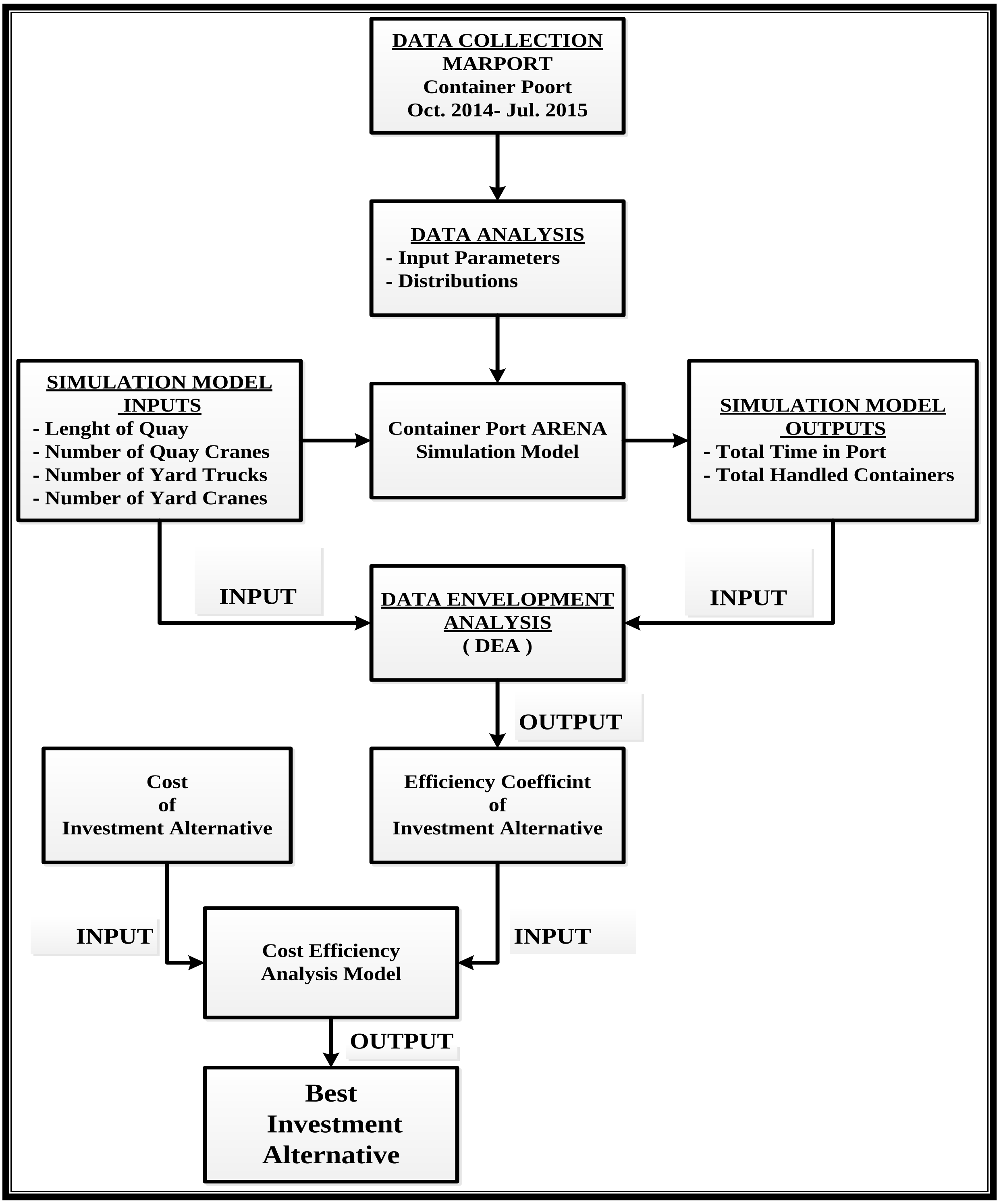


Figure 3.2. Flowchart of Mathematical Models of the Thesis.

3.3. Target Container Terminal MARPORT/ İstanbul

There are 15 major container terminal in Turkey. As it is seen in Figure 3.3., most of these ports are located on cost of Marmara Sea. The ports in or close to İstanbul which is the most developed commercial center in the region are MARPORT, KUMPORT, MARDAŞ, Haydarpaşa, EVYAP, YILPORT, Derince and LİMAŞ.

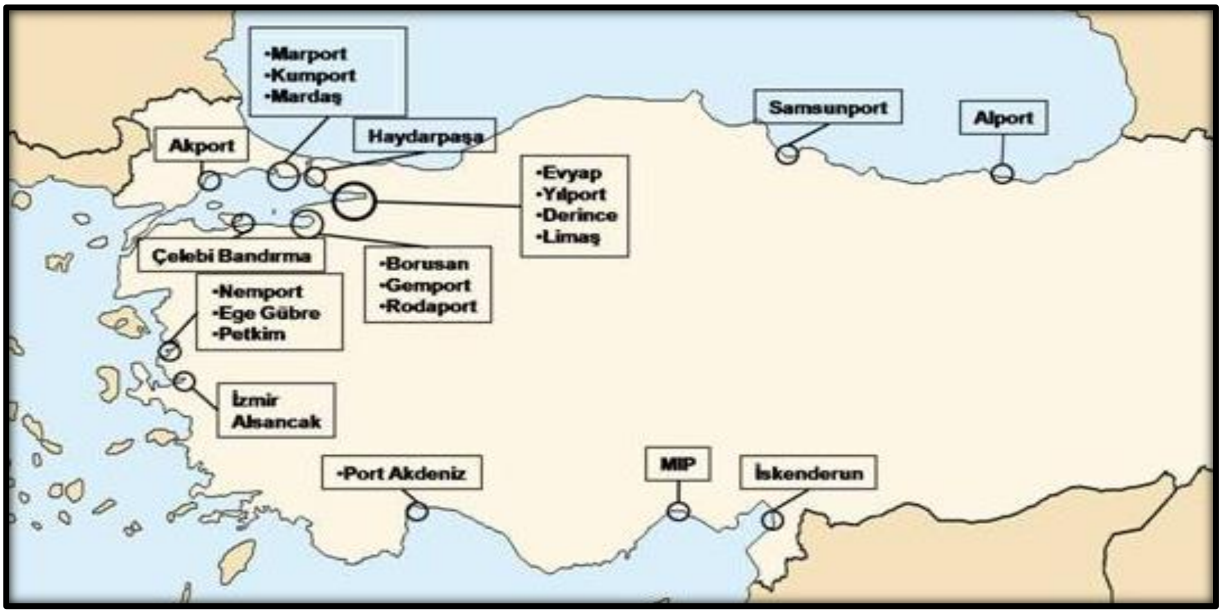


Figure 3.3. Major Container Ports in Turkey.

Main infrustrucre figures such as total length of berths, number of berths, cranes and terminal area are listed in Table 3.1. Among these ports, Mersin Port with 2.425 meters total berth length and 438.350 square meters terminal area is the biggest one. On the other hand, its annual throughput is 1.364.378 TEU, the second biggest figure just after the MARPORT figure 1.685.504 TEU annualy.

YILPORT with fairly limited infrastructure capability was able to handle total of 305.0591 TEU containers in 2013. These kind input and output comparisons for identifying efficiency figures of the ports require the application of several mathematical methods one of which is Data Envelopment Analysis.

Table 3.1. Main Infrastructure Figures of Major Turkish Container Ports (Source, www.ubak.gov.tr, 2014).

Ports	Total Length of Berths	Number of Berths	Number of Cranes	Terminal Area (M^2)	Annually Handled TEU Containers
AKDENiZ KİMYA	840	4	3	100.000	142.585
BORUSAN	450	4	5	110.000	189.099
EGE GÜBRE	705	2	3	240.000	149.429
EVYAP	500	4	4	150.000	454.551
GEMPORT	839	8	6	255.000	331.604
KUMPORT	1.930	5	6	400.000	1.276.313
MARDAŞ	910	7	10	189.308	353.523
MARPORT	1.560	7	15	310.000	1.685.504
MERSIN	2.425	16	10	438.350	1.364.378
PORT AKDENİZ	330	2	3	60.000	136.523
RODA PORT	1.257	6	3	170.000	130.224
YILPORT	325	2	6	202.000	305.0591
HAYDARPAŞA	650	5	5	219.360	158.700
İZMİR	1.050	24	7	500.000	683.430
ALPORT	1.840	7	1	40.000	29.617

3.3.1. Main Factors for Selecting MARPORT

MARPORT was chosen as a target container port for simulation modelling due to following reasons;

As it is seen from Table 3.1, MARPORT has reached the highest annual throughput (1.685.504 TEU) in Turkey with comparatively less infrastructure capabilities. This is the indication of high degree of operational efficiency. Therefore, it will be possible to get the distinct results of investment alternatives.

Due to the fact that it is located on the cross section of important maritime trade routes between the Black Sea and the Mediterranean (Figure 3.4), MARPORT has become a major container port, capable of conducting all sorts of container handling operations.

Despite the fact that, in maritime commercial World, it is normally too difficult to obtain historical data related with container operations and ship movements, management of

MARPORT gave permission to access to the historical data which covers the period between October 2014 and July 2015.

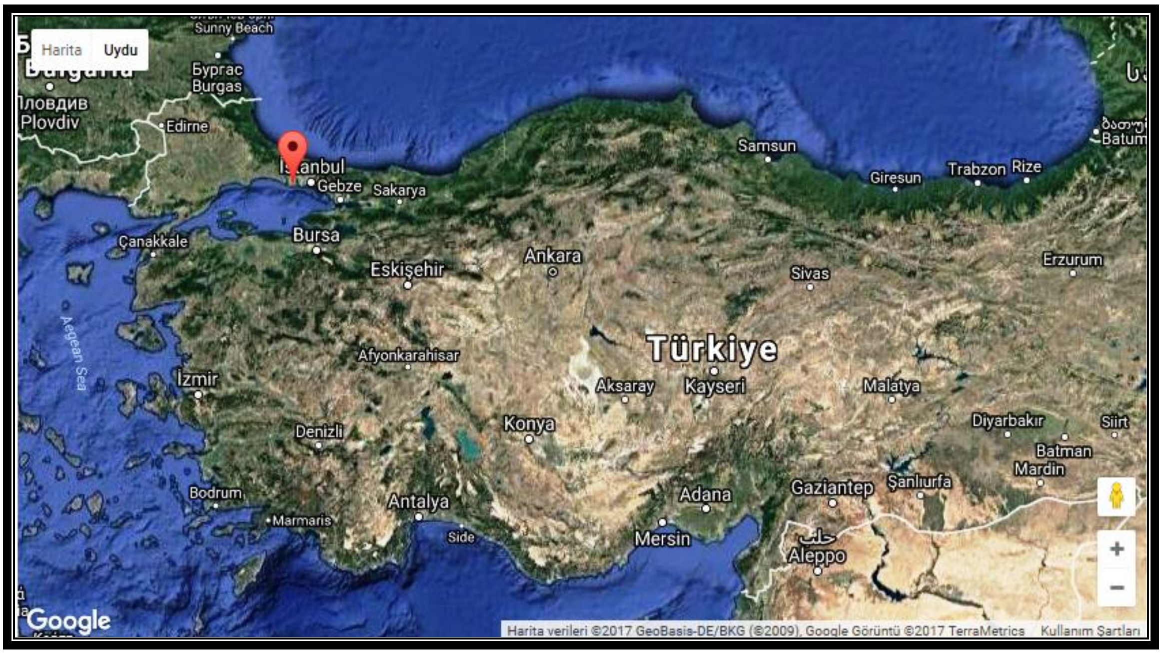


Figure 3.4. Gographical Location of MARPORT Terminal (Source, www.Google.com.tr/maps/, 2017).

MARPORT is located on the European continent side of İstanbul, surrounded with urban areas, which limits the physical enlargement. It has two main terminals, namely Main and West Terminals. General view of MARPORT is displayed in Figure 3.5.

Figure 3.5. General View of MARPORT Terminal (Source, www.marport.com.tr, 2016).

3.3.2. Site Surveys in MARPORT

Two site surveys were conducted on MARPORT container terminal (06 August and 11 September 2015). We interview with General Manager of the port Mr. Gökhan ESİN and Operational Manager Mr. Mesut ŞEN. The data about ship calls in last 10 months as well as current infrastructure such as length and draft of piers is obtained. Before each interview, a questioner was sent to managers in order to focus on main requirements for thesis.

View of MARPORT Main Terminal with all type quay and yard cranes are in Figure 3.6. Containers waiting for loading or transfer, quay and container yard cranes are also visible in the picture.

Figure 3.6. General View of MARPORT Main Terminal (Source, www.marport.com.tr , 2016).

Similarly, relatively newer section of the port, West Terminal is presented in Figure 3.7. Container yards and cranes with containers waiting for further operations are also visible in the picture.

Figure 3.7 General View of MARPORT West Terminal
(Source, www.marport.com.tr, 2016).

In order to get more comprehensive view of the Port, plan of MARPORT is presented in Figure 3.8. Berths 6 and 7 are suitable for berthing two or more ships simultaneously.

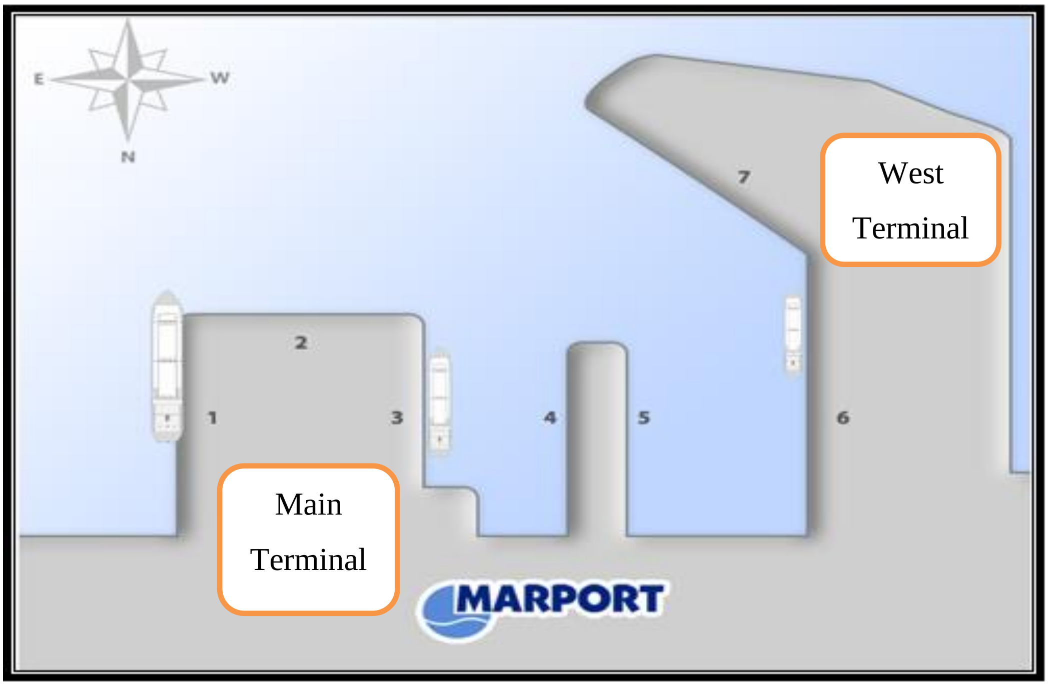


Figure 3.8. Plan of MARPORT Terminals. (Source, www.marport.com.tr, 2016).

General information about the main and west terminals are listed in Table 3.2 (www.marport.com.tr, 2016). Most of these configurational figures were used as input in simulation model. In other words, these actual values are assumed as benchmark to compare candidate investment alternatives.

Table 3.2. MARPORT Container Terminal, General Information
(Source, www.marport.com.tr, 2016).

	MAIN TERMINAL	**WEST TERMINAL**
Geographic Position	40’ 57” North 28’ 41” East	40’ 57” North 28’ 40” East
Property		
Total Area	170.000 m^2	170.000 m^2
Stacking Capacity	12.520 TEU	12.520 TEU
Handling Capacity	950.000 TEU/Year	950.000 TEU/Year
Refrigerated Container Capacity	332 TEU (380 V)	160 TEU (380 V)
CFS Area	10.000 m^2	7.425 m^2
Warehouses	3.780 m^2	700 m^2
Covered Area	4.977 m^2	697 m^2
Length of Piers	800 m	760 m
Draft	14.5 m	16.5 m
Number of Gates		
In	5	3
Out	6	4
Pier Cranes		
Ship to Shore Gantry Crane	6	4
Mobile Harbor Crane	2	3
Yard Equipment		
Rubber Tyred Gantry Crane	17	18
Top Lifter	4	6
Slide Lifter	4	4
Spreader	13	11
Terminal Trucks	41	41
Pilotage Times	24 Hours	24 Hours
Terminal IT System	Navis	Navis

In MARPORT, there are total of seven berths available for berthing of different size of container ships. Configuration of these berths, such as length, draft, number and types of cranes operating on the berth are displayed in Table 3.3.

Table 3.3. Configuration of MARPORT Terminals (Source, www.marport.com.tr, 2016).

TERMINAL LOCATION	BERTH NUMBER	LENGTH (M)	DRAFT (M)	NUMBER OF CRANES	
				MOBILE HARBOR CRANE (MHC)	SHIP TO SHORE GANTRY CRANE (STS)
MAIN TERMINAL	1	335	13.5-14.5	-	3
	2	165	15.0	1	-
	3	300	13.0-14.0	-	3
	4	210	7.5-9.0	1	-
	5	210	7.5-9.0	-	-
WEST TERMINAL	6	400	11.0-14.0	3	-
	7	360	15.5-17.0	-	4

Average distances between berths and container yards, listed in Table 3.4 are required for determining the container truck transportation time between berths and allocated container yards. The longest distance on the Table is 1.250 meters between berth no:7 and main terminal container yard.

Table 3.4. Average Distances between Berths and Container Yards (Meters).

CONTAINER YARD	BERTH NUMBER						
	1	**2**	**3**	**4**	**5**	**6**	**7**
MAIN TERMINAL CONTAINER YARD	150	180	170	390	420	900	1.250
WEST TERMINAL CONTAINER YARD	1.100	1.200	950	800	750	200	250

In a similar way, two site surveys were also conducted on ASYA PORT in Tekirdağ (03 August and 18 October 2015). General Manager of port Mr. Kadir UZUN explained the operational procedures and automated controlling of container movements in the port. Even though it wasn't fully operational at the time of visit, the port is going to be the biggest and the most modern container port of Turkey.

3.3.3. Container Ships Data Visiting MARPORT

419 container ships in different size made port calls at MARPORT/İstanbul Container Terminal to discharged or unload different size and type of containers between October 2014 and July 2015. This 10-month period which is covering almost all seasons is considered long enough to predict input parameters for simulation and to eliminate the seasonal effects of sea trade.

Each ship data set includes 32 figures. Some of these data groups related with simulation are listed below:

- SHIP DATA: Vessel name, service type, tonnage, length, draft.
- ARRIVAL TIME DATA: Arrival at pilot station, anchor (if applicable), pilot on board, arrival at berth.
- CONTAINER DATA: Number of discharged/ loaded 20 or 40-foot containers (full, empty and transit).
- OPERATION TIME: Start operation, complete operation.
- DEPARTURE TIME DATA: Departure from berth, drop pilot.

As an example, ship data and container data of vessels visiting MARPORT in January 2015 are displayed in Table 3.5.

Table 3.5. MARPORT Vessel and Container Data, January 2015
(Source, MARPORT Administration, 11 September 2015).

Vessel Name	Tonnage (DWT)	Length (M)	Draft (M)	Total Discharged Containers TEU	Total Loaded Containers TEU	Total Handled Containers TEU
MSC ADRIANA AO451R	18.779	216	8,20	206	506	712
CAPE MANILA AC501R	22.315	212	9,80	284	370	654
MSC ASLI AO452A	14.150	217	10,00	680	143	823
JASPER S DA502A	13.795	148	6,30	444	644	1088
WESTERDIEK MT501R	39.000	210	14,50	471	247	718
KAETHE C. RICK.S T50	68.282	295	7,50	2277	684	2961
MSC ELOISE MT452A	44.551	241	19,00	737	33	770
GOZDE BAYRAK. DH45	21.417	157	9,40	436	740	1176
MSC EDITH AO501A	18.779	216	8,50	2	117	119
MSC MARYLENA AN50	18.779	216	8,70	0	511	511
MSC HOGGAR DH452A	11.656	137	8,90	653	507	1160
AS VENUS DI451A	18.400	159	7,20	21	765	786
AYSE BAYRAKTAR	21.417	157	8,10	23	658	1381
MSC AMERICA AC502	45.668	216	8,00	1080	344	1424
MSC RAPALLO FT501A	154.538	366	12,70	3233	3664	6897
JASPER S DA503A	13.795	148	6,30	111	547	658
MSC LORENA NM502R	59.587	275	11,80	1028	1712	2740
WESTERTAL MT501A	38.700	211	7,40	477	44	521
MSC ELOISE MT502R	44.541	241	7,90	126	541	667

4. CONTAINER PORT SIMULATION MODELING

4.1.General Aspects of Simulation Modeling

Simulation modeling and analysis is the process of creating and experimenting with a computerized mathematical model of a physical system (Chung, 2004). A system is defined as a collection of interacting components that receives input and provides output for some purposes such as;

- Gaining insight into the operation of a system,
- Developing operating or resource policies to improve system performance,
- Testing new concepts and/or systems before implementation,
- Gaining information without disturbing the actual system.

Examples of this simple type of system would include,

- A container terminal with several berths, QCs, YTs and YCs,
- A call center in a hospital or store,
- A mortgage loan officer in a bank,
- A system of machines in a factory,
- An airport parking system.

According to Akbay, simulation studies normally have the following steps for creating a model (Akbay, K. S., 1996);

- Problem Definition: Clearly defining the goals of the study so that we know why are we studying the problem and what questions do we hope to answer.

- System Definition: Determining the boundaries and restrictions to be used in the system or process and investigating how the system works.
- Input Data Preparation: Identifying and collecting the input data needed by the model.
- Conceptual Model Formulation: Developing a preliminary model either graphically (e.g., block diagrams) or in pseudo-code to define the components, descriptive variables and interactions that constitute the system.
- Experimental Design: Selecting the measures of effectiveness to be used, the factors to be varied and the levels of those factors to be investigated.
- Model Translation: Formulating the model in an appropriate simulation language.
- Verification: Confirming that the model operates the way the analyst intended (debugging) and that the output of the model is believable.
- Validation: Confirming that output of the model is believable and representative of the output of the actual system. Experimentation: Executing the simulation to generate the desired data and to perform a sensitivity analysis.
- Analysis and Interpretation: Drawing inferences from the data generated by the simulation.
- Implementation and Documentation: Putting the results to use, recording the findings and documenting the model and its use (Chung, 2004).

4.2.Problem Definition of Simulation Modeling

The aim of this thesis is to establish an integrated mathematical model as a decision support tool to find the optimum investment package for the enlargement of a container terminal. The objective of the model is, on the one side, to minimize average ship turnaround time and, on the other side, to maximize monthly container throughput generated by the terminal by an investment on terminal equipment with minimum financial expenditure.

In the methodology, as depicted in Figure 3.1, the mathematical model consists of three sub-models; Discrete Event Simulation Model, Data Envelopment Analysis and Cost Efficiency Analysis.

The first step of this integrated mathematical model is a discrete simulation model. The goal of the simulation model is to estimate the two outputs of each port investment alternatives to be able to compare their efficiency via Data Envelope Analysis which is a second step of the integrated model. The simulation model will be designed in such a way that the main outputs will be the key measure of performances, namely monthly container throughput and monthly container throughput.

MARPORT will be the target port. In this way, its current physical port structure (infrastructure, equipment), management system and historical data will be used as a basis to construct and run the model.

4.3. System Definition of Container Terminal

After having defined the goal of the simulation modeling, within the scope of system definition which is the second step in simulation process, the phases of functional planning, and restrictions to be used in the MARPORT container terminal system are investigated and defined. In short, the aim of this phase is to clearly define the working order of the container port system. In this context, container port operational planning phases to be modelled are summarized below.

- Ship arrivals and generation of ships physical figures and container load planning,
- Berth allocation planning,
- Quay cranes loading and unloading planning,
- Truck transportation in contair terminal planning,
- Container yard planning.

The simulation software, ARENA, is used as a tool for developing simulation sub-models of above mentioned planning phases, as well as analyzing the results. To facilitate the modeling process, the modules such as create, assign and seize in ARENA provide abundant panel for users, and many modules are incorporated in the panels, which can be classified into flowchart module and data module. The flowchart module is used to describe the dynamic process of an entity from start-point to end-point. To improve the running speed of simulation, the entities in model are not endowed with pictures.

The basic structure of the SM is shown in Figure 4.1 which also illustrates integration processes. The objective is, on the one side, to minimize turnaround time ratio associated to the ships serviced, on the other side, to maximize terminal throughput generated by the berth. The SM provides detailed ARENA architecture modules of the problem presented in Figure 4.1 as well as sub-model integration (Park at al., 2009).

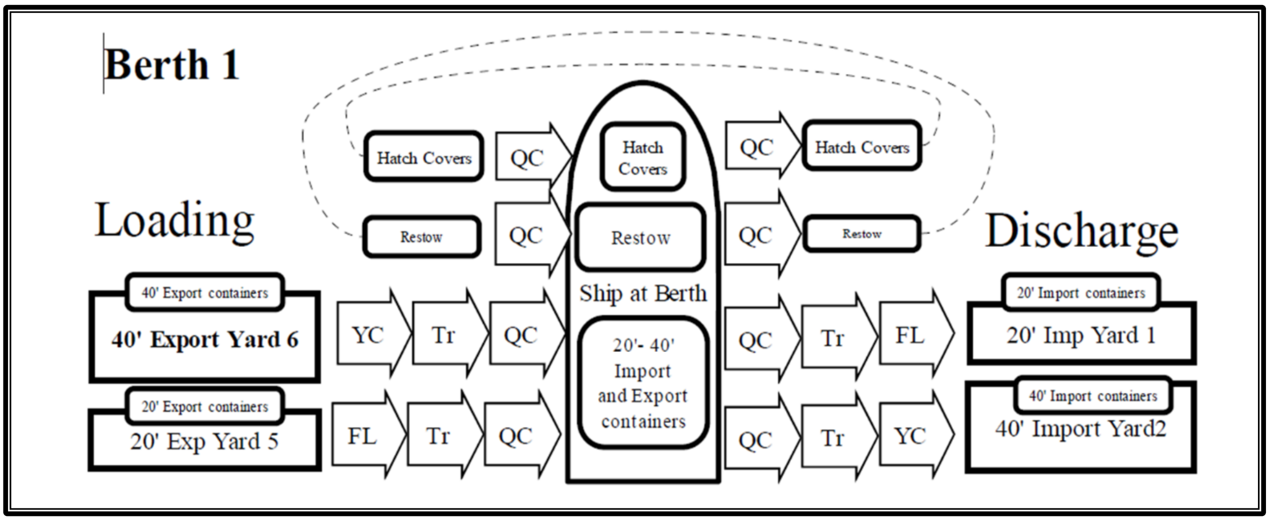


Figure 4.1. The Basic Structure of Simulation Model (Source, Solomenikovs, 2006).

A SM is proposed in Figure 4.1 for representing the processes relevant to ship and container movement inside a CT. This model is designed by ARENA block diagrams. It is developed by defining the CT entities and by describing the sequences of activities to be performed by the transient entities included in the SM (Park at al., 2009).

For the modeling of handling times, the activities related to the transfer of cargo units from the ship to the stacking area are analyzed. The first step is the identification of the main activities and the analysis of waiting and operational phases, in order to formalize the times of each phase. As an example, main activities of a container ship with containers on board to be unloaded are as follows;

- Arrival of the container ships to port,
- Check-in operations on ship arrival, berth and quay crane allocation,
- Waiting in anchoring area, if there is no available berth,
- Unloading of containers by quay cranes,
- Transfer of containers from berth area to yard (transshipment/ stocking) area by allocated yard trucks/ tractors,
- Downloading of track by yard crane and drop off on stocking area.

4.4. Input Data Preparations

4.4.1. Collection of Sample Data

A sample of data set belonging the container ship named Jasper S, which made a port call between 03 and 04 January 2015, is listed in Table 4.1. The ship handled total of 1.088 TEU container load, 444 TEU unloaded and 644 TEU loaded. The vessel stayed in MARPORT between 03 January 2015, 10^h 30^m and 04 January 2015, 06^h 50^m. This time interval also corresponds 20^h 20^m or 20,333 hours of total time in port.

Table 4.1. MARPORT Vessel Sample Data Set, January 2015
(Source, MARPORT Administration, 11 September 2015).

SHIP DATA					
VESSEL NAME	SERVICE	SERVICE TYPE	TONNAGE	LENGTH	DRAFT
JASPER S	İSTN./VARNA	FEEDER	13.795 DWT	148 M.	6,3 M.

ARRIVAL TIME DATA			
ARRIVAL AT PLOT STATION	ANCHOR	PLOT ON BOARD	ARRIVAL AT BERTH
03.Jan.2015 10:30	03.Jan.2015 10:42	03.Jan.2015 12:35	03.Jan.2015 13:15

CONTAINER DATA																		
DISCHARGED CONTAINERS									LOADED CONTAINERS									
FULL		**EMPTY**		**T/S FULL**		**T/S EMPTY**		**TOTAL TEU's**	**FULL**		**EMPTY**		**T/S FULL**		**T/S EMPTY**		**TOTAL TEU's**
20	**40**	**20**	**40**	**20**	**40**	**20**	**40**		**20**	**40**	**20**	**40**	**20**	**40**	**20**	**40**	
0	5	40	24	118	103	1	0	444	11	42	0	0	26	1	1	0	644
TOTAL HANDLED CONTAINERS: 1.088 TEU																		

OPERATION TIME DATA	
OPERATION START TIME	OPERATION COMPLETE TIME
03 Jan 2015 14:10	04 Jan 2015 05:50

DEPARTURE TIME DATA	
DEPARTURE FROM BERTH	DROP PILOT
04 Jan 2015 06:50	04 Jan 2015 07:55

4.4.2. Analysis of Container Load Distribution

To generate the container load configuration of incoming vessel in simulation model, historical data have been analayzed statistically. The overall monthly container load distribution for vessels visiting MARPORT between October 2014 and July 2015 are listed in Table 4.2. According to their load configuration, containers are classified under four categories; full, empty, transit full and transit empty. These categories are also divided into two subgroups according to their physical sizes; 20-foot and 40-foot containers. In addition to these classifications, loaded and discharged containers are analyzed separately.

The last row of the Table includes monthly average TEU equivalent value of each subgroups. The number of average total monthly handled container is 79.536 TEU while 42.219 TEU container has been discharged from vessels and 37.316 TEU container were loaded onboard vessels.

In simulation modeling, it is also required to identify the incoming container vessel according to its initial and final load configuration. Historical data indicates that there would be three possible cases. These are;

- Empty arrival, loaded departure,
- Loaded arrival, empty departure,
- Loaded arrival, loaded departure.

Table 4.2 MARPORT Monthly Container Load (TEU) Distributions. (Source, MARPORT Administration, 11 September 2015)

MOUNTH YEAR	**MONTHLY DISCHARGED CONTAINERS**									**MONTHLY LOADED CONTAINERS**									**MONTHLY HANDLED TOTAL TEUs**
	FULL		**EMPTY**		**TRANSIT FULL**		**TRANSIT EMPTY**		**DISCHARGED TOTAL TEUs**	**FULL**		**EMPTY**		**TRANSIT FULL**		**TRANSIT EMPTY**		**LOADED TOTAL T EUs**	
	20'	**40'**	**20'**	**40'**	**20'**	**40'**	**20'**	**40'**		**20'**	**40'**	**20'**	**40'**	**20'**	**40'**	**20'**	**40'**		
OCT 2014	4.308	4.833	37	849	7.827	5.184	16	23	33.966	1.416	3.081	1.749	2.185	6.320	4.738	15	34	29.576	**63.542**
NOV 2014	6.058	3.816	108	1.261	7.247	5.747	28	52	35.193	1.854	2.773	1.615	1.903	5.784	5.169	22	16	28.997	**64.190**
DEC 2014	4.827	5.068	77	702	7.439	7.031	29	38	38.050	1.361	2.903	2.056	2.482	7.059	4.938	18	29	31.198	**69.248**
JAN 2015	**4.391**	**5.767**	**410**	**1.400**	**6.273**	**4.928**	**16**	**8**	35.296	**2.442**	**4.050**	**1.900**	**2.349**	**5.911**	**5.222**	**12**	**5**	**33.517**	**68.813**
FEB 2015	**7.393**	**10.936**	**215**	**1.624**	**8.472**	**6.162**	**21**	**22**	53.589	**4.361**	**5.760**	**2.742**	**3.983**	**8.638**	**6.196**	**24**	**28**	**47.699**	**101.288**
MAR 2015	**6.804**	**9.994**	**84**	**1.820**	**6.946**	**4.890**	**32**	**79**	47.432	**4.341**	**5.987**	**1.827**	**4.136**	**7.556**	**5.376**	**21**	**19**	**44.781**	**92.213**
APR 2015	**5.177**	**6.871**	**182**	**1.026**	**6.771**	**4.159**	**50**	**11**	36.314	**3.845**	**5.259**	**1.981**	**2.036**	**5.817**	**3.834**	**40**	**65**	**34.071**	**70.385**
MAY 2015	**8.545**	**9.447**	**113**	**797**	**6.861**	**4.707**	**39**	**16**	45.492	**5.585**	**5.877**	**2.202**	**2.148**	**7.824**	**4.837**	**39**	**16**	**41.406**	**86.898**
JUN 2015	**7.308**	**9.720**	**112**	**2.122**	**7.999**	**4.793**	**51**	**17**	48.774	**4.485**	**6.206**	**1.953**	**3.116**	**7.536**	**4.758**	**52**	**9**	**42.204**	**90.978**
JUL 2015	**7.347**	**9.885**	**30**	**1.011**	**7.397**	**5.711**	**45**	**27**	48.087	**4.449**	**5.544**	**1.123**	**2.209**	**7.922**	**5.285**	**69**	**38**	**39.715**	**87.802**
TOTAL	**62.158**	**76.337**	**1.368**	**12.612**	**73.232**	**53.312**	**327**	**293**	422.193	**34.139**	**47.440**	**19.148**	**26.547**	**70.367**	**50.353**	**312**	**259**	**373.164**	**795.357**
AVARAGE	**6.216**	**7.634**	**137**	**1.261**	**7.323**	**5.331**	**33**	**29**	42.219	**3.414**	**4.744**	**1.915**	**2.655**	**7.037**	**5.035**	**31**	**26**	**37.316**	**79.536**

Monthly historical data indicating these cases is in Table 4.3. Last row the Table indicates the average number of vessels for each case.

Table 4. 3. MARPORT Monthly Ship Data According to Container Configurations (Source, MARPORT Administration, 11 September 2015).

	ARRIVAL	EMPTY ARRIVAL	EMPTY DEPARTURE	LOADED ARV./DEP.	DISCHARGED TOTAL TEU	LOADED TOTAL TEU	HANDLED TOTAL TEU
OCT 2014	49	3	0	46	33.966	29.576	63.542
NOV 2014	54	4	1	49	35.193	28.997	64.190
DEC 2014	55	4	2	49	38.050	31.198	69.248
JAN 2015	46	1	0	45	35.296	33.517	68.813
FEB 2015	52	1	1	50	53.589	47.699	101.288
MAR 2015	48	1	0	47	47.432	44.781	92.213
APR 2015	50	2	2	46	36.314	34.071	70.385
MAY 2015	47	3	0	44	45.492	41.406	86.898
JUN 2015	44	0	2	42	48.774	42.204	90.978
JUL 2015	46	1	1	44	48.087	39.715	87.802
TOTAL	491	20	9	462	422.193	373.164	795.357
AVERAGE	49,1	2	0,9	46,2	42.219	37.316	79.536

Statistical analysis of these vessel load configuration cases are presented in Table 4.4. As it is seen from the Table, the majority of incoming vessels (94 %) have arrived and left the MARPORT loaded with containers.

Table 4. 4. MARPORT Ship Categories According to Load Configurations (Source, MARPORT Administration, 11 September 2015).

SHIP CATEGORIES	NUMBER OF SHIPS	PERCENTAGE (%) NUMBER/TOTAL	CUMULATIVE PERCENTAGE	PROBABILISTIC INTERVAL
EMPTY ARRIVALS	20	4,0733	4,0733	0,0000- 0, 0407
EMPTY DEPARTURES	9	1,8330	5,9063	0,0408- 0, 0591
LOADED ARV. AND DEPRTURE	462	94,0937	100,0000	0,0592- 1,0000
TOTAL SHIP VISITS	491	100,0000		

Container load distributions for different container types are listed in Table 4.5. Full type containers for discharged ones has the highest percentage (50,8 %), while transit full containers have the highest percentage (45,8 %) in loaded container group.

Table 4. 5. MARPORT Statistics for Container Types
(Source, MARPORT Administration, 11 September 2015).

CONTAINER TYPE	DISCHARGED CONTAINERS		LOADED CONTAINERS	
	TEU	PERCENTAGE TEU/TOAL (%)	TEU	PERCENTAGE TEU/TOAL (%)
FULL	214.832	50,8848	129.019	34,5744
EMPTY	26.592	6,2985	72.242	19,3594
TRANSIT FULL	179.856	42,6004	171.073	45,8438
TRANSIT EMPTY	913	0,2163	830	0,2224
TOTAL	422.193	100,0000	373.164	100,0000

More detailed statistical analysis have also been carried out for discharged containers. In addition to type of the container, the size classification has also been taken into consideration. The result is displayed in Table 4.6.

According to these figures, 28,933 percent of discharged full containers are 20' TEU containers.

Table 4.6. MARPORT Statistics for Types of Discharged Containers
(Source, MARPORT Administration, 11 September 2015).

CONTAINER TYPE	CONTAINER SIZE	DISCHARGED CONTAINER (TEU)	PERCENTAGE TEU/TOTAL
FULL	20'	62.158	28,9333
	40'	152.674	71,0667
	TOTAL	214.832	100,0000
EMPTY	20'	1.368	5,1444
	40'	25.224	94,8556
	TOTAL	26.592	100,0000
TRANSIT FULL	20'	73.232	40,7170
	40'	106.624	59,2830
	TOTAL	179.856	100,0000
TRANSIT EMPTY	20'	327	35,8160
	40'	586	64,1840
	TOTAL	913	100,0000
GRAND TOTAL	20'	137.085	32,4697
	40'	285.108	67,5303
	TOTAL	422.193	100,0000

MARPORT statistics for types of loaded containers such as full, empty, transit full and empty are in Table 4.7. For each type, there is also a second level classification such as 20’ or 40’ containers.

Table 4. 7. MARPORT Statistics for Types of Loaded Containers (Source, MARPORT Administration, 11 September 2015).

CONTAINER TYPE	CONTAINER SIZE	LOADED CONTAINER (TEU)	PERCENTAGE TEU/TOTAL
FULL	20’	34.139	26,4604
	40’	94.880	73,5396
	TOTAL	129.019	100,0000
EMPTY	20’	19.148	26,5054
	40’	53.094	73,4946
	TOTAL	72.242	100,0000
TRANSIT FULL	20’	70.367	41,1327
	40’	100.706	58,8673
	TOTAL	171.073	100,0000
TRANSIT EMPTY	20’	312	37,5904
	40’	518	62,4096
	TOTAL	830	100,0000
GRAND TOTAL	20’	123.036	32,9710
	40’	250.128	67,0290
	TOTAL	373.164	100,0000

4.4.3. Analysis of Vessel Tonnage Distribution

Classification of container ships by their dead weight tonages (DWT) according to monthly data is depicted in Table 4.8. This data will be used to generata simulated ship tonages. The vessels between 15.001 and 30.000 DWT has the highest number (898 vessels) comparing with other DWT intervals.

Table 4. 8. MARPORT Vessel Tonnage Class Distribution
(Source, MARPORT Administration, 11 September 2015).

TONNAGE INERVALS (DWT)	**JANUARY**	**FEBRUARY**	**MARCH**	**APRIL**	**MAY**	**JUNE**	**JULY**	**AUGUST**	**SEPTEMBER**	**OCTOBER**	**NOVEMBER**	**DECEMBER**	**TOTAL**
1.001-2.000	20	16	17	15	21	17	19	16	16	18	17	30	**212**
2.001-5.000	10	2	18	10	17	26	22	22	20	9	12	15	**183**
5.001-10.000	30	25	30	40	40	39	27	26	21	27	27	31	**363**
10.001-15.000	50	48	56	55	52	49	48	57	47	48	53	46	**609**
15.001-30.000	70	65	74	75	76	71	87	91	77	72	72	68	**898**
30.001-45.000	32	35	34	37	39	36	32	36	34	34	39	39	**427**
45.001-60.000	23	18	21	16	22	18	23	15	18	18	17	19	**225**
60.001-100.000	16	15	18	18	17	20	26	27	25	37	22	23	**228**
100.001-155.000	2	1	2	2	3	2	2	4	2	2	2	2	**26**
MONTHLY TOTAL	253	225	270	268	287	278	286	294	260	252	261	263	**3197**

As a follow on study, MARPORT vessel tonnage class intervals were also analysed statistically in order to get probabilistic distributions of these intervals. The probabilistic interval figures on the right column of Table 4.9 together with the random numbers generated by simulation software are used to create DWT interval for incoming vessel.

The highest probabilistic figure, 0,28088, belongs to the interval of ships having tonnage between 15.001-30.000 DWT.

Table 4.9. MARPORT Vessel Tonnage Class Intervals Statistical Data (Source, MARPORT Administration, 11 September 2015).

VESSEL TONNAGE CLASS (DWT)	VESSEL CLASS WIDTH	TOTAL # SHIPS	CLASS PERCENTAGE	CUMULATIVE PERCENTAGE	PROBABILISTIC INTERVAL
1.001-2.000	1.000	212	6,6312	6,6312	0,0000 - 0,0663
2.001-5.000	3.000	183	5,7241	12,3553	0,0664 - 0,1236
5.001-10.000	5.000	363	11,3544	23,7097	0,1237 - 0,2371
10.001-15.000	5.000	609	19,0491	42,7588	0,2372 - 0,4276
15.001-30.000	15.000	898	28,0888	70,8477	0,4277 - 0,7085
30.001-45.000	15.000	427	13,3563	84,2039	0,7086 - 0,8420
45.001-60.000	15.000	225	7,0378	91,2418	0,8421 - 0,9124
60.001-100.000	40.000	228	7,1317	99,1867	0,9125 - 0,9919
100.001-155.000	55.000	26	0,8133	100,0000	0,9920 - 1,0000

4.4.4. Estimation of Vessel TEU Capacity

After having generated the deadweight tonnage (DWT) of incoming container vessel in the simulation model, it is possible to define maximum container capacity (TEU) of that size of ship. Regression models can be utilized to estimate maximum capacity for a given DWT. In 2010, Dr. Selçuk NAS published a book titled “Konteyner Gemileri için İstatistikel Bilgiler- Statistical Information for Container Ships”. In this research book, among several regression equations, there is also a regression formula to predict the maximum TEU capacity for a given DWT. The data set (DWT vs. maximum TEU capacity) of 1.337 different container ship are utilized to calculate the regression equation. The graph and equation are displayed in Figure 4.2 and Equation 4.1.

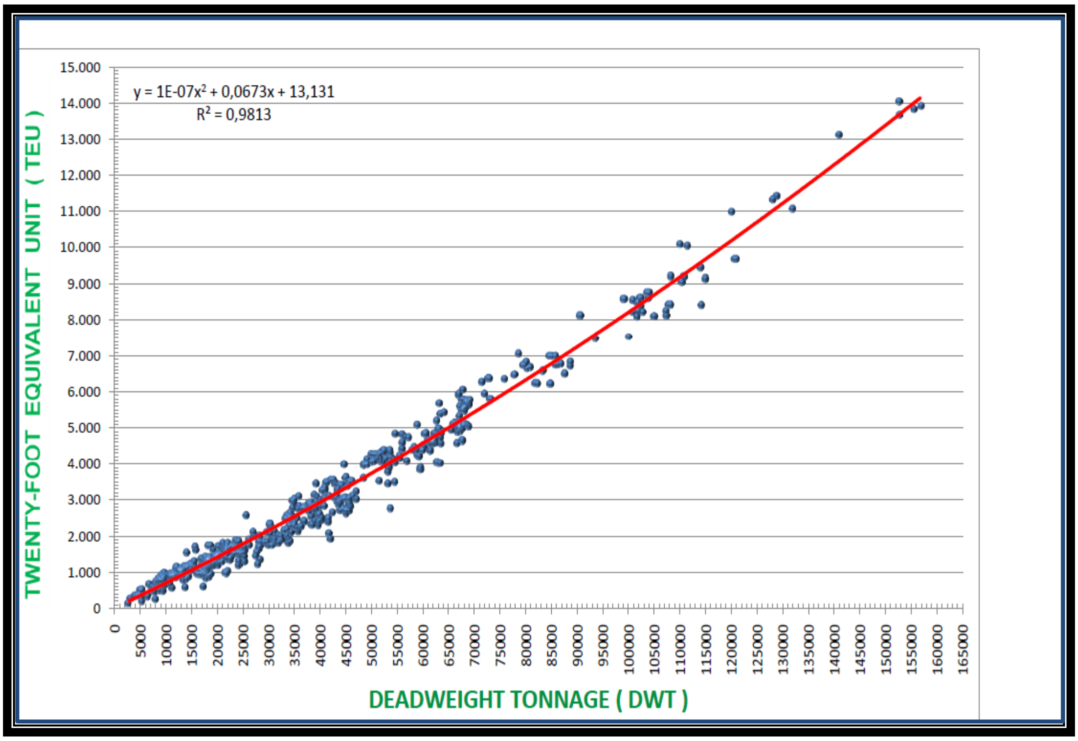


Figure 4.2. Ship Tonnage vs. Maximum TEU Capacity Regression Curve (Source, Nas, S., 2010).

$$\boldsymbol{C = x^2\, 10^{-7} + 0{,}0673\, x + 13{,}131} \tag{4.1}$$

where;

C = Maximum TEU Capacity (TEU) x = Tonnage of the vessel (DWT)

4.4.5. Estimation of Vessel Length

The nonlinear regression model is to express the dependent variable y as a linear function of p predictor variables x_i ($i = 1,2, . . ., p$) and an error term e.

$$y = c_0 + c_1x_1 + . . . + c_px_p + e$$

Note that if the relationship between the dependent variable and the predictor variables is nonlinear, it will be convenient to create new variables for the nonlinear terms and the regression model.

In this thesis as a follow on step on generating ship parameters, a regression model to estimate vessel length is created by using historical MARPORT data some of which listed in Table 4.10.

Table 4. 10. MARPORT Vessel Tonnage vs. Length Data
(Source, MARPORT Administration, 11 September 2015).

TONNAGE	LENGTH	TONNAGE	LENGTH	TONNAGE	LENGTH
17.665	184	1.853	83	35.708	212
3.115	366	1.720	81	14.193	155
17.687	184	10.282	147	27.779	222
14.865	167	35.708	212	15.120	168
1.720	81	51.931	293	1.720	81
17.687	184	3.120	89	143.521	366
8.656	137	14.236	155	1.853	83
4.182	102	15.120	169	50.963	275
3.120	89	1.720	81	17.687	184
29.115	196	27.779	222	9.983	132
14.193	155	37.902	241	14.865	167

For creating regression equation, vessel tonnage (DWT) parameter which was calculated previously by Equation 4.1 is taken as independent variable. University-supplied copy of IBM SPSS Statistics 24 software product is utilized to create nonlinear regression equation (Field, A, 2009). If we examine the plot of data sets DWT and length in Figure 4.3, it is clear that the relationship between these parameters is nonlinear. Therefore, nonlinear regression module in SPSS is deployed as tool to find the best suitable model.

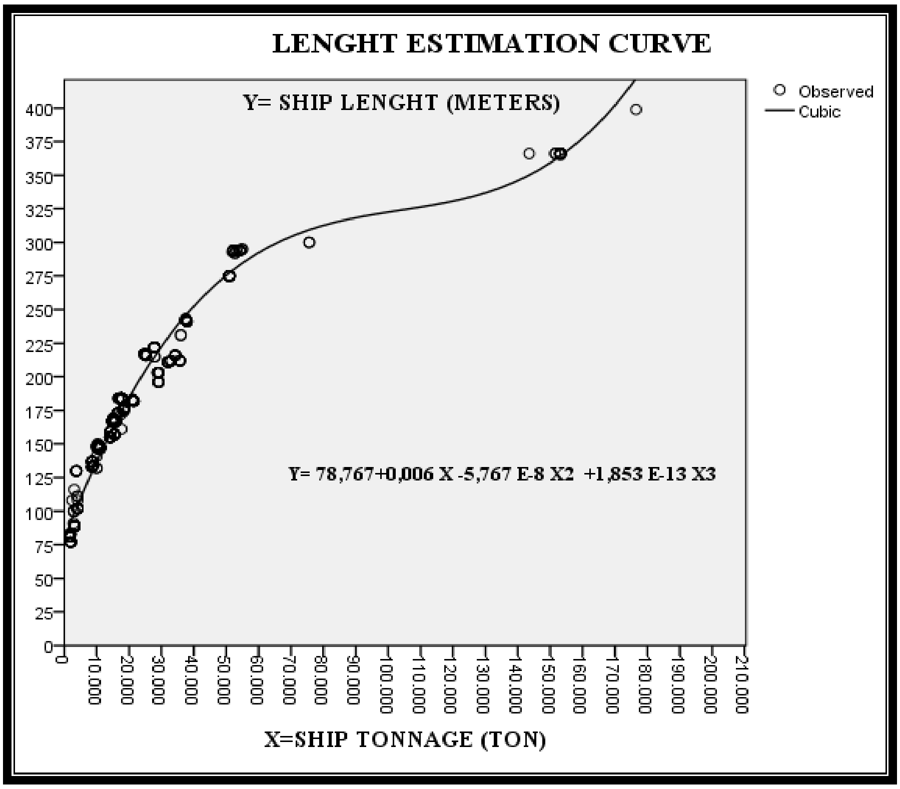
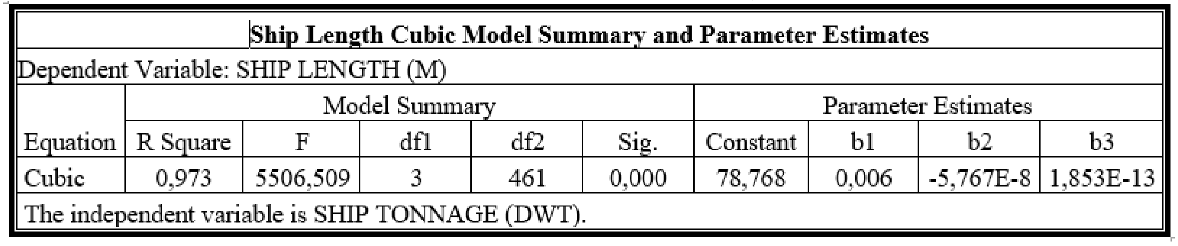


Figure 4.3. Ship Tonnage vs. Ship Length Cubic Regression Curve (Source, IBM SPSS Statistics 24).

SPSS solution for this model is a cubic equation. The statistical model summary and parameter estimates are presented in Table 4.11.

Table 4. 11 Vessel Tonnage vs. Length Estimation Parameters (Source, IBM SPSS Statistics 24).



Ship Length Cubic Model Summary and Parameter Estimates

Dependent Variable: SHIP LENGTH (M)

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Cubic	0,973	5506,509	3	461	0,000	78,768	0,006	-5,767E-8	1,853E-13

The independent variable is SHIP TONNAGE (DWT).

The cubic nonlinear regression equation is;

$$L = 1,853\, x^{3}\, 10^{-13} - 5,765\, x^{2}\, 10^{-8} + 0,006\, x + 78,7670 \qquad \textbf{(4.2)}$$

where;

L = Length of the Vessel (meters) x = Tonnage of the vessel (DWT)

4.4.6. Estimation of Vessel Draft

In a similar way, nonlinear regression model is used to predict the draft of vessel by using historical MARPORT data some of which listed in Table 4.12.

Table 4. 12. MARPORT Vessel Length vs. Draft Data
(Source, MARPORT Administration, 11 September 2015).

LENGTH	DRAFT	LENGTH	DRAFT	LENGTH	DRAFT
216	8,2	148	6,3	148	6,3
212	9,8	275	11,8	243	6,9
217	10	211	7,4	157	9,4
148	6,3	241	7,9	211	7,1
210	14,5	195	7,2	168	7,4
295	7,5	181	14,0	366	29,9
241	19,0	294	9,7	217	10,0
157	9,4	159	7,2	267	8,3
216	8,5	202	10,1	157	8,1
216	8,7	217	10	203	8,9
137	8,9	274	11,6	172	9,2
159	7,2	167	6,8	210	8,6
157	8,1	366	14,5	137	8,9
216	8	216	7	269	8,6
366	12,7	216	7,2	216	8,2
148	6,3	159	7,2	243	6,9
208	10,3	138	8,9	153	9,2
243	7,1	173	7,8	148	6,4
148	6,5	190	7,0	148	6.7

The curve in Figure 4.4 indicates that the relationship between the independent variable vessel length and dependent variable vessel length is not linear.

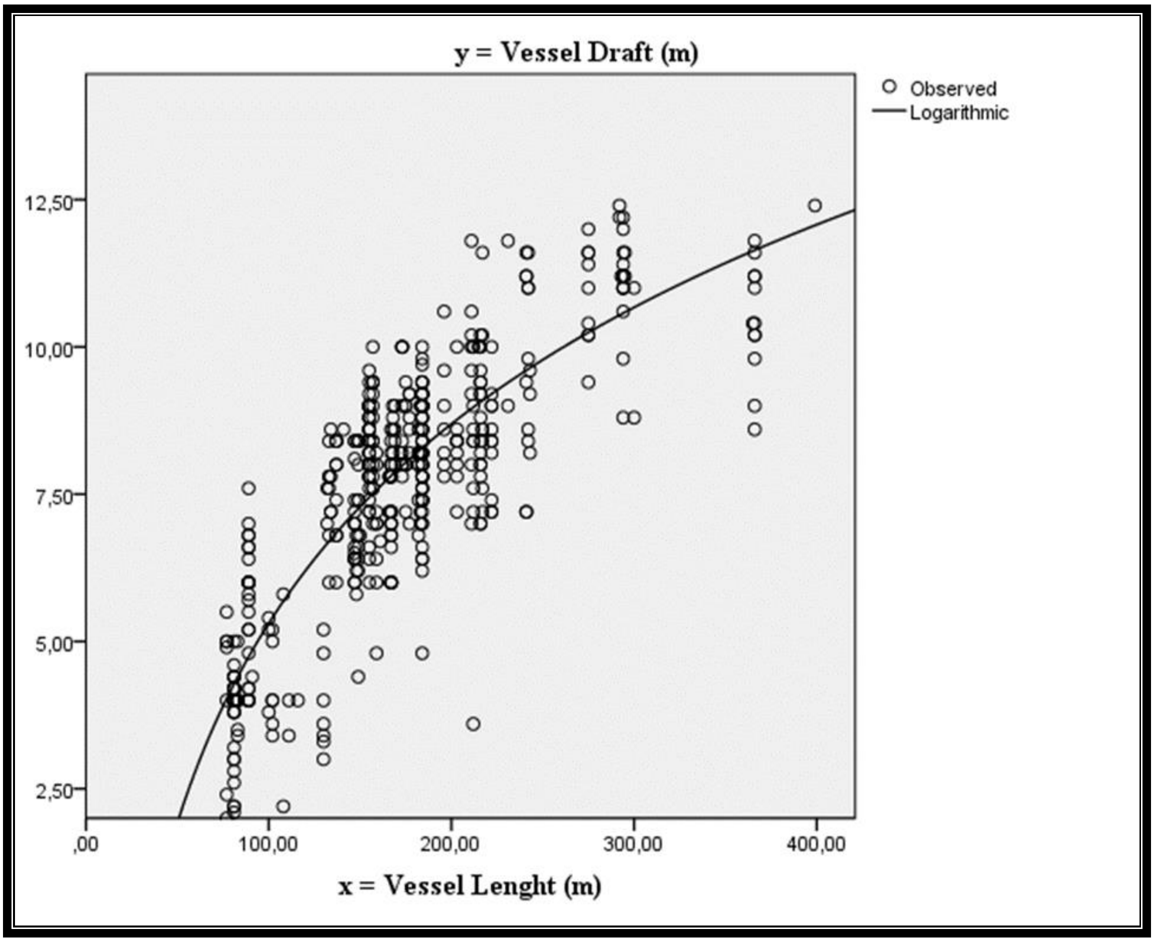
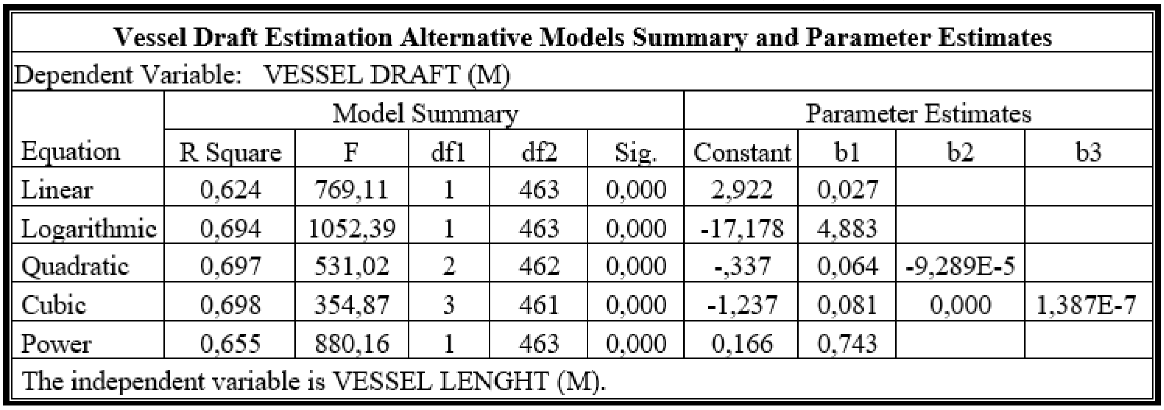


Figure 4.4. Vessel Length vs. Draft Logarithmic Regression Curve
(Source, IBM SPSS Statistics 24).

Candidate models such as logarithmic, quadratic, cubic power offered by SPSS are presented in Table 4.13. The statistical parameters such as ***R^2*** and ***F*** statistic value in this table are criteria for selecting the best curve to predict dependent variable vessel draft.

Table 4. 13. Vessel Length vs. Draft Estimation Models Parameters
(Source, IBM SPSS Statistics 24).



Vessel Draft Estimation Alternative Models Summary and Parameter Estimates

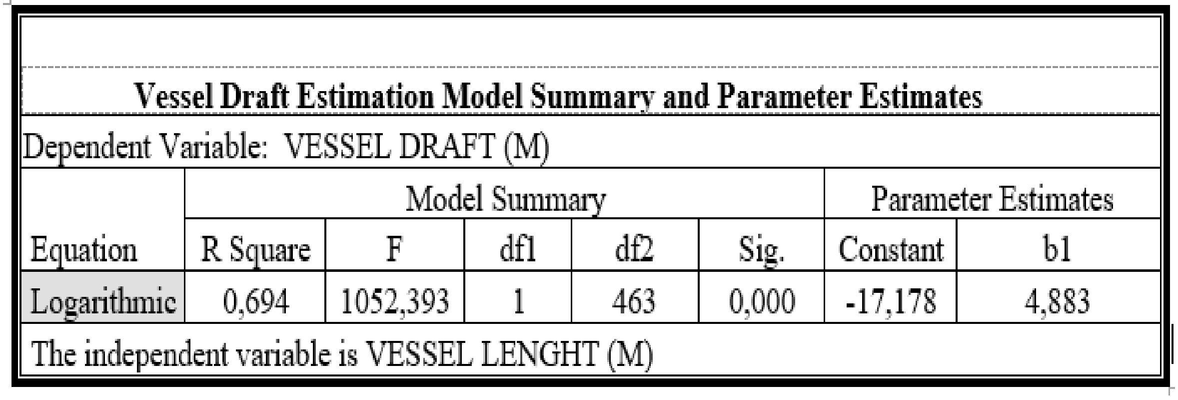
Dependent Variable: VESSEL DRAFT (M)

	Model Summary					Parameter Estimates			
Equation	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0,624	769,11	1	463	0,000	2,922	0,027		
Logarithmic	0,694	1052,39	1	463	0,000	-17,178	4,883		
Quadratic	0,697	531,02	2	462	0,000	-,337	0,064	-9,289E-5	
Cubic	0,698	354,87	3	461	0,000	-1,237	0,081	0,000	1,387E-7
Power	0,655	880,16	1	463	0,000	0,166	0,743		

The independent variable is VESSEL LENGHT (M).

Having examined these criteria, logarithmic regression model seems to be the most suitable one. The statistical model summary and coefficient estimates are listed in Table 4.14.

Table 4. 14. Vessel Length vs. Draft Logarithmic Estimation Model Parameters (Source, IBM SPSS Statistics 24).



Vessel Draft Estimation Model Summary and Parameter Estimates

Dependent Variable: VESSEL DRAFT (M)

	Model Summary					Parameter Estimates	
Equation	R Square	F	df1	df2	Sig.	Constant	b1
Logarithmic	0,694	1052,393	1	463	0,000	-17,178	4,883

The independent variable is VESSEL LENGHT (M)

Logarithmic nonlinear regression equation is;

$$D = -17,178 + 4,883 * \ln x \qquad (4.3)$$

where;

D = Draft of the Vessel (meters) ***x*** = Length of the vessel (M)

4.4.7. Estimation of Operation Time

Operation time is defined as the time a ship stays at a berth for loading and/or unloading containers. The operation time is established from the first container transfer to the last container move. Operation time is the main subcomponet of total time in port which is one of the performance measures. Even though, the simulation model actually calculates this time parameter, nonlinear regression model is also used to predict the operation time by using historical MARPORT data some of which were listed in Table 4.15.

Table 4. 15 Handled Containers (TEU) vs. Operation Time
(Source, MARPORT Administration, 11 September 2015).

HANDLED CONTAINERS (TEU)	OPERATION TIME (HOUR)	HANDLED CONTAINERS (TEU)	OPERATION TIME (HOUR)	HANDLED CONTAINERS (TEU)	OPERATION TIME (HOUR)
506	16,50	765	13,50	776	8,75
370	13,50	658	27,75	1.042	13,92
143	13,75	344	17,92	908	17,60
644	15,67	3.664	48,50	760	15,58
247	7,83	547	9,83	655	13,58
684	28,00	1.712	27,33	2.846	36,67
33	4,06	44	7,75	52	8,50
740	17,67	541	9,75	87	14,00
117	3,67	397	12,08	492	13,25
511	11,83	168	4,58	29	6,67
507	27,00	1.178	31,42	651	17,92

Similar to previous models, the curve in Figure 4.5 also indicates that the relationship between the independent variable handled containers (TEU) for each vessel in MARPORT and dependent variable operation time is not linear.

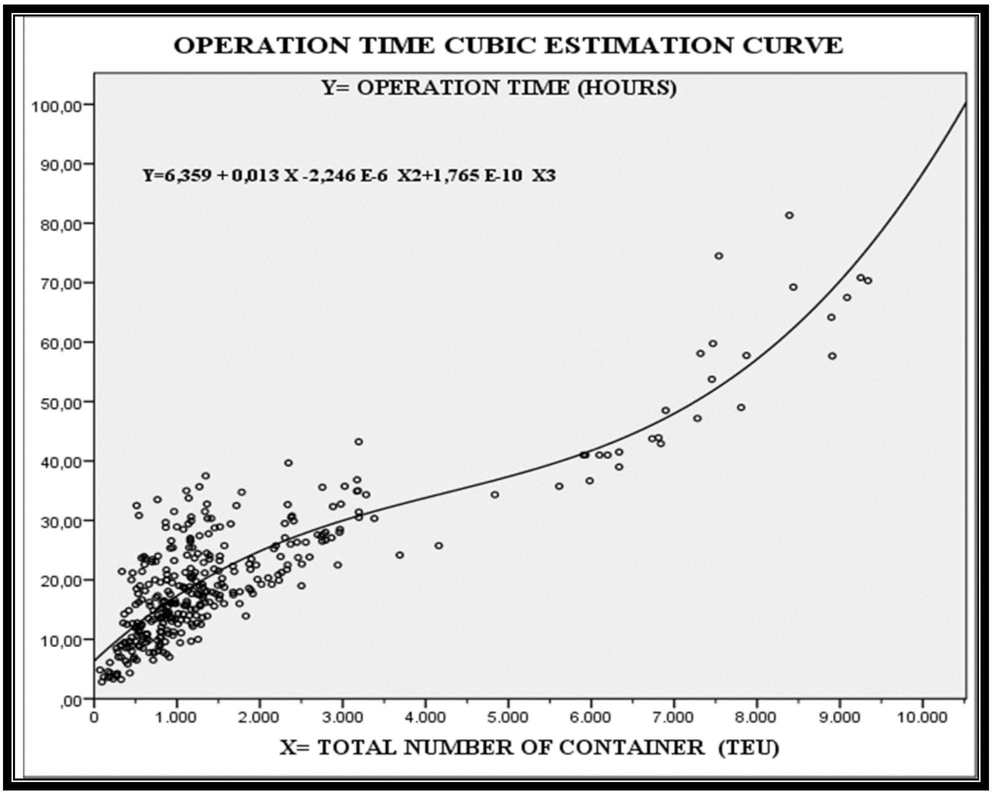
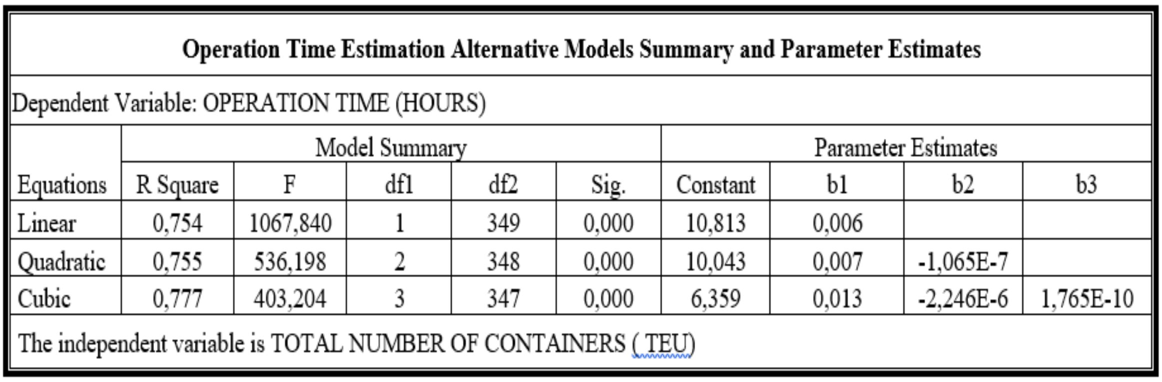


Figure 4. 5. Handled Containers vs. Operation Time Cubic Regression Curve
(Source, IBM SPSS Statistics 24)

Alternative models such as quadratic and cubic, offered by SPSS are presented in Table 4.16. The statistical parameters such as R^2 and F statistic value in this table are criteria for selecting the best curve to predict dependent variable operation time.

Table 4. 16 Containers (TEU) vs. Operation Time Estimation Models Parameters (Source, IBM SPSS Statistics 24).



Operation Time Estimation Alternative Models Summary and Parameter Estimates

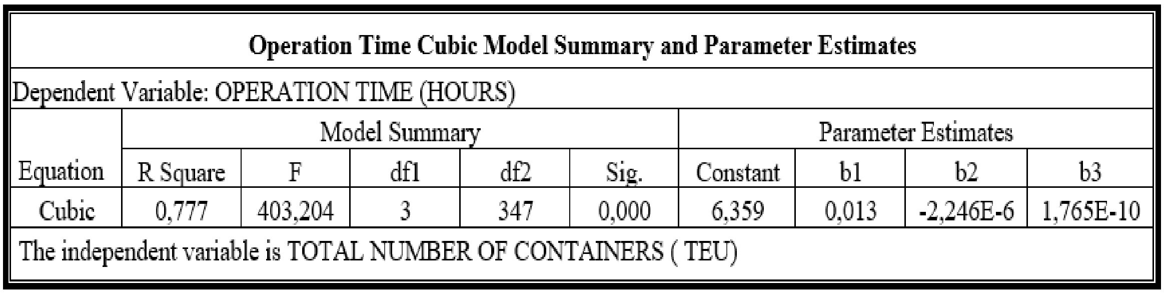
Dependent Variable: OPERATION TIME (HOURS)

Equations	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Linear	0,754	1067,840	1	349	0,000	10,813	0,006		
Quadratic	0,755	536,198	2	348	0,000	10,043	0,007	-1,065E-7	
Cubic	0,777	403,204	3	347	0,000	6,359	0,013	-2,246E-6	1,765E-10

The independent variable is TOTAL NUMBER OF CONTAINERS (TEU)

Having examined these criteria, nonlinear cubic regression model seems to be the most suitable one. The statistical model summary and coefficient estimates are listed in Table 4.17.

Table 4. 17 Containers (TEU) vs. Operation Time Cubic Estimation Model Parameters (Source, IBM SPSS Statistics 24).



Operation Time Cubic Model Summary and Parameter Estimates

Dependent Variable: OPERATION TIME (HOURS)

Equation	Model Summary					Parameter Estimates			
	R Square	F	df1	df2	Sig.	Constant	b1	b2	b3
Cubic	0,777	403,204	3	347	0,000	6,359	0,013	-2,246E-6	1,765E-10

The independent variable is TOTAL NUMBER OF CONTAINERS (TEU)

Cubic nonlinear regression equation is;

$$O = 1{,}765\, x^{3}\, 10^{-10} - 2{,}246\, x^{2}\, 10^{-6} + 0{,}013\, x + 6{,}359 \tag{4.4}$$

where;

O = Operation Time (hours) x =Total Handled Containers for each Vessel (TEU)

4.4.8. Time Parameters to Calculate Average Total Time in Port

Among several port performance indicators, two of them, namely Monthly Port Throughput (TEU) and Average Total Time in Port (in hour) are used as main performance indicators. Therefore, the simulation model structure is designed in such a way that the outputs should contain these two port performance indicators.

4.4.8.1. Definition of Time Parameters

The Total Time in Port (TOT) is the time the ship spends in the container port from arrival at the port to final departure. Actually, it is the sum of the following time intervals;

- Arrival to Berth (ABT)

If there is an available berth for incoming ship, it enters the port and ties up at that berth. This time interval starts with the arrival of the vessel to port and ends with its tying up at the berth.

ABT = ABDH - APDH
Where
ABDH is the time ship tyes up at available berth.

APDH is the time ship arrives the port. This is defined as the sum of the previous ship's arrival time and interarrival time (IAT).

- Arrival to Anchoring Area (AAT)

If all berths are busy or vacant berths aren't suitable for the incoming ship because of the length of the ship or/and draft, the ship has to proceed to a special sea area within the borders of the port, which is called as anchoring area to wait for next available berth. This time interval starts with the arrival of the vessel to port and ends with the arrival to anchoring area.

AAT = AADH - APDH

Where

APDH is the time ship arrives the port. This is defined as the sum of the previous ship's arrival time and interarrival time (IAT).

AADH is the time ship anchors in the waiting area.

- Waiting Time in Anchoring Time (WAT)

It is defined as the time a ship spends in anchoring area, waiting for an available berth. That is the delay between a ship's arrival in the port and its tying up at the berth.

WAT = DADH -AADH

Where
AADH is the time ship anchors in the waiting area and

DADH is the time ship leaves the waiting area.

- Anchoring Area to Berthing Time (APT)

This is the time required for the ship to proceed from waiting area to the berth.

APT = ABDH -.DADH

Where
DADH is the time ship leaves the waiting area.

ABDH is the time ship ties up at available berth.

- Berthing to Operation Time (BOT)

This is the delay between a ship's arrival to berth and commence of the container transfer due to preparation and possible bureaucratic process.

BOT = SODH – ABDH

Where
ABDH is the time ship ties up at available berth.

SODH is the staring time for container transfer either from the ship or berth.

- Operation Time (OPT)

Operation time is defined as the time a ship stays at a berth for loading and/or unloading containers. The operation time is established from the first container transfer to the last container move.

OPT = CODH – SODH

Where
SODH is the staring time for container transfer either from the ship or berth.

CODH is the finishing time for container transfer.

- Operation to Departure Time (ODT)

It is defined as the time a ship stays at a berth for departure after container transfer operation finishes. The operation time is established from the last container transfer to the time the last line is let go.

ODT = DBDH - CODH

Where
CODH is the finishing time for container transfer.

DBDH is the departure time of the ship.

- Total Time in Port (TOT)

After having defined all time steps in the model, the total time in port (TOT) is defined as the time the ship spends in the container port from arrival at the port to final departure. According to availability of berth, it may calculated either of the following formulas;

  - CASE-1

When ship enters the port, there is an available berth to tie up.

TOT = DBDH –APDH or,

TOT = ABT + BOT +OPT + ODT

- CASE-2

When ship enters the port, there is no available berth to tie up.

TOT = DBDH –APDH or,

TOT = AAT + WAT + APT + BOT +OPT + ODT

For each case, the chart diagrams in Figure 4.16 and Figure 4.17 are desined to get a visual description of time process.

4.4.8.2. Time Parameters to Calculate Average Total Time in Port

After having identified the time parameters to calculate the Average Total Time in Port (TOT) which is one of the key performance indicator, it is time to find some probabilistic distributions which may represent the historical data gathered from

MARPORT. As an example, the historical MARPORT data for the month January 2015 is listed in Table 4.18.

One fundamental issue in quantitative modeling is whether to model an input quantity as a deterministic (non-random) quantity, or to model it as a random variable. Since there is enough number of historical actual data related with time steps of the process, random variables for each time parameter will be deployed.

There exist a real system, MARPORT, to observe and to collect real life data on what corresponds to input quantitative modeling (Kelton et al., 2015). The basic choice is whether to use existing data directly or whether to fit a probability distribution to the existing one. In this thesis, ARENA Input Analyzer is used as tool to fit data, which is listed in Appendix A, to a probability distribution and to provide numerical estimates of the appropriate parameters. When the Input Analyzer fits a distribution to the historical data, it also estimates the distribution's parameters. Theoretical continuous distributions such as Normal, Gamma, Lognormal, Triangular and Erlang are used to generate random time figures in simulation model. To prepare data file, ASCII text file containing real historical data in free format is created.

In the following section, the results of Input Analysis of each time parameters are explained. Each analysis contains;

- Theoretical probability distribution which fits best to the related historical data,
- Estimates of the distribution parameters,
- Chi Square Test for the fitness test,
- Kolmogorov-Smirnov Test as an alternative fitness test,
- Data Summary including sample mean and standard deviation,
- Histogram Summary and histogram of the data with theoretical distribution curve,
- List of all candidate probability functions with their square errors, and
- Tables of cumulative probability values for actual and related probability functions in Appendix B.

Table 4. 18. MARPORT Vessel Load and Time Data, January 2015, (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Tonnage	Lenght	Draft	Total Discharged Containers TEU	Total Loaded Containers TEU	Total Handeled Containers TEU	Arrival at Port Station	Arrival at Anchoring Area	Departure from Anchoring Area	Arrival at Berth	Start Operation	Complete Operation	Departure From Berth	Inter Arrival Time (Hr)	Arrival to Anch. Area Time (Hr)	Waiting at Anch. Area Time (Hr)	Anch. Area to Bert. Time (Hr)	Arrival to Bert. Time (Hr)	Total Arrival to Bert. Time (Hr)	Berthing To Oprt. Time (Hr)	Operation Time (Hr)	Operation to Deprt. Time (Hr)	Total Port Time (Hr)
	(DWT)	(M)	(M)				(APDH)	(AADH)	(DADH)	(ABDH)	(SODH)	(CODH)	(DBDH)	(IAT)	(AAT)	(WAT)	(APT)	(ABT)	(TAT)	(BOT)	(OPT)	(ODT)	(TOT)
MSC ADRIANA AO451R	18.779	216	8,20	206	506	712	31.12.2014 23:00	31.12.2014 23:36	01.01.2015 11:00	01.01.2015 11:45	01.01.2015 16:30	01.01.2015 23:00	02.01.2015 00:05	16,25000	0,60000	11,40000	0,75000	_	12,75000	4,75000	6,50000	1,08333	25,08333
CAPE MANILA AC501R	22.315	212	9,80	284	370	654	31.12.2014 23:50	01.01.2015 00:50	02.01.2015 12:08	02.01.2015 12:50	02.01.2015 13:35	03.01.2015 03:05	03.01.2015 04:05	0,83333	1,00000	35,30000	0,70000	_	37,00000	0,75000	13,50000	1,00000	52,25000
MSC ASLI AO452A	14.150	217	10,00	680	143	823	02.01.2015 03:00	–	–	02.01.2015 04:05	02.01.2015 05:15	02.01.2015 19:00	02.01.2015 19:50	27,16667	_	_	_	1,08333	1,08333	1,16667	13,75000	0,83333	16,83333
JASPER S DA502A	13.795	148	6,30	444	644	1088	03.01.2015 10:30	–	–	03.01.2015 13:15	03.01.2015 14:10	04.01.2015 05:50	04.01.2015 06:50	31,50000	_	_	_	2,75000	2,75000	0,91667	15,66667	1,00000	20,33333
WESTERDIEK MT501R	39.000	210	14,50	471	247	718	04.01.2015 07:00	–	–	04.01.2015 08:30	04.01.2015 09:15	04.01.2015 17:05	04.01.2015 18:30	20,50000	_	_	_	1,50000	1,50000	0,75000	7,83333	1,41667	11,50000
KAETHE C. RICKMERS NT501R	68.282	295	7,50	2277	684	2961	04.01.2015 10:20	04.01.2015 11:37	04.01.2015 21:40	04.01.2015 22:25	04.01.2015 23:15	06.01.2015 03:15	06.01.2015 04:15	3,33333	1,28333	10,05000	0,75000	_	12,08333	0,83333	28,00000	1,00000	41,91667
MSC ELOISE MT452A	44.551	241	19,00	737	33	770	04.01.2015 16:00	04.01.2015 16:43	05.01.2015 23:20	05.01.2015 23:55	06.01.2015 00:50	06.01.2015 14:50	06.01.2015 16:00	5,66667	0,71667	30,61667	0,58333	_	31,91667	0,91667	14,00000	1,16667	48,00000
GOZDE BAYRAKTAR DH451A	21.417	157	9,40	436	740	1176	04.01.2015 17:20	04.01.2015 18:00	05.01.2015 00:35	05.01.2015 01:00	05.01.2015 02:00	05.01.2015 19:40	05.01.2015 21:45	1,33333	0,66667	6,58333	0,41667	_	7,66667	1,00000	17,66667	2,08333	28,41667
MSC EDITH AO501A	18.779	216	8,50	2	117	119	05.01.2015 00:00	05.01.2015 01:10	06.01.2015 12:05	06.01.2015 12:50	06.01.2015 13:30	06.01.2015 17:10	06.01.2015 19:40	6,66667	1,16667	34,91667	0,75000	_	36,83333	0,66667	3,66667	2,50000	43,66667
MSC MARYLENA AN501A	18.779	216	8,70	0	511	511	05.01.2015 00:30	05.01.2015 01:40	05.01.2015 22:05	05.01.2015 22:45	05.01.2015 23:10	06.01.2015 11:00	06.01.2015 11:45	0,50000	1,16667	20,41667	0,66667	_	22,25000	0,41667	11,83333	0,75000	35,25000
MSC HOGGAR DH452A	11.656	137	8,90	653	507	1160	05.01.2015 16:40	05.01.2015 16:55	06.01.2015 04:30	06.01.2015 04:55	06.01.2015 06:15	07.01.2015 09:15	07.01.2015 10:55	16,16667	0,25000	11,58333	0,41667	_	12,25000	1,33333	27,00000	1,66667	42,25000
AS VENUS DI451A	18.400	159	7,20	21	765	786	05.01.2015 17:00	05.01.2015 17:20	06.01.2015 05:20	06.01.2015 06:00	06.01.2015 06:30	06.01.2015 20:00	06.01.2015 22:00	0,33333	0,33333	12,00000	0,66667	_	13,00000	0,50000	13,50000	2,00000	29,00000
AYSE NAZ BAYRAKTAR DD451A	21.417	157	8,10	723	658	1381	05.01.2015 23:35	06.01.2015 00:15	06.01.2015 20:55	06.01.2015 21:45	06.01.2015 22:30	08.01.2015 02:15	08.01.2015 03:15	6,58333	0,66667	20,66667	0,83333	_	22,16667	0,75000	27,75000	1,00000	51,66667
MSC AMERICA AC502R	45.668	216	8,00	1080	344	1424	06.01.2015 08:00	06.01.2015 08:46	09.01.2015 15:30	09.01.2015 16:15	09.01.2015 17:15	10.01.2015 11:10	10.01.2015 16:30	8,41667	0,76667	78,73333	0,75000	_	80,25000	1,00000	17,91667	5,33333	104,50000
MSC RAPALLO FT501A	154.538	366	12,70	3233	3664	6897	06.01.2015 22:20	–	–	07.01.2015 01:05	07.01.2015 02:20	09.01.2015 02:50	09.01.2015 03:50	14,33333	_	_	_	2,75000	2,75000	1,25000	48,50000	1,00000	53,50000
JASPER S DA503A	13.795	148	6,30	111	547	658	08.01.2015 16:30	08.01.2015 16:54	10.01.2015 17:30	10.01.2015 18:05	10.01.2015 22:00	11.01.2015 07:50	11.01.2015 08:50	42,16667	0,40000	48,60000	0,58333	_	49,58333	3,91667	9,83333	1,00000	64,33333
MSC LORENA NM502R	59.587	275	11,80	1028	1712	2740	09.01.2015 16:00	–	_	09.01.2015 17:00	09.01.2015 18:30	10.01.2015 21:50	10.01.2015 22:30	23,50000	_	_	_	1,00000	1,00000	1,50000	27,33333	0,66667	30,50000
WESTERTAL MT501A	38.700	211	7,40	477	44	521	11.01.2015 22:45	–	_	12.01.2015 00:15	12.01.2015 01:15	12.01.2015 12:00	12.01.2015 12:30	54,75000	_	_	_	1,50000	1,50000	1,00000	10,75000	0,50000	13,75000
MSC ELOISE MT502R	44.541	241	7,90	126	541	667	11.01.2015 23:10	–	_	12.01.2015 01:20	12.01.2015 02:00	12.01.2015 09:45	12.01.2015 10:50	0,41667	_	_	_	2,16667	2,16667	0,66667	7,75000	1,08333	11,66667
NORTHERN VITALITY AC501A	40.004	195	7,20	157	397	554	12.01.2015 21:30	12.01.2015 22:00	16.01.2015 16:35	16.01.2015 17:05	16.01.2015 17:45	17.01.2015 05:50	17.01.2015 06:50	22,33333	0,50000	90,58333	0,50000	_	91,58333	0,66667	12,08333	1,00000	105,33333
SANTA GIORGINA YG502A	30.201	181	14,00	0	168	168	12.01.2015 21:30	–	–	12.01.2015 22:30	12.01.2015 23:15	13.01.2015 03:50	13.01.2015 04:20	0,00000	_	_	_	1,00000	1,00000	0,75000	4,58333	0,50000	6,83333
MSC MATILDE NT502R	67.615	294	9,70	2016	1178	3194	13.01.2015 19:40	–	–	13.01.2015 21:55	13.01.2015 23:00	15.01.2015 06:25	15.01.2015 09:05	22,16667	_	_	_	2,25000	2,25000	1,08333	31,41667	2,66667	37,41667
AS VENUS DI452A	18.400	159	7,20	7	776	783	14.01.2015 00:30	14.01.2015 01:30	17.01.2015 07:50	17.01.2015 08:20	17.01.2015 09:00	17.01.2015 17:45	17.01.2015 22:35	4,83333	1,00000	78,33333	0,50000	_	79,83333	0,66667	8,75000	4,83333	94,08333
MSC ELEONORA AC501A	41.667	202	10,10	789	1042	1831	14.01.2015 16:00	14.01.2015 16:50	17.01.2015 14:30	17.01.2015 15:20	17.01.2015 16:10	18.01.2015 06:05	18.01.2015 08:05	15,50000	0,83333	69,66667	0,83333	_	71,33333	0,83333	13,91667	2,00000	88,08333
MSC ASLI AN502A	14.150	217	10,00	1	908	909	14.01.2015 18:00	14.01.2015 18:48	15.01.2015 05:54	15.01.2015 06:30	15.01.2015 07:30	15.01.2015 14:30	15.01.2015 19:50	2,00000	0,80000	11,10000	0,60000	_	12,50000	1,00000	7,00000	5,33333	25,83333
MSC CORDOBA NM503R	63.352	274	11,60	689	760	1449	15.01.2015 02:20	15.01.2015 02:30	15.01.2015 09:40	15.01.2015 10:25	15.01.2015 10:50	16.01.2015 02:25	16.01.2015 03:30	8,33333	0,16667	7,16667	0,75000	_	8,08333	0,41667	15,58333	1,08333	25,16667
MSC EQUATOR DI451A	20.147	167	6,80	150	655	805	15.01.2015 16:10	15.01.2015 16:24	15.01.2015 22:00	15.01.2015 22:30	16.01.2015 00:15	16.01.2015 13:50	16.01.2015 14:35	13,83333	0,23333	5,60000	0,50000	_	6,33333	1,75000	13,58333	0,75000	22,41667
MSC GAIA FT502A	162.867	366	14,50	3134	2846	5980	15.01.2015 19:40	–	–	15.01.2015 21:40	15.01.2015 22:40	17.01.2015 11:20	17.01.2015 12:20	3,50000	_	_	_	2,00000	2,00000	1,00000	36,66667	1,00000	40,66667
MSC CAITLIN AO502A	18.779	216	7,00	217	52	269	16.01.2015 01:30	–	–	16.01.2015 05:00	16.01.2015 05:30	16.01.2015 14:00	16.01.2015 16:00	5,83333	_	_	_	3,50000	3,50000	0,50000	8,50000	2,00000	14,50000
MSC MARYLENA AO502A	18.779	216	7,20	1059	87	1146	16.01.2015 13:30	–	–	16.01.2015 15:50	16.01.2015 16:15	17.01.2015 06:15	17.01.2015 07:10	12,00000	_	_	_	2,33333	2,33333	0,41667	14,00000	0,91667	17,66667
JASPER S DA504A	13.795	148	6,30	626	492	1118	16.01.2015 17:50	16.01.2015 18:00	19.01.2015 05:05	19.01.2015 05:50	19.01.2015 06:45	19.01.2015 20:00	19.01.2015 20:50	4,33333	0,16667	59,08333	0,75000	_	60,00000	0,91667	13,25000	0,83333	75,00000
MSC KOREA MT502A	42.980	243	6,90	445	29	474	17.01.2015 11:30	–	–	17.01.2015 13:40	17.01.2015 14:20	17.01.2015 21:00	17.01.2015 22:00	17,66667	_	_	_	2,16667	2,16667	0,66667	6,66667	1,00000	10,50000
GOZDE BAYRAKTAR DH452A	21.417	157	9,40	686	651	1337	17.01.2015 21:10	–	–	17.01.2015 23:30	18.01.2015 00:15	18.01.2015 18:10	18.01.2015 19:05	9,66667	_	_	_	2,33333	2,33333	0,75000	17,91667	0,91667	21,91667
WESTERTAL MT503R	38.700	211	7,10	476	322	798	18.01.2015 16:00	–	–	18.01.2015 16:55	18.01.2015 17:45	19.01.2015 02:50	19.01.2015 03:55	18,83333	_	_	_	0,91667	0,91667	0,83333	9,08333	1,08333	11,91667
MACARO DC501A	22.083	168	7,40	590	720	1310	19.01.2015 13:30	–	–	19.01.2015 15:00	19.01.2015 16:35	20.01.2015 06:15	20.01.2015 07:20	21,50000	_	_	_	1,50000	1,50000	1,58333	13,66667	1,08333	17,83333
MSC EVA FT503A	162.867	366	29,90	3537	2798	6335	19.01.2015 21:00	19.01.2015 21:37	20.01.2015 09:30	20.01.2015 10:30	20.01.2015 12:30	22.01.2015 03:30	22.01.2015 04:20	7,50000	0,61667	11,88333	1,00000	_	13,50000	2,00000	39,00000	0,83333	55,33333
MSC ASLI AO503A	14.150	217	10,00	204	175	379	21.01.2015 03:00	–	–	21.01.2015 04:05	21.01.2015 05:05	21.01.2015 13:40	21.01.2015 15:45	30,00000	_	_	_	1,08333	1,08333	1,00000	8,58333	2,08333	12,75000
MSC ATLANTA NM504R	55.482	267	8,30	798	881	1679	21.01.2015 15:10	–	–	21.01.2015 17:00	21.01.2015 18:00	22.01.2015 11:30	22.01.2015 12:20	12,16667	_	_	_	1,83333	1,83333	1,00000	17,50000	0,83333	21,16667
AYSE NAZ BAYRAKTAR DD452A	21.417	157	8,10	800	718	1518	21.01.2015 18:45	21.01.2015 19:40	22.01.2015 09:55	22.01.2015 10:35	22.01.2015 14:20	23.01.2015 19:15	23.01.2015 19:50	3,58333	0,91667	14,25000	0,66667	_	15,83333	3,75000	28,91667	0,58333	49,08333
MSC MEDITERRANEAN AC502A	41.583	203	8,90	903	772	1675	21.01.2015 23:25	–	–	22.01.2015 06:40	22.01.2015 07:40	23.01.2015 06:00	23.01.2015 07:00	4,66667	_	_	_	7,25000	7,25000	1,00000	22,33333	1,00000	31,58333
SCT SANTIAGO NT503R	31.759	172	9,20	1138	1250	2388	22.01.2015 12:00	–	–	22.01.2015 13:30	22.01.2015 15:00	23.01.2015 21:45	23.01.2015 23:15	12,58333	_	_	_	1,50000	1,50000	1,50000	30,75000	1,50000	35,25000
MSC CELINE MT503A	39.000	210	8,60	276	3	279	23.01.2015 07:00	23.01.2015 07:50	24.01.2015 00:05	24.01.2015 00:25	24.01.2015 01:15	24.01.2015 05:30	24.01.2015 07:45	19,00000	0,83333	16,25000	0,33333	_	17,41667	0,83333	4,25000	2,25000	24,75000
MSC HOGGAR DH502A	11.656	137	8,90	169	445	614	24.01.2015 07:00	–	–	24.01.2015 07:05	24.01.2015 08:50	25.01.2015 03:00	25.01.2015 03:40	24,00000	_	_	_	0,08333	0,08333	1,75000	18,16667	0,66667	20,66667
POHORJE NT504R	52.683	269	8,60	1755	844	2599	24.01.2015 07:05	–	–	24.01.2015 09:30	24.01.2015 10:00	25.01.2015 09:50	25.01.2015 10:55	0,08333	_	_	_	2,41667	2,41667	0,50000	23,83333	1,08333	27,83333
MSC ADRIANA AO504A	18.779	216	8,20	0	94	94	24.01.2015 10:30	24.01.2015 11:00	24.01.2015 21:30	24.01.2015 22:15	24.01.2015 23:10	25.01.2015 02:00	25.01.2015 03:15	3,41667	0,50000	10,50000	0,75000	_	11,75000	0,91667	2,83333	1,25000	16,75000
MSC KOREA MT504R	42.980	243	6,90	417	457	874	25.01.2015 06:30	–	–	25.01.2015 08:00	25.01.2015 09:00	25.01.2015 16:30	25.01.2015 17:10	20,00000	_	_	_	1,50000	1,50000	1,00000	7,50000	0,66667	10,66667
MSC ELEONORA AC504R	41.667	202	10,10	260	378	638	25.01.2015 07:50	–	–	25.01.2015 09:00	25.01.2015 09:40	25.01.2015 19:50	25.01.2015 20:50	1,33333	_	_	_	1,16667	1,16667	0,66667	10,16667	1,00000	13,00000
AS VENUS DI501A	18.400	159	7,20	210	421	631	25.01.2015 09:00	–	–	25.01.2015 12:00	25.01.2015 13:00	25.01.2015 23:50	26.01.2015 00:50	1,16667	_	_	_	3,00000	3,00000	1,00000	10,83333	1,00000	15,83333
JASPER S DA505A	13.795	148	6,30	798	421	1219	26.01.2015 03:55	–	–	26.01.2015 05:15	26.01.2015 06:35	26.01.2015 21:40	26.01.2015 22:35	18,91667	_	_	_	1,33333	1,33333	1,33333	15,08333	0,91667	18,66667

- **Interarrival Time (IAT) Distribution Summary**

Before using the ARENA Input Analyzer to find the best probability distribution which represents the historical vessel interarrival data set, the process of calculating interarrival data is explained in detail. In general, the interarrival time is the amount of time between the arrival of one customer and the arrival of the next customer or time between successive arrivals (www.sciencing.com, 2017). In port operations, the vessel interarrival time means the amount of time between the arrival of one vessel and the arrival of the next vessel or time between successive arrivals of container vessels.

In order to have more understandable calculation, arrival times of eight ships in the first week of January 2015 are listed in Table 4.19. First container vessel MSC ASLI entered the MARPORT on 02 January 2015 at $03^h\,00^m$. One day later, the follow on vessel named JASPER S arrived the port on 03 January 2015 at $10^h\,30^m$. The interarrival time of JASPER S is the time difference of these to arrivals which is calculated by subtracting the first value (02 Jan 15, $03^h\,00^m$) from the second time value (03 Jan 2015, $10^h\,30^m$). As listed in the right columns of the Table 4.19, the result is $31^h\,30^m$ or 31,500 hours.

Table 4.19. Sample Data for MARPORT Vessel Arrival, Interarrival Time, Jan 15 (Source, MARPORT Administration, 11 September 2015).

	Arrival Time (APDH)		Interarrival Time (IAT)	
Vessel Name	**Date**	**Hour&Min.**	**Hour&Min.**	**Hour**
MSC ASLI	02 Jan 2015	$03^h\,00^m$	------	------
JASPER S	03 Jan 2015	$10^h\,30^m$	$31^h\,30^m$	31,500
WESTERDIEK	04 Jan 2015	$07^h\,00^m$	$20^h\,30^m$	20,500
KAETHE C. RICK.S	04 Jan 2015	$10^h\,20^m$	$03^h\,20^m$	3,333
MSC ELOISE	04 Jan 2015	$16^h\,00^m$	$05^h\,40^m$	5,337
GOZDE BAYRAK	04 Jan 2015	$17^h\,20^m$	$06^h\,40^m$	6,337
MSC EDITH	05 Jan 2015	$00^h\,00^m$	$31^h\,30^m$	31,500
MSC MARYLENA	05 Jan 2015	$00^h\,30^m$	$00^h\,30^m$	0,500

Similar calculations are executed for other container vessels whose data are displayed in Appendix A. Total of 815 interarrival time values are calculated. This number is assessed to be big enough to reach statistically significant estimation. 40 of these figures are listed in Table 4.20

Table 4.20. Sample Data for MARPORT Vessel Interarrival Time (IAT) (Source, MARPORT Administration, 11 September 2015).

Interarrival Time (IAT) (Hour)	Interarrival Time (IAT) (Hour)	Interarrival Time (IAT) (Hour)	Interarrival Time (IAT) (Hour)
31,500	37,000	8,833	29,000
20,500	1,000	13,000	5,917
3,333	26,500	6,000	28,417
5,337	17,167	6,500	2,083
6,337	15,083	2,500	14,167
31,500	4,583	5,837	6,250
0,500	3,667	4,417	0,333
0,833	6,167	10,837	11,667
27,167	0,833	5,417	19,833
51,500	14,500	13,250	16,667

As a following step, by using Histogram tool of IBM SPSS Statistics Viewer, Histogram of 815 interarrival values are displayed in Figure 4.6. There are total of 30 intervals starting with 0,00 hours and ending at 60,00 hours. Each of them has two hour time interval. ***X*** axis represents the interarrival time value as hour. On the other hand, ***Y*** axis shows frequency, the number of the data points falling into this specific interval.

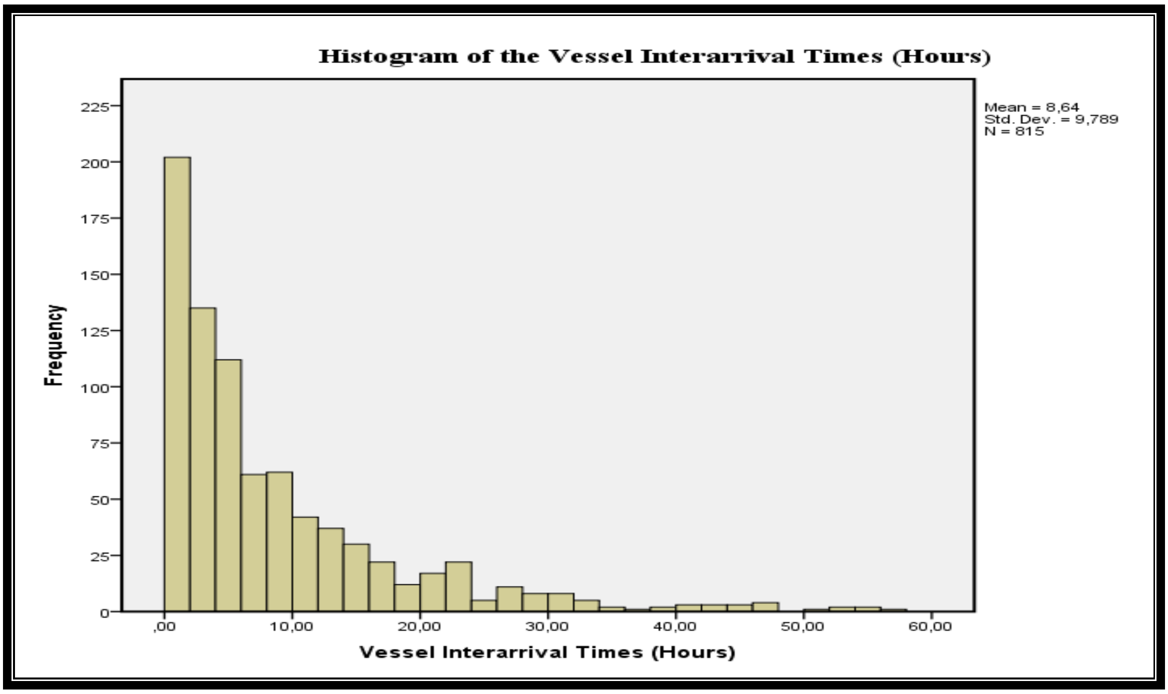


Figure 4.6. Histogram of Interarrival Times (IAT).

The mean value and standard deviation of these vessel interarrival times are 8,64 hours and 9,789 hours respectively. The highest frequency, 202, belongs to the interval between 0,00-2,00 hours which means that interarrival times of 202 vessels out of 815 vessels stand between 0,00-2,00 hours. Histogram intervals and associated frequencies are listed in Table 4.21.

Table 4. 21. Histogram Intervals and Frequencies of Vessel Interarrival Times (Source, MARPORT Administration, 11 September 2015).

Histogram Interval (Hours)	Number of Data Points (Frequency)	Histogram Interval (Hours)	Number of Data Points (Frequency)	Histogram Interval (Hours)	Number of Data Points (Frequency)
0,00-2,00	202	20,01-22,00	20	40,01-42,00	3
2,01-4,00	128	22,01-24,00	22	42,01-44,00	3
4,01-6,00	113	24,01-26,00	6	44,01-46,00	3
6,01-8,00	60	26,01-28,00	10	46,01-48,00	5
8,01-10,00	61	28,01-30,00	9	48,01-50,00	0
10,01-12,00	41	30,01-32,00	9	50,01-52,00	1
12,01-14,00	36	32,01-34,00	6	52,01-54,00	2
14,01-16,00	28	34,01-36,00	2	54,01-56,00	2
16,01-18,00	22	36,01-38,00	1	56,01-58,00	1
18,01-20,00	12	38,01-40,00	2	58,01-60,00	0

After calculating and examine the interarrival time data set, ARENA Input Analyzer is deployed to get the best probability distribution function with parameters to represent statistically these vessel interarrival times. The result and the statistic tests such as Chi Square Test and Kolmogorov-Smirnov Test including histogram with best curve fitting are explained in following paragraphs. According to these tests, the Gamma distribution with parameters 10,6 and 0,814 can represent the interarrival times of MARPORT interarrival data sets of 815 independent vessel arrival.

During the running phase of the simulation model, these distributions with associated parameters will be used to generate related time figures. In Chapter 4.9.2 under the heading of " Generation of time Parameters of Incoming Container Ship", example of single run simulation explains this process in detail. The results of ARENA Input Analyzer calculations for interarrival times are as follows;

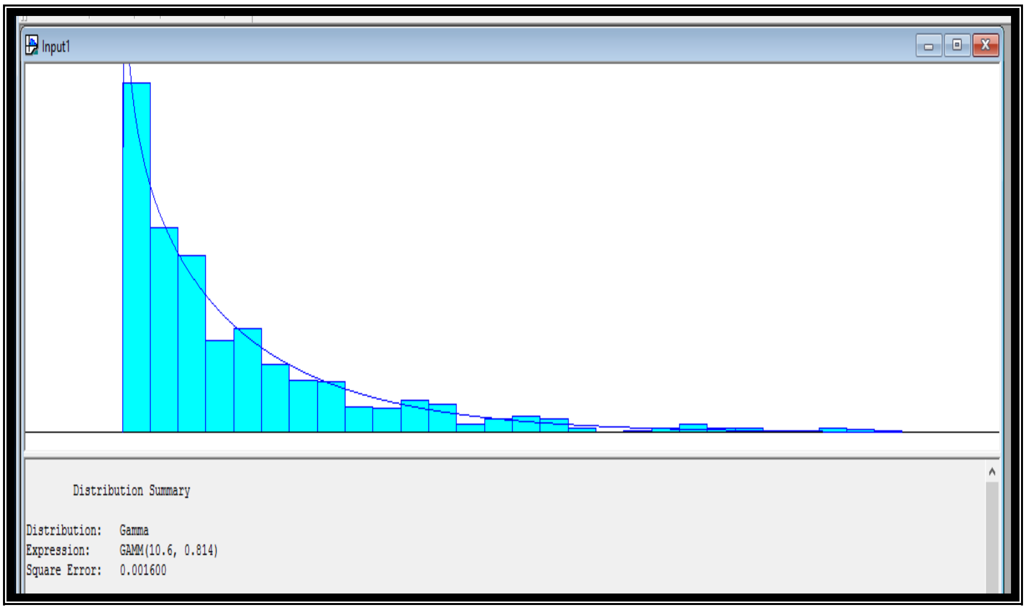
```
Distribution:               Gamma
        Expression   :              GAMM(10,6; 0,814)
        Square Error:               0,00160
Chi Square Test

        Number of intervals      = 21
        Degrees of freedom       = 18
        Test Statistic           = 29,7
        Corresponding p-value  = 0,042
Kolmogorov-Smirnov Test

        Test Statistic           = 0,0251
        Corresponding p-value   > 0,15
Data Summary

        Number of Data Points = 815
        Min Data Value          = 0,001
        Max Data Value         = 56,5
        Sample Mean             = 8,64
        Sample Std Dev          = 9,79
Histogram Summary

        Histogram Range        = 0 to 57
        Number of Intervals     = 30
```



```
Distribution Summary

Distribution:   Gamma
Expression:     GAMM(10.6, 0.814)
Square Error:   0.001600
```

Figure 4.7. Probabilty Curve Fitting for Vessel Interarrival Times (IAT).

Candidate probability functions are listed below. These are possible functions with square errors. The smaller the square error value means the better curve fitting. The Gamma distribution with the smallest square error (0,00160) is the best function to represent sample data.

Function :	Square Error :
Gamma	0,00160
Weibull	0,00215
Beta	0,00245
Lognormal	0,00495
Exponential	0,00514
Erlang	0,00514
Normal	0,05870
Triangular	0,06800
Uniform	0,09880

Similar systematic approach has also been followed for other time parameters. Summary of these tests and distribution fittings are as follows.

- **Arrival to Berth Time (ABT) Distribution Summary**

If there is an available berth for incoming ship, it enters the port and ties up at that berth. This time interval starts with the arrival of the vessel to port and ends with its tying up at the berth.

ABT = ABDH – APDH

Where

APDH is the time ship arrives the port. This is defined as the sum of the previous ship’s arrival time and interarrival time (IAT).

ABDH is the time ship ties up at available berth.

As an example, arrival and berthing times of eight ships on January 2015 are listed in Table 4.22. First container vessel ASLI entered the MARPORT on 02 January 2015 at $03^h 00^m$. Since there exists an available berth, ASLI proceeded directly to the allocated berth. Berthing completed same day at 04^h 05^m. The arrival to berth time (ABT) of ASLI is calculated by subtracting the first value (APDH) (02 Jan 15, $03^h 00^m$) from the second time value (AADH) (02 Jan 2015, $04^h 05^m$). As listed in the right columns of the Table 4.22, the result is $01^h 05^m$ or 1,0833 hours.

Table 4.22. Sample Data for MARPORT Vessels Arrival to Berth Time, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Arrival to Port (APDH)		Berthing (AADH)		Arrival to Berth Time (ABT)	
	Date	Hour&Min.	Hour&Min.	Hour	Hour&Min	Hour
ASLI	02 Jan 15	$03^h 00^m$	02 Jan 15	$04^h 05^m$	$01^h 05^m$	1,0833
WESTERDIEK	04 Jan 15	$07^h 00^m$	04 Jan 15	$08^h 30^m$	$01^h 30^m$	1,5000
KAETHE C.	04 Jan 15	$10^h 20^m$	04 Jan 15	$12^h 25^m$	$02^h 05^m$	2,0833
ELOISE	04 Jan 15	$16^h 00^m$	05 Jan 15	$00^h 55^m$	$08^h 55^m$	8,9167
AMERICA	06 Jan 15	$08^h 00^m$	06 Jan 15	$16^h 15^m$	$08^h 15^m$	8,2500
RAPALLO	06 Jan 15	$22^h 20^m$	07 Jan 15	$01^h 05^m$	$02^h 45^m$	2,7500
LORENA	09 Jan 15	$16^h 00^m$	09 Jan 15	$17^h 00^m$	$01^h 00^m$	1,0000
WESTERTAL	11 Jan 15	$22^h 45^m$	12 Jan 15	$00^h 15^m$	$01^h 30^m$	1,5000

Similar calculations are executed for other container vessels whose data are displayed in Appendix A. Total of 396 interarrival time values are calculated. This number is assessed as big enough to reach statistically significant estimations. 40 of these figures are listed in Table 4.23.

Table 4.23. MARPORT Vessel Arrival to Berth Time (ABT) Data (Source, MARPORT Administration, 11 September 2015).

Arrival to Berth Time (ABT) (Hour)	**Arrival to Berth Time (ABT) (Hour)**	**Arrival to Berth Time (ABT) (Hour)**	**Arrival to Berth Time (ABT) (Hour)**
1,75000	0,83333	1,83333	1,16667
1,33333	0,75000	1,25000	2,00000
1,50000	0,91667	1,50000	1,41667
1,08333	0,58333	0,08333	0,66667
1,50000	0,91667	2,41667	1,25000
1,00000	0,83333	1,50000	1,08333
1,66667	1,20000	1,16667	1,65000
0,91667	1,30000	1,40000	1,00000
1,26000	1,33333	7,33333	1,76667
1,00000	1,16667	0,58333	0,66667

ARENA Input Analyzer is deployed to get the best probability distribution function with parameters to represent statistically these arrival to berth times. According to these tests, the Beta distribution with parameters 2,2 and 1,7 can represent the interarrival times of data sets of 396 independent vessel arrival.

Distribution: Beta

Expression : 2 * BETA (2,2; 1,7)
Square Error: 0,008114

Chi Square Test

Number of intervals = 16
Degrees of freedom = 13
Test Statistic = 61,8
Corresponding p-value < 0,005

Kolmogorov-Smirnov Test

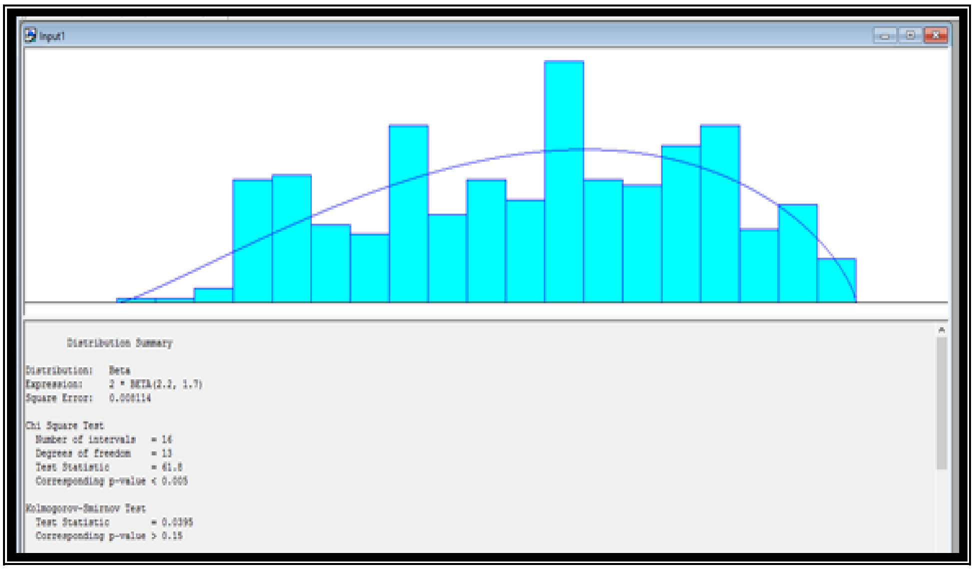
Test Statistic = 0,0395
Corresponding p-value > 0,15

Data Summary

Number of Data Points = 396
Min Data Value = 0,0833
Max Data Value = 9,92
Sample Mean = 1,13
Sample Std. Dev = 0,448

Histogram Summary

Histogram Range = 0 to 2
Number of Intervals = 19



```
        Distribution Summary

Distribution:   Beta
Expression:     2 * BETA(2.2, 1.7)
Square Error:   0.008114

Chi Square Test
  Number of intervals   = 16
  Degrees of freedom    = 13
  Test Statistic        = 61.8
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0395
  Corresponding p-value > 0.15
```

Figure 4.8. Probabilty Curve Fitting for Arrival to Berth Time (ABT).

Fit All Functions

Function :	Square Error :
Beta	0,00811
Triangular	0,01130
Normal	0,01180
Weibull	0,01180
Gamma	0,01480
Erlang	0,01480
Uniform	0,01800
Lognormal	0,01820
Exponential	0,04160

- **Arrival to Anchoring Area Time (AAT) Distribution Summary**

If all berths are busy or vacant berths aren’t suitable for the incoming ship, the ship has to proceed to a anchoring area to wait for next available berth. This time interval starts with the arrival of the vessel to port and ends with the arrival to anchoring area.

AAT = AADH - APDH

Where

APDH is the time ship arrives the port.

AADH is the time ship anchors in the waiting area.

As an example, arrival to anchoring area times of eight ships on January 2015 are listed in Table 4.24. JASPER S entered the MARPORT on 03 January 2015 at 10^h 30^m (APDH). Since there is no available berth, the vessel sailed directly to the waiting area and anchored at 10^h 42^m (AADH). The arrival to anchoring area time (AAT) of JASPER S is the time difference of these to arrivals which is calculated by subtracting the first value (03 Jan 15, 10^h 30^m) from the second time value (03 Jan 2015, 10^h 42^m). As listed in the right columns of the Table 4.24, the result is 00^h 12^m or 0,20 hours.

Table 4.24. Sample Data for MARPORT Vessels Arrival to Anchoring Area Time, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Arrival to Port (APDH)		Arrival to Anchorage (AADH)		Vessels Arrival to Anchoring Area Time (AAT)	
	Date	Hour&Min.	Hour&Min.	Hour	Hour&Min	Hour
JASPER S	03 Jan 15	10^h 30^m	03 Jan 15	10^h 42^m	00^h 12^m	0,2000
G. BAYRAKTAR	04 Jan 15	17^h 20^m	04 Jan 15	18^h 00^m	00^h 40^m	0,6667
EDITH	05 Jan 15	00^h 00^m	05 Jan 15	01^h 10^m	01^h 10^m	1,1667
MARYLENA	05 Jan 15	00^h 30^m	05 Jan 15	01^h 40^m	01^h 10^m	1,1667
HOGGAR	05 Jan 15	16^h 40^m	05 Jan 15	16^h 55^m	00^h 15^m	0,2500
VENUS	05 Jan 015	17^h 00^m	05 Jan 15	17^h 20^m	00^h 20^m	0,3333
A. BAYRAKTAR	05 Jan 015	23^h 35^m	06 Jan 15	00^h 15^m	00^h 40^m	0,6667
N.VITALITY	14 Jan 15	21^h 30^m	14 Jan 15	22^h 00^m	00^h 30^m	0,5000

Similar calculations are executed for other container vessels whose data are displayed in Tables in Appendix A. Total of 234 arrival to anchoring area time values are calculated. There is big enough number of data to reach statistically significant estimations. 40 of these figures are listed in Table 4.25.

Table 4.25. MARPORT Vessel Arrival to Anchoring Area Time (AAT) Data (Source, MARPORT Administration, 11 September 2015).

Arrival to Anchoring Area Time (AAT) (Hour)	Arrival to Anchoring Area Time (AAT) (Hour)	Arrival to Anchoring Area Time (AAT) (Hour)	Arrival to Anchoring Area Time (AAT) (Hour)
0,600	0,233	1,283	0,833
1,000	0,166	0,716	0,799
1,280	0,616	0,667	0,166
0,716	0,916	1,167	0,233
0,667	0,833	1,167	0,166
1,167	0,499	0,250	0,616
1,167	0,070	0,333	0,916
0,250	0,590	0,666	0,833
0,333	0,610	0,766	0,499
0,667	0,640	0,400	0,070

According to the tests in ARENA Input Analyzer, the Triangular distribution with parameters 0,0, 0,622 and 1,41 can represent the data sets of the arrival to anchoring area times of 234 independent vessel arrival.

Distribution: Triangular

Expression : TRIA(0,0; 0,622; 1,41)
Square Error: 0,019905
Chi Square Test
Number of intervals = 11
Degrees of freedom = 9
Test Statistic = 85
Corresponding p-value < 0,005

Kolmogorov-Smirnov Test

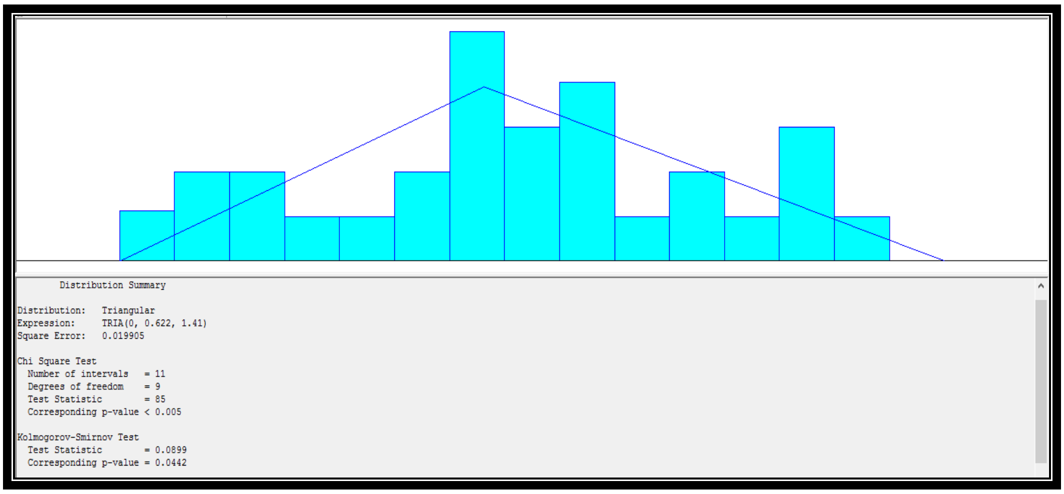
Test Statistic = 0,0899
Corresponding p-value = 0,0442

Data Summary

Number of Data Points = 234
Min Data Value = 0,07
Max Data Value = 1,28
Sample Mean = 0,677
Sample Std Dev = 0,33

Histogram Summary

Histogram Range = 0 to 1,41
Number of Intervals = 15



```
        Distribution Summary

Distribution:   Triangular
Expression:     TRIA(0, 0.622, 1.41)
Square Error:   0.019905

Chi Square Test
  Number of intervals   = 11
  Degrees of freedom    = 9
  Test Statistic        = 85
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0899
  Corresponding p-value = 0.0442
```

Figure 4.9. Probabilty Curve Fitting for Arrival to Anchoring Area Time (AAT).

Fit All Functions

Function :	Square Error :
Triangular	0,0199
Normal	0,0204
Beta	0,0211
Weibull	0,0239
Uniform	0,0298
Erlang	0,0300
Gamma	0,0302
Lognormal	0,0397
Exponential	0,0492

- **Waiting Time at Anchor (WAT) Distribution Summary**

It is defined as the time ship spends in anchoring area, waiting for an available berth. That is the delay between a ship's arrival in the port and its tying up at the berth.

WAT = DADH -AADH

Where

AADH is the time ship anchors in the waiting area and

DADH is the time ship leaves the waiting area.

Vessels waiting time at anchor of eight ships in January 2015 are listed in Table 4.26.

Table 4.26. Sample Data for MARPORT Vessels Waiting Time at Anchor, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	**Arrival to Anchorage (AADH)**		**Departure from Anchorage (DADH)**		**Vessels Waiting Time at Anchor (WAT)**	
	Date	**Hour&Min.**	**Hour&Min.**	**Hour**	**Hour&Min**	**Hour**
JASPER S	03 Jan 15	$10^h 42^m$	03 Jan 15	$12^h 35^m$	$01^h 53^m$	1,8833
G. BAYRAKTAR	04 Jan 15	$18^h 00^m$	05 Jan 15	$00^h 35^m$	$06^h 35^m$	6,5833
EDITH	05 Jan 15	$01^h 10^m$	06 Jan 15	$12^h 05^m$	$34^h 55^m$	34,9167
MARYLENA	05 Jan 15	$01^h 40^m$	05 Jan 15	$22^h 05^m$	$20^h 25^m$	20,4167
HOGGAR	05 Jan 15	$16^h 55^m$	06 Jan 15	$04^h 30^m$	$11^h 35^m$	11,5833
VENUS	05 Jan 15	$17^h 20^m$	06 Jan 15	$05^h 20^m$	$12^h 00^m$	12,0000
A. BAYRAKTAR	06 Jan 15	$00^h 15^m$	06 Jan 15	$20^h 55^m$	$20^h 40^m$	20,6667
N.VITALITY	14 Jan 15	$22^h 00^m$	16 Jan 15	$16^h 35^m$	$42^h 35^m$	42,5833

Similar calculations are executed for other container vessels whose data are displayed in Appendix A. Total of 234 waiting time at anchor (WAT) values are calculated. This number is assessed to be big enough to reach statistically significant estimations. 40 of these figures are listed in Table 4.27.

Table 4.27. MARPORT Vessels Waiting Time at Anchor (WAT) Data (Source, MARPORT Administration, 11 September 2015).

Waiting Time at Anchor (WAT) (Hour)	Waiting Time at Anchor (WAT) (Hour)	Waiting Time at Anchor (WAT) (Hour)	Waiting Time at Anchor (WAT) (Hour)
13,880	11,470	78,120	11,040
16,180	1,860	45,250	7,060
17,000	6,580	5,210	16,250
15,750	34,910	59,010	10,180
20,090	20,430	14,250	37,500
9,500	11,900	19,750	4,000
4,870	12,000	4,750	12,030
24,970	20,240	5,960	10,120
15,990	48,210	6,120	8,920
4,710	90,190	24,980	1,750

The tests in ARENA Input Analyzer gives the following results. The Lognormal distribution with parameters 24,4 and 33,7 can represent the data sets of the waiting time at anchor of 234 independent vessel arrival.

Distribution: Lognormal

Expression : 1 + LOGN(24,4; 33,7)
Square Error: 0,003396

Chi Square Test
Number of intervals = 8
Degrees of freedom = 5
Test Statistic = 15,2
Corresponding p-value = 0,00965

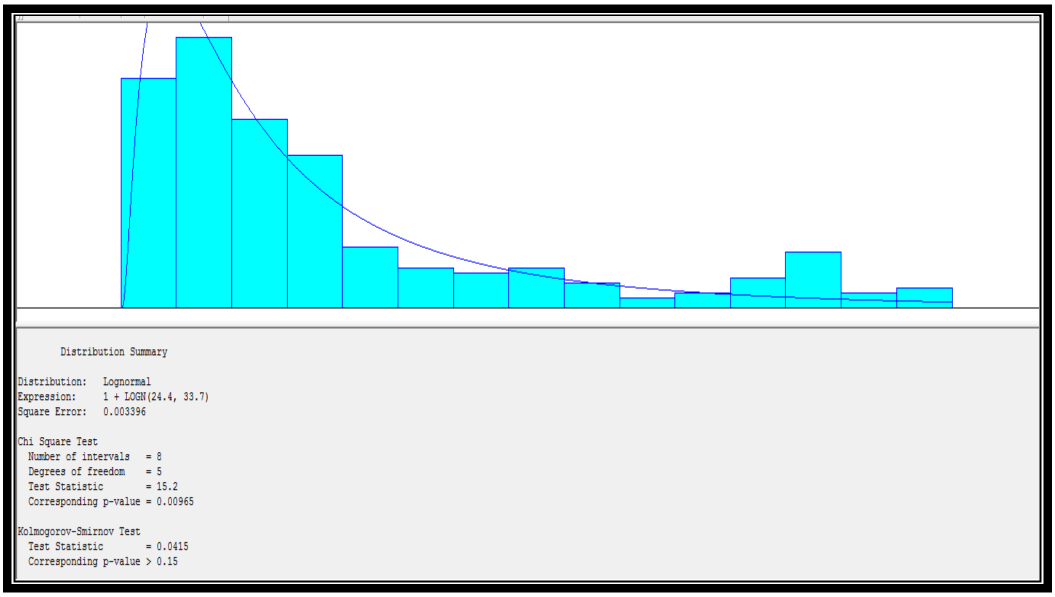
Kolmogorov-Smirnov Test
Test Statistic = 0,0415
Corresponding p-value > 0,15

Data Summary

Number of Data Points = 234
Min Data Value = 1,75
Max Data Value = 90,2
Sample Mean = 24,1
Sample Std Dev = 22,6

Histogram Summary

Histogram Range = 1 to 91
Number of Intervals = 15



```
      Distribution Summary

Distribution:   Lognormal
Expression:     1 + LOGN(24.4, 33.7)
Square Error:   0.003396

Chi Square Test
  Number of intervals   = 8
  Degrees of freedom    = 5
  Test Statistic        = 15.2
  Corresponding p-value = 0.00965

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0415
  Corresponding p-value > 0.15
```

Figure 4.10. Probabilty Curve Fitting for Waiting Time at Anchor (WAT).

Fit All Functions

Function :	Square Error :
Lognormal	0,00339
Gamma	0,00744
Weibull	0,00793
Exponential	0,00880
Erlang	0,00880
Beta	0,01900
Triangular	0,05090
Normal	0,05200
Uniform	0,07290

- **Anchoring Area to Berthing Time (APT) Distribution Summary**

This is the time required for the ship to proceed from waiting area to the berth.

APT = ABDH -DADH

Where
DADH is the time ship leaves the waiting area.

ABDH is the time ship ties up at available berth.

As an example, vessel anchoring area to berthing times (APT) of eight ships are listed in the right columns of the Table 4.28.

Table 4.28. Sample Data for MARPORT Vessel Anchoring Area to Berthing Time, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	**Departure from Anchorage (AADH)**		**Berthing (ABDH)**		**Vessel Anchoring Area to Berthing Time (APT)**	
	Date	**Hour&Min.**	**Hour&Min.**	**Hour**	**Hour&Min**	**Hour**
JASPER S	03 Jan 15	$12^{h} 35^{m}$	03 Jan 15	$13^{h} 15^{m}$	$00^{h} 40^{m}$	0,6667
G. BAYRAKTAR	05 Jan 15	$00^{h} 35^{m}$	05 Jan 15	$01^{h} 00^{m}$	$00^{h} 25^{m}$	0,4167
EDITH	06 Jan 15	$12^{h} 05^{m}$	06 Jan 15	$12^{h} 50^{m}$	$00^{h} 45^{m}$	0,7500
MARYLENA	05 Jan 15	$22^{h} 05^{m}$	05 Jan 15	$22^{h} 45^{m}$	$00^{h} 40^{m}$	0,6667
HOGGAR	06 Jan 15	$04^{h} 30^{m}$	06 Jan 15	$04^{h} 55^{m}$	$00^{h} 15^{m}$	0,2500
VENUS	06 Jan 15	$05^{h} 20^{m}$	06 Jan 15	$06^{h} 00^{m}$	$00^{h} 40^{m}$	0,667
A. BAYRAKTAR	06 Jan 15	$20^{h} 55^{m}$	06 Jan 15	$21^{h} 45^{m}$	$00^{h} 50^{m}$	0,8333
N.VITALITY	16 Jan 15	$16^{h} 35^{m}$	16 Jan 15	$17^{h} 05^{m}$	$00^{h} 30^{m}$	0,5000

Same method is followed for other container vessels whose data are displayed in Appendix A. Total of 234 vessel anchoring area to berthing time values are calculated. This number is assessed to be big enough to reach statistically significant estimations. 40 of these figures are listed in Table 4.29.

Table 4.29. MARPORT Vessel Anchoring Area to Berthing Time (APT) Data (Source, MARPORT Administration, 11 September 2015).

Anchoring Area to Berthing Time (APT) (Hour)	Anchoring Area to Berthing Time (APT) (Hour)	Anchoring Area to Berthing Time (APT) (Hour)	Anchoring Area to Berthing Time (APT) (Hour)
0,600	0,750	0,410	0,680
0,750	0,700	0,410	0,830
0,500	0,580	0,540	0,330
1,000	0,910	0,650	0,950
0,660	0,600	0,840	0,500
0,330	0,830	1,000	0,700
0,410	0,650	0,500	0,650
0,770	0,660	0,330	0,750
0,950	0,750	0,580	0,410
0,600	0,770	0,600	0,680

The tests in ARENA Input Analyzer gives the following results. The Triangular distribution with parameters 0,26, 0,729 and 1,0 can represent the data sets of the anchoring area to berthing time of 234 independent vessel arrival.

Distribution: Triangular

Expression : TRIA (0,26; 0,729; 1,0)
Square Error : 0,019581

Chi Square Test

Number of intervals = 12
Degrees of freedom = 10
Test Statistic = 65
Corresponding p-value < 0,005

Kolmogorov-Smirnov Test

Test Statistic = 0,149
Corresponding p-value < 0,01

Data Summary

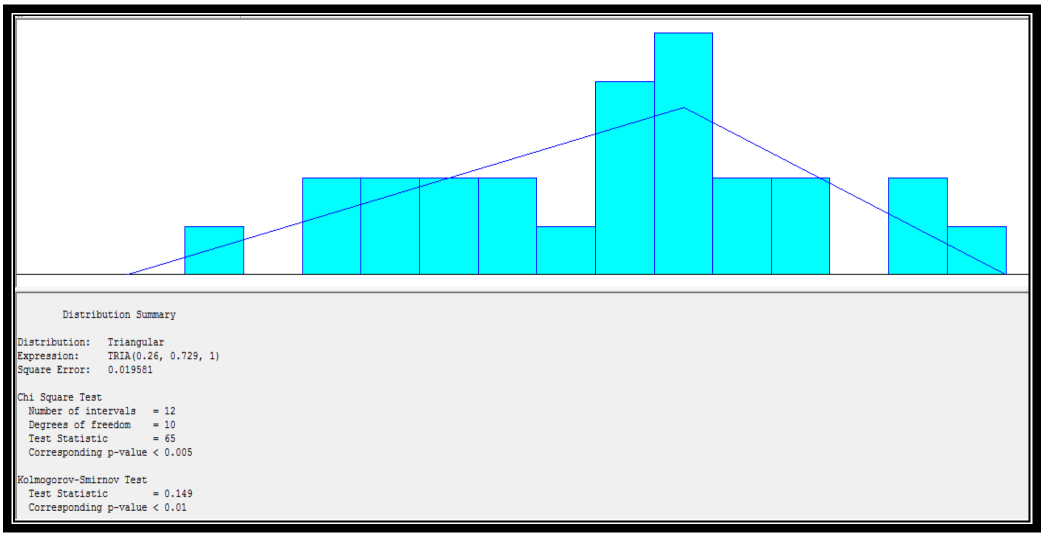
Number of Data Points = 234

Min Data Value = 0,33

Max Data Value = 1
Sample Mean = 0,675
Sample Std Dev = 0,166

Histogram Summary

Histogram Range = 0,26 to 1
Number of Intervals = 15



```
        Distribution Summary

Distribution:   Triangular
Expression:     TRIA(0.26, 0.729, 1)
Square Error:   0.019581

Chi Square Test
  Number of intervals   = 12
  Degrees of freedom    = 10
  Test Statistic        = 65
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.149
  Corresponding p-value < 0.01
```

Figure 4.11. Probabilty Curve Fitting for Anchoring Area to Berthing Time (APT).

Fit All Functions

Function :	Square Error :
Triangular	0,0196
Normal	0,0222
Weibull	0,0231
Beta	0,0245
Erlang	0,0279
Gamma	0,0281
Lognormal	0,0335
Uniform	0,0398
Exponential	0,0687

- **Berthing to Operation Time (BOT) Distribution Summary**

This is the delay between a ship's arrival to berth and commence of the container transfer due to preparation and possible bureaucratic process.

BOT = SODH – ABDH

Where
ABDH is the time ship ties up at available berth.
SODH is the staring time for container transfer either from the ship or berth

In order to have more understandable calculation, vessel berthing to operation times (BOT) of eight ships in January 2015 are listed in Table 4.30.

Table 4.30. Sample Data for MARPORT Vessels Berthing to Operation Time, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Berthing (ABDH)		Start Operation (SODH)		Vessels Berthing to Operation Time (BOT)	
	Date	Hour&Min.	Hour&Min.	Hour	Hour&Min	Hour
JASPER S	03 Jan 15	$13^h 15^m$	03 Jan 15	$14^h 10^m$	$00^h 55^m$	0,9167
G. BAYRAKTAR	05 Jan 15	$01^h 00^m$	05 Jan 15	$02^h 00^m$	$01^h 00^m$	1,0000
EDITH	06 Jan 15	$12^h 50^m$	06 Jan 15	$13^h 30^m$	$00^h 40^m$	0,6667
MARYLENA	05 Jan 15	$22^h 45^m$	05 Jan 15	$23^h 10^m$	$00^h 25^m$	0,4167
HOGGAR	06 Jan 15	$04^h 55^m$	06 Jan 15	$06^h 15^m$	$01^h 20^m$	1,3333
VENUS	06 Jan 15	$06^h 00^m$	06 Jan 15	$06^h 30^m$	$00^h 30^m$	0,5000
A. BAYRAKTAR	06 Jan 15	$21^h 45^m$	06 Jan 15	$22^h 30^m$	$00^h 45^m$	0,7500
N.VITALITY	16 Jan 15	$17^h 05^m$	16 Jan 15	$17^h 45^m$	$00^h 40^m$	0,6667

Total of 824 vessels berthing to operation time values are calculated. This number is big enough to reach statistically significant estimations. 40 of these figures are listed in Table 4.31.

Table 4.31. MARPORT Vessel Berthing to Operation (BOT) Data (Source, MARPORT Administration, 11 September 2015).

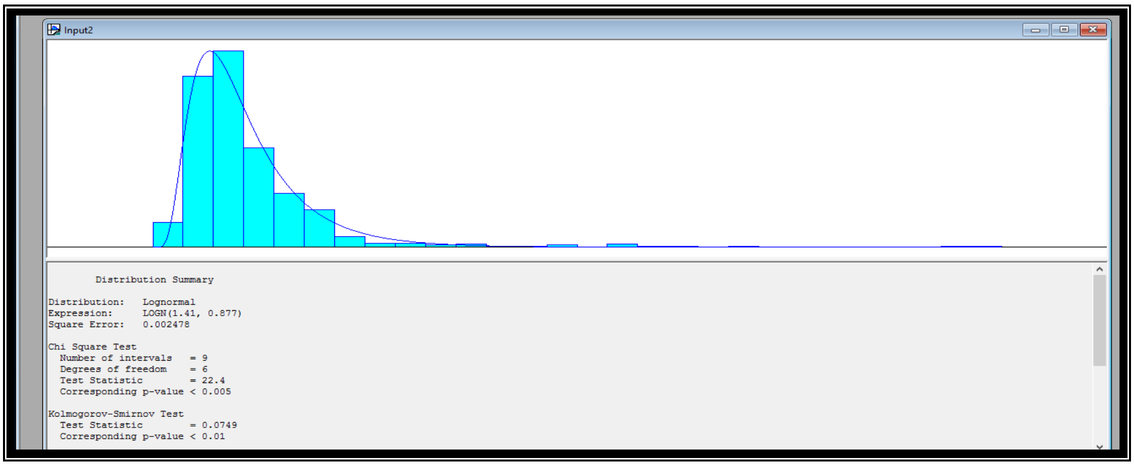
Berthing to Operation (BOT) (Hour)	Berthing to Operation (BOT) (Hour)	Berthing to Operation (BOT) (Hour)	Berthing to Operation (BOT) (Hour)
0,50000	1,00000	0,33333	1,08333
1,58333	1,50000	1,16667	1,16667
0,83333	0,83333	8,00000	1,58333
3,58333	1,75000	1,50000	1,00000
1,41667	0,50000	1,33333	0,75000
1,08333	0,91667	2,00000	1,08333
2,25000	1,00000	2,66667	2,00000
2,00000	0,66667	0,83333	2,33333
0,83333	1,00000	1,00000	1,41667
0,50000	1,33333	0,58333	0,75000

The tests in ARENA Input Analyzer gives the following results. The Lognormal distribution with parameters, 1,41 and 0,877 can represent the data sets of the berthing to operation (BOT) time of 824 independent vessel arrival.

Distribution: Lognormal
Expression : LOGN(1,41; 0,877)
Square Error: 0,002478
Chi Square Test
Number of intervals = 9
Degrees of freedom = 6
Test Statistic = 22,4
Corresponding p-value < 0,005
Kolmogorov-Smirnov Test
Test Statistic = 0,0749
Corresponding p-value < 0,01
Data Summary
Number of Data Points = 824
Min Data Value = 0,0833
Max Data Value = 12,6
Sample Mean = 1,44
Sample Std Dev = 1,13

Histogram Summary

Histogram Range = 0 to 13
Number of Intervals = 28



```
        Distribution Summary

Distribution:   Lognormal
Expression:     LOGN(1.41, 0.877)
Square Error:   0.002478

Chi Square Test
  Number of intervals   = 9
  Degrees of freedom    = 6
  Test Statistic        = 22.4
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0749
  Corresponding p-value < 0.01
```

Figure 4.12. Probabilty Curve Fitting for Berthing to Operation Time (BOT).

Fit All Functions

Function :	Square Error :
Lognormal	0,00248
Beta	0,01570
Erlang	0,01650
Gamma	0,01680
Weibull	0,03850
Normal	0,05360
Exponential	0,08930
Triangular	0,11900
Uniform	0,14400

- **Operation Time (OPT) Distribution Summary**

Operation time is defined as the time a ship stays at a berth for loading and/or unloading containers. The operation time is established from the first container transfer to the last container move.

OPT = CODH – SODH

Where
SODH is the staring time for container transfer either from the ship or berth.

CODH is the finishing time for container transfer.

As an example, these time figures and calculation of operation times are listed in Table 4.32.

Table 4.32. Sample Data for MARPORT Vessels Operation Time, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Start Operation (SODH)		Complete Operation (CODH)		Vessels Operation Time (OPT)	
	Date	Hour&Min.	Hour&Min.	Hour	Hour&Min	Hour
JASPER S	03 Jan 15	$14^h 10^m$	04 Jan 15	$05^h 50^m$	$15^h 40^m$	15,6667
G. BAYRAKTAR	05 Jan 15	$02^h 00^m$	05 Jan 15	$19^h 40^m$	$17^h 40^m$	17,6667
EDITH	06 Jan 15	$13^h 30^m$	06 Jan 15	$17^h 10^m$	$03^h 40^m$	3,6667
MARYLENA	05 Jan 15	$23^h 10^m$	06 Jan 15	$11^h 00^m$	$11^h 50^m$	11,8333
HOGGAR	06 Jan 15	$06^h 15^m$	07 Jan 15	$09^h 15^m$	$27^h 00^m$	27,0000
VENUS	06 Jan 15	$06^h 30^m$	06 Jan 15	$20^h 00^m$	$13^h 30^m$	13,5000
A. BAYRAKTAR	06 Jan 15	$22^h 30^m$	08 Jan 15	$02^h 15^m$	$27^h 45^m$	27,7500
N.VITALITY	16 Jan 15	$17^h 45^m$	17 Jan 15	$05^h 50^m$	$12^h 05^m$	12,0833

Similar calculations are executed for other container vessels whose data are displayed in Appendix A. Total of 767 operation time values are calculated. This number is assessed to be big enough to reach statistically significant estimations. 40 of these figures are listed in Table 4.33

Table 4.33. MARPORT Vessel Operation Time (OPT) Data (Source, MARPORT Administration, 11 September 2015).

Operation Time (OPT) (Hour)	Operation Time (OPT) (Hour)	Operation Time (OPT) (Hour)	Operation Time (OPT) (Hour)
36,16667	12,08333	9,41667	18,08333
16,91667	4,58333	18,16667	30,33333
46,66667	31,41667	12,75000	27,08333
17,25000	8,75000	41,00000	12,50000
23,91667	13,91667	19,00000	69,25000
23,25000	7,00000	19,25000	34,91667
17,50000	15,58333	15,58333	17,66667
31,00000	13,58333	4,33333	18,83333
4,50000	36,66667	21,41667	33,50000
19,41667	8,50000	35,00000	20,00000

Distribution: Erlang

Expression : ERLA(8,29; 2,0)
Square Error: 0,001113

Chi Square Test

Number of intervals = 18
Degrees of freedom = 15
Test Statistic = 19,2
Corresponding p-value = 0,215

Kolmogorov-Smirnov Test

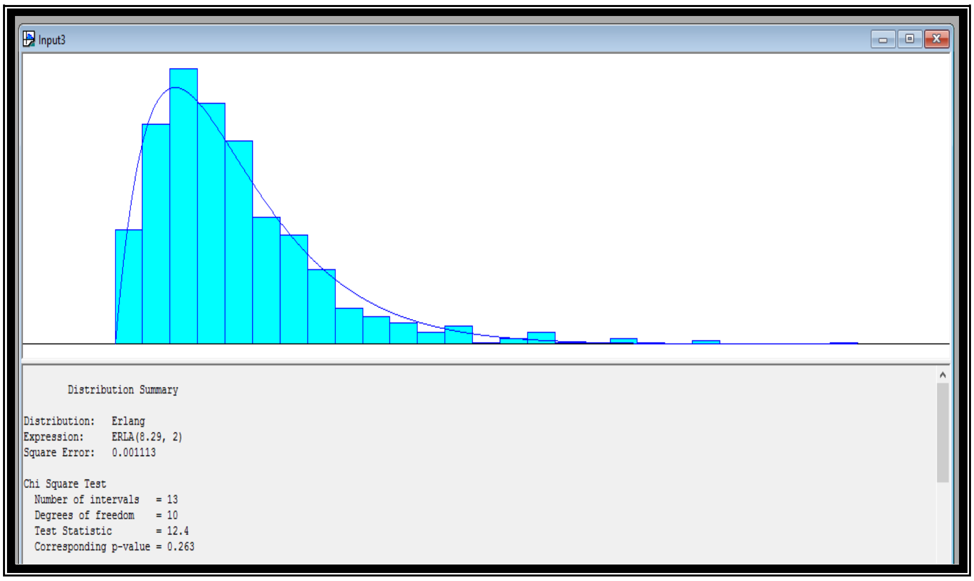
Test Statistic = 0,0294
Corresponding p-value > 0,15

Data Summary

Number of Data Points = 767
Min Data Value = 0,0833
Max Data Value = 102
Sample Mean = 16,6
Sample Std Dev = 12,6

Histogram Summary

Histogram Range = 0 to 103
Number of Intervals = 40



```
        Distribution Summary

Distribution:   Erlang
Expression:     ERLA(8.29, 2)
Square Error:   0.001113

Chi Square Test
  Number of intervals   = 13
  Degrees of freedom    = 10
  Test Statistic        = 12.4
  Corresponding p-value = 0.263
```

Figure 4.13. Probabilty Curve Fitting for Operation Time (OPT).

Function :	Square Error :
Erlang	0,001113
Gamma	0,001160
Beta	0,002140

Weibull	0,002210
Lognormal	0,004410
Normal	0,010800
Exponential	0,018900
Triangular	0,034300
Uniform	0,055300

- **Operation to Departure Time (ODT) Distribution Summary**

It is defined as the time a ship stays at a berth for departure after container transfer operation finishes. The operation time is established from the last container transfer to the time the last line is let go.

ODT = DBDH - CODH

Where
CODH is the finishing time for container transfer.

DBDH is the departure time of the ship.

In order to have more understandable calculation, operation to departure times of eight ships in the first week of January 2015 are listed in Table 4.34.

Table 4.34. Sample Data for MARPORT Vessels Operation to Departure Time, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	**Complete Operation (CODH)**		**Departure (DBDH)**		**Vessels Operation to Departure Time (ODT)**	
	Date	**Hour&Min.**	**Hour&Min.**	**Hour**	**Hour&Min**	**Hour**
JASPER S	04 Jan 15	$05^h 50^m$	04 Jan 15	$06^h 50^m$	$01^h 00^m$	1,0000
G. BAYRAKTAR	05 Jan 15	$19^h 40^m$	05 Jan 15	$21^h 45^m$	$02^h 05^m$	2,08333
EDITH	06 Jan 15	$17^h 10^m$	06 Jan 15	$19^h 40^m$	$02^h 30^m$	2,5000
MARYLENA	06 Jan 15	$11^h 00^m$	06 Jan 15	$11^h 45^m$	$00^h 45^m$	0,7500
HOGGAR	07 Jan 15	$09^h 15^m$	07 Jan 15	$10^h 55^m$	$01^h 40^m$	1,6667
VENUS	06 Jan 15	$20^h 00^m$	06 Jan 15	$22^h 00^m$	$02^h 00^m$	2,0000
A. BAYRAKTAR	08 Jan 15	$02^h 15^m$	08 Jan 15	$03^h 15^m$	$01^h 00^m$	1,0000
N.VITALITY	17 Jan 15	$05^h 50^m$	17 Jan 15	$06^h 50^m$	$01^h 00^m$	1,0000

Total of 820 interarrival time values are calculated. This number is big enough to reach statistically significant estimations. 40 of these figures are listed in Table 4.35.

Table 4.35. MARPORT Vessel Operation to Departure Time (ODT) Data (Source, MARPORT Administration, 11 September 2015).

Operation to Departure Time (ODT) (Hour)	Operation to Departure Time (ODT) (Hour)	Operation to Departure Time (ODT) (Hour)	Operation to Departure Time (ODT) (Hour)
0,91667	0,75000	1,00000	3,83333
2,16667	1,66667	1,83333	3,41667
1,33333	2,00000	1,16667	1,50000
0,91667	1,00000	2,00000	0,58333
1,25000	5,33333	0,83333	0,75000
2,16667	1,00000	1,08333	2,00000
1,00000	1,00000	2,08333	2,16667
1,00000	0,66667	1,41667	1,91667
1,16667	0,50000	1,16667	1,08333
1,83333	1,08333	1,66667	1,58333

Distribution:	Lognormal
Expression :	LOGN (1,39; 0,811)
Square Error:	0,015717

Chi Square Test

Number of intervals	= 9
Degrees of freedom	= 6
Test Statistic	= 75,9
Corresponding p-value	< 0,005

Kolmogorov-Smirnov Test

Test Statistic	= 0,0776
Corresponding p-value	< 0,01

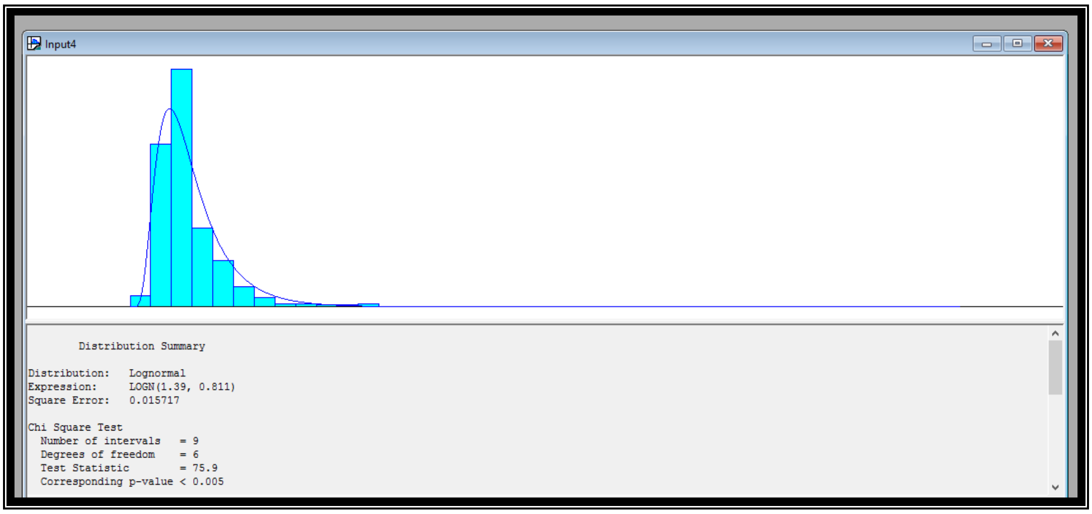
Data Summary

Number of Data Points	= 820
Min Data Value	= 0,0833
Max Data Value	= 18,5
Sample Mean	= 1,44
Sample Std Dev	= 1,38

Histogram Summary

Histogram Range	= 0 to 19

Number of Intervals = 40



```
        Distribution Summary

Distribution:   Lognormal
Expression:     LOGN(1.39, 0.811)
Square Error:   0.015717

Chi Square Test
  Number of intervals   = 9
  Degrees of freedom    = 6
  Test Statistic        = 75.9
  Corresponding p-value < 0.005
```

Figure 4.14. Probabilty Curve Fitting for Operation to Departure Time (ODT).

Fit All Functions

Function:	Square Error:
Lognormal	0,015717
Erlang	0,033300
Gamma	0,033700
Weibull	0,074100
Beta	0,091300
Normal	0,113000
Exponential	0,143000
Triangular	0,216000
Uniform	0,241000

- **Total Time in Port (TOT) Distribution Summary**

Total time in ports of eight ships on January 2015 are listed in Table 4.36. First container vessel JASPER entered the MARPORT on 03 January 2015 at 10^{h} 30^{m} . Upon complition the container handling operation, the ship left the port on 04 January 2015 at 06^{h} 50^{m}. The total time in port of JASPER S is the time difference of these to events, which is calculated by subtracting the first value (02 Jan 15, 10^{h} 30^{m}) from the second time value (04 Jan 2015, 06^{h} 50^{m}). As listed in the right columns of the Table 4.36, the result is 20^{h} 20^{m} or 20,3333 hours.

Table 4.36. Sample Data for MARPORT Vessels Total Time in Port, Jan 15 (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Arrival to Port (APDH)		Departure (DBDH)		Vessels Total Time in Port (TOT)	
	Date	Hour&Min.	Hour&Min.	Hour	Hour&Min	Hour
JASPER S	03 Jan 15	$10^h 30^m$	04 Jan 15	$06^h 50^m$	$20^h 20^m$	20,3333
G. BAYRAKTAR	04 Jan 15	$17^h 20^m$	05 Jan 15	$21^h 45^m$	$28^h 25^m$	28,4167
EDITH	05 Jan 15	$00^h 00^m$	06 Jan 15	$19^h 40^m$	$19^h 40^m$	19,6667
MARYLENA	05 Jan 15	$00^h 30^m$	06 Jan 15	$11^h 45^m$	$35^h 15^m$	35,2500
HOGGAR	05 Jan 15	$16^h 40^m$	07 Jan 15	$10^h 55^m$	$42^h 15^m$	42,2500
VENUS	05 Jan 015	$17^h 00^m$	06 Jan 15	$22^h 00^m$	$29^h 00^m$	29,0000
A. BAYRAKTAR	05 Jan 015	$23^h 35^m$	08 Jan 15	$03^h 15^m$	$51^h 40^m$	51,6667
N.VITALITY	14 Jan 15	$21^h 30^m$	17 Jan 15	$06^h 50^m$	$57^h 20^m$	57,3333

Similar calculations are executed for other container vessels whose data are displayed in Table A.1. Total of 824 interarrival time values are calculated. This number is big enough to reach statistically significant estimation of. 40 of these figures are listed in Table 4.37.

Table 37. MARPORT Vessel Total Time in Port (TOT) Data (Source, MARPORT Administration, 11 September 2015).

Total Time in Port (TOT) (Hour)	Total Time in Port (TOT) (Hour)	Total Time in Port (TOT) (Hour)	Total Time in Port (TOT) (Hour)
21,33333	20,91667	105,33333	16,91667
34,83333	11,25000	6,83333	23,41667
33,91667	29,00000	37,41667	25,33333
15,58333	7,75000	94,08333	49,25000
76,16667	11,16667	88,08333	26,25000
39,08333	25,00000	25,83333	23,75000
25,83333	9,41667	25,16667	19,33333
27,25000	13,25000	22,41667	13,08333
38,08333	35,75000	40,66667	35,50000
41,33333	2,73333	14,50000	38,91667

Distribution: Lognormal
Expression : 2 + LOGN(27,2; 26,6)
Square Error: 0,002938

Chi Square Test

Number of intervals = 14
Degrees of freedom = 11
Test Statistic = 21,2
Corresponding p-value = 0,0334

Kolmogorov-Smirnov Test

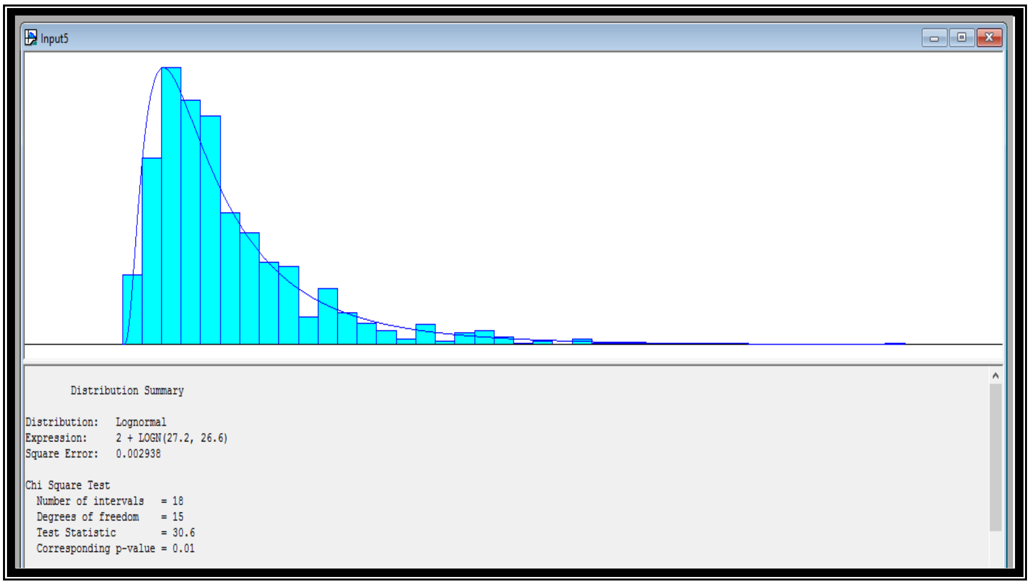
Test Statistic = 0,0501
Corresponding p-value = 0,0326

Data Summary

Number of Data Points = 824
Min Data Value = 2,42
Max Data Value = 194,0
Sample Mean = 33,9
Sample Std Dev = 21,7

Histogram Summary

Histogram Range = 2 to 194
Number of Intervals = 28



```
       Distribution Summary

Distribution:   Lognormal
Expression:     2 + LOGN(27.2, 26.6)
Square Error:   0.002938

Chi Square Test
  Number of intervals   = 18
  Degrees of freedom    = 15
  Test Statistic        = 30.6
  Corresponding p-value = 0.01
```

Figure 4.15. Probabilty Curve Fitting for Total Time in Port (TOT).

Fit All Functions

Function :	Square Error :
Lognormal	0,002938
Erlang	0,003160
Gamma	0,003500
Weibull	0,009900
Beta	0,010500
Exponential	0,029600
Normal	0,030000
Triangular	0.078500
Uniform	0.105000

Summary of the above analysis are listed in Table 4.38.

Table 4.38. Statistical Analysis of Input Time Parameters.

PARAMETER NAME	DISTRIBUTION NAME	DISTRIBUTION EXPRESSION	SQUARE ERROR	NUMBER OF DATA POINTS	MINIM. DATA VALUE	MAXIM. DATA VALUE	SAMPLE MEAN VALUE	SAMPLE STD. DEV. VALUE
Interarrival Time (IAT)	Gamma	GAMM (10,6; 0,814)	0,001600	815	0,0010	56,50	8,640	9,79
Arrival to Anchoring Area Time (AAT)	Triangular	TRIA (0,0; 0,62; 1,41)	0,019905	234	0,0700	1,28	0,677	0,33
Waiting at Anchoring Area Time (WAT)	Lognormal	1+LOGN (24,4; 33,7)	0,003396	234	1,7500	90,20	24,100	22,60
Anchoring Area to Berthing Time (APT)	Triangular	TRIA (0,26; 0,72; 1,0)	0,019581	234	0,3300	1,00	0,675	0,166
Arrival to Berthing Time (ABT)	Beta	2*BETA (2,2; 1,7)	0,008114	396	0,08330	1,92	1,130	0,45
Berthing to Operation Time (BOT)	Lognormal	LOGN (1,41; 0,877)	0,002478	824	0,0833	12,60	1,440	1,13
Operation Time (OPT)	Erlang	ERLA (8,29; 2,0)	0,001113	767	0,0833	102,00	16,600	12,60
Operation to Departure Time (ODT)	Lognormal	LOGN (1,39; 0,811)	0,015717	820	0,0833	18,54	1,440	1,38
Total Time in Port (TOT)	Lognormal	2+LOGN (27,2; 26,6)	0,002938	824	2,4200	194,00	33,905	21,70

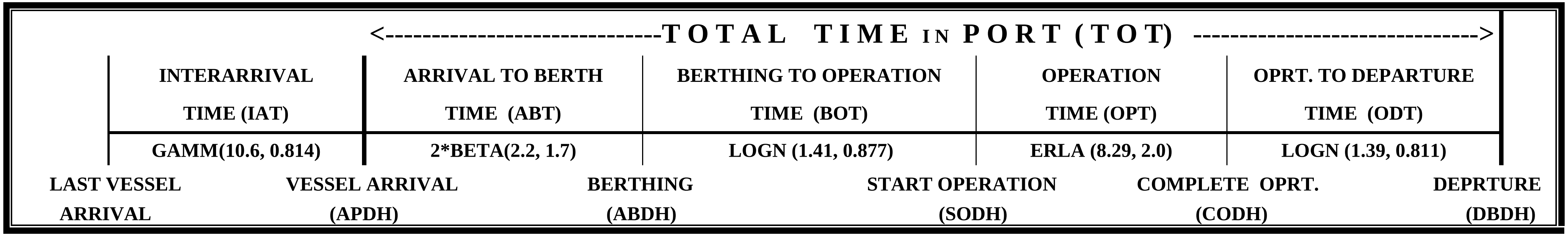


Figure 4.16. Time Chart Diagram When There Is An Available Berth to Tie Up.

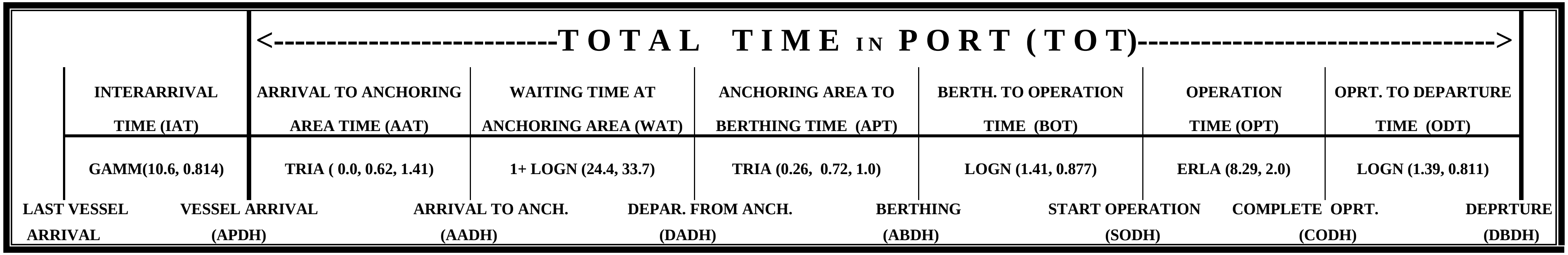


Figure 4.17. Time Chart Diagram When There Is No Available Berth to Tie Up.

4.5. Assumptions for Simulation Model

In the simulation model, several assumptions were made for each stage of the operations in order to simplify the model. For further studies, these assumptions may be modified to gain more realistic results.

4.5.1. Managerial Assumptions

- The ships are being worked on first-come-first-served basis.
- All equipment and port facilities, including employees work 24 hours a day and seven days in a week. No breakdown for equipment or strike for employees are planned.
- Feasible investment options should create at least 10 percent improvement for each key performance indicator, namely monthly container throughput and average total time in port.
- In a similar way, feasible investment options should also posses at least 0.90 efficiency score of Data Envelopment Analyses.

4.5.2. Assumptions for Containers Vessels

The historical data belonging to 815 container ships in different size making port calls at MARPORT/İstanbul Container Terminal are taken as a basis to generate tonnage, length and draft of simulated container vessels. These models which were explained in previous section are as follows;

- Vessel Tonnage (DWT): As explained in Table 4.8 and 4.9.
- Vessel Length (Meters): The regression Equation (4.2)

$$L = 1{,}853\, x^3\, 10^{-13} - 5{,}765\, x^2\, 10^{-8} + 0{,}006\, x + 78{,}7670$$

Where L = Length of the vessel x = Tonnage of the vessel

- Vessel Draft (Meters): The regression Equation (4.3)

$$D = -17{,}178 + 4{,}883 * \ln x$$

Where D= Draft of the vessel x = Length of the Vessel

4.5.3. Assumptions for Containers Onboard Vessels

There are different types of containers handled in CT: Mainly, there are two types of containers; discharged and loaded. Each type has four sub-branches; full, empty, transit full and transit empty. In addition to this classification, 20 feet and 40 feet containers are also generated in SM module.

Two more assumptions are made about container distribution on board ship;

- Fixed container location distribution (equally spitted) for the different areas of the ship (bow, central and stern),
- For each incoming vessel, random distribution of container types are generated in the model, based on the data obtained from the actual MARPORT port values. These container load distributions are presented in previous section in Table 4.5, 4.6 and 4.7.

4.5.4. Operational Time Distribution Assumptions

Probabilistic time distribution functions for each stage of the operation such as interarrival time, sailing time from anchoring area to berth, as listed in Table 4.21, are generated by ARENA Input Analyser in previous section. Actual MARPORT time data which belongs the period of October 2014 and July 2015 is taken as input for Analyser. Time distribution functions and their parameters in hour are;

- Interarrival Time (IAT), GAMMA (10,6, 0,814),
- Arrival to Anchoring Area Time (AAT), TRIANGULAR (0,0, 0,62, 1,41),
- Anchoring Area to Berthing Time (APT), TRIANGULAR (0,26, 0,72, 1,0),
- Arrival to Berthing Time (ABT), 2*BETA (2,2, 1,7),
- Berthing to Operation Time (BOT), LOGNORMAL (1,41, 0,877),
- Operation to Departure Time (ODT), LOGNORMAL (1,39, 0,811).

4.5.5. Assumptions for Container Cranes

Probability distribution of container cranes operation capacity (TEU per hour) is triangular with parameters depending on the crane type;

- For Mobile Harbor Crane, TRIA (12, 17, 20 TEU per hour),
- For Stationary Harbor Crane, TRIA (20, 23, 27 TEU per hour),
- For Container Yard Crane, (14, 16, 17 TEU per hour).

4.5.6. Assumptions for Container Trucks

Three different assumptions are also made for container truck movement between quay and container yard;

- If a truck arrives under a busy crane, it is sent to the first free crane waiting for truck,
- There exsists no operational traffic rules and congestion,
- Probability distribution of container truck speed is triangular with parameters depending on the container load it carries;

  - For 20’ Full Container, TRIA (7, 10, 12 km/h.),

  - For 20’ Empty Container, TRIA (9, 12, 15 km/h.),

  - For 40’ Full Container, TRIA (5, 8, 10 km/h.),

  - For 40’ Empty Container, TRIA (6, 9, 11 km/h.).

4.6. Conceptual Model Formulation

Conceptual model formulation is to develop graphical block diagrams to define the components, descriptive variables and interactions that constitute the system.

In this thesis, flowchart method is deployed as tool for conceptual model formulation. Three interconnected flowcharts of ARENA Simulation model which is designed to function according to operations conducted in a container port are presented in Figures 4.18, 4.19 and 4.20.

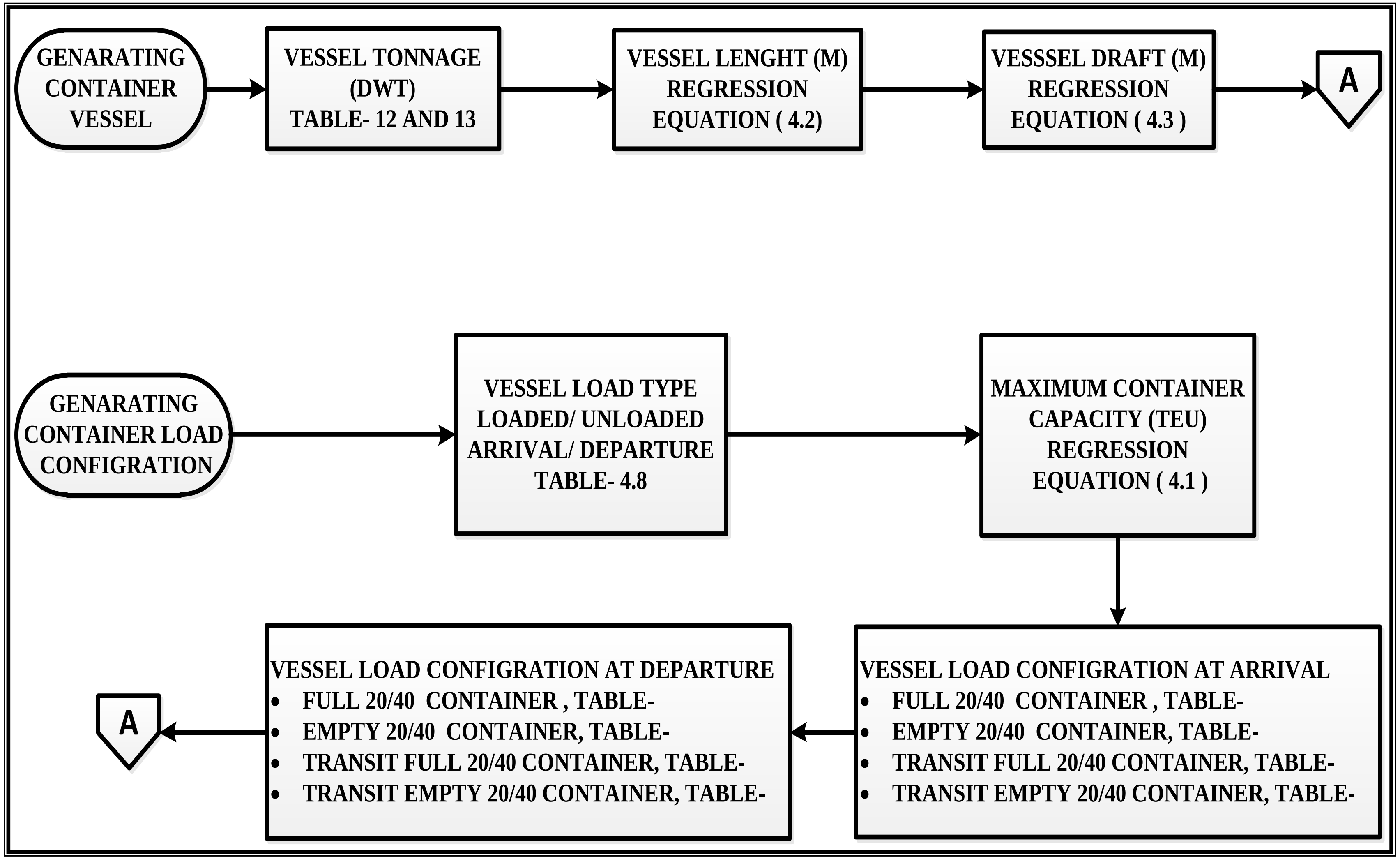


Figure 4.18. ARENA Simulation Flowchart – 1.

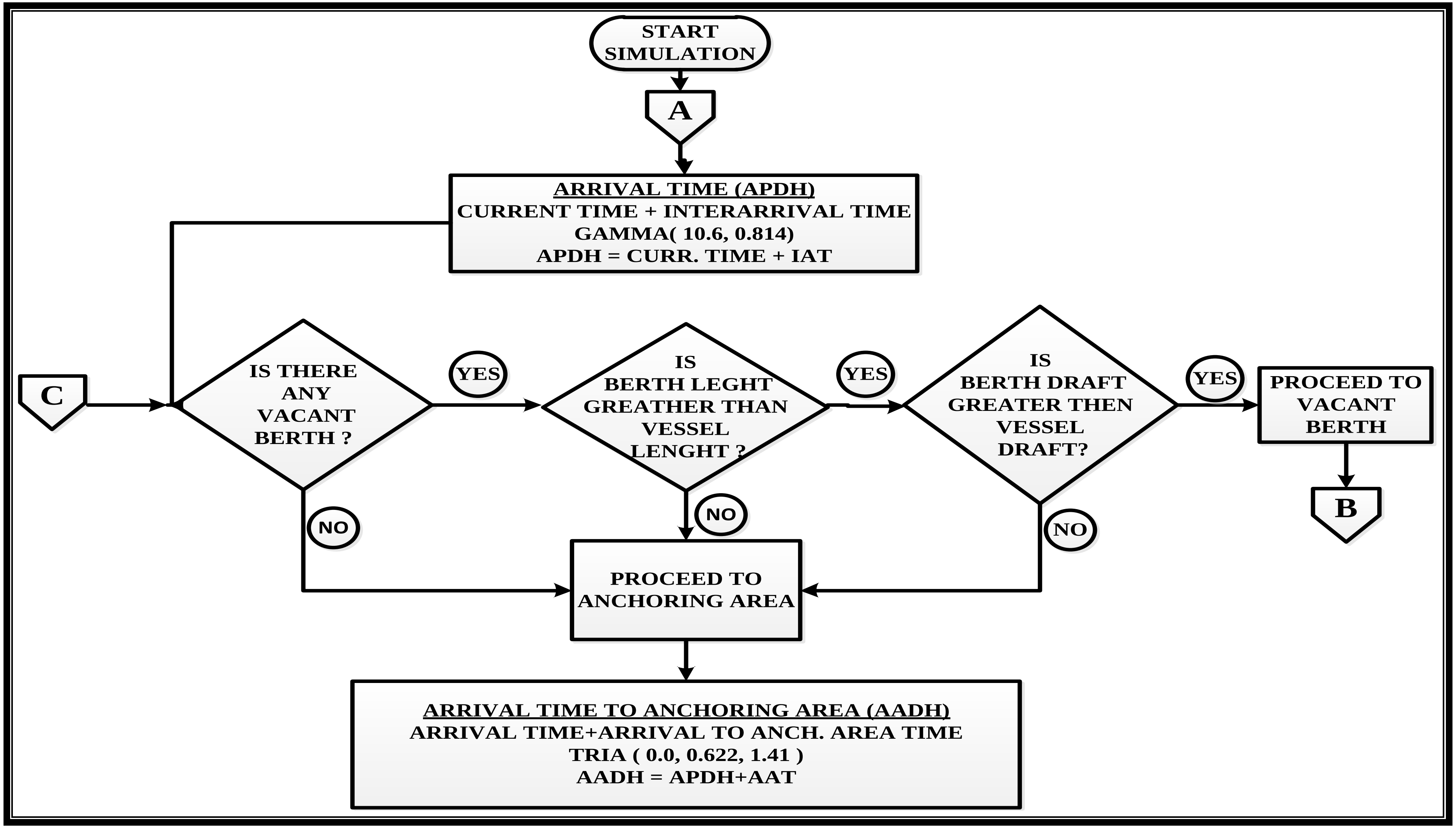


Figure 4.19. ARENA Simulation Flowchart – 2.

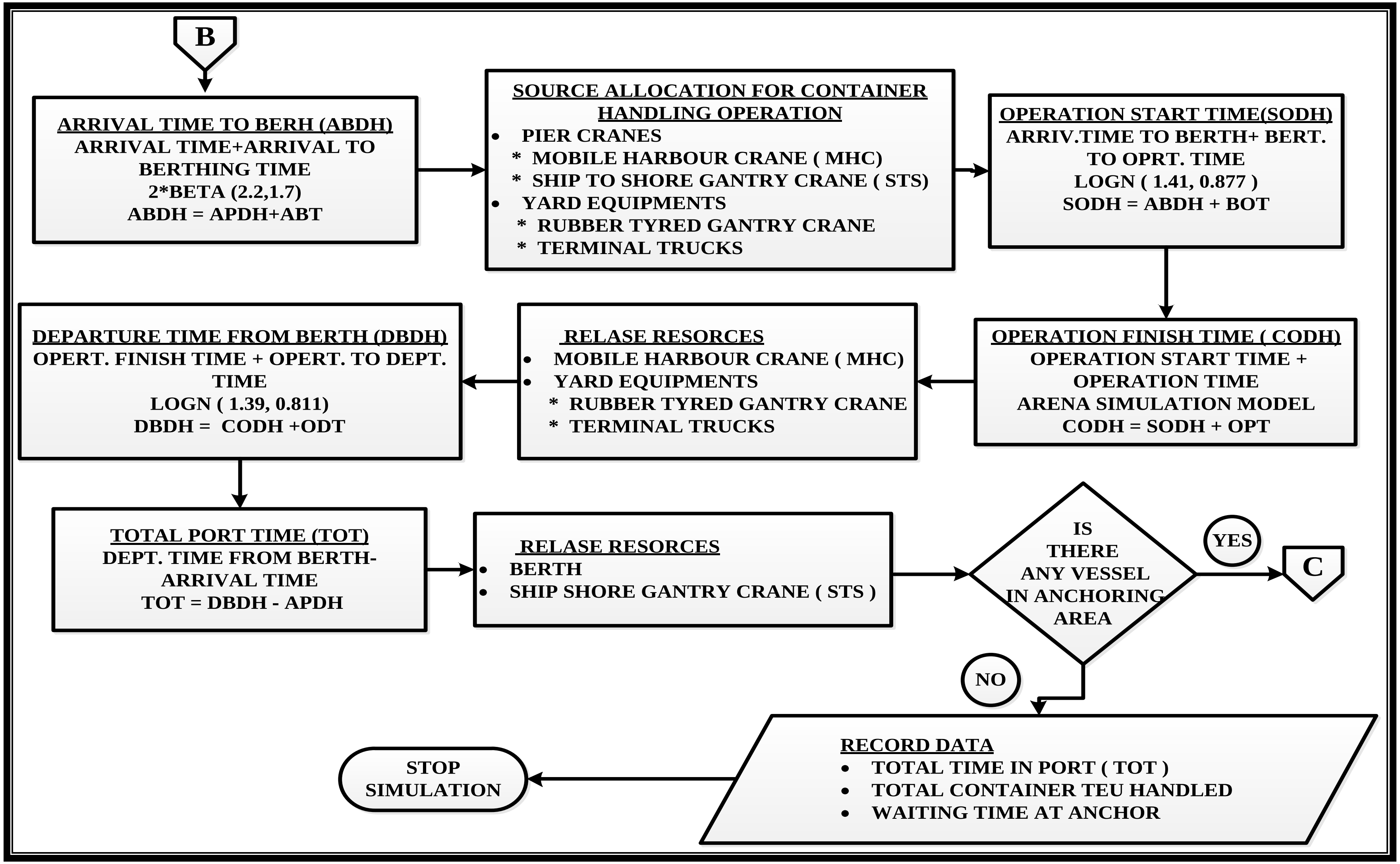


Figure 4.20. ARENA Simulation Flowchart – 3.

4.7. Experimental Design

Experimental design is to select the measures of effectiveness to be used, the factors to be varied and the levels of those factors to be investigated, i.e., what data need to be gathered from the model, in what form and to what extent. In this context, port performance indicators will be defined in the following section.

Port performance indicators basically deals with the calculation of ship's waiting time and its container loading performance in port. A problem for port managers is to ensure optimum use of berths in the port. Insufficient berth capacity will result in delays to the vessel and excess capacity will be a wasted use of port capital and resource (Institute of Chartered Shipbrokers, 2007). The main indicators used to assess container port performance are;

- Port Throughput

The port throughput indicator is the total number of containers (TEU) handled in port in a given period of time (weeks, months or years). In this thesis, month will be used as a period of time.

- Waiting Time

It is defined as the time a ship spends in anchoring area or waiting for an available berth that is, the delay between a ship’s arrival in the port and its tying up at the berth.

- Service Time

Service time is defined as the time a ship stays at berth whether it is working or not. The service time is established from first line ashore to the time the last line is let go.

- Time in Port or Turnaround Time

This is the total time the ship spends in the container port from arrival at the port to final departure. The second performance indicator in the thesis, Average Time in Port can be established using the formula;

$$Average\ Time\ in\ Port = \frac{Cumulated\ Waiting\ Time + Cumulated\ Service\ Time}{Total\ Number\ of\ Ships}$$

As the container transport system is capital intensive, the turnaround time of ships at container terminals is an important factor for liner shipping companies to decrease their cost.

As explained above, the turnaround time includes arrival, time in waiting area, berthing, unloading, loading and departure, therefore, the feasible scheduling of loading and unloading operations is critical to the efficiency of container transport system

- Grade of Waiting

For commercial reasons it is very frequent to calculate a Grade of Waiting ratio. The comparison of the waiting time with the service time provides an efficient indicator of what is acceptable by ship-owners. The lower the ratio, the more acceptable by ship-owners In general, ship-owners accept a 10 percent Grade of Waiting ratio beyond which the port is considered as inefficient or of low quality.

$$Grade\ of\ Waiting\ Ratio = \frac{Cumulated\ Waiting\ Time}{Cumulated\ Service\ Time}$$

- Berth Occupancy Ratio

It is the ratio determined by dividing the time a berth has been occupied (in hours per year) by the total number of hours in a year (8.760 hours). It indicates the level of demand for port services (Institute of Chartered Shipbrokers, 2007).

$$Berth\ Occupancy\ Ratio = \frac{Total\ Service\ Time\ (per\ berth)}{Total\ Hours\ in\ Year\ (8.760)}$$

- Cargo Dwell Time

This is the time elapsed since when the cargo is unloaded from a ship until it exit the port, or vice versa. It is measured in days. The smaller the value of the indicator, the higher the efficiency of the port. A high value for this indicator points towards cargo management problems; such problems could be;

- Poor performance of administrative services such as customs procedures and/or other mandatory inspections,
- Poor coordination between importers/exporters and surface modes of transport.

While cargo dwell time is a very important indicator for shippers, it is even crucial to those dealing with perishable goods e.g. vegetables, fruits and fish (Sumatra, 2009).

Among these port performance indicators, two of them, namely Monthly Port Throughput (TEU) and Average Time in Port (in hour) are used as main performance indicators. Therefore, the simulation model structure is designed in such a way that the outputs will be these two port performance indicators. These indicators will also be deployed in the follow on mathematical model, Data Envelope Analysis.

4.8. Model Translation

Model translation means to formulate the model in an appropriate simulation language. Virtually any general purpose high-level programming language can be used to create simulation models. This includes programming languages such as Visual Basic, C++, FORTRAN, and Pascal. On the other hand, there are number of simulation-specific packages currently on the market. The number of these types of programs is increasing on a yearly basis. A few of the most commonly used packages are;

- ARENA,
- AUTOMOD,
- SIMSCRIPT,

Among these package programs, ARENA is used as tool to translate the simulation modeling into a simulation programing which operates under the various Windows operating systems. ARENA combines the ease of use found in high-level simulators with the flexibility of simulation languages (Kelton at al, 2015).

4.8.1. Pieces of Simulation Model in ARENA

- Entities

Entities which are dynamic objects in the simulations move around, change status, affect and affected by other entities and the state of the system and affect the output performance measures. The basic entities for this simulation modeling are arriving container ships to MARPORT. They are created when they arrive, sail to either available berth or anchoring area to wait for the first convenient berth to be tied up.

- Attributes

An attribute is a common characteristic of all entities, but differs from one entity to another. For example, arriving container ship could have attributes such as arrival time, tonnage, length, draft and composition of the container load. The values of attributes are tied to specific entities. An attribute could be thought as a tag attached to each entity, but what is written on this tag can differ across entities to characterize them individually.

- Global Variables

A global variable is an information that reflects the characteristic of the system. In contrast to attributes, variables are not tied to any specific entity, but rather deal with the system at large. As an example, the distance between two stations, such as berth number two and container yard three, in port might be same throughout the model.

- Resources

Resources represent objects like worker, container terminal equipment or space in container yard of limited size. An entity seizes a resource when available and releases it when finished. An entity could also need simultaneous service from multiple resources.

- Events

An event is something that happens at an instant of a time that might change attributes, variables or statistical accumulators. In the thesis, there are three kinds of main events:

- Arrival: A new container ship arrives MARPORT.

- Departure: A container ship finishes its loading/unloading operations and leaves the MARPORT.

- The End: The simulation is stopped at time 888 hours (37 days).

In addition to these main events, there are other events such as leaving the anchoring area, berthing, starting and finishing the operation.

- Statistical Accumulators

To get the key performance measures, it is required to keep track of various intermediate statistical variables as the simulation progresses. In MARPORT simulation model some of these variables are;

- The number of container ships arrive the port,
- The total waiting times in anchoring area,
- The longest time spend in anchoring area,
- The number (TEU) of total containers handled in the system,
- The total of time spent in the MARPORT by all arriving container ships,
- The longest/shortest time in system.

4.8.2. Model Blocks Used in ARENA

There are several model blocks available to the ARENA simulation system designers. In this thesis, the most frequently used model blocks are Create, Assign, Queue, Seize, Delay, Release, Tally and Dispose.

- **Create**

The create block is generally used to generate entity in the system. In MARPORT simulation model, arriving container ships are created by this module. Interarrival times between consecutive arrivals is a random variable which has a probabilitiy distribution of GAMMA with parameters of 10,6 and 0,814. Time unit is defined as hour and arrival batch size is just one ship(Chung, 2004).

- **Assign**

The assign block is used to set global variable and entity attributes to particular values. The most common use of the assign block is to record when each entity enters in the system.. An entity attribute such as *arrtime* can be used to record this time by placing its name in the new variable. Similarly, the simulation time variable tnow value is assigned to the attribute *arrtime* by placing tnow in the assign value text box. For each arriving ship, some stochastic variables such as tonnage, length, draft and container load are assigned to these incoming vessels(Chung, 2004).

- **Queue**

The queue block is used to represent a system waiting line or queue. The practitioner must specify the name of the queue in the queue ID text box. It is also possible to limit the number of entities that can be in the queue at any given time. If any entities arrive in the queue when the maximum number has been reached, they can also be diverted to a program structure with the specified label identified in the balk label text box. The main queue in this system is the ships in the anchorage area waiting for available berth. First come first served rule is used for the ships in anchorage area(Chung, 2004).

- **Seize**

The seize block is used by the entity to seize control of a particular resource. This corresponds to a vessel engaging the services of a loading and/or unloading container operations. The seize block requires that the resource be added from the seize block window. When a resource is added, the resource window appears. In this window, it is possible to specify the resource ID and the number of resources that the entity should seize. Normally, entities will seize only one resource at a time. However, a single entity may seize more than one resource. As an example, more than one quay crane could be assigned to a single ship in berth(Chung, 2004)..

- **Delay**

The delay block is deployed to model the service times that the source of the asset is captured. A deterministic value or probability distribution can be added for the delay time. The service time may also be a variable set to a predetermined value or probability distribution value. The time required to sail from anchoring area to berth could be considered a delay time which is a probabilistic value with triangular distribution (0,26- 0,729-1,0 hours) (Chung, 2004)..

- **Release**

The release block frees the resource from the entity at the end of the previous delay block time. At the end of harbor operation, ship releases the resources such as berth, quay cranes and container trucks which were previously allocated to this vessel(Chung, 2004)..

- **Tally**

The tally block is used to compile observational statistics generated by individual entities. A typical use of the tally block is to compile the system time for each individual entity. The system time in this simulation model is used to get the parameter of “average total time in port” which is one of the key performance measures. (Chung, 2004).

- **Dispose**

The dispose block simply disposes of the system entity which is container vessel in the model. Once the entity has traveled though the system, and the necessary statistics have been recorded, there is no need to continue maintaining the entity. By disposing of the entity, program resources are freed for other uses(Chung, 2004).

4.8.3 Setting the Run Conditions

Run Setup module in ARENA controls several number of aspects about the running of simulation model. Summary of control parameters which define the running conditions are as follows;

- Run Length

Time unit is defined as hours. Total length of each replication is selected to be 37 days or 888 hours. It means that each replication stops at the end of hour 888.

- Warm-up Period

It is also required to specify a Warm-up period at beginning of each replications, after which the statistical accumulators are cleared to allow the effect of possibly atypical conditions to wear off. Warm-up period for each replication is selected to be 7 days or 168 hours, which is almost one fifth of overall run length. The simulation model warms up initially during the first period of 168 hours until it appears that the effects of the artificial initial conditions have worn off. At the end of this period, the system clears the statistical accumulators and stars afresh, gathering output values. 7 day Warm up period is selected in order to have a period of 30 days to collect monthly data for the second performance indicator of total monthly container throughput.

- Number of Replications

Number of replications is selected to be 100. This number will produce enough number of sample data to be able to reach statistically significant conclusions. Each replication is statistically independent and has the same initial conditions. In other words, replications start fresh (fresh system state and fresh statistical accumulators) and use separate random numbers.

- Terminating or Steady State

Most simulations can be classified as either terminating or steady-state.

A terminating simulation is one in which the model dictates specific starting and stopping conditions. The simulation will terminate according to some model-specified rule or condition. For instance, a job shop operates for as long as it takes to produce a “run” of 300 completed assemblies specified by order.

The alternative approach which is a steady-state simulation is one in which the quantities to be estimated are defined in the long run; that is, over theoretically infinite time frame. In principle, the initial conditions for the simulation don’t matter.

The simulation model in the thesis is designed as a terminating system. The initial conditions, which are explained in the following section, will be same for all alternative investment scenarios. It is assumed that, there will be four ships in the container port, one in the anchoring area waiting for available berth for service, three in the berths dealing with loading/unloading operation. The detailed information for initial condition is listed in Table 4.39 below. The notation t_0 in the Table indicates the simulation start time which corresponds to the date of 12 August 2016, $10^h\,00^m$.

Table 4.39. Simulation Initial Condition Figures

STATUS	**SHIP NAME**			
	ALPHA	BRAVO	CHARLIE	DELTA
POSITION OF THE SHIP IN PORT	BERTH-6	BERTH-7	BERTH-1	WAITING AREA
TONNAGE (DWT)	153.000	127.000	174.000	193.000
LENGTH (M)	155 m.	136 m.	170 m.	210 m.
DRAFT (M)	10,3 m	8,7 m	13,4 m	14,9 m
TOTAL CONTAINER LOAD TO BE HANDLED	1.284 TEU	875 TEU	2.437 TEU	3.115 TEU
SHIP ARRIVAL (APDH)	$t_0 - 28$ hours	$t_0 - 21$ hours	$t_0 - 17$ hours	$t_0 - 11$ hours
ARRIVAL TO WAITING AREA (AADH)	-	-	$t_0 - 16$ hours	$t_0 - 10$ hours
DEPARTURE FROM WAITING AREA (DADH)			$t_0 - 10$hours	-
BERTHING (ABDH)	$t_0 - 25$ hours	$t_0 - 19$ hours	$t_0 - 9$ hours	-
START OPERATION (SODH)	$t_0 - 23$ hours	$t_0 - 15$ hours	$t_0 - 6$ hours	-
COMPLETE OPERATION (CODH)	$t_0 - 1$ hour	-	-	-
SHIP DEPARTURE (DBDH)	-	-	-	-

4.9. Verification of Model

Verification is to confirm that the model operates the way the analyst intended and that the outputs of the model are believable. Verification discusses a variety of techniques available for the user to help insure that the simulation model operates as intended (Chung, 2004).

In this modeling, a single run simulation for a single incoming container ship is conducted to test and verify the model. As a first step structural parameters of ship such as tonnage, length and container load configuration are generated according to historical data. In the second phase of the verification process, time parameters related with port operation such as arrival time, operation time are generated in a similar methodology with ship structural parameters.

4.9.1. Generation of Structural Parameters of Incoming Container Ship

- Vessel Tonnage (DWT)

- Tonnage Interval

R is the random number between 0,0-100,0 generated by ARENA.

R = 45,506 ==> Table 4.9 ==> 15.001 – 30.000 DWT

- Tonnage

R = 5,020 ==> UNIFORM (15.001 , 30.000)

TONN = 15.001 + $((30.000 - 15.001) * 5{,}020)/100$ = 15.001 + 752,95

TONN = 15.754 DWT

- Vessel Length (M)

Cubic regression equation (4.2)

L = Length of the vessel *x = Tonnage of the vessel = 15.754 DWT*

$L = 1{,}853\, x^{3}\, 10^{-13} – 5{,}765\, x^{2}\, 10^{-8} + 0{,}006\, x + 78{,}7670$

$L = 1{,}853 * 15.754^{3} * 10^{-13} – 5{,}765 * 15.754^{2} * 10^{-8} + 0{,}006 * 15.754 + 78{,}7670$

$L = 1{,}853 * 3{,}909 * 10^{12} * 10^{-13} – 5{,}765 * 2{,}481 * 10^{8} * 10^{-8} + 0{,}006 * 15.754 + 78{,}7670$

$L = 0{,}7243 – 14{,}3029 + 94{,}5240 + 78{,}7670$

$L = 159{,}7124\ M$

Length of the vessel is 159,7 M

- Vessel Draft (M)

Logarithmic regression equation (4.3)

D = *Draft of the Vessel* L = *Length of the Vessel* = $159{,}712$ *M*

$D = -17{,}178 + 4{,}883 * \ln L$

$D = -17{,}178 + 4{,}883 * \ln 159{,}712$

$D = -17{,}178 + 4{,}883 * 5{,}073$

$D = 7{,}595$

Draft of the vessel is 7,6 M.

- Container Load Configuration of the Vessel

- Loading or Unloading Vessel

R = 40,954   ==>   Table 4.4   ==> Loaded arrival and departure

- Maximum number of containers (TEU) vessel can carry.

Squared regression equation (4.1)

C = *Max. TEU capacity* x = *Tonnage of the vessel* = 15.754 *DWT*

$C = 10^{-7} x^2 + 0{,}0673\, x + 13{,}131 = 10^{-7} * 15.754^2 + 0{,}0673 * 15.754 + 13{,}131$

$C = 24{,}811 + 1.060{,}24 + 13{,}131$

$C = 1.098$ *TEU*

- Vessel container load at the arrival based on max. TEU capacity.

R = 59,025   ==>   UNIFORM (1 , 1.098)

LOADARV = 1 + $((1.098 - 1) * 59{,}025)/100$ = 1 + 647,5 = 648,5

LOADARV = 649 TEU

Vessel container load configuration at the arrival.

- Full Container

Table 4.5   ==>   Average percentage of full containers at arrival = 0,508848

LOADARVFUL = LOADARV* 0,508848 = 649 * 0,508848 = 330,242

LOADARVFUL = 330 TEU

- 20’ Full Container

Table 4.6   ==>   Average percentage of 20’ full containers at arrival = 0,28933

LOADARVFUL20 = LOADARVFUL* 0,28933 = 330 * 0,28933 = 95,48

LOADARVFUL20 = 95 TEU

- 40’ Full Container

Table 4.6 ==> Average percentage of 40’ full containers at arrival = 0,710667

LOADARVFUL40 = LOADARVFUL* 0,710667= 330 * 0,710667 = 234,523

LOADARVFUL40 = 235 TEU ==> 118 pieces 40’ Full Containers

- Empty Container

Table 4.5 ==> Average percentage of empty containers at arrival = 0,0629

LOADARVEMP = LOADARV* 0,0629 = 649 * 0,0629 = 40,8221

LOADARVEMP = 41 TEU

- 20’ Empty Container

Table 4.6 ==> Average percentage of 20’ empty containers at arrival = 0,05144

LOADARVEMP20 = LOADARVEMP* 0,05144 = 41 * 0,05144= 2,109

LOADARVEMP20 = 2 TEU

- 40’ Empty Container

Table 4.6 ==> Average percentage of 40’ empty containers at arrival = 0,948556

LOADARVEMP40 = LOADARVEMP* 0,948556= 41 * 0,948556= 38,89

LOADARVEMP40 = 39 TEU ==> 20 pieces 40’ Empty Containers

- Transit Full Container

Table 4.5 ==> Average percentage of transit full containers at arrival = 0,426004

LOADARVTRFUL = LOADARV* 0,426004= 649 * 0,426004= 276,476

LOADARVTRFUL = 276 TEU

- 20’ Transit Full Container

Table 4.6 ==> Average percentage of 20’ transit full containers at arrival = 0,407170

LOADARVTRFUL20 = LOADARVTRFUL* 0,407170= 276 * 0,426004= 112,378

LOADARVTRFUL20 = 112 TEU

- 40’ Transit Full Container

Table 4.6 ==> Average percentage of 40’ transit full containers at arrival = 0,59283

LOADARVTRFUL40 = LOADARVTRFUL* 0,407170= 276 * 0,426004= 163,621

LOADARVTRFUL40 = 164 TEU ==> 82 pieces 40’ Transit Full Containers

- Transit Empty Container

Table 4.5 ==> Average percentage of transit empty containers at arrival = 0,002163

LOADARVTREMP = LOADARV* 0,002163= 649 * 0,002163= 1,403

LOADARVTREMP = 1 TEU

- 20’ Transit Empty Container

Table 4.6 ==> Average percentage of 20’ transit empty containers at arrival = 0,35816

LOADARVTREMP20 = LOADARVTREMP * 0,002163= 1 * 0,35816= 0,35816

LOADARVTREMP20 = 0 TEU

- 40’ Transit Empty Container

Table 4.6 ==> Average percentage of 40’ transit empty containers at arrival = 0,64184

LOADARVTREMP40 = LOADARVTREMP * 0,64184= 1 * 0,64184= 0,64184

LOADARVTREMP40 = 1 TEU ==> 1piece 40’ Transit Empty Containers

- Vessel container load at the departure based on max. TEU capacity.

R = 68,728 ==> UNIFORM (1 , 1.098)

LOADARV = 1 + $((1.098 - 1) * 68{,}728)/100$ = 1 + 753,946 = 754,946

LOADDEP = 755 TEU

- Vessel container load configuration at departure.
  - Full Container

Table 4.5 ==> Average percentage of full containers at departure = 0,345744

LOADDEPFUL = LOADDEP* 0,345744= 755 * 0,345744= 261,036

LOADDEPFUL = 261 TEU

- 20’ Full Container

Table 4.7 ==> Average percentage of 20’ full containers at departure = 0,264604

LOADDEPFUL20 = LOADDEPFUL* 0,264604 = 261 * 0,264604 = 69,06

LOADDEPFUL20 = 69 TEU

- 40’ Full Container

Table 4.7 ==> Average percentage of 40’ full containers at departure = 0,735396

LOADDEPFUL40 = LOADDEPFUL* 0,735396 = 261 * 0,735396 = 191,913

LOADDEPFUL40 = 192 TEU ==> 96 pieces 40’Full Containers

- Empty Container

Table 4.5 ==> Average percentage of empty containers at departure = 0,193594

LOADDEPEMP = LOADDEP* 0,193594 = 755 * 0,193594 = 146,163

LOADDEPEMP = 146 TEU

- 20’ Empty Container

Table 4.7 ==> Average percentage of 20’empty containers at departure = 0,265054

LOADDEPEMP20 = LOADDEPEMP* 0,265054 = 146 * 0,265054 = 38,704

LOADDEPEMP20 = 39 TEU

- 40’ Empty Container

Table 4.7 ==> Average percentage of 40’empty containers at departure = 0,734946

LOADDEPEMP40 = LOADDEPEMP* 0,734946 = 146 * 0,734946 = 107,295

LOADDEPEMP40 = 107 TEU ==> 54 pieces 20’ Empty Containers

- Transit Full Container

Table 4.5 ==> Average percentage of transit full containers at departure = 0,458438

LOADDEPTRFUL = LOADDEP* 0,458438 = 755 * 0,458438 = 346,121

LOADDEPTRFUL = 346 TEU

- 20’ Transit Full Container

Table 4.7 ==> Average percentage of 20’ transit full containers at departure = 0,411327

LOADDEPTRFUL20 = LOADDEPTRFUL* 0,411327 = 346 * 0,411327 = 142,319

LOADDEPTRFUL20 = 142 TEU

- 40’ Transit Full Container

Table 4.7 ==> Average percentage of 40’ transit full containers at departure = 0,588657

LOADDEPTRFUL40 = LOADDEPTRFUL* 0,588657= 346 * 0,588657= 203,675

LOADDEPTRFUL40 = 204 TEU ==> 102 pieces 40’ Transit Full Containers

- Transit Empty Container

Table 4.5 ==> Average percentage of transit empty containers at departure = 0,00224

LOADDEPTREMP = LOADDEP * 0,00224 = 755 * 0,00224 = 1,694

LOADDEPTREMP = 2 TEU

- 20’ Transit Empty Container

Table 4.7 ==>Average percentage of 20’ transit empty containers at departure = 0,37590

LOADDEPTREMP20 = LOADDEPTREMP * 0,37590 = 2 * 0,37590 = 0,7518

LOADDEPTREMP20 = 1 TEU

- 40’ Transit Empty Container

Table 4.7 ==> Average percentage of 40’ transit empty containers at departure=0,62409

LOADDEPTREMP40 = LOADDEPTREMP * 0,624096 = 2 * 0,624096= 1,2481

LOADDEPTREMP40 = 1 TEU ==> 1 piece 40’ Transit Empty Containers

Structural figures generated for single incoming container ship by means of single run simulation are presented in Table 4.40.

Table 4.40. Results of Generated Structural Parameters for Incoming Container Ship.

STRUCTURAL PARAMETERS	REFERENCE TABLE/ EQUATION	GENERATED FIGURES OF PARAMETERS
Vessel Tonnage	Table 4.9	**15. 754 DWT**
Vessel Length	Equation 4.2	**159,7 M**
Vessel Draft	Equation 4.3	**7,6 M**
Type of Vessel (Loaded/Unloaded Arv. /Dep.)	Table 4.4	Loaded Arv/Dep
Maximum Container Capacity of Vessel	Equation 4.1	1.098 TEU
Container load at Arrival		**649 TEU**
Full Container at Arrival	Table 4.5	330 TEU
20’ Full Container at Arrival	Table 4.6	95 TEU
40’ Full Container at Arrival	Table 4.6	235 TEU
Empty Container at Arrival	Table 4.5	41 TEU
20’ Empty Container at Arrival	Table 4.6	2 TEU
40’ Empty Container at Arrival	Table 4.6	39 TEU
Transit Full Container at Arrival	Table 4.5	276 TEU
20’ Transit Full Container at Arrival	Table 4.6	112 TEU
40’ Transit Full Container at Arrival	Table 4.6	164 TEU
Transit Empty Container at Arrival	Table 4.5	1 TEU
20’ Transit Empty Container at Arrival	Table 4.6	0 TEU
40’ Transit Empty Container at Arrival	Table 4.6	1 TEU
Container load at Departure		**755 TEU**
Full Container at Departure	Table 4.5	261 TEU
20’ Full Container at Departure	Table 4.7	69 TEU
40’ Full Container at Departure	Table 4.7	192 TEU
Empty Container at Departure	Table 4.5	146 TEU
20’ Empty Container at Departure	Table 4.7	39 TEU
40’ Empty Container at Departure	Table 4.7	107 TEU
Transit Full Container at Departure	Table 4.5	346 TEU
20’ Transit Full Container at Departure	Table 4.7	142 TEU
40’ Transit Full Container at Departure	Table 4.7	204 TEU
Transit Empty Container at Departure	Table 4.5	2 TEU
20’ Transit Empty Container at Departure	Table 4.7	1 TEU
40’ Transit Empty Container at Departure	Table 4.7	1 TEU
Total Numbers of Handled Containers(TEU)	**1.404 TEU**	

4.9.2. Generation of Time Parameters of Incoming Container Ship

As a final step of verification process, time parameters are generated according to probability distribution functions generated by input analysis module of ARENA program in Section 4.4.8. For this special case, it has been assumed that there was no available berth for incoming ship at the arrival. Therefore, ship had to proceed to the anchoring area and wait for suitable berth. The simulated total time in port is 41 hours and 57 minutes. Results are presented in Table 4.41.

Table 4.41. Results of Generated Time Parameters for Incoming Container Ship

TIME PARAMETER	GENERATED TIME PERIOD		GENERATED TIME PARAMETER
	Hour	Hour Min.	
Last Vessel Arrival			12 Agu.16 10^h:00^m
Interarrival Time (IAT)	8,7491	08^h 45^m	
Vessel Arrival to Port (APDH)			12 Agu.16 18^h:45^m
Arrival to Anchoring Area Time (AAT)	0,5335	00^h 32^m	
Arrival to Anchoring Area (AADH)			12 Agu.16 19^h:17^m
Waiting Time at Anchoring Area (WAT)	11,0690	11^h 04^m	
Departure from Anchoring Area (DADH)			13Agu.16 06^h:21^m
Anchoring Area to Berthing Time (APT)	0,7943	00^h 48^m	
Arrival to Berthing (ABDH)			13Agu.16 07^h:09^m
Berthing to Operation Time (BOT)	1,9842	01^h 59^m	
Start Operation (SODH)			13Agu.16 09^h:08^m
Operation Time (OPT)	24,9966	24^h 59^m	
Complete Operation (CODH)			14 Agu.16 10^h:07^m
Operation to Departure Time (ODT)	2,5654	02^h 34^m	
Vessel Departure from Port (DBDH)			14 Agu.16 12^h:41^m
Total Time in Port (TOT)	41,9430	41^h 57^m	

Generation of the time parameters using probability distributions and random numbers are summarized in Table 4.42. Time chart diagrams in Figure 4.21 and Figure 4.22 also explain the verification process graphically.

Table 4.42. Single Run Simulation of Time Values (Generation of Time Values).

Random Numbers	Interarrival Time	Arrival to Anchorage	Wait. at Anchorage	Anchorage to Berth	Arrival to Berth Time	Berthing to Oprt. Tiıme	Operation Time	Operation to Depr. Time	Total Time in Port
	IAT	**AAT**	**WAT**	**APT**	**ABT**	**BOT**	**OPT**	**ODT**	**TOT**
	GAMM	**TRIA**	**1+LOGN**	**TRIA**	**2*BETA**	**LOGN**	**ERLA**	**LOGN**	**2+LOGN**
(0.0, 1.0)	(10.6, 0.814)	(0, 0.622, 1.41)	(24.4, 33.7)	(0.26, 0.729, 1)	(2.2, 1.7)	(1.41, 0.877)	(8.29, 2.0)	(1.39, 0.811)	(27.2, 26.6)
0,5588	8,7491	0,7879	17,9070	0,7109	1,2301	1,6629	16,9935	1,3553	24,1976
0,3784	7,5787	0,5335	9,3793	0,5901	0,9853	0,9912	11,5887	1,0731	17,5691
0,7609	10,3423	1,0729	11,0690	0,8463	1,5018	1,8363	22,6138	1,8414	38,6805
0,5936	8,9902	0,8370	9,5223	0,7943	1,2761	1,4504	16,5503	1,4387	26,7655
0,7943	10,6821	1,1200	33,5740	0,8687	1,5496	1,9842	24,0206	1,8982	41,0559
0,7843	10,5760	1,1058	34,8210	0,8620	1,5350	1,8317	24,9966	1,8760	40,7407
0,9199	12,5634	1,2970	61,9895	0,9528	1,7541	2,6503	34,8257	2,5654	59,5017
0,5754	8,8630	0,8113	17,1543	0,7220	1,2520	1,8839	16,6898	1,3968	25,3761
0,6734	9,5828	0,9495	24,5058	0,7877	1,3819	1,5807	19,6878	1,5578	30,2167
0,9945	16,8202	1,4022	89,8703	1,0028	1,9513	5,1703	59,4359	4,7652	103,2756

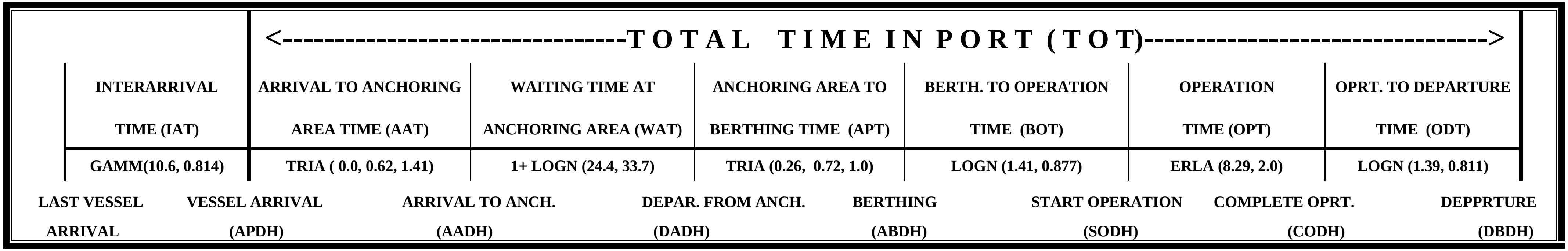


Figure 4.21. Time Chart Diagram When There Is No Available Berth to Tie Up.

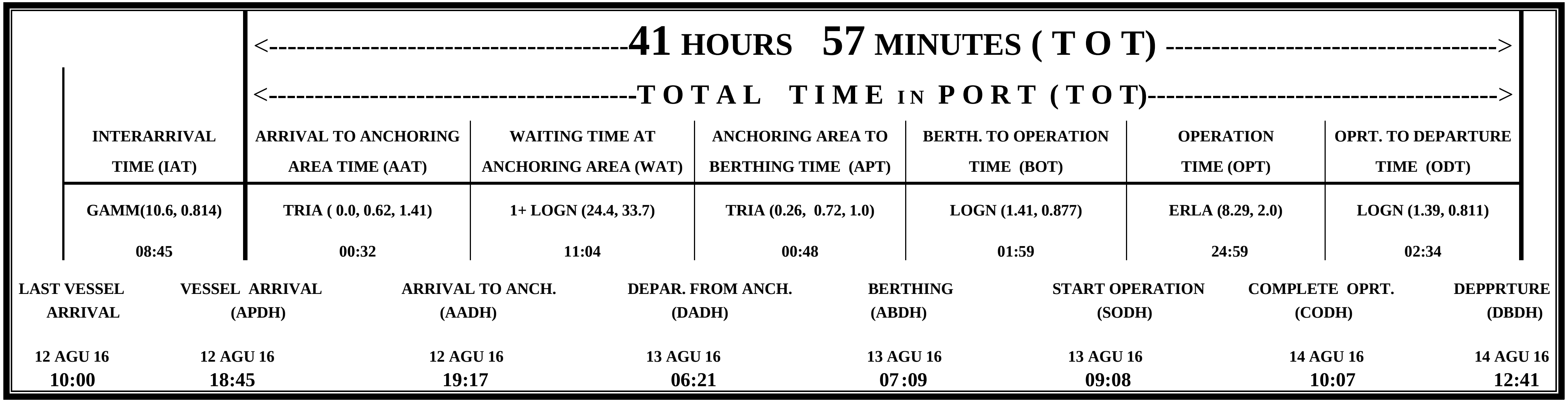


Figure 4.22. Results of Single Run Simulation Time Chart Diagram When There Is No Available Berth to Tie Up.

At the end of verification, it has been confirmed that the model operates the way it is designed and that two major outputs of the model which are the key performance measures are believable. These values, total numbers of handled containers and total time in port are depicted in Table 4.43.

Table 4.43. Results of Single Run Simulation of Input and Output Values.

INPUT VALUES		**OUTPUT VALUES**	
Total Lengths of Berths	1.560 meters	Total Numbers of Handled Containers (TEU)	1.404 TEU
Number of Quay Cranes	15 cranes		
Number of Yard Trucks	82 trucks	Total Time in Port (TOT)	$41^{h}\,57^{m}$
Number of Yard Cranes	35 cranes		

4.10. Validation of Model

Validation shows that the simulation model represents real system which is operational systems of MARPORT container terminal. At the beginning of validation process, interviews are organized with domain experts to get their comments for the structure of simulation model. At the end of model development phase, we interviewed with General Manager of the MARPORT Mr. Gökhan ESİN and Operational Manager Mr. Mesut ŞEN. In a similar way, the draft simulation model was also examined by Mr. Kadir UZUN who is the General Manager of ASYA Port. Consulting with these container port experts created an opportunity to make some adjustments to the simulation model before beginning the second phase of validity process which is called as statistical validity.

The main objective of statistical validity is to make a quantitative comparison between the real system and the simulation model. If there is no statistically significant difference between the data sets, then the model is considered valid. Conversely, if there is a statistically significant difference, then the model is not valid and needs additional work before further analysis may be conducted. In this context, we discuss the following main topics (Chung, 2004);

- Data collection for validation,
- Data analysis process.

4.10.1. Validation Data Collection

Validation data collection involves collecting data from both the actual system and the base simulation model that is designed to represent the actual system. Validation data may be based on either individual observations or summary statistics. In the case of individual observations, we perform the analysis using data from individual entity measures of performance. Conversely, the summary statistic approach involves analysis using mean data from multiple sets of observations of individual entity measures of performance. Significantly less data is required for the individual observational method than the summary method. The simpler and more rapidly executed individual observation approach is probably of more utility to the practitioner (Chung, 2004).

4.10.2. System Validation Data Collection

System validation data collection varies significantly from input data collection processes. In system validation data collection, the major concern is collecting data which reflects the overall performance of the system. A common method is to collect system or flow time. This is the time that it takes an entity to be processed or flow through the entire system under study.

In the research, total time in port (TOT) data is chosen as a major output which reflects the overall performance of container port. At this point, we may choose to use either;

- Individual entity data,
- Entire system and model run data(Chung, 2004).
-

4.10.2.1. Individual Entity Validation Data Approac

Individual entity validation data involve the collection of system times for individual entity, which is a container vessel in the model, going through the system and through the model. This type of data may be collected for as few as 30 actual orders in order to make a comparison with the orders from the simulation model. Depending on the exact system, this type of data could be collected in a number of hours or days.

The limitation to this approach is principally the issue of autocorrelation. This means, for example, if a given container vessel has a long system time, then the next incoming vessel arriving the port right after the given vessel may also have a long system time. Similarly, if a given vessel has a short total port time, then the vessel right after this container vessel may also have a short total port time. The problem with the existence of autocorrelation is that it violates some statistical requirements for the appropriate use of validation tests. (Chung, 2004).

4.10.2.2. Entire System and Model Run Validation Data Approach

The alternative approach is to use a number of entire system and model run data. This approach requires a significantly greater amount of actual system data collection than the individual entity approach.

Here, we would pick a particular time period and collect all of the processing times observed during the time period. An average for all of the processing times for that time period would be calculated. This process would be repeated many more times until perhaps a total of 30 average processing times were collected. The model would similarly be run 30 different times in order to generate the comparison data.

This approach does not suffer from the potential problem of autocorrelation. However, the practitioner must individually decide whether this advantage is worth the greater data collection effort over the individual entity approach(Chung, 2004).

In this thesis, ‘Entire System and Model Run Validation Data Approach’ is followed. Actual data covers ten -month period (October 2014- July 2015). Ten-day time interval is taken as a basis to calculate the average ‘Vessel Total Time in Port (TOT)’. For each month, we obtain three average TOT value. As a result, we obtained 30 (10*3) average TOT actual output value. These average TOTs are listed in Table 4.44(Chung, 2004).

Table 4.44. Average Actual Total Time in Port (TOT) Values (Hours).

Month and Year	10-Day Interval of the Month		
	01-10 Average TOT	11-20 Average TOT	21-31 Average TOT
October 2014	20,91	30,79	28,37
November 2014	25,19	21,90	31,08
December 2014	16,12	33,19	35,80
January 2015	41,78	38,71	24,14
February 2015	48,31	38,01	46,33
March 2015	44,39	37,19	32,46
April 2015	29,82	32,37	33,92
May 2015	41,30	27,84	29,52
June 2015	32,92	29,41	36,89
July 2015	45,36	43,65	38,65

4.10.2.3. Record System Validation Data Collection Conditions

A very important issue in the collection of system validation data is that the researcher record the state of the system when the data are collected. This includes the state of all entities and resources in the system. Entities can be in queues, or they can be in transit to different parts of the system(Chung, 2004). In the model, these entities are the number of infrastructure assets such as number of piers and their length, cranes and trucks, the number of vessels in anchoring area and in piers,

4.10.24.4. Model Validation Data Collection

Model validation data collection consists of recording the same type of output data as were collected in the system validation data collection process. In order to collect these data properly, we must load the model in the same manner that it was observed when the system validation data were collected (Chung, 2004).

It is also advised to utilize the same number of observations from the model as the number of observations obtained from the actual system. The use of the same number of data points simplifies subsequent statistical calculations. In this case, the model was similarly run 40 different times in order to generate the comparison data. Similar to actual data, each run covers ten-day period to generate average ‘Total Time in Port (TOT)’ Values in hours. These average TOT output values are presented in Table 4.45(Chung, 2004).

Table 4.45. Average Simulation Total Time in Port (TOT) Values (Hours).

Simulated Average TOT Values (Hours)			
15,03	17,76	18,78	21,13
22,47	23,98	24,86	25,17
26,06	26,13	27,57	27,88
28,32	28,75	28,76	29,79
29,92	30,38	30,57	30,69
31,48	31,93	31,98	32,88
33,61	33,83	34,57	34,74
35,31	35,94	36,95	37,06
37,24	37,93	38,89	39,16
42,73	43,58	46,07	47,91

4.10.3. Validation Data Analysis Process

The validation data analysis process consists of first determining the appropriate statistical comparison of means test to execute. This is performed by determining whether or not one or both of the validation data sets are normal. If both of the data sets are normal, then a version of a *t*-test is performed. If only one or neither of the data sets is normal, then a nonparametric test is performed (Chung, 2004).

There is a total of four different types of hypothesis tests (Johnson et al., 1999). The selection of the appropriate comparison test is dependent on whether or not the data is normally distributed, paired, or independently generated and similar or not in variance. The flowchart in Figure 4.23 explains the methods of selecting the most appropriate hypothesis test.

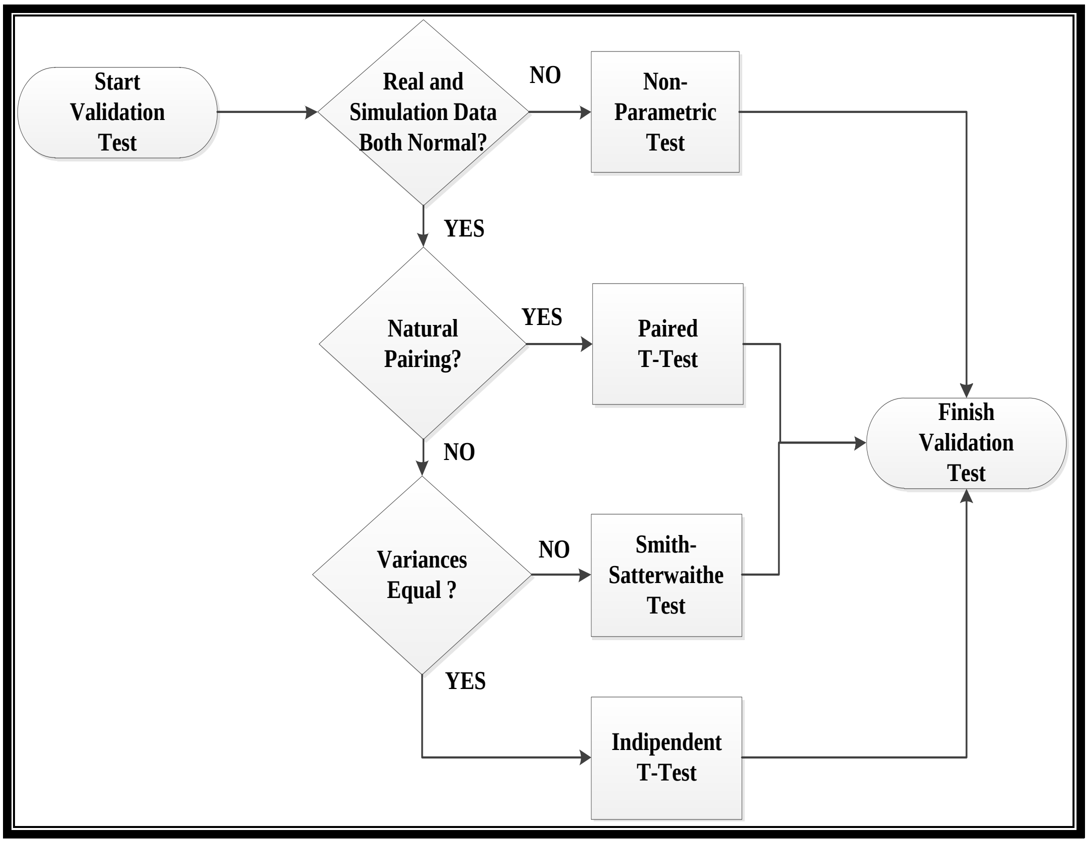


Figure 4.23. Statistical Validity Test Flowchart (Source, Chung, 2004).

As the flow chart indicates, the first step is to determine whether or not the two data sets are normally distributed. In order to determine this, we must either revisit the chi-square test or make an assumption that the data are either normally or not normally distributed. In the event that either one or both of the data sets are not normally distributed or that we assume that either one or both of the data sets are not normally distributed, the appropriate test is a nonparametric rank sum *U* test. Conversely, if we determine or assume that both of the data sets are normal, we must continue down the flow chart. If the data are naturally paired, we must perform a paired *t*-test. If the data are not naturally paired, then we must next determine whether or not the variance is similar. We can perform this process with an *F*-test. If the variance between the two data sets is similar, we use an independent *t*-test. If the variance is not similar, then we run a Smith–Satterthwaite test.

4.10.3.1. Examining the Validation Data for Normality

As the flow chart indicates, the first step is to determine whether or not the two data sets are normally distributed. In order to determine this, we must either revisit the chi-square test or make an assumption that the data are either normally or not normally distributed. In the event that either one or both of the data sets are not normally distributed or that we assume that either one or both of the data sets are not normally distributed, the appropriate test is a nonparametric rank sum *U* test. Conversely, if we determine or assume that both of the data sets are normal, we must continue down the flow chart. If the data are naturally paired, we must perform a paired *t*-test. If the data are not naturally paired, then we must next determine whether or not the variance is similar. We can perform this process with an *F*-test. If the variance between the two data sets is similar, we use an independent *t*-test. If the variance is not similar, then we run a Smith–Satterthwaite test.

- **Test of Normality of Average Actual Total Time in Port (TOT) Values.**

Distribution:	Normal
Expression:	NORM (33,9 7,85)
Square Error:	0,012408

Chi Square Test

Number of intervals	= 5
Degrees of freedom	= 3
Level of Significance	= 0,05
Test Statistic	= 0,969
Corresponding p-value	= 3,182

The last step in the chi-square test is to compare the calculated test statistic with the critical value from the chi-square distribution table. If the calculated test statistic is less than the critical value, the data set can be considered approximately normal. Conversely, if the test statistic exceeds the critical value, then the data cannot be considered approximately normally distributed. In statistical terms, if the test statistic was less than the critical value, then we could not reject the null hypotheses of the data’s being approximately normally distributed. Likewise, if the test statistic were greater than the critical value, we could reject the null hypothesis of the data being approximately normally distributed (Chung, 2004).

In the test, the calculated test statistic, 0,969 is less than the critical value, 3,182 (for an α of 0,05 and 3 degree of freedom). Therefore, the Average Actual Total Time in Port (TOT) data set can be considered approximately normal. In addition to chi-square test, Kolmogorov-Smirnov Test and square error value, 0,0124, also indicate the normal distribution of the data. These test values and histogram are as follows;

Kolmogorov-Smirnov Test

Test Statistic = 0,0683
Corresponding p-value > 0,15

Data Summary

Number of Data Points = 30
Min Data Value = 16,1
Max Data Value = 48,3
Sample Mean = 33,9
Sample Std. Deviation = 7,98

Histogram Summary

Histogram Range = 16 to 49
Number of Intervals = 15

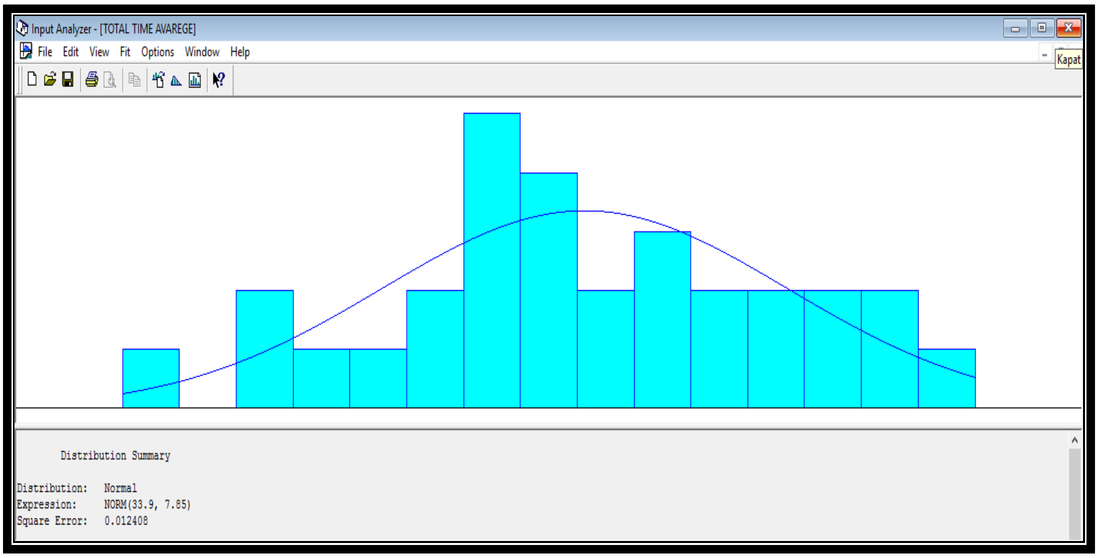
Fit All Functions

Function:	Square Error:
Normal	0,0124
Beta	0,0145
Weibull	0,0152
Triangular	0,0153
Gamma	0,0241
Uniform	0,0244
Erlang	0,0277
Lognormal	0,0431
Exponential	0,0514

Table 4.46. Average Actual Total Time in Port (TOT) Probabilistic Values.

INTERVAL NUMBER	NUMBER OF DATA POINTS	ACTUAL TOT VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	1	18,2	0,0333	0,0115	0,0333	0,0225
1	0	20,4	0,0000	0,0201	0,0333	0,0426
2	2	22,6	0,0667	0,0324	0,1000	0,0750
3	1	24,8	0,0333	0,0484	0,1330	0,1230
4	1	27,0	0,0333	0,0667	0,1670	0,1900
5	2	29,2	0,0667	0,0852	0,233	0,2750
6	5	31,4	0,1670	0,1010	0,4000	0,3760
7	4	33,6	0,1330	0,1100	0,5330	0,4860
8	2	35,8	0,0667	0,1110	0,6000	0,5960
9	3	38,0	0,1000	0,1040	0,7000	0,7000
10	2	40,2	0,0667	0,0894	0,7670	0,7890
11	2	42,4	0,0667	0,0715	0,8330	0,8610
12	2	44,6	0,0667	0,0528	0,9000	0,9140
13	2	46,8	0,0667	0,0361	0,9670	0,9500
14	1	49,0	0,0333	0,0228	1,0000	0,9730

As it has been obsereved in Figure 4.24, the curve has a bell shape, which is a indication of normal distribution.



```
        Distribution Summary

Distribution:   Normal
Expression:     NORM(33.9, 7.85)
Square Error:   0.012408
```

Figure 4.24. Histogram of Average Actual Total Time in Port (TOT).

- **Test of Normality of Average Simul. Total Time in Port (TOT) Values.**

Distribution: Normal

Expression:	NORM(31,5, 7,32)
Square Error:	0,007482

Chi Square Test

Number of intervals = 6
Degrees of freedom = 4
Level of Significance = 0,05
Test Statistic = 1,62
Corresponding p-value = 2,776

In the test, the calculated test statistic, 1,62 is less than the critical value, 2,776 (for an α of 0,05 and 4 degree of freedom). Therefore, the Average Simulation Total Time in Port (TOT) data set can be considered approximately normal.

In a similar way, Kolmogorov-Smirnov Test and the histogram also support the normality of simulation data

Kolmogorov-Smirnov Test

Test Statistic = 0,0475
Corresponding p-value > 0,15

Data Summary

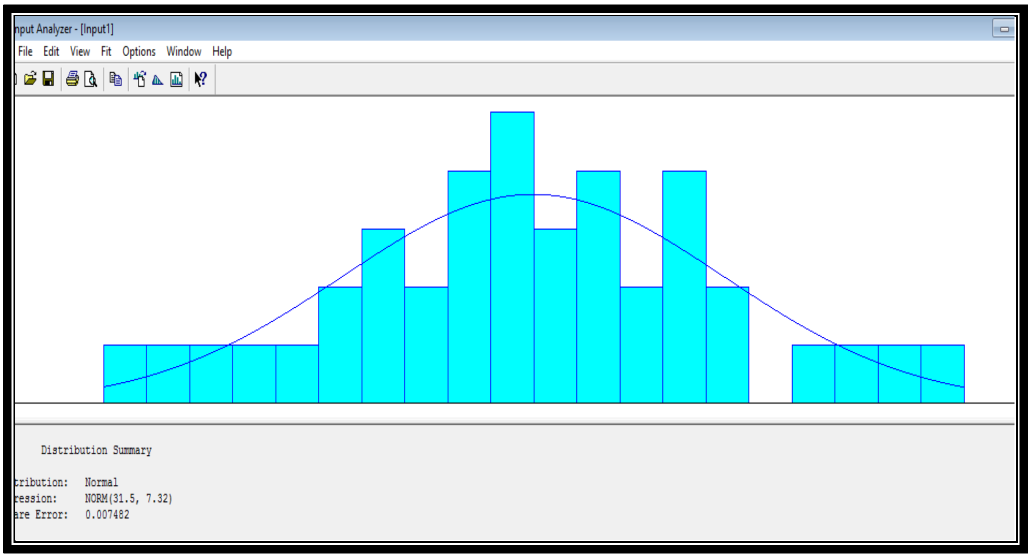
Number of Data Points = 40
Min Data Value = 15
Max Data Value = 47,9
Sample Mean = 31,5
Sample Std, Deviation = 7,42

Fit All Functions

Function	Square Error
Normal	0,0117
Triangular	0,0127
Beta	0,0176
Weibull	0,0182
Gamma	0,0296
Erlang	0,0321
Uniform	0,0333
Lognormal	0,0523
Exponential	0,0574

Table 4.47. Average Simulation Total Time in Port (TOT) Probabilistic Values.

INTERVAL NUMBER	NUMBER OF DATA POINTS	SIMULATION TOT VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	1	16,6	0,0250	0,0098	0,0250	0,0215
1	1	18,3	0,0250	0,0146	0,0500	0,0361
2	1	19,9	0,0250	0,0218	0,0750	0,0580
3	1	21,6	0,0250	0,0311	0,1000	0,0891
4	1	23,2	0,0250	0,0420	0,1250	0,1310
5	2	24,9	0,0500	0,0541	0,1750	0,1850
6	3	26,5	0,0750	0,0661	0,2500	0,2510
7	2	28,2	0,0500	0,0768	0,3000	0,3280
8	4	29,8	0,1000	0,0849	0,4000	0,4130
9	5	31,5	0,1250	0,0892	0,5250	0,5020
10	3	33,1	0,0750	0,0891	0,6000	0,5910
11	4	34,8	0,1000	0,0846	0,7000	0,6760
12	2	36,4	0,0500	0,0764	0,7500	0,7520
13	4	38,1	0,1000	0,0655	0,8500	0,8180
14	2	39,7	0,0500	0,0535	0,9000	0,8710
15	0	41,4	0,0000	0,0415	0,9000	0,9130
16	1	43,0	0,0250	0,0306	0,9250	0,9430
17	1	44,7	0,0250	0,0214	0,9500	0,9650
18	1	46,3	0,0250	0,0143	0,9750	0,9790
19	1	48,0	0,0250	0,0091	1,0000	0,9880



```
Distribution Summary

tribution:   Normal
ression:     NORM(31.5, 7.32)
are Error:   0.007482
```

Figure 4.25. Histogram of Average Simulation Total Time in Port (TOT).

Since both the actual system and the model validation data sets are found to be normal, we next need to establish if the system and model data are statistically similar with a hypothesis test as indicated in Figure 4.23, Statistical Validity Test Flowchart. Hypothesis tests involve the establishment of a null hypothesis that the variances of the data sets are statistically similar. The null hypothesis, is either accepted or rejected. If it is accepted, then the follow on test for validation is conducted.

4.10.4. *F*-Test for Comparing the Variances

The *F*-test compares the variance of the actual system validation data set and that of the model validation data set. There are a number of specific implementations of the *F*-test. In this research, we are interested in calculating a test statistic of the ratio of the larger variance divided by the smaller variance. It does not matter whether the larger or the smaller variance is from the system validation data set or the model validation set. This test statistic is compared to a critical *F* value at a particular level of statistical significance. A common level of statistical significance is α = 0,05. We may acquire the critical *F* value using commonly available statistical tables. In addition to the level of significance, it is also required to specify the number of degrees of freedom for the variance in the numerator and the number of degrees of freedom for the variance in the denominator.

There are a number of different implementations of the *F*-test. In this version, the data set with the larger variance will be the numerator and the data set with the smaller variance will be the denominator. This gives us the ability to simplify the calculations. The formula for using this version of the *F*-test is;

$$F = \frac{S_M^2}{S_m^2}$$

Where

S_M^2 is the variance of the data set with the larger variance.

S_m^2 is the variance of the data set with the smaller variance.

The steps involved in implementing the *F*-test are;

- H_0 Null hypothesis: variances of both groups are equal.
- H_a Alternative hypothesis: variances of both groups are not equal.
- Select a level of significance.

- Determine the critical value for *f* at the level of significance divided by 2 with degrees of freedom according to the number of samples in the data set with the larger variance and samples in the data set with the smaller variance.
- Calculate the test statistic *f* according to the formula above.
- Reject the null hypothesis if the test statistic exceeds the critical value.

The *F*-Test for the Simulation Model;

In this model, the variance of the actual system is 7,98, and the variance of the simulation model is 7,42. With this statistical information, the *F*-test calculations are as follows;

- *H*o: The variance of actual average values of total times in port is equal to the variance of simulation average values of total times in port.
- *H*a: The variance of actual average values of total times in port is not equal to the variance of simulation average values of total times in port.
- We select a 0,95 level of significance or 0,05 as an α level.
- The critical value for *F* at α/2 with 29 degrees of freedom for the numerator and 39 for the denominator is 1,70.
- The *F* statistic is calculated by;

$$F = \frac{7.98^2}{7.42^2} = \frac{63.6804}{55.0564} = 1{,}1566$$

- The test statistic 1,1566 is less than the critical value of 1,70, so we cannot reject the null hypothesis that the data have similar variance.

4.10.5. Independent *t*-Test for Two Data Sets

The independent *t*-test is utilized when the data are normal and the data sets have similar variance. This test will determine if there is a statistically significant difference between two models at a given level of significance. In order to perform this test, we will use the mean and sample standard deviation of both data sets. The procedure is as follows:

- *Ho* Null hypothesis: means of both groups are equal.
- *Ha* Alternative hypothesis: means of both groups are not equal.
- Select a level of significance.

- Determine the critical value for *t* at the level of significance divided by 2 with degrees of freedom according to number of samples in both the data sets minus 2.
- Calculate the test statistic *t* according to the formula above.
- Reject the null hypothesis if the test statistic is either greater than the critical value or less than the negative of the critical value.

The formula for calculating the test statistic *t* is;

$$t = \frac{(\overline{x_1} - \overline{x_2})}{\sqrt{(n_1-1)\,s_1^2+(\,n_2-1)s_2^2}}\ \sqrt{\frac{n_1\ n_2\ (n_1+n_2-2)}{n_1+n_2}}$$

Where;

t = calculated test statistic.

$\overline{x_1}$ = mean of the actual total time in port data (first alternative).

$\overline{x_2}$ = mean the simulation total time in port data (second alternative).

s_1^2 = variance of the first alternative.

s_2^2 = variance of the second alternative

n_1 = number of data points in the first alternative.

n_2 = number of data points in the second alternative.

- **Independent *t*-Test for the Simulation Model**

Since the data sets of the container port simulation model are both normal and the variations are same, we could perform an independent *t*-test to determine if a difference exists between the two data sets, namely actual and simulation output data sets.

The mean and standard deviation of the actual average values of total time in port data, in hours, are 33,90 and 7,85 respectively. The mean and standard deviation for the simulation model, in hours, are 31,50 and 7,32.

- *Ho*: The mean of the actual output data is equal to the mean of the simulation output data.
- *Ha*: The mean of the actual output data is not equal to the mean of the simulation output data.

- The level of significance α = 0,05.
- The degrees of freedom is 68 ($n_1 + n_2 - 2 = 30 + 40 - 2 = 68$).
- The critical value for t at α/2, 68 degrees of freedom, is 1,9973.

The test statistic is;

$$t = \frac{(33.9-31.5)}{\sqrt{(30-1)\,7.85^{2}+(40-1)\,7.32^{2}}}\sqrt{\frac{30*40*(30+40-2)}{30+40}}$$

$t = 1{,}316$

The test statistic t of 1,316 is between −1,9973 and +1,9973, so we cannot reject the null hypothesis. This means that there is no statistically significant difference between the actual system and the simulation model. As a result of these hypothesis tests, it can be said that this simulation model is statistically validated.

4.11. Container Terminal Infrastructure Investment Alternatives

As explained previously in Sub-Chapter 4.7, port performance indicators Monthly Port Throughput (TEU) and Average Time in Port (in hour) are used as main performance indicators. Therefore, the simulation model structure is designed in such a way that the outputs will be these two port performance indicators. After selecting these performance indicators, possible infrastructure investment alternatives will be identified to improve the capacity at the CT while reducing the average total time in port. Possible solutions including managerial measures are:

- To increase the length, draught or number of berths,
- To increase the number of cranes and/or trucks,
- To enlarge the container yard,
- To increase the productivity at the berth by using new technologies or machinery,

- To increase the avaible time that berths can be operated (i.e. 24 hours, 7-days a week),
- To increase the efficiency in allocation of actual resources,
- To generate the policies and management decisions, which often have non-optimal objectives.

By taking into consideration above mentioned approaches, total of 16 alternative simulation scenarios were employed to be able to evaluate the optimum infrastructure investment decision for the target container terminal (MARPORT). For each test scenario, different sets of terminal equipment were assigned to the simulation model as input parameter. These four basic parameters are;

- Length of quay(LENG),
- Total number of quay cranes(QCRN), MHC and STS (Figure 4.26),
- Total number of yard trucks(YRDT) (Figure 4.27) , and
- Total number of yard cranes(YRDC) (Figure 4.28).

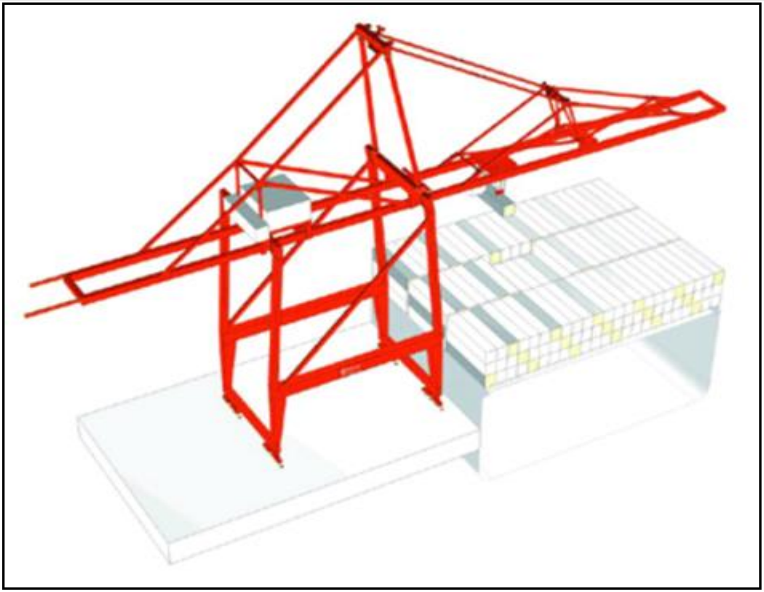


Figure 4.26. Ship to Shore Gantry Crane (STS).
(Source, www. kalmarind.com).

Current assets in MARPORT are accepted as base values for each parameter. These are;

- Total length of quays in MARPORT (LENG-1)= 1.560 meters,
- Total number of quay cranes in MARPORT(QCRN-1)= 15 quay cranes (10 STS+ 5 MHC),
- Total number of yard trucks in MARPORT (YRDT-1)= 82 yard trucks,
- Total number of yard cranes in MARPORT (YRDC-1)= 35 yard cranes.

Figure 4.27. Yard Truck (YRDT)
(Source, www. kalmarind.com).

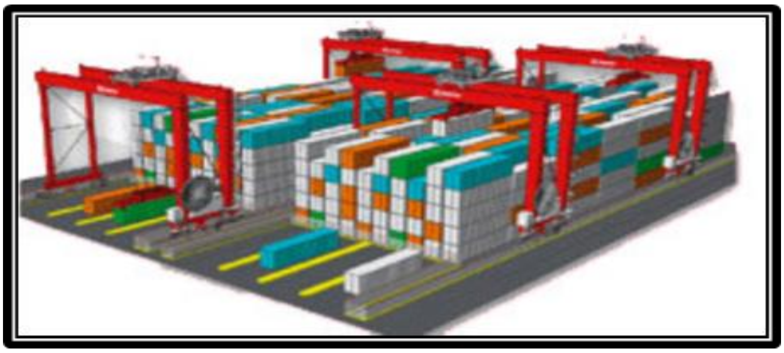


Figure 4.28. Yard Crane (YRDC)
(Source, www. kalmarind.com).

Then, for each parameter four different values in an increasing order are taken as an representative of each investment scenario while keeping other three parameters constant in their base values. By employing this method, initially total of 16 different scenarios, listed in Table 4.48, are obtained.

Table 4.48. Alternative Simulation Scenarios.

SCENARIOS	INPUTS			
	LENGTH OF QUAY (M)	NUMBER OF QUAY CRANES	NUMBER OF YARD TRUCKS	NUMBER OF YARD CRANES
LENG-1	1.750	15	82	35
LENG-2	2.000	15	82	35
LENG-3	2.250	15	82	35
LENG-4	2.500	15	82	35
QCRN-1	1.560	17	82	35
QCRN-2	1.560	19	82	35
QCRN-3	1.560	21	82	35
QCRN-4	1.560	23	82	35
YRDT-1	1.560	15	90	35
YRDT-2	1.560	15	100	35
YRDT-3	1.560	15	110	35
YRDT-4	1.560	15	120	35
YRDC-1	1.560	15	82	40
YRDC-2	1.560	15	82	45
YRDC-3	1.560	15	82	50
YRDC-4	1.560	15	82	55

The four LENG scenarios envisage that the total length of the existing seven berths at MARPORT, 1.560 meters, would be extended to 1.750, 2.000, 2.250 and 2.500 meters respectively. The dispersion of these suggested berth extensions among the berths are displayed in Table 4.49.

Table 4.49. Alternative Simulation Scenarios for Length of Quays (Meters).

TERMINAL LOCATION	BERTH NUMBER	ACTUAL LENGTH	LENGTH OF QUAYS (M) MARPORT SIMULATION SCENARIOS			
			LENG-1	LENG-2	LENG-3	LENG-4
MAIN TERMINAL	1	245	340	460	530	570
	2	135	135	135	135	135
	3	265	360	490	550	585
	4	140	140	140	200	200
	5	140	140	140	200	200
WEST TERMINAL	6	310	310	310	310	310
	7	325	325	325	325	500
TOTAL LENGTH (M)		1.560	1.750	2.000	2.250	2.500

Currently some number of mobile (MHC) and stationary (STS) cranes are allocated for each berth. QCRN scenarios suggest an increase in the total number of cranes. The detailed increase in the number of cranes for each QCRN scenario are displayed in Table 4.50.

Table 4.50. Alternative Simulation Scenarios for Quay Cranes (MHC and STS).

TERMINAL LOCATION	BERTH NUMBER	ACTUAL CRANE NUMBERS		TOTAL NUMBER OF QUAY CRANES MARPORT SIMULATION SCENARIOS							
				QCRN-1		QCRN-2		QCRN-3		QCRN-4	
		MHC	STS	MHC	STS	MHC	STS	MHC	STS	MHC	STS
MAIN TERMINAL	1	-	3	-	3	-	3	-	3		3
	2	1	-	1	1	1	2	1	2	1	3
	3	-	3	-	3	-	3	-	3		3
	4	1	-	1	-	1	-	2	-	2	-
	5	-	-	-	-	-	-	1	-	1	-
WEST TERMINAL	6	3	-	3	1	3	2	3	2	3	2
	7	-	4	-	4	-	4	-	4	1	4
TOTAL NUMBER OF CRANES MHC+STS		5	10	5	12	5	14	7	14	8	15
		15		17		19		21		23	

In a similar way, YRDT scenarios offer an increase for yard trucks which are allocated for tranportataion operations between berths and Main or West Terminals. The distribution of increased truck numbers among the terminals are depicted in Table 4.51.

Table 4.51. Alternative Simulation Scenarios for Yard Trucks.

ALLOCATED TERMINAL	ACTUAL NUMBERS	TOTAL NUMBER OF YARD TRUCKS SIMULATION SCENARIOS			
		YRDT-1	YRDT-2	YRDT-3	YRDT-4
MAIN TERMINAL	41	45	50	60	65
WEST TERMINAL	41	45	50	50	55
TOTAL NUMBER	82	90	100	110	120

Currently, there are total of 35 yard cranes used in loading and unloading operations for containers in container yards. Four YRDC senarios envisage different level of increases for the number of yard cranes. In Table 4.52, the new increased yard crane numbers are listed.

Table 4.52. Alternative Simulation Scenarios for Yard Cranes.

ALLOCATED CONTAINER YARD	ACTUAL NUMBERS	TOTAL NUMBER OF YARD CRANES SIMULATION SCENARIOS			
		YRDC-1	YRDC-2	YRDC-3	YRDC-4
MAIN TERMINAL YARD	17	20	22	25	27
WEST TERMINAL YARD	18	20	23	25	28
TOTAL NUMBER	35	40	45	50	55

4.12. Experimentation and Analysis of Results

At the end of the execution of 100 independent replication, ARENA would take the summary results for an output performance measure from each replication, average them over the replications, compute the sample standard deviation from them, and finally compute the half width of a 95% confidence interval on the expected value of this performance measure. Since the model contains two performance measures, there are two main column groups namely average total time in port and total monthly handled containers as displayed in Table 4.53. Each of these groups has three sub-columns; average sample mean, standard deviation and half width of 95% confidence interval for sample mean of performance measure.

The sample mean provides a more stable indication of what to expect from each performance measure then what happens on an individual replication and sample standard deviation measures cross-replication variation.

Since the individual replication results are independent and identically distributed, it is possible to form a confidence interval for true expected performance measure as

$$\overline{x_1} \pm t_{n-1,\ 1-\alpha/2} \frac{s}{\sqrt{n}}$$

Where $\overline{x_1}$ is the mean of the first performance measure, s_1 is the sample standard devition, n is the number of replication (n =100), and $t_{n-1,\ 1-\alpha/2}$ is the upper $1-\alpha/2$ critical point from Student's t distribution with n-1 degrees of freedom. For the first scenario LENG-1 and first performance measure which is average total time in port, this formula works out for a 95 % confidence interval (α = 0,05) to;

$$31{,}596 \pm 2{,}042 \frac{7{,}834}{\sqrt{100}}$$

$$31{,}596 \pm 1{,}599$$

Or 31,596 ± 1,599; the half width for 95 % confidence intervals on expectations of the first performance measure as displayed in the column titled '95 % Half Width'. The interpretation of this value is that in about 95 % of the cases of making 100 simulation replication, the interval formed like this which is between 29,997 and 33,195 hours will contain the true expected value of average total time in port for the scenario LENG-1.

In a similar way, the half width 95 % confidence interval for the second performance measure, total monthly handled container in scenario LENG-1 can be calculated as 3.826.

$$82.261 \pm 2{,}042 \frac{18.736}{\sqrt{100}}$$

$$82.261 \pm 3.826$$

It also means that second performance measure has the confidence interval between 78.435 and 86.087 TEU/month. The values for other 15 scenarios are in the rows of Table 4. 53.

Table 4.53. Output Performance Measures from Simulation Experimentation.

SCENARIOS	PERFORMANCE MEASURES					
	Average Total Time in Port			Total Monthly Handled Container		
	AVERAGE SAMPLE MEAN	STANDARD DEVIATION	95 % HALF WIDTH	AVERAGE SAMPLE MEAN	STANDARD DEVIATION	95 % HALF WIDTH
LENG-1	31,596	7,834	1,599	82.261	18.736	3.826
LENG-2	30,006	8,006	1,635	87.371	20.074	4.099
LENG-3	28,284	7,651	1,562	90.606	21.693	4.430
LENG-4	25,623	5,968	1,219	92.219	19.798	4.043
QCRN-1	29,419	9,062	1,850	81.550	21.553	4.401
QCRN-2	27,866	7,448	1,521	84.005	18.395	3.756
QCRN-3	26,403	7,407	1,513	88.128	21.260	4.341
QCRN-4	24,772	6,183	1,263	89.052	22.274	4.548
YRDT-1	30,019	8,917	1,821	80.417	18.057	3.687
YRDT-2	29,176	6,085	1,243	80.113	18.624	3.803
YRDT-3	28,283	7,439	1,519	82.425	20.072	4.099
YRDT-4	27,992	6,117	1,249	85.782	19.844	4.052
YRDC-1	30,506	7,318	1,494	79.794	17.926	3.660
YRDC-2	30,147	6,941	1,417	83.664	18.308	3.738
YRDC-3	28,917	5,925	1,210	86.212	21.437	4.377
YRDC-4	27,062	8,384	1,712	87.805	19.881	4.060

The other outputs, such as total monthly number of visiting vessels, daily average number of waiting vessels in anchoring area, average total monthly discharged and loaded containers are also displayed in Table 4. 54.

Table 4. 54. Detailed Output Result of Simulation Scenarios.

SCENARIOS	Total Monthly Number of Visiting Vessel	Daily Average Number of Waiting Vessel	Average Vessel Total Time in Port	Average Total Monthly Handled Container	Average Total Monthly Discharged Container	Average Total Monthly Loaded Container
	Vess./Month	**Vess./Day**	**Hour**	**TEU/Month**	**TEU/Month**	**TEU/Month**
ACTUAL	49,137	1,003	33,905	79.536	42.219	37.317
LENG-1	47,381	0,908	31,596	82.261	42.913	39.348
LENG-2	56,317	0,963	30,006	87.371	49.035	38.336
LENG-3	51,276	0,817	28,284	90.606	41.986	48.620
LENG-4	53,722	0,794	25,623	92.219	50.153	42.066
QCRN-1	46,395	0,855	29,419	81.550	42.417	39.133
QCRN-2	54,082	0,879	27,866	84.005	41.312	42.693
QCRN-3	56,135	0,793	26,403	88.128	49.045	39.083
QCRN-4	50,466	0.701	24,772	89.052	49.049	40.003
YRDT-1	55,184	0,971	30,019	80.417	49.444	30.973
YRDT-2	53,923	0,813	29,176	80.113	40.745	39.368
YRDT-3	48,151	0,731	28,283	82.425	46.412	36.013
YRDT-4	47,590	0,685	27,992	85.782	47.630	38.152
YRDC-1	52,273	0,883	30,506	79.794	50.900	28.894
YRDC-2	55,088	0,869	30,147	83.664	43.260	40.404
YRDC-3	49,839	0,704	28,917	86.212	46.632	39.580
YRDC-4	52,174	0,727	27,062	87.805	43.322	44.483

Output performance measures for each scenario have been compared with the current values of MARPORT to make subsequent efficiency analyses easier. The actual values for these parameters are 33,915 hours and 79.536 TEU/month. The result of this analysis are listed in Table 4.55. For comparison, the difference between the MARPORT actual value and the performance measure found in the simulation is calculated. As it is seen in the Table, all these values indicate an improvement comparing with the current MARPORT outputs as a result of different infrastructure investment scenarios. In order to make this comparison more meaningful, improvement percentage values comparing the actual situation are also included in the Table.

Table 4. 55. Analysis of Simulation Results According to Actual MARPORT Values.

SCENARIOS	Total Time in Port (TOT) Hour			Monthly Handled Container TEU/Month		
	Results	Difference from Actual Value	Percentage of Difference	Results	Difference from Actual Value	Percentage of Difference
ACTUAL	33,905	0,000	0,00	79.536	0,0000	0,00
LENG-1	31,596	2,309	6,810	82.261	2.725	3,42
LENG-2	30,006	3,899	11,49	87.371	7.835	9,85
LENG-3	28,284	5,621	16,57	90.606	11.070	13,91
LENG-4	25,623	8,282	24,42	92.219	12.683	15,94
QCRN-1	29,419	4,486	13,23	81.550	2.014	2,53
QCRN-2	27,866	6,039	17,81	84.005	4.469	5,61
QCRN-3	26,403	7,502	22,12	88.128	8.592	10,80
QCRN-4	24,772	9,133	26,93	89.052	9.516	11,96
YRDT-1	30,019	3,886	11,46	80.417	881	1,10
YRDT-2	29,176	4,729	13,94	80.113	577	0,72
YRDT-3	28,283	5,622	16,58	82.425	2.889	3,63
YRDT-4	27,992	5,913	17,44	85.782	6.246	7,85
YRDC-1	30,506	3,399	10,02	79.794	258	0,32
YRDC-2	30,147	3,758	11,08	83.664	4.128	5,19
YRDC-3	28,917	4,988	14,71	86.212	6.676	8,39
YRDC-4	27,062	6,843	20,18	87.805	8.269	10,39

The highest percentage of improvement for first performance measure is 26.93 % which was achieved as a result of investment scenario QCRN-4. For the second performance measure, improvement on the number of monthly handled container, the highest percentage is 15,94 % which belongs to investment scenario LENG-4.

5. DATA ENVELOPMENT ANALYSIS (DEA)

Data Envelopment Analysis (DEA) is a non-parametric technique that can be used to measure the relative efficiency of operating units with the same general goals and objectives. In DEA, the organization under evaluation, is identified as DMU (Decision Making Unit). Generically a DMU is regarded as the entity responsible for converting inputs and whose performances are to be evaluated. In managerial applications, DMUs may include banks, department stores and ports, and extend to car makers, hospitals, schools, public libraries and so forth. In engineering, DMUs may take such forms as airplanes or their components such as jet engines. For the purpose of securing relative comparisons, a group of DMUs is used to evaluate each other with each DMU having a certain degree of managerial freedom in decision making (Cooper at al., 2007).

In this case, each container terminal which is defined by different set of input parameters explained in simulation scenarios are considered DMUs of the analysis. Since we created 16 Infrastructure investment scenarios, we have total of 16 DMUs of which their performance would be evaluated according to their simulation outputs, namely average vessel turnaround time (total time in port) and monthly handled container (TEU). In other words, we have 16 different container ports whose performance will be evaluated according to these simulation outputs.

DEA can separate the efficient operating units (ports, firms, organizations etc.) from the inefficient ones on the basis of whether they lie on the efficient frontier which is spanned by the best units in a data set (Wöber, 2007). In other words, DEA detects an efficiency frontier by accepting the most efficient decision making unit as a reference point and evaluates the other DMUs efficiencies comparatively according to their distances to this reference point as displayed in Figure 5.1.

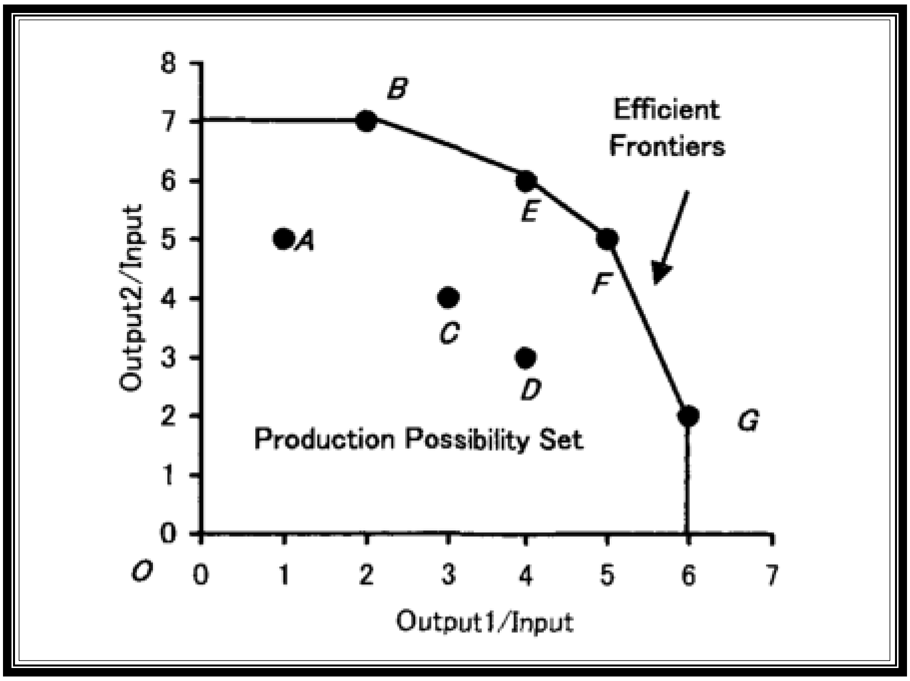


Figure 5.1. DEA Efficiency Frontier.

The efficiency measure employed in DEA is established mathematically by the ratio of the weighted sum of outputs to the weighted sum of inputs. DEA seeks to identify, either for a given level of output, the operating units which achieved the lowest observed costs (input-orientated model), or for a given level of costs the operating units which achieved the highest observed output (output-oriented model) (Wöber, 2007).

DEA starts by building a relative ratio consisting of total weighted outputs to total weighted inputs for each institution, organization, operating unit, object, etc. in a given data set. The best organizations in the data set are frequently termed as non-dominated solutions and form an 'efficient frontier'. The degree of the inefficiencies of the other dominated units relative to the efficient frontier are then determined using a linear programming algorithm(Wöber, 2007).

The main advantages of DEA compared with conventional approaches, are the following;

- It enables simultaneous analysis of several outputs and several inputs,
- It enables the inclusion of environmental and other qualitative factors that are of importance in assessing performance,

- It recognizes the possibility of different but equally efficient combinations of outputs and inputs (in different proportions),
- It does not require an explicit a priori determination of relationships between output and inputs (a production function), or the setting of rigid importance weights for the various factors,
- The DEA approach locates an 'efficient frontier' within the group analyzed, and the salient units comprising it, thus, efficiency is measured relative to the highest performance rather than against some average, and
- The approach points to specific sub-groups of the efficient units, which are appropriate as a reference level for each of the non-efficient units. These characteristics of DEA make it a most suitable tool for measuring port efficiency.

5.1. Charnes, Cooper and Rhodes (CCR) DEA Model

The most basic model for DEA is the CCR model, which was initially proposed by Charnes, Cooper and Rhodes in 1978. There, for each DMU, the virtual input, output and their weights are formed.

Given the data, the efficiency of each DMU is measured once. Therefore, n separate optimizations is required, one for each DMU_j to be evaluated as illustrated in Figure 5.2. Let the DMU_j to be evaluated on any trial be designated as DMUc where c ranges over 1, 2,..., n. We solve the following fractional programming problem (FP_c) to obtain values for the input ‘weights’ (v_i) {i = l,2,3,...,m) and the output ‘weights’ (u_r) {r = l,2,3...,s) as variables (Cooper at al., 2007).

x_{ic} = i^{th} input of c^{th} DMU $(i = 1, . . . ,m) \quad (c = 1, . . . ,n)$

y_{rc} = r^{th} output of c^{th} DMU $(r = 1, . . . ,s) \quad (c = 1, . . . ,n)$

v_i = weight of input x_i $(i = 1, . . . ,m)$

$\boldsymbol{u_r}$ = *weight of output* y_r $(r = 1, \ldots, s)$

$$\text{Virtual input} = v_1\, x_{1c} + v_2\, x_{2c} + \ldots + v_m\, x_{mc}$$

$$\text{Virtual output} = u_1\, y_{1c} + u_2\, y_{2c} + \ldots + u_s\, y_{sc}$$

Then, for each DMU, it is tried to determine the weights, using linear programming so as to maximize the ratio of;

$$\boldsymbol{E_c} = \frac{\text{virtual output}}{\text{virtual input}} = \frac{u_1\, y_{1c} + u_{12}\, y_{12c} + \ldots + u_s\, y_{sc}}{v_1\, x_{1c} + v_2\, x_{2c} + \ldots + v_m\, x_{mc}} \tag{5.1}$$

Where $\boldsymbol{E_c}$ is the efficiency score of DMU_c .

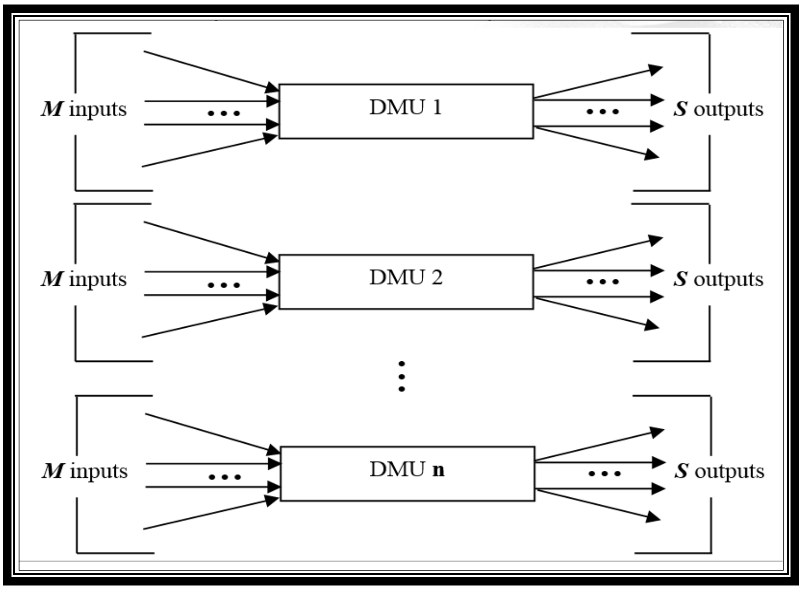


Figure 5.2. DEA Input and Output Model.

The optimal weights may vary from one DMU to another DMU. Thus, the ‘weights’ in DEA are derived from the data instead of being fixed in advance. For each DMU, a best set of weights with values are assigned.

Suppose there are n DMUs: DMU_1, DMU_2... and DMU_n. Some common input and output items for each of these DMUs are selected as follows:

- Numerical data are available for each input and output, with the data assumed to be positive for all DMUs.

- The items (inputs, outputs and choice of DMUs) should reflect an analyst's or a manager's interest in the components that will enter into the relative efficiency evaluations of the DMUs.
- In principle, smaller input amounts are preferable and larger output amounts are preferable so the efficiency scores should reflect these principles (Cooper at al., 2007).

The measurement units of the different inputs and outputs need not be congruent. Some may involve number of persons, areas of floor space or number of equipment used, etc. (Cooper at al., 2007).

Given the data, we measure the efficiency of each DMU once and hence need n separate optimizations, one for each DMU_j to be evaluated. Let the DMU_j to be evaluated on any trial be designated as DMU_c where c ranges over 1, 2,..., n. We solve the following fractional programming problem (FP_c) to obtain values for the input 'weights' (v_i) {i = l,2,3,...,m) and the output 'weights' (u_r) {r = l,2,3...,s) as variables (Cooper at al., 2007).

$$(FP_c) \quad max_{uv}\, \boldsymbol{E_c} = \frac{u_1\, y_{1c} + .u_2\, y_{2c} + . . . + u_s\, y_{sc}}{v_1\, x_{1c} + v_2\, x_{2c} + . . . + v_m\, x_{mc}} \tag{5.2}$$

$$\text{Subject to} \quad \frac{u_1\, y_{1j} + .u_2\, y_{2j} + . . . + u_s\, y_{sj}}{v_1\, x_{1j} + v_2\, x_{2j} + . . . + v_m\, x_{mj}} \leq 1 \quad (j = 1, . . . ,n) \tag{5.3}$$

$$v_1, v_2, . . . , v_m \geq 0 \tag{5.4}$$

$$u_1, u_2, . . . , u_s \geq 0 \tag{5.5}$$

The constraints mean that the ratio of 'virtual output' vs. 'virtual input' should not exceed 1 for every DMU. The objective is to obtain weights (v_i) and (u_r) that maximize the ratio of DMU_c (E), the DMU being evaluated. By virtue of the constraints, the optimal objective value E* is at most 1.0. All outputs and inputs have some nonzero value and this is to be reflected in the weights u_r and v_i being assigned some positive value.

We now replace the above fractional program FP_c by the following linear program LPc

$$(LP_c) \quad max_{uv}\ E_c = u_1\, y_{1c} + u_2\, y_{2c} + \ldots + u_s\, y_{sc} \tag{5.6}$$

Subject to

$$v_1\, x_{1c} + v_2\, x_{2c} + \ldots + v_m\, x_{mc} = 1 \tag{5.7}$$

$$u_1\, y_{1j} + u_2\, y_{2j} + \ldots + u_s\, y_{sj} \leq v_1\, x_{1j} + v_2\, x_{2j} + \ldots + v_m\, x_{mj} \qquad (j = 1, \ldots, n) \tag{5.8}$$

$$v_1, v_2, \ldots, v_m \geq 0$$

$$u_1, u_2, \ldots, u_s \geq 0$$

This set of maximizing problem can be solved by the simplex method of linear programing. Specially designed several computer package programs such as DEAP Coelli can be utilized to solve these type of linear programing problems. As a result, we obtain an optimal solution for each DMU, which is represented by the data set **E***, **v** and **u.**

5.2. Application of DEA Model on Turkish Container Ports

Before using DEA method as a follow on mathematical model, the performance of 15 major Turkish container ports are examined in order to visualize the application of DEA methodology. This example, which is similar to the thesis model, but contains different input and less output parameter, will help us to understand non-parametric techniques of DEA.

5.2.1. Input and Output Scores of Turkish Container Ports

These Turkish container ports, one of which is MARPORT, are Akdeniz Kimya, BORUSAN, Ege Gübre, EVYAP, GEMPORT, KUMPORT, MARDAŞ, MARPORT, Mersin, Port Akdeniz, RODA PORT, YILPORT, Haydarpaşa, İzmir, and ALPORT.

In the model, four inputs and one output are employed to measure the effectiveness of these Turkish ports. Input parameters are the length of berth (m), number of container berths, the number of cranes in port and the size of the terminal area (m^2) used for storage and handling of containers. The number of TEU containers handled annually in that port is plugged in the DEA model as a unique output. The values which indicate the year 2013 actual figures are transferred from the web site of Turkish Ministry of Transportation and Communication, called “ Deniz Ticareti 2013 İstatistikleri” (www.ubak.gov.tr). These input and output values were displayed previously in Table 3.1.

5.2.2. DEA Efficiency Scores of Turkish Container Ports

Both Constant Variable Returns to Scale (CRS) (CCR) and Variable Returns to Scale (VRS) (BCC) methods are used as a tool to calculate the relative efficiencies of Turkish container ports in 2013. In addition to these alternative methods, separate model applications based on the input or output oriented methods are also used. As a result of the applications of these different DEA methodologies, total of four different sets of port efficiency scores, which are displayed in Table 5.1 are obtained. The software DEAP Coelli Version 2.1 from CEPA (Centre for Efficiency and Productivity Analysis) is applied to solve the DEA with four different models (www.uq.edu.au).

Table 5.1. CCR and BCC Efficiency Scores of Turkish Container Ports.

Container Ports (DMUs)	**CCR Model**		**BCC Model**	
	Input Oriented	**Output Oriented**	**Input Oriented**	**Output Oriented**
AKDENiZ KİMYA	0,381	0,381	0,867	0,533
BORUSAN	0,472	0,472	0,774	0,577
EGE GÜBRE	0,306	0,306	1,000	1,000
EVYAP	1,000	1,000	1,000	1,000
GEMPORT	0,456	0,456	0,591	0,485
KUMPORT	1,000	1,000	1,000	1,000
MARDAŞ	0,441	0,441	0,561	0,449
MARPORT	1,000	1,000	1,000	1,000
MERSIN	0,897	0,879	0,987	0,998
PORT AKDENİZ	0,515	0,515	1,000	1,000
RODA PORT	0,233	0,233	0,768	0,338
YILPORT	1,000	1,000	1,000	1,000
HAYDARPAŞA	0,272	0,272	0,603	0,283
İZMİR	0,774	0,774	0,812	0,833
ALPORT	0,204	0,204	1,000	1,000
AVERAGE SCORE	0,597	0,597	0,864	0,766

In general, Turkish container ports received relatively poor efficiency scores. Based on their CCR figures, only four ports out of 15 are considered efficient (EVYAP, KUMPORT, MARPORT and YILPORT) while 11 of them inefficient compared to these four ports. Among them, ALPORT (0.204) and Haydarpaşa (0.272) are the least efficient ones. The average efficiency score for CCR model is 0.597. It is also observed that in CCR model, input and output oriented figures are identical, which is the expected result of these mathematical approaches.

According to the BCC (VRS) efficiency scores, total of seven ports are classified as efficient among 15 ports (EVYAP, KUMPORT, MARPORT, YILPORT, ALPORT, Ege Gübre and Port Akdeniz). Average values for input and output oriented VRS models are 0.864 and 0.766 respectively. As it is observed, target container port of this thesis, MARPORT, was one the most efficient container ports in Turkey with input and output figures in 2013.

5.3. DEA Model for Evaluating the Efficiency of Simulation Scenario Outputs

Discrete event simulation has been a useful tool for evaluating the performance of complex systems such as container terminals. However, simulation by itself can only evaluate a given design, but can not provide more feasible solutions. Therefore, the integration of simulation and optimization is required. Simulation optimization is the process of finding the best values of some decision variables for a system where the performance is evaluated based on the output of a simulation model of this system.

Combining the simulation analysis and the optimal decision-making mechanism, the simulation optimization method cannot only enhance intelligent decision making of the simulation, but also build the complex system model easily that is more difficult by traditional optimization methods (Zeng and Yang, 2008).

5.3.1. Application of DEA Model

In the model, the performance of 16 container simulation scenarios are examined as displayed in Figure 5.3.

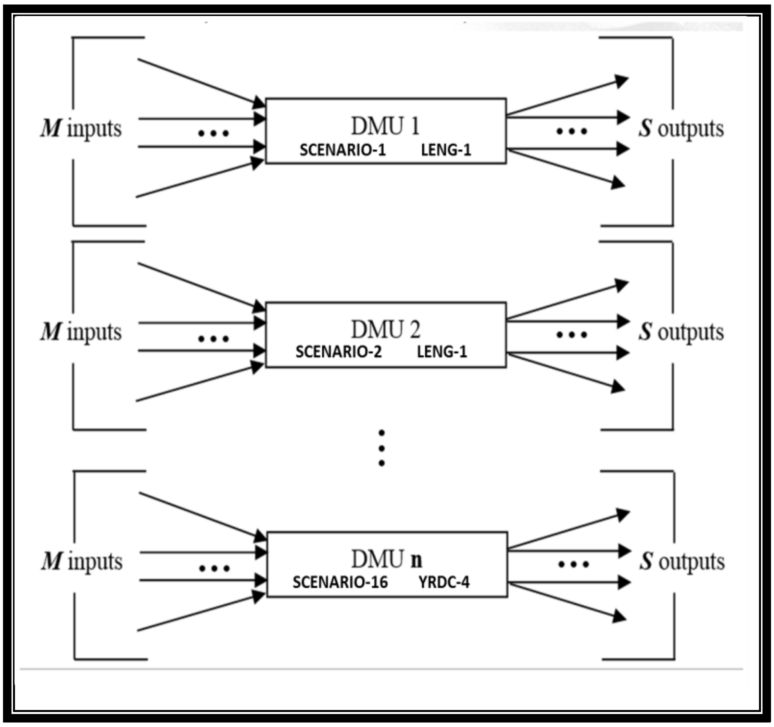


Figure 5.3. DEA Input and Output Model of Simulation Results.

Each DMU represents different combination of container terminal equipment. Four inputs and two outputs are employed to measure the effectiveness of these DMUs. Input parameters are the total length of quays, number of quay cranes, yard trucks and yard cranes. The simulation results, namely average vessel turnaround time (total time in port) and monthly handled containers (TEU) are plugged into the DEA model as inputs. These input and output values are displayed in Table 5.2.

Table 5.2. Input and Output Values of MARPORT Simulation Scenarios.

SCENARIOS (DMUs)	INPUTS				OUTPUTS	
	Total Length of Quays	Total Number of Quay Cranes	Total Number of Yard Trucks	Total Number of Yard Cranes	Average Vessel Total Time in Port	Average Monthly Handled Container
	Meter				Hour	TEU/Month
ACTUAL	1.560	15	82	35	33,905	79.536
LENG-1	1.750	15	82	35	31,596	82.261
LENG-2	2.000	15	82	35	30,006	87.671
LENG-3	2.250	15	82	35	28,284	90.606
LENG-4	2.500	15	82	35	25,623	92.219
QCRN-1	1.750	17	82	35	29,419	81.550
QCRN-2	1.750	19	82	35	27,866	84.005
QCRN-3	1.750	21	82	35	26,403	88.128
QCRN-4	1.750	23	82	35	24,772	89.052
YRDT-1	1.750	15	90	35	30,019	80.417
YRDT-2	1.750	15	100	35	29,176	80.113
YRDT-3	1.750	15	110	35	28,283	82.425
YRDT-4	1.750	15	120	35	27,992	85.782
YRDC-1	1.750	15	82	50	30,506	79.794
YRDC-2	1.750	15	82	55	30,147	83.664
YRDC-3	1.750	15	82	60	28,917	86.212
YRDC-4	1.750	15	82	65	27,062	87.805

In DEA linear equation model, objective equation is designed to get maximum values. On the other hand, one of the performance measures of simulation model, namely average total time in port, should be minimized to get more efficient results. To solve this problem, a new output parameter is established. Actual MARPORT values are taken as a basis. The difference between actual value and simulation output is considered as an improvement due to the infrastructure investment scenario. Calculation of these new input values are explained in the following paragraph and listed in Table 5.3. Positive values of new performance measures indicate improvements on the outputs.

- Improvement on Total Time in Port (TOT)

TOT Improvement = Actual TOT – Simulation Scenario TOT

Percentage of TOT Improvement = TOT Improvement/ Actual TOT

Example: For scenario LENG-1.

TOT Improvement for LENG-1 = Actual TOT – LENG-1 TOT

TOT Improvement for LENG-1 = 33,905- 31,596 = 2,309 hours

Percentage of TOT Improvement for LENG-1 = TOT Imp. for LENG-1/ Actual TOT

Percentage of TOT Improvement for LENG-1 = 2,309 / 33,905 = 6,81 %

- Improvement on Monthly Handled Containers (TEU)

TEU Improvement = Simulation Scenario TEU - Actual TEU

Percentage of TEU Improvement = TEU Improvement / Actual TOT

Example: For scenario QCRN-1.

TEU Improvement for QCRN -1 = QCRN -1 TEU - Actual TEU

TEU Improvement for QCRN -1 = 81.550- 79.536 = 2.014 TEU

Percentage of TEU Improvement for QCRN -1 = TEU Imp. for QCRN -1/ Actual TEU

Percentage of TEU Improvement for QCRN -1 = 2.014 / 79.536 = 2,53 %

Table 5.3. Analysis of Simulation Results According to Actual MARPORT Values.

SCENARIOS (DMUs)	Total Time in Port (TOT) Hour			Monthly Handled Container TEU		
	Simulation Results	Improvement from Actual Value	Percentage of Improvment %	Simulation Results	Improvement from Actual Value	Percentage of Improvment %
ACTUAL	33,905	0,000	0,00	79,536	0,0000	0,00
LENG-1	31,596	2,309	6,81	82,261	2,725	3,42
LENG-2	30,006	3,899	11,49	87,671	8,135	10,22
LENG-3	28,284	5,621	16,57	90,606	11,070	13,91
LENG-4	25,623	8,282	24,42	92,219	12,683	15,94
QCRN-1	29,419	4,486	13,23	81,550	2,014	2,53
QCRN-2	27,866	6,039	17,81	84,005	4,469	5,61
QCRN-3	26,403	7,502	22,12	88,128	8,592	10,80
QCRN-4	24,772	9,133	26,93	89,052	9,516	11,96
YRDT-1	30,019	3,886	11,46	80,417	881	1,10
YRDT-2	29,176	4,729	13,94	80,113	577	0,72
YRDT-3	28,283	5,622	16,58	82,425	2,889	3,63
YRDT-4	27,992	5,913	17,43	85,782	6,246	7,85
YRDC-1	30,506	3,399	10,02	79,794	258	0,32
YRDC-2	30,147	3,758	11,08	83,664	4,128	5,19
YRDC-3	28,917	4,988	14,71	86,212	6,676	8,39
YRDC-4	27,062	6,843	20,18	87,805	8,269	10,39

DEA input and modified positive output figures are listed in Table 5.4. Since all parameters have positive values, it will be possible to construct DEA model with maximized efficiency equation.

Table 5. 4. Inputs and Improvements on Output Result of Simulation Scenarios.

SCENARIOS (DMUs) *J=1,…,16*	**INPUTS**				**IMPROVEMENTS ON OUTPUTS**	
	Total Length of Quays	**Total Number of Quay Cranes**	**Total Number of Yard Trucks**	**Total Number of Yard Cranes**	**Improvement on Vessel Total Time in Port**	**Improvement on Monthly Handled Container**
	x_{1j}	x_{2j}	x_{3j}	x_{4j}	y_{1j}	y_{1j}
ACTUAL	1.560	15	82	35	0,000	0,000
LENG-1	1.750	15	82	35	2,309	2,725
LENG-2	2.000	15	82	35	3,899	8,135
LENG-3	2.250	15	82	35	5,621	11,070
LENG-4	2.500	15	82	35	8,282	12,683
QCRN-1	1.560	17	82	35	4,486	2,014
QCRN-2	1.560	19	82	35	6,039	4,469
QCRN-3	1.560	21	82	35	7,502	8,592
QCRN-4	1.560	23	82	35	9,133	9,516
YRDT-1	1.560	15	90	35	3,886	881
YRDT-2	1.560	15	100	35	4,729	577
YRDT-3	1.560	15	110	35	5,622	2,889
YRDT-4	1.560	15	120	35	5,913	6,246
YRDC-1	1.560	15	82	50	3,399	258
YRDC-2	1.560	15	82	55	3,758	4,128
YRDC-3	1.560	15	82	60	4,988	6,676
YRDC-4	1.560	15	82	65	6,843	8,269

- Inputs of DEA model;

x_{1i} = Total length of quays in i^{th} scenario

x_{2i} = Total number of quay cranes in ith scenario

x_{3i} = Total number of yard trucks in i^{th} scenario

x_{4i} = Total number of yard cranes in i^{th} scenario

- Outputs of DEA model;

y_{1i} = Improvment on average vessel total time in port (TOT) in $_{\text{ith}}$ scenario

y_{2i} = Improvment on average monthly handled container (TEU) in $_{\text{ith}}$ scenario

For i = 1 to 16

Example: $i = 1$ LENG-1 Scenario;

$(LP_c) \quad max_{uv}\ E_1 = u_1\, y_{11} + u_2\, y_{21}$

Subject to

$v_1\, x_{11} + v_2\, x_{21} + v_3\, x_{31} + v_4\, x_{41} = 1$

$u_1\, y_{11} + u_2\, y_{21} \leq v_1\, x_{11} + v_2\, x_{21} + v_3\, x_{31} + v_4\, x_{41}$

$u_1\, y_{12} + u_2\, y_{22} \leq v_1\, x_{12} + v_2\, x_{22} + v_3\, x_{32} + v_4\, x_{42}$

$u_1\, y_{18} + u_2\, y_{28} \leq v_1\, x_{18} + v_2\, x_{28} + v_3\, x_{38} + v_4\, x_{48}$

$u_1\, y_{116} + u_2\, y_{216} \leq v_1\, x_{116} + v_2\, x_{216} + v_3\, x_{316} + v_4\, x_{416}$

$v_1, v_2, v_3, v_4 \geq 0 \qquad u_1, u_2 \geq 0$

$(LP_c) \quad max_{uv}\ E_1 = u_1\, 2{,}309 + u_2\, 2{,}725$

Subject to

$v_1\, 15{,}60 + v_2\, 15 + v_3\, 82 + v_4\, 35 = 1$

$u_1\, 2{,}309 + u_2\, 2{,}725 \leq v_1\, 15{,}60 + v_2\, 15 + v_3\, 82 + v_4\, 35$

$u_1\, 3{,}899 + u_2\, 8{,}135 \leq v_1\, 17{,}50 + v_2\, 15 + v_3\, 82 + v_4\, 35$

$u_1\, 9{,}133 + u_2\, 9{,}516 \leq v_1\, 15{,}60 + v_2\, 23 + v_3\, 82 + v_4\, 35$

$u_1\, 6{,}843 + u_2\, 8{,}269 \leq v_1\, 15{,}60 + v_2\, 15 + v_3\, 82 + v_4\, 65$

$v_1, v_2, v_3, v_4 \geq 0 \qquad u_1, u_2 \geq 0$

5.3.2. Results of DEA Application

In comparing the efficiency, we don’t take into account the managerial skills. Same managerial methods or skills were valid for all scenarios. Therefore, only Constant Variable Returns to Scale (CRS) (CCR) method is used as a tool to calculate the relative efficiencies of these container port simulation models.

Result of the applications of these CRS DEA methodology, input oriented efficiency scores are displayed in Table 5.5. The software DEAP Coelli Version 2.1 from CEPA (Centre for Efficiency and Productivity Analysis) is applied to solve the DEA (www.uq.edu.au).

Table 5.5. Input Oriented CRS Efficiency Scores of Simulation Scenarios**.**

SCENARIOS (DMUs)	Input Oriented CRS Efficiency	Sum of Lambdas	RDS	Optimal Lambdas with Benchmarks			
LENG-1	0,32994	0,267	Increasing	0,148	LENG-4	0,119	QCRN-4
LENG-2	0,93072	0,864	Increasing	0,581	LENG-4	0,283	QCRN-4
LENG-3	0,96334	0,902	Increasing	0,786	LENG-4	0,116	QCRN-4
LENG-4	1,00000	1,000	Constant	1,000	LENG-4		
QCRN-1	0,59560	0,510	Increasing	0,200	LENG-4	0,310	QCRN-4
QCRN-2	0,74873	0,677	Increasing	0,168	LENG-4	0,509	QCRN-4
QCRN-3	0,91269	0,869	Increasing	0,102	LENG-4	0,767	QCRN-4
QCRN-4	1,00000	1,000	Constant	1,000	QCRN-4		
YRDT-1	0,55528	0,449	Increasing	0,249	LENG-4	0,200	QCRN-4
YRDT-2	0,67574	0,546	Increasing	0,303	LENG-4	0,243	QCRN-4
YRDT-3	0,80335	0,649	Increasing	0,360	LENG-4	0,289	QCRN-4
YRDT-4	0,84493	0,683	Increasing	0,379	LENG-4	0,304	QCRN-4
YRDC-1	0,48570	0,392	Increasing	0,218	LENG-4	0,175	QCRN-4
YRDC-2	0,53699	0,434	Increasing	0,241	LENG-4	0,193	QCRN-4
YRDC-3	0,73300	0,592	Increasing	0,328	LENG-4	0,264	QCRN-4
YRDC-4	0,97782	0,790	Increasing	0,438	LENG-4	0,352	QCRN-4

5.3.3. Analysis of DEA Model Results

According to the input oriented DEA model, LENG-4 and QCRN-4 scenarios with efficiency score of 1,00, are classified as the most efficient DMUs among 16 container terminal simulation model. These scenarios envisage 940 meters extension of berth length and an increase in the number of quay cranes. Relative order of DEA efficiency scores are displayed in Table 5.6.

Table 5. 6. Relative Order of DEA Efficiency Scores.

Order Number	**Scenarios (DMOs)**	**Input Oriented CRS Efficiency**	**Improvement on Outputs**	
			Average Total Time in Port (Hours)	**Average Monthly Troughouts (TEU)**
1	LENG-4	1,00000	8,282	12,683
2	QCRN-4	1,00000	9,133	9,516
3	YRDC-4	0,97782	6,843	8,269
4	LENG-3	0,96334	5,621	11,070
5	LENG-2	0,93072	3,899	8,135
6	QCRN-3	0,91269	7,502	8,592
7	YRDT-4	0,84493	5,913	6,246
8	YRDT-3	0,80335	5,622	2,889
9	QCRN-2	0,74873	6,039	4,469
10	YRDC-3	0,73300	4,988	6,676
11	YRDT-2	0,67574	4,729	577
12	QCRN-1	0,59560	4,486	2,014
13	YRDT-1	0,55528	3,886	881
14	YRDC-2	0,53699	3,758	4,128
15	YRDC-1	0,48570	3,399	258
16	LENG-1	0,32994	2,309	2,725

Based on the input oriented CRS scores, DEAP software package also advised the input target values for each inefficient investment scenario, which has efficiency value less than 1,0, to promote the efficiency level while keeping the current outputs values fixed. In other words, excessive input values are to be subtracted from current input figures to be able to reach the efficiency level of 1,000. The final suggested target input values for CRS model are presented in Table 5.7. For example, LENG-1 scenario with efficiency score 0,329 which is a very low value, should decrease its input values, length of quays from 1.750 m. to 577 m., number of quay cranes from 15 to 4,949 to reach efficiency score of 1,000 while keeping its output values fixed, improvement on average total time in port 2,309 hours and improvement on monthly handled containers 2.725 TEU.

Table 5.7. DEA Target Values for Input Figures.

Scenarios (DMOs	Input Oriented Efficiency	Length of Quays		Quay Cranes		Yard Trucks		Yard Cranes	
		Simulation	Target	Simulation	Target	Simulation	Target	Simulation	Target
LENG-1	0,329	1.750	577	15	4,949	82	21,861	35	9,331
LENG-2	0,930	2.000	1.871	15	11,411	82	54,394	35	23,217
LENG-3	0,963	2.250	2.068	15	14,450	82	73,938	35	31,559
LENG-4	1,000	2.500	2.500	15	15,000	82	82,000	35	35,000
QCRN-1	0,595	1.560	842	17	10,125	82	41,806	35	17,844
QCRN-2	0,748	1.560	1.110	19	14,226	82	55,502	35	23,690
QCRN-3	0,912	1.560	1.397	21	19,166	82	71,248	35	30,411
QCRN-4	1,000	1.560	1.560	23	23,000	82	82,000	35	35,000
YRDT-1	0,555	1.560	772	15	8,329	90	36,791	35	15,703
YRDT-2	0,675	1.560	983	15	10,136	100	44,772	35	19,110
YRDT-3	0,803	1.560	1.206	15	12,050	110	53,227	35	22,719
YRDT-4	0,844	1.560	1.290	15	12,674	120	55,982	35	23,895
YRDC-1	0,485	1.560	650	15	7,285	82	32,180	50	13,735
YRDC-2	0,536	1.560	740	15	8,055	82	35,579	55	15,186
YRDC-3	0,733	1.560	1.083	15	10,995	82	48,566	60	20,729
YRDC-4	0,977	1.560	1.511	15	14,667	82	64,786	65	27,653

In a similar approach, output targets for output oriented CRS model are displayed in Table 5.8. For example, QCRN-1 investment scenario is expected to increase its improvement on monthly handled container value from 2.014 TEU to 5.485 TEU while keeping its current input values fixed to reach the efficiency level of 1.000. On the other hand, no increase is suggested for efficient investment scenarios such as LENG-4 and QCRN-4 since they have been already classified as efficient scenarios.

Table 5.8. DEA Target Values for Output Improvement Figures.

Scenarios (DMOs	Input Oriented Efficiency	Improvement of Vessel Total Time in Port (Hour)		Improvement of Monthly Handled Container (TEU)	
		Simulation	Target	Simulation	Target
LENG-1	0,329	2,309	3,309	2.725	4.005
LENG-2	0,930	3,899	4,649	8.135	9.835
LENG-3	0.963	5,621	7,566	11.070	11.070
LENG-4	1,000	8,282	8,282	12.683	12.683
QCRN-1	0,595	4,486	4,486	2.014	5.485
QCRN-2	0,748	6,039	6,039	4.469	6.972
QCRN-3	0,912	7,502	7,848	8.592	8.592
QCRN-4	1,000	9,133	9,133	9.516	9.516
YRDT-1	0,555	3,886	3,886	881	5.057
YRDT-2	0,675	4,729	4,729	577	6.155
YRDT-3	0,803	5,622	5,622	2.889	7.317
YRDT-4	0,844	5,913	5,913	6.246	7.695
YRDC-1	0,485	3,399	3,399	258	4.424
YRDC-2	0,536	3,758	3,758	4.128	5.891
YRDC-3	0,733	4,988	5,130	6,676	6.676
YRDC-4	0,977	6,843	6,843	8,269	8.906

6. COST AND EFFICIENCY ANALYSIS

Final step of the analysis is to find the investment package which meets the requirements of the objectives with minimum financial expenditure.

6.1. Cost of Infrastructure Investment Equipment and Investment Alternatives

Based on the information received from MARPORT authorities, the cost of one square meter quay construction is approximately 750 $. It is assumed that the minimum width of the container quay is 40 meters. Then, we suppose that the cost of the construction of one meter is 30.000 U.S. dollars (40*750).

Acquisition of port infrastructure equipment proposed by simulation scenarios are listed in Table 6.1. These prices are found in the related internet sites such as www.alibaba.com/showroom/container-crane-cost.html.

As result of internet search, it is assumed that the price of each quay crane is 3,750 million U.S. dollars. This implies that total purchase amount of four cranes is 15,000 million $ (4*3,750 = 15,000).

Table 6.1. Cost of Infrastructure Investment Equipment
(Source, www.alibaba.com/showroom/container-crane-cost).

Type of Infrastructure Investment	Unit Cost USA $
1 Meter Quay Extension Investment	30.000
Additional 1 Quay Crane Acquistion Investment	3.750.000
Additional 1 Quay Crane Acquistion Investment	2.800.000
Additional 1 Yard Truck Acquistion Investment	385.000
Additional 1 Yard Crane Acquisition Investment	1.200.000

Total cost of each investment scenario has been calculated by taking unit prices of each investment equipment, as listed in Table 6.1. The cheapest investment scenario, YRDT-1, total of 3,080 million US dollars, suggests an acquisition of eight container trucks. On the other hand, the total cost of the most expensive one, LENG-4, which envisages 940 meters extension for quays costs 28,200 million US.

Table 6.2. Total Cost of Investment Alternatives

SCENARIOS (DMUs)	**Cost of Quay Extension Investment Scenarios**		**Cost of Additional Quay Crane Acquistion Investment Scenarios**		**Cost of Additional Yard Truck Acquisition Investment Scenarios**		**Cost of Additional Yard Crane Acquisition Investment Scenarios**		**Total Cost of Investment Scenario $(10^6\$)$**
	Addition	**Cost $(10^6\$)$**	**Addition**	**Cost $(10^6\$)$**	**Addition**	**Cost $(10^6\$)$**	**Addition**	**Cost $(10^6\$)$**	
LENG-1	190	5,700	-	-	-	-	-	-	5,700
LENG-2	440	13,200	-	-	-	-	-	-	13,200
LENG-3	690	20,700	-	-	-	-	-	-	20,700
LENG-4	940	28,200	-	-	-	-	-	-	28,200
QCRN-1	-	-	0+2	7,500	-	-	-	-	7,500
QCRN-2	-	-	0+4	15,000	-	-	-	-	15,000
QCRN-3	-	-	2+4	20,600	-	-	-	-	20,600
QCRN-4	-	-	3+5	27,150	-	-	-	-	27,150
YRDT-1	-	-	-	-	8	3,080	-	-	3,080
YRDT-2	-	-	-	-	18	6,930	-	-	6,930
YRDT-3	-	-	-	-	28	10,780	-	-	10,780
YRDT-4	-	-	-	-	38	14,630	-	-	14,630
YRDC-1	-	-	-	-	-	-	5	6,000	6,000
YRDC-2	-	-	-	-	-	-	10	12,000	12,000
YRDC-3	-	-	-	-	-	-	15	18,000	18,000
YRDC-4	-	-	-	-	-	-	20	24,000	24,000

6.2. Cost Efficiency Analysis of Investment Alternatives

To calculate cost efficiency scores, two different criteria is used.

- First Criteria :Unit Cost of DEA Efficiency Score:

For each investment scenario, DEA model calculates efficiency score which is between 0,000 and 1,000. The greater the score means the more efficient investment alternative. According to this criteria, the total investment cost is divided by DEA efficiency score. The result represents the cost of unit DEA efficiency score. In this case, the smaller the value means the more cost efficient investment.

Unit Cost of DEA Efficiency Score =Total Investment Cost / DEA Efficiency Score *100
For LENG-1 Scenario
Unit Cost of DEA Efficiency Score = 5,700 / 0,32994*100
Unit Cost of DEA Efficiency Score = 0,172758 Million $
Table 6.3 displays the results for all alternatives.

Table 6.3. Cost of Unit DEA Efficiency Score

SCENARIOS	**Total Cost of Investment Scenario (10^6 $)**	**Improvement Percentages**			**DEA Efficiency Score (*100)**	**Cost of Each DEA Efficiency Score (10^6 $)**
		Total Time in Port Improvement Percentage %	**Monthly Thorugh Improvement Percentage %**	**Total Improvement Percentage %**		
LENG-1	5,700	6,81	3,42	10,23	32,994	0,172758
LENG-2	13,200	11,49	10,22	21,71	93,072	0,141825
LENG-3	20,700	16,57	13,91	30,48	96,334	0,214877
LENG-4	28,200	24,42	15,94	40,36	100,000	0,282000
QCRN-1	7,500	13,23	2,53	15,76	59,560	0,125924
QCRN-2	15,000	17,81	5,61	23,42	74,873	0,200338
QCRN-3	20,600	22,12	10,80	32,92	91,269	0,225707
QCRN-4	27,150	26,93	11,96	38,89	100,000	0,271500
YRDT-1	3,080	11,46	1,10	12,56	55,528	0,055467
YRDT-2	6,930	13,94	0,72	14,66	67,574	0,102554
YRDT-3	10,780	16,58	3,63	20,21	80,335	0,134188
YRDT-4	14,630	17,44	7,85	25,29	84,493	0,173151
YRDC-1	6,000	10,02	0,32	10,34	48,570	0,123534
YRDC-2	12,000	11,08	5,19	16,27	53,699	0,223466
YRDC-3	18,000	14,71	8,39	23,10	73,300	0,245565
YRDC-4	24,000	20,18	10,39	30,57	97,782	0,245444

At the beginning of the research, it was assumed that the alternative investment scenarios that possess DEA efficiency score of 0.90 or more would only have been taken into consideration. According to this managerial decision, six feasible alternatives listed in Table 6.4 will be further investigated.

The most cost effective one is LENG-2 investment alternative with 0,14182 million $ for each unit DEA efficiency score.

Table 6.4. Cost of Unit DEA Efficiency Score of Feasible Alternatives.

SCENARIOS	Total Cost of Investment Scenario (10^6 $)	Improvement Percentages			DEA Efficiency Score (*100)	Cost of Each DEA Efficiency Score (10^6 $)
		Total Time in Port Improvement Percentage %	Monthly Thorugh Improvement Percentage %	Total Improvement Percentage %		
LENG-2	13,200	11,49	10,22	21,71	93,072	0,141825
LENG-3	20,700	16,57	13,91	30,48	96,334	0,214877
LENG-4	28,200	24,42	15,94	40,36	100,000	0,282000
QCRN-3	20,600	22,12	10,80	32,92	91,269	0,225707
QCRN-4	27,150	26,93	11,96	38,89	100,000	0,271500
YRDC-4	24,000	20,18	10,39	30,57	97,782	0,245444

- Second Criteria :Unit Cost of Output Improvement Percentages:

For each investment scenario, improvement percentages for each output parameters were calculated. Then total of these percentages will be taken as an indicator for the scale of improvements obtained result of investment. The greater the score means the more efficient investment alternative. According to this criteria, the total investment cost is divided by total improvement percentage. The result represents the cost of unit improvement. In this case, the smaller the value means the more cost efficient investment.

Unit Cost of Improvement Percentage =Total Investment Cost / Total Imp. Percentage
For QCRN-1 Scenario
Total Imp. Percentage = Total Time in Port Imp. Per. + Monthly Throughput Imp. Per.
Total Imp. Percentage = 13,23 + 2,53 = 15,76
Unit Cost of Improvement Percentage = 7;500 / 15,76
Unit Cost of Improvement Percentage = 0,475888 Million $
Table 6.5 displays the results for all alternatives.

Table 6.5. Cost of Unit Output Improvement Percentage.

SCENARIOS	Total Cost of Investment Scenario (10^6 $)	DEA Efficiency Score (*100)	Improvement Percentages			Cost of Each Percentage of Improvement (10^6 $)
			Total Time in Port Improvement Percentage %	Monthly Thorughput Improvement Percentage %	Total Improvement Percentage %	
LENG-1	5,700	32,994	6,81	3,42	10,23	0,557185
LENG-2	13,200	93,072	11,49	10,22	21,71	0,608014
LENG-3	20,700	96,334	16,57	13,91	30,48	0,679134
LENG-4	28,200	100,000	24,42	15,94	40,36	0,698712
QCRN-1	7,500	59,560	13,23	2,53	15,76	0,475888
QCRN-2	15,000	74,873	17,81	5,61	23,42	0,640478
QCRN-3	20,600	91,269	22,12	10,80	32,92	0,625759
QCRN-4	27,150	100,000	26,93	11,96	38,89	0,698123
YRDT-1	3,080	55,528	11,46	1,10	12,56	0,245223
YRDT-2	6,930	67,574	13,94	0,72	14,66	0,472715
YRDT-3	10,780	80,335	16,58	3,63	20,21	0,533399
YRDT-4	14,630	84,493	17,44	7,85	25,29	0,578490
YRDC-1	6,000	48,570	10,02	0,32	10,34	0,580271
YRDC-2	12,000	53,699	11,08	5,19	16,27	0,737554
YRDC-3	18,000	73,300	14,71	8,39	23,10	0,779221
YRDC-4	24,000	97,782	20,18	10,39	30,57	0,785083

Similar to first criteria, at the beginning of the research, it was assumed that the alternative investment scenarios that possess total improvement percentages of 20 or more would only have been taken into consideration. According to this managerial decision, six feasible alternatives listed in Table 6.6 will be further investigated.

The most cost effective one is LENG-2 investment alternative with 0,60801 million $ for each improvement percentage.

Table 6.6. Cost of Unit Output Improvement Percentage of Feasible Alternatives

SCENARIOS	Total Cost of Investment Scenario (10^6 $)	DEA Efficiency Score (*100)	Improvement Percentages			Cost of Each Percentage of Improvement (10^6 $)
			Total Time in Port Improvement Percentage %	Monthly Thorugh Improvement Percentage %	Total Improvement Percentage %	
LENG-2	13,200	93,072	11,49	10,22	21,71	0,608014
LENG-3	20,700	96,334	16,57	13,91	30,48	0,679134
LENG-4	28,200	100,000	24,42	15,94	40,36	0,698712
QCRN-3	20,600	91,269	22,12	10,80	32,92	0,625759
QCRN-4	27,150	100,000	26,93	11,96	38,89	0,698123
YRDC-4	24,000	97,782	20,18	10,39	30,57	0,785083

The graphical presentation of these feasible alternatives is in Figure 6.1. All feasible six alternative investments are positioned in the upper right shaded corner of the graph.

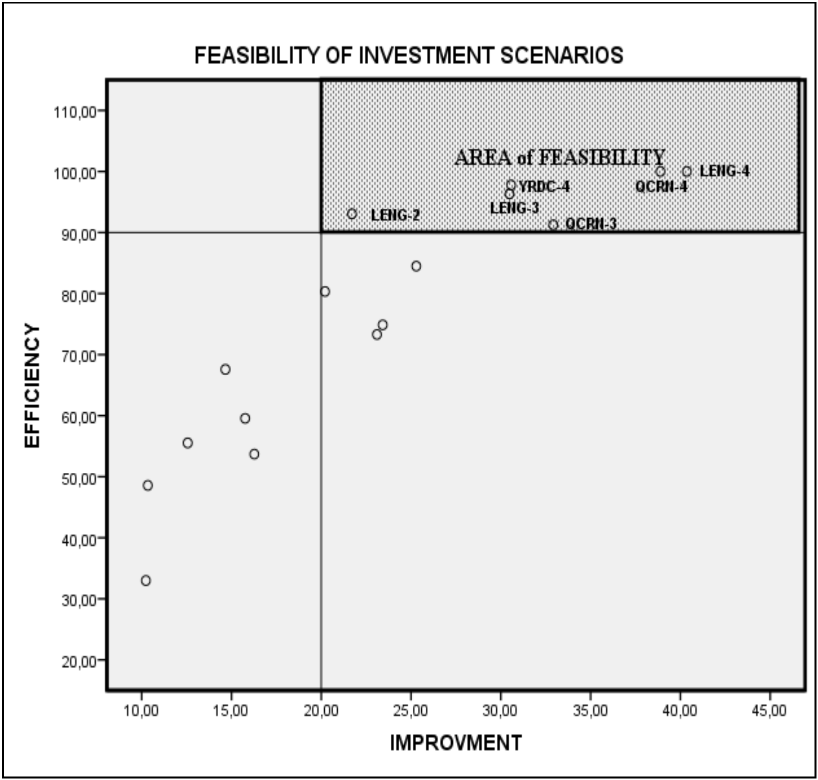


Figure 6.1. Feasibilty of Investment Alternatives.

6.3. Results of Cost Efficiency Analysis

According to both criteria, LENG-2 investment scenario is considered the most cost effective one among 16 scenarios. Table 6.7 shows all detailed information about LENG-2.

T**able 6.7.** Figures of Optimum Investment Scenario, LENG-2.

		MARPORT ACTUAL VALUES	**OPTIMUM SCENARIO LENG-2**
INPUTS	LENGTH OF QUAY (M)	1.560	2.000
	NUMBER OF QUAY CRANES	15	15
	NUMBER OF YARD TRUCKS	82	82
	NUMBER OF YARD CRANES	35	35
OUTPUTS	AVERAGE TOTAL TIME IN PORT (HOUR)	33,905	30,006
	AVERAGE MONTHLY THROUGHPUT (TEU)	79.536	87.761
COST EFFICIENCY ANALYSIS	DEA EFFICIENCY SCORE	-	93,072
	IMPROVEMENT ON AVERAGE TOTAL TIME IN PORT (HOUR)	-	3,899
	PERCENTAGE IMPROVEMENT ON AVERAGE TOTAL TIME IN PORT (%)	-	11,49
	OUTPUT IMPROVEMENT ON AVERAGE MONTHLY THROUGHPUT (TEU)	-	8.135
	PERCENTAGE OF OUTPUT IMPROVEMENT ON AVERAGE MONTHLY THROUGHPUT (%)	-	10,22
	PERCENTAGE OF TOTAL IMPROVEMENT ON OUTPUTS (%)		21,71
	TOTAL INVESTMENT COST (MIL. $)	-	13,200
	COST OF UNIT DEA SCORE (MIL. $)		0,141825
	COST OF TOTAL IMPROVEMENT PERCENTAGE UNIT (MIL. $)	-	0,608014

7. CONCLUSIONS

7.1. Results

The shipping industry is one of the oldest industries and still plays an important role in the modern society. Demand for maritime transport services and seaborne trade volumes continue to be shaped by global economic growth and the need to carry merchandise trade.

The introduction of standardized container has drastically improved the efficiency of the global shipping industry and will continue to provide a foundation for an efficient method of transport; for many more years to come. Without shipping containers, the import and export of goods necessary for the international community would not be possible. This makes them a vital part of the world’s economy. Without the transportation services container ships provide, the world would not be as prosperous as it is today, and many countries would not be able to participate in world trade.

Within this context, container port owners may decide to make infrastructure investments to extend the capacity of terminals to be able to get more share from growing markets. The capital cost of such investments may require prior mathematical analyses to be made to select the most financially optimal one among the possible alternatives. This thesis is designed to find a mathematical solution for such an investment decision. This mathematical approach combines the advantages of simulation models and Data Envelopment Analysis optimization method in order to reach an optimum infrastructure investment decision for the enhancement of a container terminal capacity.

For this purpose, it was decided to approach the problem by a discrete event simulation model, in order to reproduce the activities carried out inside a container terminal. ARENA software package with its components Input and Output Analyzers has been used as a tool to build the container port simulation model.

MARPORT container terminal was taken as a basis for the defining of the input parameters and physical figures of the container terminal. The data set belonging to 419 container ships visited the MARPORT between October 2014 and July 2015 were used to derive the probability distribution functions and their parameters which were used to generate the incoming container vessel configurations in the simulation model.

To be able to evaluate the optimum investment decision for the target container terminal, total of 16 simulation scenario were employed. For each scenario, different sets of terminal equipment were assigned to simulation model as input. These parameters are total length of quay, number of quay cranes, yard trucks and yard cranes. The objective is, on the one side, to minimize average ship turnaround time and on the other side, to maximize container throughput generated by the terminal. These are the key performance measures of the model.

As a follow on step, Data Envelopment Analyses method is utilized as a tool to evaluate the relative efficiencies of these outputs gathered from container simulation scenarios.

As a final stage in the research, cost efficiency analysis is conducted to be able to decide best investment package for the enlargement of the target container terminal with minimum cost. According to the results of this analysis, in order to be able to reach optimum outputs with minimum cost, MARPORT container terminal managers may decide to extent current total length of quays from 1.560 meters to 2.000 meters as it is envisaged by Scenario LENG-2.

Experimental results achieved by thesis show that the integrated mathematical model which is composed of three submodels namely simulation model, data envelopment analyses and cost efficiency analysis can be used to determine the optimal investment strategy with regard to the various objectives in container port capacity improvement initiatives.

By taking into account the previous studies conducted on this subject, it is assessed that this is a new method which has been developed by establishing a relation between three different scientific methods. Therefore, the thesis is an original work both in terms of the method used and the results.

The thesis has also provided a framework mathematical model that can be used to determine the cost effectiveness of investment alternatives not only for container ports but also for other industrial facilities.

The results of this thesis are regarded as a suitable resource for studies on the development of ports and other industrial facilities, especially in cost effectiveness evaluations.

7.2. Recommendations

Although much research has concentrated on optimizing the resources at the operational level, future work may include extending it to models which cover;

- The other subsystems, such as the ‘land’ side operations of the terminal in the context of intermodal transportations,
- Different objective parameters such as the minimization of dwell times of the containers in the yard or total traveling distance of yard trucks,
- Different feasibility assumptions for further cost effectiveness analysis of investment scenarios,
- Alternative management policies such as changes in working hours, assignment of yard trucks to quay cranes without any increase on the terminal equipment.

It is also possible to deploy this integrated model for other container ports in Turkey provided that historical port data be available.

Mathematical model could be improved by a computer software algorithm which automatically connects three sub-models, namely simulation, DEA and cost efficiency models.

It is also concluded that the model in the thesis is flexible enough to cover not only the infrastructure investment alternatives but also the possible changes on other input parameters such as expected arrival rates of incoming container ships.

In a similar way, the algorithm of the model also be used for other transportation terminals such as airports and other industrial facilities as a framemwork model to create a decision support tool.

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APPENDIX-A

Table A. 1. MARPORT Vessel and Time Data, January 2015, (Source, MARPORT Administration, 11 September 2015)

Vessel Name	Arrival at Pilot Station	Proforma Pilot Arrival	Anchor In	Pilot on Board	Arrival at Berth	Proforma Berth Arrival	Start Operation	Complete Operation	Departure from Berth	Proforma Berth Departure	Drop Pilot
MSC ADRIANA AO451R	31.12.2014 23:00		31.12.2014 23:36	01.01.2015 11:00	01.01.2015 11:45		01.01.2015 16:30	01.01.2015 23:00	02.01.2015 00:05		02.01.2015 00:15
CAPE MANILA AC501R	31.12.2014 23:50			02.01.2015 12:08	02.01.2015 12:50		02.01.2015 13:35	03.01.2015 03:05	03.01.2015 04:05		03.02.2015 04:20
MSC ASLI AO452A	02.01.2015 03:00			02.01.2015 03:20	02.01.2015 04:05		02.01.2015 05:15	02.01.2015 19:00	02.01.2015 19:50		02.01.2015 20:10
JASPER S DA502A	03.01.2015 10:30		03.01.2015 10:42	03.01.2015 12:35	03.01.2015 13:15		03.01.2015 14:10	04.01.2015 05:50	04.01.2015 06:50		04.01.2015 07:05
WESTERDIEK MT501R	04.01.2015 07:00	03.01.2015 17:00		04.01.2015 07:42	04.01.2015 08:30	03.01.2015 19:00	04.01.2015 09:15	04.01.2015 17:05	04.01.2015 18:30	04.01.2015 10:00	04.01.2015 18:45
KAETHE C. RICKMERS	04.01.2015 10:20			04.01.2015 21:40	04.01.2015 12:25		04.01.2015 23:15	06.01.2015 03:15	06.01.2015 04:15		06.01.2015 04:25
MSC ELOISE MT452A	04.01.2015 16:00	01.01.2015 22:00		05.01.2015 00:20	05.01.2015 00:55	02.01.2015 00:00	06.01.2015 00:50	06.01.2015 14:50	06.01.2015 16:00	02.01.2015 11:00	06.01.2015 16:10
GOZDE BAYRAKTAR	04.01.2015 17:20		04.01.2015 18:00	05.01.2015 00:35	05.01.2015 01:00		05.01.2015 02:00	05.01.2015 19:40	05.01.2015 21:45		05.01.2015 21:55
MSC EDITH AO501A	05.01.2015 00:00		05.01.2015 01:10	06.01.2015 12:05	06.01.2015 12:50		06.01.2015 13:30	06.01.2015 17:10	06.01.2015 19:40		06.01.2015 19:50
MSC MARYLENA AN501A	05.01.2015 00:30	04.01.2015 12:41	05.01.2015 01:40	05.01.2015 22:05	05.01.2015 22:45	04.01.2015 13:41	05.01.2015 23:10	06.01.2015 11:00	06.01.2015 11:45	05.01.2015 13:41	06.01.2015 11:55
MSC HOGGAR DH452A	05.01.2015 16:40		05.01.2015 16:55	06.01.2015 04:30	06.01.2015 04:55		06.01.2015 06:15	07.01.2015 09:15	07.01.2015 10:55		07.01.2015 11:10
AS VENUS DI451A	05.01.2015 17:00		05.01.2015 17:20	06.01.2015 05:20	06.01.2015 06:00		06.01.2015 06:30	06.01.2015 20:00	06.01.2015 22:00		06.01.2015 22:10
AYSE NAZ BAYRAKTAR	05.01.2015 23:35		06.01.2015 00:15	06.01.2015 20:55	06.01.2015 21:45		06.01.2015 22:30	08.01.2015 02:15	08.01.2015 03:15		08.01.2015 03:25
MSC AMERICA AC502R	06.01.2015 08:00			06.01.2015 15:30	06.01.2015 16:15		09.01.2015 17:15	10.01.2015 11:10	10.01.2015 16:30		10.01.2015 16:50
MSC RAPALLO FT501A	06.01.2015 22:20			06.01.2015 23:35	07.01.2015 01:05		07.01.2015 02:20	09.01.2015 02:50	09.01.2015 03:50		09.01.2015 04:00
JASPER S DA503A	08.01.2015 16:30		08.01.2015 16:54	10.01.2015 17:30	10.01.2015 18:05		10.01.2015 22:00	11.01.2015 07:50	11.01.2015 08:50		11.01.2015 09:10
MSC LORENA NM502R	09.01.2015 16:00	05.01.2015 16:30		09.01.2015 16:15	09.01.2015 17:00	05.01.2015 18:30	09.01.2015 18:30	10.01.2015 21:50	10.01.2015 22:30	06.01.2015 22:00	10.01.2015 22:40
WESTERTAL MT501A	11.01.2015 22:45	08.01.2015 22:00		11.01.2015 23:30	12.01.2015 00:15	09.01.2015 00:00	12.01.2015 01:15	12.01.2015 12:00	12.01.2015 12:30	09.01.2015 11:00	12.01.2015 12:40
MSC ELOISE MT502R	11.01.2015 23:10	10.01.2015 17:00		12.01.2015 00:42	12.01.2015 01:20	10.01.2015 19:00	12.01.2015 02:00	12.01.2015 09:45	12.01.2015 10:50	11.01.2015 10:00	12.01.2015 11:05
NORTHERN VITALITY	14.01.2015 21:30	16.01.2015 05:20	14.01.2015 22:00	16.01.2015 16:35	16.01.2015 17:05	16.01.2015 06:20	16.01.2015 17:45	17.01.2015 05:50	17.01.2015 06:50	17.01.2015 21:20	17.01.2015 07:00
SANTA GIORGINA	12.01.2015 21:30	11.01.2015 23:31		12.01.2015 22:00	12.01.2015 22:30	12.01.2015 01:31	12.01.2015 23:15	13.01.2015 03:50	13.01.2015 04:20	12.01.2015 15:31	13.01.2015 04:35
MSC MATILDE NT502R	13.01.2015 19:40			13.01.2015 21:15	13.01.2015 21:55		13.01.2015 23:00	15.01.2015 06:25	15.01.2015 09:05		15.01.2015 09:15
AS VENUS DI452A	14.01.2015 00:30		14.01.2015 01:30	17.01.2015 07:50	17.01.2015 08:20		17.01.2015 09:00	17.01.2015 17:45	17.01.2015 22:35		17.01.2015 22:45

Table A. 2. MARPORT Vessel and Container Load Data, January 2015, (Source, MARPORT Administration, 11 September 2015)

Vessel Name	Arrival at Pilot Station	DISCHARGED CONTAINERS PER CALL									LOADED CONTAINERS PER CALL								
		FULL		EMPTY		T/S FULL		T/S EMPTY		Total	FULL		EMPTIES		T/S FULL		T/S EMPTIES		Total
		20	40	20	40	20	40	20	40	TEU'S	20	40	20	40	20	40	20	40	TEU'S
MSC ADRIANA AO451R	31.12.2014 23:00	0	10	150	0	4	16	0	0	206	13	36	0	0	103	159	0	0	506
CAPE MANILA AC501R	31.12.2014 23:50	1	0	0	0	149	67	0	0	284	17	124	10	10	23	26	0	0	370
MSC ASLI AO452A	02.01.2015 03:00	27	76	0	144	185	14	0	0	680	22	18	0	0	19	33	0	0	143
JASPER S DA502A	03.01.2015 10:30	21	5	40	24	118	103	1	0	444	11	42	0	0	266	141	1	0	644
WESTERDIEK MT501R	04.01.2015 07:00	17	148	1	0	55	51	0	0	471	8	70	1	0	18	40	0	0	247
KAETHE C. RICKMERS	04.01.2015 10:20	219	649	0	0	52	354	0	0	2277	60	198	5	0	89	67	0	0	684
MSC ELOISE MT452A	04.01.2015 16:00	59	129	0	0	206	107	0	0	737	2	0	0	0	3	14	0	0	33
GOZDE BAYRAKTAR D	04.01.2015 17:20	0	0	0	51	270	32	0	0	436	40	49	0	0	150	226	0	0	740
MSC EDITH AO501A	05.01.2015 00:00	0	0	0	0	0	1	0	0	2	33	13	0	0	26	16	0	0	117
MSC MARYLENA	05.01.2015 00:30	0	0	0	0	0	0	0	0	0	15	41	0	0	160	127	0	0	511
MSC HOGGAR DH452A	05.01.2015 16:40	0	85	0	170	25	59	0	0	653	38	51	0	0	67	150	0	0	507
AS VENUS DI451A	05.01.2015 17:00	0	0	1	8	0	1	0	1	21	0	0	0	0	69	348	0	0	765
AYSE NAZ BAYRAKTAR	05.01.2015 23:35	0	0	2	76	441	62	4	0	723	0	1	0	0	128	263	2	0	658
MSC AMERICA AC502R	06.01.2015 08:00	113	168	0	0	173	229	0	0	1080	33	90	0	50	1	15	0	0	344
MSC RAPALLO FT501A	06.01.2015 22:20	734	585	0	0	497	416	0	0	3233	554	277	610	641	450	107	0	0	3664
JASPER S DA503A	08.01.2015 16:30	6	0	0	0	11	47	0	0	111	11	16	0	0	206	149	0	0	547
MSC LORENA NM502R	09.01.2015 16:00	113	274	0	0	96	135	1	0	1028	43	249	6	402	165	95	4	1	1712
WESTERTAL MT501A	11.01.2015 22:45	30	87	0	0	95	89	0	0	477	0	0	0	0	0	22	0	0	44
MSC ELOISE MT502R	11.01.2015 23:10	20	16	0	1	48	11	0	1	126	20	93	0	0	246	44	1	0	541
NORTHERN VITALITY	12.01.2015 21:30	41	41	0	0	26	4	0	0	157	46	156	0	0	23	8	0	0	397
SANTA GIORGINA	12.01.2015 21:30	0	0	0	0	0	0	0	0	0	24	60	0	0	6	9	0	0	168
MSC MATILDE NT502R	13.01.2015 19:40	239	552	0	0	137	268	0	0	2016	106	231	5	115	279	44	0	4	1178
AS VENUS DI452A	14.01.2015 00:30	0	0	0	2	0	0	1	1	7	0	0	0	0	76	350	0	0	776

Table A. 3. MARPORT Vessel and Time Data, February 2015, (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Arrival at Pilot Station	Proforma Pilot Arrival	Anchor In	Pilot on Board	Arrival at Berth	Proforma Berth Arrival	Start Operation	Complete Operation	Departure from Berth	Proforma Berth Departure	Drop Pilot
MSC DANIT FT504A	29.01.2015 23:00			02.02.2015 11:30	02.02.2015 13:00		02.02.2015 14:00	04.02.2015 07:00	04.02.2015 08:00		04.02.2015 08:15
KRETA XA505A	31.01.2015 12:00		31.01.2015 12:05	03.02.2015 01:35	03.02.2015 02:35		03.02.2015 03:20	04.02.2015 01:55	04.02.2015 04:15		04.02.2015 04:30
JASPER S DA506A	31.01.2015 13:00		31.01.2015 13:18	04.02.2015 05:30	04.02.2015 06:05		04.02.2015 07:30	05.02.2015 15:00	05.02.2015 15:35		05.02.2015 15:50
MSC LORENA NM505R	01.02.2015 15:30	26.01.2015 16:30		02.02.2015 14:00	02.02.2015 14:40	26.01.2015 18:30	02.02.2015 15:30	03.02.2015 09:10	03.02.2015 10:00	27.01.2015 22:00	03.02.2015 10:15
MSC EQUATOR DI452A	02.02.2015 08:40		02.02.2015 08:42	04.02.2015 04:36	04.02.2015 04:50		04.02.2015 05:45	05.02.2015 07:10	05.02.2015 09:20		05.02.2015 09:30
GOZDE BAYRAKTAR	02.02.2015 23:45			03.02.2015 00:40	03.02.2015 01:30		03.02.2015 02:15	04.02.2015 07:40	04.02.2015 08:35		04.02.2015 08:50
MSC VIDHI NT505R	03.02.2015 04:20			03.02.2015 10:35	03.02.2015 11:30		03.02.2015 13:10	04.02.2015 21:30	04.02.2015 23:00		04.02.2015 23:15
MSC ELOISE MT504A	03.02.2015 08:00	29.01.2015 22:00	03.02.2015 09:00	05.02.2015 07:36	05.02.2015 08:20	30.01.2015 00:00	05.02.2015 09:30	05.02.2015 18:00	05.02.2015 19:20	30.01.2015 11:00	05.02.2015 19:30
MSC CELINE MT505R	03.02.2015 14:10	31.01.2015 17:00	03.02.2015 14:40	05.02.2015 20:55	05.02.2015 21:30	31.01.2015 19:00	05.02.2015 22:00	06.02.2015 16:40	06.02.2015 18:00	01.02.2015 10:00	06.02.2015 18:10
MSC EDITH AO505A	03.02.2015 15:00		03.02.2015 15:18	04.02.2015 11:06	04.02.2015 11:45		04.02.2015 13:10	05.02.2015 01:30	05.02.2015 02:30		05.02.2015 02:45
MACARO DC502A	04.02.2015 05:30		04.02.2015 06:25	07.02.2015 06:50	07.02.2015 07:40		07.02.2015 08:40	08.02.2015 02:00	08.02.2015 03:50		08.02.2015 04:00
AYSE NAZ	04.02.2015 17:35		04.02.2015 18:00	05.02.2015 21:55	05.02.2015 22:30		05.02.2015 23:15	07.02.2015 04:00	07.02.2015 05:10		07.02.2015 05:40
MSC CORDOBA	04.02.2015 22:30	02.02.2015 16:30		04.02.2015 23:40	05.02.2015 00:30	02.02.2015 18:30	05.02.2015 01:15	05.02.2015 19:30	05.02.2015 21:30	03.02.2015 22:00	05.02.2015 21:45
MSC MEDITERRANEAN	05.02.2015 04:35			06.02.2015 06:10	06.02.2015 06:50		06.02.2015 07:40	06.02.2015 14:40	06.02.2015 15:30		06.02.2015 15:40
CAPE MANILA AC503A	05.02.2015 05:00	30.01.2015 05:20		06.02.2015 17:20	06.02.2015 18:00	30.01.2015 06:20	06.02.2015 19:00	07.02.2015 09:20	07.02.2015 10:25	31.01.2015 21:20	07.02.2015 10:35
MSC CAMILLE FT505A	06.02.2015 23:30	03.02.2015 15:30		07.02.2015 01:50	07.02.2015 02:40	03.02.2015 17:30	07.02.2015 04:30	09.02.2015 00:15	09.02.2015 02:20	06.02.2015 01:30	09.02.2015 02:30
MSC MATILDE NT506R	08.02.2015 06:40			08.02.2015 07:30	08.02.2015 08:30		08.02.2015 09:30	09.02.2015 19:50	09.02.2015 21:15		09.02.2015 21:20
AS VENUS DI502A	08.02.2015 18:25			08.02.2015 18:50	08.02.2015 19:30		08.02.2015 20:40	09.02.2015 23:10	10.02.2015 00:20		10.02.2015 00:30
MSC HANNAH MT505A	08.02.2015 21:00	05.02.2015 22:00		09.02.2015 07:20	09.02.2015 08:05	06.02.2015 00:00	09.02.2015 08:30	09.02.2015 23:20	10.02.2015 01:00	06.02.2015 11:00	10.02.2015 01:05
MSC AMERICA AC506R	08.02.2015 23:20			09.02.2015 03:40	09.02.2015 04:35		09.02.2015 05:40	09.02.2015 15:05	09.02.2015 16:15		09.02.2015 16:15
JASPER S DA507A	09.02.2015 15:10		09.02.2015 15:35	09.02.2015 17:20	09.02.2015 17:55		09.02.2015 19:30	10.02.2015 13:40	10.02.2015 14:35		10.02.2015 14:45
MSC LEA AO506A	10.02.2015 05:10	08.02.2015 04:22	10.02.2015 06:00	10.02.2015 15:05	10.02.2015 15:35	08.02.2015 06:22	10.02.2015 16:45	11.02.2015 05:30	11.02.2015 06:30	08.02.2015 18:22	11.02.2015 06:35

Table A. 4. MARPORT Vessel and Container Load Data, February 2015, (Source, MARPORT Administration, 11 September 2015)

Vessel Name	Arrival at Pilot Station	DISCHARGED CONTAINERS PER CALL									LOADED CONTAINERS PER CALL								
		FULL		EMPTY		T/S FULL		T/S EMPTY		Total	FULL		EMPTIES		T/S FULL		T/S EMPTIES		Total
		20	40	20	40	20	40	20	40	TEU'S	20	40	20	40	20	40	20	40	TEU'S
MSC DANIT FT504A	29.01.2015 23:00	516	738	30	0	484	364	0	0	3234	488	153	7	441	754	117	0	0	2671
KRETA XA505A	31.01.2015 12:00	0	0	0	0	0	0	0	0	0	39	13	0	0	92	225	0	0	607
JASPER S DA506A	31.01.2015 13:00	16	4	29	54	299	79	0	0	618	19	12	0	0	143	80	0	0	346
MSC LORENA NM505R	01.02.2015 15:30	117	236	0	0	36	71	0	0	767	50	395	1	0	61	121	4	0	1148
MSC EQUATOR DI452A	02.02.2015 08:40	0	56	4	46	95	78	0	0	459	3	2	0	0	228	227	0	0	689
GOZDE BAYRAKTAR	02.02.2015 23:45	0	0	0	0	516	32	0	0	580	0	0	802	19	126	51	0	0	1068
MSC VIDHI NT505R	03.02.2015 04:20	143	380	0	0	44	320	0	0	1587	146	327	13	173	23	49	3	6	1295
MSC ELOISE MT504A	03.02.2015 08:00	91	105	0	0	101	86	0	0	574	0	0	0	0	12	1	0	0	14
MSC CELINE MT505R	03.02.2015 14:10	64	77	3	0	78	205	1	3	716	64	97	0	0	10	54	0	0	376
MSC EDITH AO505A	03.02.2015 15:00	55	9	0	61	221	2	2	0	422	9	30	15	0	7	28	0	0	147
MACARO DC502A	04.02.2015 05:30	0	0	2	7	184	21	0	0	242	19	1	0	0	74	489	0	0	1073
AYSE NAZ BAYRAKTAR	04.02.2015 17:35	0	36	4	251	222	33	1	0	867	0	1	0	0	128	229	0	0	588
MSC CORDOBA NM506R	04.02.2015 22:30	107	192	0	7	13	185	2	0	890	64	397	1	0	43	50	0	0	1002
MSC MEDITERRANEAN	05.02.2015 04:35	0	0	0	0	10	59	0	3	134	50	119	0	0	30	15	0	0	348
CAPE MANILA AC503A	05.02.2015 05:00	65	90	0	0	81	25	0	0	376	14	45	0	1	194	170	0	0	640
MSC CAMILLE FT505A	06.02.2015 23:30	765	700	53	0	297	231	0	0	2977	584	270	364	495	754	263	0	0	3758
MSC MATILDE NT506R	08.02.2015 06:40	200	496	0	0	75	353	2	0	1975	122	280	4	0	521	49	2	0	1307
AS VENUS DI502A	08.02.2015 18:25	0	1	1	203	70	49	0	0	577	35	11	0	0	105	211	0	0	584
MSC HANNAH MT505A	08.02.2015 21:00	116	115	0	0	113	117	0	0	693	0	3	0	0	0	8	0	0	22
MSC AMERICA AC506R	08.02.2015 23:20	86	125	0	1	228	96	0	0	758	17	79	0	50	0	2	1	0	280
JASPER S DA507A	09.02.2015 15:10	1	0	14	67	255	149	0	0	702	6	19	51	0	182	76	0	0	429
MSC LEA AO506A	10.02.2015 05:10	1	23	0	0	173	28	0	0	276	26	26	0	0	63	52	0	0	245

Table A. 5. MARPORT Vessel and Time Data, March 2015, (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Arrival at Pilot Station	Proforma Pilot Arrival	Anchor In	Pilot on Board	Arrival at Berth	Proforma Berth Arrival	Start Operation	Complete Operation	Departure from Berth	Proforma Berth Departure	Drop Pilot
NORTHERN VITALITY	02.03.2015 10:10	28.02.2015 22:58	02.03.2015 10:42	02.03.2015 20:00	02.03.2015 20:35	28.02.2015 23:58	02.03.2015 21:30	03.03.2015 08:25	03.03.2015 09:15	01.03.2015 23:58	03.03.2015 09:30
MSC CAITLIN AO509A	02.03.2015 19:00		02.03.2015 20:00	03.03.2015 14:30	03.03.2015 15:20		03.03.2015 16:30	04.03.2015 03:30	04.03.2015 04:20		04.03.2015 04:30
MSC AMERICA AC508A	03.03.2015 08:00	03.03.2015 19:30		03.03.2015 10:00	03.03.2015 10:45	03.03.2015 21:30	03.03.2015 13:00	03.03.2015 23:50	04.03.2015 02:05	04.03.2015 13:30	04.03.2015 02:20
MSC LAURA XA510A	03.03.2015 14:00			04.03.2015 00:15	04.03.2015 01:00		04.03.2015 01:45	04.03.2015 12:00	04.03.2015 13:15		04.03.2015 13:30
MSC VIDHI NT509R	03.03.2015 20:30			04.03.2015 02:30	04.03.2015 03:20		04.03.2015 04:45	05.03.2015 23:59	06.03.2015 01:10		06.03.2015 01:25
AS VENUS DC510A	03.03.2015 23:00		03.03.2015 23:10	04.03.2015 14:40	04.03.2015 15:10		04.03.2015 17:50	05.03.2015 03:10	05.03.2015 03:10		05.03.2015 09:40
MSC ELOISE MT508A	03.03.2015 23:35	26.02.2015 22:00	04.03.2015 00:30	04.03.2015 04:50	04.03.2015 05:50	27.02.2015 00:00	04.03.2015 06:45	05.03.2015 06:00	05.03.2015 07:10	27.02.2015 11:00	05.03.2015 07:20
MACARO DC507R	04.03.2015 04:00	21.02.2015 18:00	04.03.2015 04:10	05.03.2015 09:35	05.03.2015 10:25	21.02.2015 20:00	05.03.2015 11:00	06.03.2015 08:25	06.03.2015 09:10	21.02.2015 20:00	06.03.2015 09:25
MSC MEDITERRANEAN	04.03.2015 14:50			05.03.2015 08:50	05.03.2015 09:30		05.03.2015 10:20	06.03.2015 03:20	06.03.2015 04:15		06.03.2015 04:30
AYSE NAZ BAYRAKTAR	04.03.2015 20:15		04.03.2015 21:05	05.03.2015 13:10	05.03.2015 13:50		05.03.2015 16:30	07.03.2015 00:00	07.03.2015 03:50		07.03.2015 04:00
MSC ATLANTA NM510R	05.03.2015 09:30	02.03.2015 16:30		06.03.2015 01:55	06.03.2015 02:30	02.03.2015 18:30	06.03.2015 03:30	06.03.2015 23:45	07.03.2015 03:10	03.03.2015 22:00	07.03.2015 03:20
MSC EQUATOR DI502A	06.03.2015 07:40		06.03.2015 08:10	06.03.2015 18:15	07.03.2015 22:35		08.03.2015 00:30	08.03.2015 11:45	08.03.2015 13:15		08.03.2015 13:25
JASPER S DA510A	06.03.2015 07:55		06.03.2015 08:40	09.03.2015 14:00	09.03.2015 14:40		09.03.2015 18:00	10.03.2015 23:55	11.03.2015 00:30		11.03.2015 05:30
MSC CELINE MT509R	06.03.2015 10:55	19.02.2015 22:00	06.03.2015 11:10	07.03.2015 04:10	07.03.2015 04:55	20.02.2015 00:00	07.03.2015 06:20	08.03.2015 04:00	08.03.2015 04:45	20.02.2015 11:00	08.03.2015 04:55
MSC HOGGAR DH509A	08.03.2015 02:45		08.03.2015 03:00	08.03.2015 18:45	08.03.2015 19:30		08.03.2015 20:45	09.03.2015 00:20	09.03.2015 02:20		09.03.2015 02:30
MSC FAUSTINA FT511E	08.03.2015 06:50			08.03.2015 13:25	08.03.2015 14:25		08.03.2015 16:30	11.03.2015 12:00	11.03.2015 14:10		11.03.2015 14:20
MSC MATILDE NT510R	08.03.2015 14:05			08.03.2015 17:35	08.03.2015 18:20		08.03.2015 19:15	10.03.2015 06:50	10.03.2015 08:45		10.03.2015 09:00
MSC MARIA DI510A	08.03.2015 15:40		08.03.2015 16:15	09.03.2015 12:20	09.03.2015 13:00		09.03.2015 14:45	10.03.2015 14:10	10.03.2015 15:15		10.03.2015 15:25
MSC ELOISE MT510R	10.03.2015 15:10	26.02.2015 22:00	10.03.2015 16:00	11.03.2015 01:30	11.03.2015 02:10	27.02.2015 00:00	11.03.2015 03:10	11.03.2015 17:10	11.03.2015 18:45	27.02.2015 11:00	11.03.2015 18:55
MSC HANNAH AC510R	11.03.2015 22:00	07.03.2015 22:58		11.03.2015 23:30	11.03.2015 23:50	07.03.2015 23:58	12.03.2015 00:30	12.03.2015 18:35	12.03.2015 19:20	08.03.2015 23:58	12.03.2015 19:35
GOZDE BAYRAKTAR DH509A	12.03.2015 13:50			12.03.2015 14:55	12.03.2015 15:30		12.03.2015 17:00	13.03.2015 23:20	14.03.2015 00:40		14.03.2015 01:00
SCT SANTIAGO NM511R	12.03.2015 23:00	09.03.2015 16:30		13.03.2015 04:00	13.03.2015 04:30	09.03.2015 18:30	13.03.2015 05:15	14.03.2015 08:20	14.03.2015 08:55	10.03.2015 22:00	14.03.2015 09:05

Table A. 6. MARPORT Vessel and Container Load Data, March 2015, (Source, MARPORT Administration, 11 September 2015)

Vessel Name	Arrival at Pilot Station	DISCHARGED CONTAINERS PER CALL									LOADED CONTAINERS PER CALL								
		FULL		EMPTY		T/S FULL		T/S EMPTY		Total	FULL		EMPTIES		T/S FULL		T/S EMPTIES		Total
		20	40	20	40	20	40	20	40	TEU'S	20	40	20	40	20	40	20	40	TEU'S
NORTHERN VITALITY	02.03.2015 10:10	36	28	0	0	106	12	0	0	222	105	118	0	2	50	9	0	0	413
MSC CAITLIN AO509A	02.03.2015 19:00	13	13	0	45	102	232	0	4	703	54	50	0	0	9	15	0	0	193
MSC AMERICA AC508A	03.03.2015 08:00	117	176	0	0	45	53	0	0	620	0	0	0	0	2	5	0	0	12
MSC LAURA XA510A	03.03.2015 14:00	0	0	0	0	0	0	0	0	0	50	98	12	115	293	7	0	0	795
MSC VIDHI NT509R	03.03.2015 20:30	228	507	0	0	29	149	0	0	1569	156	476	1	0	235	140	0	0	1624
AS VENUS DC510A	03.03.2015 23:00	0	0	0	2	0	0	0	1	6	0	0	0	0	117	128	0	0	373
MSC ELOISE MT508A	03.03.2015 23:35	51	210	0	0	67	212	0	0	962	2	1	0	0	0	0	0	0	4
MACARO DC507R	04.03.2015 04:00	0	1	0	207	29	67	0	0	579	0	0	0	0	0	0	0	0	0
MSC MEDITERRANEAN	04.03.2015 14:50	54	69	0	0	39	10	0	0	251	23	84	0	0	82	111	0	0	495
AYSE NAZ BAYRAKTAR	04.03.2015 20:15	0	35	0	0	541	28	1	0	668	39	58	0	0	123	194	4	0	670
MSC ATLANTA NM510R	05.03.2015 09:30	81	236	0	0	10	16	0	0	595	44	376	8	0	29	58	0	0	949
MSC EQUATOR DI502A	06.03.2015 07:40	1	13	0	6	1	0	0	0	40	7	12	0	0	92	397	0	0	917
JASPER S DA510A	06.03.2015 07:55	7	6	4	34	292	97	0	0	577	28	31	0	0	215	145	0	0	595
MSC CELINE MT509R	06.03.2015 10:55	92	40	2	1	24	213	0	3	632	26	33	3	0	65	40	0	0	240
MSC HOGGAR DH509A	08.03.2015 02:45	0	0	0	0	0	2	0	0	4	0	1	0	0	26	68	0	0	164
MSC FAUSTINA FT511E	08.03.2015 06:50	1208	1551	0	0	375	260	0	0	5205	478	345	310	731	437	252	0	0	3881
MSC MATILDE NT510R	08.03.2015 14:05	209	438	0	0	68	196	0	0	1545	83	283	29	128	232	14	0	8	1210
MSC MARIA DI510A	08.03.2015 15:40	0	0	0	173	2	22	0	0	392	24	64	0	0	76	40	0	0	308
MSC ELOISE MT510R	10.03.2015 15:10	66	93	4	1	92	30	0	0	410	79	93	2	0	59	67	0	0	460
MSC HANNAH AC510R	11.03.2015 22:00	58	137	0	0	173	37	0	0	579	224	112	0	0	233	51	1	0	784
GOZDE BAYRAKTAR	12.03.2015 13:50	0	40	5	112	217	84	2	0	696	0	0	0	0	118	300	0	0	718
SCT SANTIAGO NM511R	12.03.2015 23:00	109	270	0	0	57	133	2	0	974	62	320	19	150	123	92	0	0	1328

Table A.7. MARPORT Vessel and Time Data, April 2015, (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Arrival at Pilot Station	Proforma Pilot Arrival	Anchor In	Pilot on Board	Arrival at Berth	Proforma Berth Arrival	Start Operation	Complete Operation	Departure from Berth	Proforma Berth Departure	Drop Pilot
SCT SANTIAGO NM514R	01.04.2015 19:50	30.03.2015 16:30		01.04.2015 20:42	01.04.2015 21:25	30.03.2015 18:30	01.04.2015 22:25	02.04.2015 19:40	02.04.2015 20:55	31.03.2015 22:00	02.04.2015 21:10
MSC ELOISE MT513R	03.04.2015 00:50	30.03.2015 11:30		03.04.2015 01:30	03.04.2015 02:25	30.03.2015 13:00	03.04.2015 03:15	03.04.2015 16:00	03.04.2015 17:20	31.03.2015 09:00	03.04.2015 17:30
MSC HOGGAR DH513A	03.04.2015 06:45			03.04.2015 08:50	03.04.2015 09:15		03.04.2015 10:30	03.04.2015 20:00	03.04.2015 21:00		03.04.2015 21:10
MSC NITA YG514A	04.04.2015 11:10	05.04.2015 23:31		04.04.2015 13:50	04.04.2015 14:30	06.04.2015 01:31	04.04.2015 15:00	05.04.2015 00:10	05.04.2015 01:30	06.04.2015 15:31	05.04.2015 01:40
GOZDE BAYRAKTAR DH511R	04.04.2015 13:15	21.03.2015 19:00		04.04.2015 14:15	04.04.2015 14:45	21.03.2015 20:00	04.04.2015 15:30	05.04.2015 07:30	05.04.2015 08:30	26.03.2015 01:40	05.04.2015 08:45
MSC KOREA MT514R	05.04.2015 03:25	06.04.2015 11:30	05.04.2015 03:55	06.04.2015 00:40	06.04.2015 01:20	06.04.2015 13:00	06.04.2015 02:10	06.04.2015 18:15	06.04.2015 18:50	07.04.2015 09:00	06.04.2015 19:00
MSC EQUATOR DA515A	05.04.2015 09:40			05.04.2015 10:00	05.04.2015 10:30		05.04.2015 11:20	05.04.2015 19:00	05.04.2015 19:50		05.04.2015 20:00
NORTHERN VITALITY	05.04.2015 10:00	04.04.2015 22:58		05.04.2015 10:40	05.04.2015 11:10	04.04.2015 23:58	05.04.2015 13:00	05.04.2015 23:00	05.04.2015 23:55	05.04.2015 23:58	05.04.2015 23:59
MSC ASLI AO514A	05.04.2015 21:40			05.04.2015 21:50	05.04.2015 22:35		05.04.2015 23:00	06.04.2015 04:50	06.04.2015 06:30		06.04.2015 06:40
SANTA GIULIANA AC514A	06.04.2015 17:30			06.04.2015 17:42	06.04.2015 18:15		06.04.2015 19:15	07.04.2015 05:40	07.04.2015 06:30		07.04.2015 06:45
MSC CORDOBA NM515R	07.04.2015 15:15	06.04.2015 16:30		07.04.2015 15:35	07.04.2015 16:15	06.04.2015 18:30	07.04.2015 17:00	08.04.2015 12:00	08.04.2015 13:10	07.04.2015 22:00	08.04.2015 13:20
MSC MATILDE NT514R	07.04.2015 22:40	04.04.2015 00:00		07.04.2015 23:30	08.04.2015 00:20	04.04.2015 02:00	08.04.2015 01:00	08.04.2015 23:30	09.04.2015 00:50	05.04.2015 14:00	09.04.2015 01:00
GOZDE BAYRAKTAR DH514A	07.04.2015 23:30		07.04.2015 23:45	08.04.2015 11:15	08.04.2015 11:55		08.04.2015 13:10	09.04.2015 02:30	09.04.2015 03:55		09.04.2015 04:05
REECON EAGLE DI514R	08.04.2015 15:00	03.04.2015 19:00		08.04.2015 15:25	08.04.2015 16:00	03.04.2015 20:00	08.04.2015 17:20	09.04.2015 06:40	09.04.2015 08:30	04.04.2015 22:00	09.04.2015 08:40
MSC MARYLENA AO515A	09.04.2015 18:50		09.04.2015 19:00	10.04.2015 08:12	10.04.2015 09:00		10.04.2015 11:00	10.04.2015 22:25	10.04.2015 23:30		10.04.2015 23:45
MSC EQUATOR DA516A	10.04.2015 05:20		10.04.2015 05:30	13.04.2015 05:10	13.04.2015 05:40		13.04.2015 06:30	13.04.2015 22:15	13.04.2015 23:00		13.04.2015 23:15
MSC MEDITERRANEAN	10.04.2015 17:55	10.04.2015 05:20	10.04.2015 18:12	11.04.2015 00:12	11.04.2015 00:55	10.04.2015 06:20	11.04.2015 01:45	11.04.2015 11:20	11.04.2015 12:05	11.04.2015 21:20	11.04.2015 12:20
MSC HANNAH AC515R	11.04.2015 13:40			11.04.2015 14:24	11.04.2015 15:10		11.04.2015 16:30	12.04.2015 10:30	12.04.2015 11:00		12.04.2015 11:10
SAINTY VOGUE UI514R	11.04.2015 14:00	10.04.2015 13:00		11.04.2015 15:00	11.04.2015 15:30	10.04.2015 14:00	11.04.2015 16:30	11.04.2015 19:50	11.04.2015 22:00	11.04.2015 08:00	11.04.2015 22:10
MSC FABIOLA FT516E	11.04.2015 16:30			11.04.2015 17:05	11.04.2015 18:00		11.04.2015 19:10	14.04.2015 00:55	14.04.2015 01:45		14.04.2015 02:00
MSC CELINE MT515R	12.04.2015 15:30	13.04.2015 11:30		12.04.2015 16:24	12.04.2015 17:00	13.04.2015 13:00	12.04.2015 17:40	13.04.2015 03:30	13.04.2015 04:10	14.04.2015 09:00	13.04.2015 04:20
MSC ATLANTA NM516R	13.04.2015 15:00	13.04.2015 16:30		13.04.2015 16:00	13.04.2015 16:40	13.04.2015 18:30	13.04.2015 17:30	14.04.2015 13:35	14.04.2015 14:30	14.04.2015 22:00	14.04.2015 14:40
MSC TOKYO NT515R	15.04.2015 18:30			15.04.2015 19:10	15.04.2015 20:00		15.04.2015 21:00	16.04.2015 18:45	16.04.2015 19:15		16.04.2015 19:25

Table A. 8 MARPORT Vessel and Container Load Data, April 2015, (Source, MARPORT Administration, 11 September 2015)

Vessel Name	Arrival at Pilot Station	DISCHARGED CONTAINERS PER CALL									LOADED CONTAINERS PER CALL								
		FULL		EMPTY		T/S FULL		T/S EMPTY		Total	FULL		EMPTIES		T/S FULL		T/S EMPTIES		Total
		20	40	20	40	20	40	20	40	TEU'S	20	40	20	40	20	40	20	40	TEU'S
SCT SANTIAGO NM514R	01.04.2015 19:50	114	266	0	0	24	110	2	0	892	55	403	13	49	122	133	2	4	1370
MSC ELOISE MT513R	03.04.2015 00:50	38	124	0	0	130	65	0	0	546	32	75	2	100	77	114	9	0	698
MSC HOGGAR DH513A	03.04.2015 06:45	0	0	0	0	1	1	0	0	3	5	0	0	0	120	146	0	0	417
MSC NITA YG514A	04.04.2015 11:10	0	0	0	0	0	0	0	0	0	50	57	198	100	84	15	4	56	792
GOZDE BAYRAKTAR DH511R	04.04.2015 13:15	2	68	1	6	255	57	0	0	520	0	0	587	230	0	0	0	0	1047
MSC KOREA MT514R	05.04.2015 03:25	32	195	0	0	133	51	0	0	657	72	58	0	0	46	35	0	0	304
MSC EQUATOR DA515A	05.04.2015 09:40	46	29	2	42	223	75	0	0	563	1	11	0	0	59	37	0	0	156
NORTHERN VITALITY AC514R	05.04.2015 10:00	26	45	0	185	148	81	1	1	799	75	90	0	100	0	0	0	0	455
MSC ASLI AO514A	05.04.2015 21:40	18	17	1	38	11	21	0	0	182	24	22	0	0	105	25	0	0	223
SANTA GIULIANA AC514A	06.04.2015 17:30	27	54	1	63	95	67	1	3	498	25	8	0	0	200	33	0	0	307
MSC CORDOBA NM515R	07.04.2015 15:15	155	385	0	0	64	88	2	0	1167	76	312	20	199	55	81	0	0	1335
MSC MATILDE NT514R	07.04.2015 22:40	210	487	0	0	117	174	0	0	1649	300	269	1	2	254	97	0	0	1291
GOZDE BAYRAKTAR DH514A	07.04.2015 23:30	0	0	0	0	22	0	0	0	22	12	7	0	0	127	272	0	0	697
REECON EAGLE DI514R	08.04.2015 15:00	0	0	0	232	170	25	6	1	692	0	0	100	0	96	43	0	0	282
MSC MARYLENA AO515A	09.04.2015 18:50	0	1	22	0	22	110	0	0	266	10	17	15	0	147	33	0	0	272
MSC EQUATOR DA516A	10.04.2015 05:20	39	32	3	35	226	111	0	0	624	0	0	0	110	248	94	0	0	656
MSC MEDITERRANEAN AC513A	10.04.2015 17:55	56	81	0	0	49	127	0	0	521	31	6	50	0	35	104	0	0	336
MSC HANNAH AC515R	11.04.2015 13:40	140	181	0	0	127	304	0	0	1237	53	112	20	100	17	3	0	0	520
SAINTY VOGUE UI514R	11.04.2015 14:00	14	40	1	0	71	21	0	0	208	2	0	0	0	1	9	0	0	21
MSC FABIOLA FT516E	11.04.2015 16:30	1308	855	0	10	291	347	0	0	4023	641	627	301	200	670	83	0	0	3432
MSC CELINE MT515R	12.04.2015 15:30	39	60	0	0	253	11	0	0	434	60	47	1	60	30	11	1	0	328
MSC ATLANTA NM516R	13.04.2015 15:00	152	236	0	0	39	97	1	0	858	67	339	21	71	38	75	7	5	1113
MSC TOKYO NT515R	15.04.2015 18:30	201	398	0	0	56	164	0	0	1381	92	278	2	30	107	65	0	0	947

Table A.9 MARPORT Vessel and Time Data, May 2015, (Source, MARPORT Administration, 11 September 2015).

Vessel	Arrival at Pilot Station	Proforma Pilot Arrival	Anchor In	Pilot on Board	Arrival at Berth	Proforma Berth Arrival	Start Operation	Complete Operation	Departure from Berth	Proforma Berth Departure	Drop Pilot
MSC LEA AO518A	01.05.2015 01:20	03.05.2015 04:22		01.05.2015 02:55	01.05.2015 03:30	03.05.2015 06:22	01.05.2015 05:30	01.05.2015 14:30	01.05.2015 16:00	03.05.2015 18:22	01.05.2015 16:00
MSC HOGGAR DC518A	01.05.2015 10:50			01.05.2015 11:15	01.05.2015 12:00		01.05.2015 13:30	02.05.2015 01:45	02.05.2015 02:30		02.05.2015 02:40
HS DISCOVERER AC516A	01.05.2015 11:10	01.05.2015 05:20		01.05.2015 14:50	01.05.2015 15:25	01.05.2015 06:20	01.05.2015 16:30	02.05.2015 15:10	02.05.2015 16:10	02.05.2015 21:20	02.05.2015 16:20
MSC EQUATOR DA519A	01.05.2015 22:05		01.05.2015 22:35	05.05.2015 21:55	05.05.2015 22:25		05.05.2015 23:10	06.05.2015 18:45	06.05.2015 19:30		06.05.2015 19:40
AYSE NAZ BAYRAKTAR	02.05.2015 16:00		02.05.2015 06:40	04.05.2015 10:30	04.05.2015 11:20		04.05.2015 11:45	05.05.2015 00:20	05.05.2015 01:45		05.05.2015 02:00
MSC BETTINA FT519E	02.05.2015 18:00			02.05.2015 18:10	02.05.2015 19:30		02.05.2015 21:30	04.05.2015 07:50	04.05.2015 08:30		04.05.2015 08:45
MICHIGAN TRADER UI517R	03.05.2015 08:00	01.05.2015 13:00		03.05.2015 08:35	03.05.2015 09:05	01.05.2015 14:00	03.05.2015 10:00	03.05.2015 21:10	03.05.2015 21:45	02.05.2015 08:00	03.05.2015 22:00
AS VENUS DI518A	03.05.2015 18:40		03.05.2015 19:35	05.05.2015 04:50	05.05.2015 05:30		05.05.2015 06:20	05.05.2015 18:50	05.05.2015 20:30		05.05.2015 20:40
MSC CELINE MT518R	04.05.2015 08:10	04.05.2015 10:30	04.05.2015 08:54	04.05.2015 13:30	04.05.2015 14:20	04.05.2015 12:00	04.05.2015 15:00	05.05.2015 01:40	05.05.2015 02:40	05.05.2015 12:00	05.05.2015 02:50
MSC MATILDE NM519R	04.05.2015 21:30	04.05.2015 16:30		04.05.2015 22:00	04.05.2015 22:35	04.05.2015 18:30	05.05.2015 00:30	06.05.2015 07:00	06.05.2015 08:10	05.05.2015 22:00	06.05.2015 08:20
MSC HANNAH AC517A	05.05.2015 11:00	08.05.2015 05:20	05.05.2015 11:10	08.05.2015 12:50	08.05.2015 13:30	08.05.2015 06:20	08.05.2015 14:30	09.05.2015 06:30	09.05.2015 08:10	09.05.2015 21:20	09.05.2015 08:20
MSC ATLANTA NT518R	05.05.2015 21:30	02.05.2015 13:00		05.05.2015 22:30	05.05.2015 23:00	02.05.2015 15:00	06.05.2015 00:45	07.05.2015 06:40	07.05.2015 07:35	03.05.2015 23:00	07.05.2015 07:45
GOZDE BAYRAKTAR DH519A	07.05.2015 07:00			07.05.2015 09:00	07.05.2015 09:35		07.05.2015 10:45	08.05.2015 07:15	08.05.2015 08:40		08.05.2015 08:50
SAINTY VOGUE UI518R	07.05.2015 07:30	08.05.2015 13:00		07.05.2015 09:40	07.05.2015 10:30	08.05.2015 14:00	07.05.2015 11:30	07.05.2015 19:30	07.05.2015 22:20	09.05.2015 08:00	07.05.2015 22:30
MSC HOGGAR DC519A	09.05.2015 04:00		09.05.2015 04:45	12.05.2015 15:40	12.05.2015 16:10		12.05.2015 17:45	13.05.2015 03:15	13.05.2015 03:50		13.05.2015 04:00
MSC GENOVA FT520E	09.05.2015 05:30			09.05.2015 07:10	09.05.2015 08:00		09.05.2015 09:00	11.05.2015 02:00	11.05.2015 02:35		11.05.2015 02:45
MSC ADRIANA AN519R	09.05.2015 09:05	08.05.2015 04:16		09.05.2015 12:55	09.05.2015 13:30	08.05.2015 06:16	09.05.2015 14:20	10.05.2015 02:55	10.05.2015 03:50	08.05.2015 20:16	10.05.2015 04:00
MSC TOKYO NT519R	09.05.2015 20:00			09.05.2015 20:40	09.05.2015 21:25		09.05.2015 22:15	10.05.2015 22:00	10.05.2015 22:20		10.05.2015 22:30
HS DISCOVERER AC519R	10.05.2015 05:10	09.05.2015 22:58		10.05.2015 05:30	10.05.2015 06:25	09.05.2015 23:58	10.05.2015 07:25	10.05.2015 19:30	10.05.2015 20:20	10.05.2015 23:58	10.05.2015 20:30

Table A. 10 MARPORT Vessel and Container Load Data, May 2015, (Source, MARPORT Administration, 11 September 2015)

Vessel Name	Arrival at Pilot Station	DISCHARGED CONTAINERS PER CALL									LOADED CONTAINERS PER CALL								
		FULL		EMPTY		T/S FULL		T/S EMPTY		Total	FULL		EMPTIES		T/S FULL		T/S EMPTIES		Total
		20	40	20	40	20	40	20	40	TEU'S	20	40	20	40	20	40	20	40	TEU'S
MSC LEA AO518A	01.05.2015 01:20	14	2	0	0	159	45	0	0	267	1	3	0	0	44	0	0	0	51
MSC HOGGAR DC518A	01.05.2015 10:50	0	0	0	0	2	0	1	0	3	1	0	0	0	105	205	0	0	516
HS DISCOVERER	01.05.2015 11:10	121	106	0	0	155	236	0	0	960	17	24	0	200	315	66	0	0	912
MSC EQUATOR DA519A	01.05.2015 22:05	23	3	0	5	183	93	0	0	408	0	0	0	0	211	90	0	0	391
AYSE NAZ BAYRAKTAR	02.05.2015 16:00	0	0	7	6	46	15	3	0	98	0	0	0	0	123	479	0	0	1081
MSC BETTINA FT519E	02.05.2015 18:00	1020	740	0	5	236	171	0	0	3088	496	277	381	39	209	15	0	0	1748
MICHIGAN TRADER	03.05.2015 08:00	37	114	0	0	10	42	0	2	363	2	0	0	0	73	49	1	0	174
AS VENUS DI518A	03.05.2015 18:40	0	0	0	0	0	0	0	0	0	24	16	0	0	143	188	0	0	575
MSC CELINE MT518R	04.05.2015 08:10	42	117	0	0	145	91	0	0	603	38	63	0	0	121	31	0	0	347
MSC MATILDE NM519R	04.05.2015 21:30	176	371	0	0	57	142	0	0	1259	100	392	9	0	84	69	3	0	1118
MSC HANNAH AC517A	05.05.2015 11:00	45	58	0	0	30	116	0	0	423	67	46	0	150	59	23	0	0	564
MSC ATLANTA NT518R	05.05.2015 21:30	277	367	0	0	34	126	0	0	1297	87	251	0	0	335	93	0	0	1110
GOZDE BAYRAKTAR	07.05.2015 07:00	0	28	3	39	242	85	2	0	551	0	0	0	0	245	183	0	0	611
SAINTY VOGUE UI518R	07.05.2015 07:30	64	87	0	0	12	74	0	1	400	0	0	0	0	38	8	0	0	54
MSC HOGGAR DC519A	09.05.2015 04:00	0	0	0	0	1	13	0	0	27	3	0	0	0	67	265	0	0	600
MSC GENOVA FT520E	09.05.2015 05:30	1089	866	0	5	272	224	0	0	3551	789	449	180	124	200	165	0	0	2645
MSC ADRIANA AN519R	09.05.2015 09:05	0	0	0	161	0	0	0	0	322	16	20	0	0	455	89	0	0	689
MSC TOKYO NT519R	09.05.2015 20:00	115	362	1	0	66	164	0	0	1234	108	329	15	138	100	27	1	8	1228
HS DISCOVERER	10.05.2015 05:10	1	0	1	64	189	66	3	1	456	49	94	10	30	29	10	0	0	356

Table A.11. MARPORT Vessel and Time Data, June 2015, (Source, MARPORT Administration, 11 September 2015).

Vessel Name	Arrival at Pilot Station	Proforma Pilot Arrival	Anchor In	Pilot on Board	Arrival at Berth	Proforma Berth Arrival	Start Operation	Complete Operation	Departure from Berth	Proforma Berth Departure	Drop Pilot
MSC EQUATOR DA523A	31.05.2015 21:10		31.05.2015 21:50	02.06.2015 16:35	02.06.2015 17:15		02.06.2015 18:15	03.06.2015 10:20	03.06.2015 12:40		03.06.2015 12:50
MSC ELOISE MT522R	01.06.2015 13:10	01.06.2015 10:30		01.06.2015 14:50	01.06.2015 15:40	01.06.2015 12:00	01.06.2015 16:45	02.06.2015 10:20	02.06.2015 11:15	02.06.2015 12:00	02.06.2015 11:25
SCT SANTIAGO NM523R	02.06.2015 04:00	01.06.2015 16:30		02.06.2015 06:05	02.06.2015 06:50	01.06.2015 18:30	02.06.2015 07:30	03.06.2015 03:25	03.06.2015 04:30	02.06.2015 22:00	03.06.2015 04:40
MSC HOGGAR DC522R	02.06.2015 16:00	09.06.2015 20:43		02.06.2015 17:15	02.06.2015 17:45	09.06.2015 22:43	02.06.2015 18:30	03.06.2015 06:30	03.06.2015 07:30	10.06.2015 22:43	03.06.2015 07:40
MSC MIA SUMMER	03.06.2015 14:40	31.05.2015 04:22		03.06.2015 15:20	03.06.2015 16:00	31.05.2015 06:22	03.06.2015 16:55	04.06.2015 07:45	04.06.2015 09:45	31.05.2015 18:22	04.06.2015 10:00
GOZDE BAYRAKTAR	04.06.2015 06:30			04.06.2015 08:50	04.06.2015 09:30		04.06.2015 11:30	05.06.2015 10:25	05.06.2015 11:20		05.06.2015 11:30
MINERVA AC521A	04.06.2015 12:45	05.06.2015 05:20	04.06.2015 14:00	05.06.2015 07:00	05.06.2015 07:45	05.06.2015 06:20	05.06.2015 09:00	06.06.2015 06:15	06.06.2015 07:45	06.06.2015 21:20	06.06.2015 07:55
AYSE NAZ BAYRAKTAR	04.06.2015 14:55			04.06.2015 16:20	04.06.2015 16:50		04.06.2015 18:00	06.06.2015 02:30	06.06.2015 03:30		06.06.2015 03:40
SAINTY VOGUE UI522R	04.06.2015 18:00	05.06.2015 13:00		04.06.2015 18:50	04.06.2015 19:20	05.06.2015 14:00	04.06.2015 20:45	05.06.2015 09:30	05.06.2015 09:55	06.06.2015 08:00	05.06.2015 10:05
MSC ROSA M FT524E	06.06.2015 16:30			06.06.2015 17:10	06.06.2015 18:30		06.06.2015 19:30	08.06.2015 15:25	08.06.2015 16:15		08.06.2015 16:25
MSC EQUATOR DA524A	07.06.2015 04:55		07.06.2015 05:20	09.06.2015 13:00	09.06.2015 13:30		09.06.2015 14:30	10.06.2015 09:30	10.06.2015 10:20		10.06.2015 10:30
PRIWALL MT523R	08.06.2015 12:00	08.06.2015 10:30		08.06.2015 12:50	08.06.2015 13:40	08.06.2015 12:00	08.06.2015 15:30	09.06.2015 10:15	09.06.2015 11:15	09.06.2015 12:00	09.06.2015 11:25
MSC CORDOBA NM524R	09.06.2015 04:00	08.06.2015 16:30		09.06.2015 04:40	09.06.2015 05:25	08.06.2015 18:30	09.06.2015 06:00	10.06.2015 02:20	10.06.2015 03:20	09.06.2015 22:00	10.06.2015 03:30
MSC HOGGAR DC522R	09.06.2015 11:30	02.06.2015 18:00	09.06.2015 12:15	10.06.2015 11:25	10.06.2015 12:00	02.06.2015 20:00	10.06.2015 13:15	11.06.2015 02:15	11.06.2015 03:05	10.06.2015 22:43	11.06.2015 03:15
MSC ELEONORA AC523R	10.06.2015 02:30	06.06.2015 22:58		10.06.2015 04:00	10.06.2015 04:35	06.06.2015 23:58	10.06.2015 05:40	10.06.2015 19:55	10.06.2015 21:00	07.06.2015 23:58	10.06.2015 21:10
MSC TOKYO NT523R	10.06.2015 07:00	06.06.2015 13:00		10.06.2015 08:00	10.06.2015 08:35	06.06.2015 15:00	10.06.2015 09:30	11.06.2015 09:40	11.06.2015 11:00	07.06.2015 23:00	11.06.2015 11:10
MSC ASLI AN523R	11.06.2015 01:30	05.06.2015 08:14		11.06.2015 01:45	11.06.2015 02:05	05.06.2015 10:14	11.06.2015 03:00	11.06.2015 14:35	11.06.2015 15:05	06.06.2015 04:14	11.06.2015 15:15
E.R. HAMBURG AC522A	11.06.2015 07:10	12.06.2015 05:20		11.06.2015 08:05	11.06.2015 08:35	12.06.2015 06:20	11.06.2015 09:20	12.06.2015 01:00	12.06.2015 02:20	13.06.2015 21:20	12.06.2015 02:30
MSC CAITLIN AO523A	12.06.2015 05:10	07.06.2015 04:22		12.06.2015 06:25	12.06.2015 07:00	07.06.2015 06:22	12.06.2015 07:20	12.06.2015 11:10	12.06.2015 12:50	07.06.2015 18:22	12.06.2015 13:00
GOZDE BAYRAKTAR	12.06.2015 19:00			12.06.2015 19:45	12.06.2015 20:20		12.06.2015 21:20	13.06.2015 13:30	13.06.2015 16:35		13.06.2015 16:45
MSC SORAYA NT524R	13.06.2015 12:00			13.06.2015 13:35	13.06.2015 14:15		13.06.2015 15:15	14.06.2015 18:20	14.06.2015 18:40		14.06.2015 18:50
MSC AMSTERDAM FT525E	13.06.2015 20:00			13.06.2015 20:15	13.06.2015 21:45		13.06.2015 22:30	15.06.2015 21:40	15.06.2015 23:00		15.06.2015 23:10

Table A. 12 MARPORT Vessel and Container Load Data, June 2015, (Source, MARPORT Administration, 11 September 2015)

Vessel Nane	Arrival at Pilot Station	DISCHARGED CONTAINERS PER CALL									LOADED CONTAINERS PER CALL								
		FULL		EMPTY		T/S FULL		T/S EMPTY		Total	FULL		EMPTIES		T/S FULL		T/S EMPTIES		Total
		20	40	20	40	20	40	20	40	TEU'S	20	40	20	40	20	40	20	40	TEU'S
MSC EQUATOR DA523A	31.05.2015 21:10	41	3	0	30	158	96	0	0	457	13	27	80	0	171	101	0	0	520
MSC ELOISE MT522R	01.06.2015 13:10	61	90	0	0	350	62	0	0	715	64	114	0	0	112	60	2	0	526
SCT SANTIAGO NM523R	02.06.2015 04:00	194	290	0	0	51	87	0	0	999	42	425	10	0	80	123	3	0	1231
MSC HOGGAR DC522R	02.06.2015 16:00	0	0	0	0	5	0	0	0	5	0	0	0	0	87	201	0	0	489
MSC MIA SUMMER	03.06.2015 14:40	24	0	0	2	92	19	0	0	158	76	9	10	0	45	56	0	0	261
GOZDE BAYRAKTAR	04.06.2015 06:30	0	0	14	33	404	89	0	0	662	41	40	0	0	167	186	0	0	660
MINERVA AC521A	04.06.2015 12:45	85	85	0	0	54	103	0	0	515	18	91	5	0	375	62	0	0	704
AYSE NAZ BAYRAKTAR	04.06.2015 14:55	0	0	34	178	315	32	1	0	770	0	0	448	0	117	187	2	3	947
SAINTY VOGUE UI522R	04.06.2015 18:00	35	40	0	0	17	93	0	1	320	2	2	0	0	17	4	0	0	31
MSC ROSA M FT524E	06.06.2015 16:30	1099	984	0	0	374	212	0	0	3865	632	430	15	379	323	179	0	0	2946
MSC EQUATOR DA524A	07.06.2015 04:55	10	0	0	16	213	107	3	0	472	34	39	150	0	195	48	0	0	553
PRIWALL MT523R	08.06.2015 12:00	73	207	2	0	212	48	0	0	797	76	80	1	80	72	23	0	0	515
MSC CORDOBA NM524R	09.06.2015 04:00	154	271	0	0	45	44	1	0	830	73	379	24	54	82	99	19	4	1270
MSC HOGGAR DC522R	09.06.2015 11:30	0	48	0	74	77	71	10	0	473	0	0	162	0	4	26	0	0	218
MSC ELEONORA AC523R	10.06.2015 02:30	0	0	12	75	92	129	0	0	512	66	142	5	84	21	9	0	0	562
MSC TOKYO NT523R	10.06.2015 07:00	195	627	0	173	45	210	0	0	2260	68	237	3	155	341	116	0	0	1428
MSC ASLI AN523R	11.06.2015 01:30	0	0	0	0	0	0	0	0	0	13	20	0	0	349	69	0	0	540
E.R. HAMBURG AC522A	11.06.2015 07:10	124	121	0	0	42	84	0	0	576	39	74	5	0	133	105	0	0	535
MSC CAITLIN AO523A	12.06.2015 05:10	14	5	0	25	88	11	0	0	184	1	17	5	0	29	10	0	0	89
GOZDE BAYRAKTAR	12.06.2015 19:00	5	0	0	0	285	67	0	0	424	46	55	0	0	62	349	0	0	916
MSC SORAYA NT524R	13.06.2015 12:00	214	473	0	167	69	199	0	0	1961	105	223	4	132	38	23	0	0	903
MSC AMSTERDAM FT525E	13.06.2015 20:00	966	1103	0	53	328	208	0	0	4022	736	403	220	519	342	58	0	0	3258

Table A.13. MARPORT Vessel and Time Data, July 2015, (Source, MARPORT Administration, 11 September 2015).

Vessel	Arrival at Pilot Station	Proforma Pilot Arrival	Anchor In	Pilot on Board	Arrival at Berth	Proforma Berth Arrival	Start Operation	Complete Operation	Departure from Berth	Proforma Berth Departure	Drop Pilot
SAINTY VOGUE UI526R	01.07.2015 14:30	03.07.2015 13:00		01.07.2015 15:00	01.07.2015 15:45	03.07.2015 14:00	01.07.2015 16:25	01.07.2015 22:30	01.07.2015 23:05	04.07.2015 08:00	01.07.2015 23:15
E.R. SANTIAGO AC526R	01.07.2015 17:00	27.06.2015 22:58		01.07.2015 20:20	01.07.2015 21:00	27.06.2015 23:58	01.07.2015 22:10	02.07.2015 19:40	02.07.2015 20:20	28.06.2015 23:58	02.07.2015 20:30
GOZDE BAYRAKTAR DH527A	02.07.2015 22:50			02.07.2015 22:20	02.07.2015 23:55		03.07.2015 01:00	03.07.2015 20:15	03.07.2015 21:20		03.07.2015 21:30
MSC ELEONORA AC525A	04.07.2015 01:10	03.07.2015 04:27	04.07.2015 02:25	04.07.2015 11:30	04.07.2015 12:05	03.07.2015 05:27	04.07.2015 18:15	05.07.2015 15:00	05.07.2015 16:10	04.07.2015 20:27	05.07.2015 16:20
AYSE NAZ BAYRAKTAR	04.07.2015 03:15		04.07.2015 03:55	04.07.2015 11:50	04.07.2015 12:25		04.07.2015 20:10	05.07.2015 17:05	05.07.2015 18:05		05.07.2015 18:15
MSC HOGGAR DC527A	04.07.2015 07:00		04.07.2015 07:30	04.07.2015 12:30	04.07.2015 13:20		04.07.2015 17:10	05.07.2015 17:10	05.07.2015 19:05		05.07.2015 19:15
MSC EQUATOR DA528A	05.07.2015 10:15		05.07.2015 10:40	07.07.2015 01:40	09.07.2015 17:30		09.07.2015 18:20	10.07.2015 23:10	11.07.2015 00:05		11.07.2015 00:10
MSC TOKYO NT527R	05.07.2015 16:50			05.07.2015 17:30	05.07.2015 18:00		05.07.2015 19:00	07.07.2015 07:50	07.07.2015 09:20		07.07.2015 09:30
MSC PALOMA FT528E	06.07.2015 01:35			06.07.2015 02:15	06.07.2015 03:25		06.07.2015 04:30	09.07.2015 13:50	09.07.2015 14:50		09.07.2015 15:00
MSC LEA XA502A	06.07.2015 02:40		06.07.2015 03:05	06.07.2015 13:20	06.07.2015 13:50		06.07.2015 15:00	07.07.2015 01:20	07.07.2015 03:00		07.07.2015 03:10
MSC GIOVANNA AO527A	06.07.2015 04:50	03.07.2015 18:00	06.07.2015 06:10	06.07.2015 20:30	06.07.2015 21:00	03.07.2015 20:00	06.07.2015 23:00	08.07.2015 05:50	08.07.2015 07:45	04.07.2015 16:00	08.07.2015 07:55
AENNE RICKMERS AC527R	06.07.2015 10:30	26.06.2015 04:27	06.07.2015 10:55	08.07.2015 02:40	08.07.2015 03:20	26.06.2015 05:27	08.07.2015 04:30	09.07.2015 10:10	09.07.2015 12:35	27.06.2015 20:27	09.07.2015 12:45
MSC MATILDE NM528R	07.07.2015 19:00	06.07.2015 16:30		07.07.2015 19:35	07.07.2015 20:20	06.07.2015 18:30	07.07.2015 22:10	09.07.2015 06:50	09.07.2015 07:25	07.07.2015 22:00	09.07.2015 07:35
MICHIGAN TRADER UI527R	09.07.2015 12:00	10.07.2015 13:00	09.07.2015 12:30	09.07.2015 17:50	09.07.2015 18:20	10.07.2015 14:00	09.07.2015 22:00	10.07.2015 01:15	10.07.2015 07:15	11.07.2015 08:00	10.07.2015 07:25
MSC CELINE MT527R	09.07.2015 18:00	06.07.2015 10:30	09.07.2015 18:30	10.07.2015 10:20	10.07.2015 11:15	06.07.2015 12:00	10.07.2015 15:45	11.07.2015 06:45	11.07.2015 07:35	07.07.2015 12:00	11.07.2015 07:45
MSC HANNAH AC526A	10.07.2015 11:20	10.07.2015 04:27		10.07.2015 18:10	10.07.2015 18:50	10.07.2015 05:27	10.07.2015 19:30	11.07.2015 19:00	11.07.2015 19:20	11.07.2015 20:27	11.07.2015 19:40
MSC CAMILLE FT529E	11.07.2015 06:00			11.07.2015 06:25	11.07.2015 07:25		11.07.2015 08:45	13.07.2015 20:30	13.07.2015 22:45		13.07.2015 22:55
MSC SORAYA NT528R	11.07.2015 22:30			12.07.2015 00:20	12.07.2015 01:05		12.07.2015 03:45	13.07.2015 15:30	13.07.2015 16:20		13.07.2015 16:20
MSC ELEONORA AC528R	12.07.2015 07:00	03.07.2015 04:27	12.07.2015 07:35	12.07.2015 16:25	12.07.2015 17:00	03.07.2015 05:27	12.07.2015 18:00	13.07.2015 19:45	13.07.2015 20:45	04.07.2015 20:27	13.07.2015 20:55
GOZDE BAYRAKTAR DH528A	12.07.2015 08:10			12.07.2015 08:40	13.07.2015 14:00		13.07.2015 15:15	15.07.2015 09:40	15.07.2015 11:10		15.07.2015 11:20

Table A. 14 MARPORT Vessel and Container Load Data, July 2015, (Source, MARPORT Administration, 11 September 2015

Vessel Name	Arrival at Pilot Station	DISCHARGED CONTAINERS PER CALL									LOADED CONTAINERS PER CALL								
		FULL		EMPTY		T/S FULL		T/S EMPTY		Total	FULL		EMPTIES		T/S FULL		T/S EMPTIES		Total
		20	40	20	40	20	40	20	40	TEU'S	20	40	20	40	20	40	20	40	TEU'S
SAINTY VOGUE UI526R	01.07.2015 14:30	1	47	0	0	51	16	0	0	178	0	0	0	0	6	3	0	0	12
E.R. SANTIAGO AC526R	01.07.2015 17:00	25	14	16	0	231	306	3	1	917	132	173	0	50	3	2	0	0	585
GOZDE BAYRAKTAR	02.07.2015 22:50	0	0	0	0	436	48	3	0	535	42	35	65	0	104	244	0	0	769
MSC ELEONORA AC525A	04.07.2015 01:10	56	69	0	0	17	82	0	0	375	67	56	0	0	362	140	0	0	821
AYSE NAZ BAYRAKTAR	04.07.2015 03:15	0	0	0	87	17	46	0	3	289	33	28	0	0	259	121	0	0	590
MSC HOGGAR DC527A	04.07.2015 07:00	0	0	0	0	150	10	0	0	170	32	5	0	0	80	239	0	0	600
MSC EQUATOR DA528A	05.07.2015 10:15	2	26	0	21	166	103	0	0	468	38	4	1	0	128	111	0	0	397
MSC TOKYO NT527R	05.07.2015 16:50	242	445	2	130	158	174	0	4	1908	162	376	11	0	146	97	0	0	1265
MSC PALOMA FT528E	06.07.2015 01:35	1140	1479	0	13	436	198	0	0	4956	645	479	50	364	603	225	0	0	3434
MSC LEA XA502A	06.07.2015 02:40	41	31	0	32	227	29	0	0	452	0	0	0	0	0	0	0	0	0
MSC GIOVANNA AO527A	06.07.2015 04:50	6	2	0	0	69	21	0	0	121	65	59	8	0	160	34	0	0	419
AENNE RICKMERS	06.07.2015 10:30	7	3	0	1	25	294	0	4	636	49	86	0	0	0	3	0	0	227
MSC MATILDE NM528R	07.07.2015 19:00	186	368	0	0	99	107	0	0	1235	32	308	9	0	214	115	0	0	1101
MICHIGAN TRADER	09.07.2015 12:00	4	65	0	0	89	26	0	4	283	0	0	0	0	22	10	0	0	42
MSC CELINE MT527R	09.07.2015 18:00	41	95	0	0	274	57	0	0	619	55	133	3	0	83	71	3	0	552
MSC HANNAH AC526A	10.07.2015 11:20	102	69	0	0	25	159	0	0	583	16	36	0	150	321	50	0	0	809
MSC CAMILLE FT529E	11.07.2015 06:00	1248	1362	0	13	394	176	0	0	4744	607	437	300	102	290	224	0	0	2723
MSC SORAYA NT528R	11.07.2015 22:30	174	456	0	0	102	195	0	0	1578	145	270	17	180	181	62	27	26	1446
MSC ELEONORA AC528R	12.07.2015 07:00	2	43	0	246	187	245	0	0	1257	116	88	14	0	6	1	0	0	314
GOZDE BAYRAKTAR	12.07.2015 08:10	0	0	1	0	302	115	0	0	533	0	4	0	0	207	200	0	4	623

APPENDIX-B

Table B. 1. Arrival to Anchoring Area Time (AAT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	AAT X VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	9	0,0940	0,0385	0,0101	0,0385	0,0101
1	16	0,1880	0,0684	0,0302	0,1070	0,0403
2	16	0,2820	0,0684	0,0503	0,1750	0,0906
3	8	0,3760	0,0342	0,0705	0,2090	0,1610
4	8	0,4700	0,0342	0,0906	0,2440	0,2520
5	16	0,5640	0,0684	0,1110	0,3120	0,3620
6	41	0,6580	0,1750	0,1280	0,4870	0,4910
7	24	0,7520	0,1030	0,1190	0,5900	0,6100
8	32	0,8460	0,1370	0,1030	0,7260	0,7140
9	8	0,9400	0,0342	0,0875	0,7610	0,8010
10	16	1,0300	0,0684	0,0716	0,8290	0,8730
11	8	1,1300	0,0342	0,0557	0,8630	0,9280
12	24	1,2200	0,1030	0,0398	0,9660	0,9680
13	8	1,3200	0,0342	0,0239	1,0000	0,9920
14	0	1,4100	0,0000	0,0079	1,0000	1,0000

Table B. 2. Waiting Time at Anchor (WAT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	WAT X VALUE	DENSITYPROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	45	7	0,1920	0,1990	0,1920	0,1990
1	53	13	0,2260	0,2320	0,4190	0,4310
2	37	19	0,1580	0,1560	0,5770	0,5870
3	30	25	0,1280	0,1040	0,7050	0,6910
4	12	31	0,5130	0,0717	0,7560	0,7630
5	8	37	0,0342	0,0510	0,7910	0,8140
6	7	43	0,0299	0,0374	0,8210	0,8510
7	8	49	0,0342	0,0280	0,8550	0,8790
8	5	55	0,0214	0,0214	0,8760	0,9010
9	2	61	0,0086	0,0167	0,8850	0,9170
10	3	67	0,0128	0,0132	0,8970	0,9300
11	6	73	0,0256	0,0106	0,9230	0,9410
12	11	79	0,0470	0,0086	0,9700	0,9500
13	3	85	0,0128	0,0070	0,9830	0,9570
14	4	91	0,0171	0,0058	1,000	0,9620

Table B. 3. Anchoring Area to Berthing Time (APT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	APT X VALUE	DENSITYPROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	0	0,3090	0,0000	0,0070	0,0000	0,0070
1	9	0,3590	0,0385	0,0211	0,0385	0,0281
2	0	0,4080	0,0000	0,0351	0,0385	0,0632
3	18	0,4580	0,0769	0,0491	0,1150	0,1120
4	18	0,5070	0,0769	0,0632	0,1920	0,1750
5	18	0,5560	0,0769	0,0772	0,2690	0,2530
6	18	0,6060	0,0769	0,0912	0,3460	0,3440
7	9	0,6550	0,0385	0,1050	0,3850	0,4490
8	36	0,7050	0,1540	0,1190	0,5380	0,5680
9	45	0,7540	0,1920	0,1290	0,7310	0,6970
10	18	0,8030	0,0769	0,1090	0,8080	0,8060
11	18	0,8530	0,0769	0,0848	0,8850	0,8910
12	0	0,9020	0,0000	0,0606	0,8850	0,9520
13	18	0,9520	0,0769	0,0364	0,9620	0,9880

Table B. 4. Arrival to Berthing Time (ABT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	ABT X VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	1	0,1050	0,0025	0,0035	0,0025	0,0035
1	1	0,2110	0,0025	0,0123	0,0050	0,0158
2	3	0,3160	0,0076	0,0218	0,0126	0,0376
3	25	0,4210	0,0631	0,0312	0,0758	0,0688
4	26	0,5260	0,0657	0,0402	0,1410	0,1090
5	16	0,6320	0,0404	0,0487	0,1820	0,1580
6	14	0,7370	0,0354	0,0564	0,2170	0,2140
7	36	0,8420	0,0909	0,0632	0,3080	0,2770
8	18	0,9470	0,0455	0,0690	0,3540	0,3460
9	25	1,0500	0,0631	0,0735	0,4170	0,4200
10	21	1,1600	0,0530	0,0767	0,4700	0,4970
11	49	1,2600	0,1240	0,0784	0,5930	0,5750
12	25	1,3700	0,0631	0,0785	0,6570	0,6540
13	24	1,4700	0,0606	0,0766	0,7170	0,7300
14	32	1,5800	0,0808	0,0725	0,7980	0,8030
15	36	1,6800	0,0909	0,0659	0,8890	0,8690
16	15	1,7900	0,0379	0,0562	0,9270	0,9250
17	20	1,8900	0,0505	0,0421	0,9770	0,9670

Table B. 5. Berthing to Operation Time (BOT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	BOT X VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	5	0,3250	0,0061	0,0111	0,0061	0,0111
1	70	0,6500	0,0850	0,1310	0,0910	0,1420
2	189	0,9750	0,2290	0,2170	0,3200	0,3580
3	226	1,3000	0,2740	0,1980	0,5950	0,5560
4	118	1,6300	0,1430	0,1460	0,7380	0,7020
5	64	1,9500	0,0777	0,1000	0,8160	0,8030
6	57	2,2700	0,0692	0,0662	0,8850	0,8690
7	38	2,60	0,0461	0,0434	0,9310	0,9120
8	16	2,9300	0,0194	0,0285	0,9500	0,9410
9	10	3,2500	0,0121	0,0188	0,9620	0,9600
10	2	3,5800	0,0024	0,0125	0,9650	0,9720
11	5	3,9000	0,0061	0,0085	0,9710	0,9800
12	3	4,2300	0,0036	0,0058	0,9750	0,9860
13	3	4,5500	0,0036	0,0040	0,9780	0,9900
14	3	4,8800	0,0036	0,0028	0,9820	0,9930
15	1	9,1000	0,0012	0,0000	0,9980	1,0000

Table B. 6. Operation Time (OPT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	OPT X VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	34	2,58	0,0443	0,0393	0,0443	0,0393
1	56	5,15	0,0730	0,0896	0,1170	0,1290
2	83	7,73	0,1080	0,1100	0,2260	0,2390
3	96	10,3	0,1250	0,1130	0,3510	0,3530
4	85	12,9	0,1110	0,1070	0,4620	0,4600
5	76	15,4	0,0991	0,0961	0,5610	0,5560
6	76	18,0	0,0991	0,0833	0,6600	0,6390
7	54	20,6	0,0704	0,0705	0,7300	0,7090
8	41	23,2	0,0535	0,0586	0,7840	0,7680
9	39	25,7	0,0508	0,0480	0,8340	0,8160
10	27	28,3	0,0352	0,0389	0,8700	0,8550
11	26	30,9	0,0339	0,0312	0,9040	0,8860
12	11	33,5	0,0143	0,0249	0,9180	0,9110
13	12	36,0	0,0156	0,0197	0,9340	0,9310
14	6	38,6	0,0078	0,0155	0,9410	0,9460
15	9	41,2	0,0117	0,0122	0,9530	0,9580

Table B. 7. Operation to Departure Time (ODT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	ODT X VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	16	0,475	0,195	0,0427	0,0195	0,0427
1	227	0,950	0,2770	0,2880	0,2960	0,3310
2	331	1,1200	0,4040	0,2920	0,7000	0,6230
3	110	1,9000	0,1340	0,1780	0,8340	0,8010
4	65	2,3800	0,0793	0,0948	0,9130	0,8960
5	28	2,8500	0,0341	0,0489	0,9480	0,9450
6	13	3,3300	0,0159	0,0253	0,9630	0,9700
7	5	3,8000	0,0061	0,0133	0,9700	0,9830
8	5	4,2800	0,0061	0,0072	0,9760	0,9910
9	3	4,7500	0,0037	0,0040	0,9790	0,9940
10	3	5,2200	0,0037	0,0022	0,9830	0,9970
11	4	5,7000	0,0049	0,0013	0,9880	0,9980
16	1	17,6000	0,0012	0,0000	0,9980	1,0000
17	0	19,0000	0,000	0,0000	1,0000	1,0000

Table B. 8. Total Time in Port (TOT) Distribution Summary.

INTERVAL NUMBER	NUMBER OF DATA PONITS	IAT X VALUE	DENSITY PROBABILITY		CUMULATIVE PROBABILITY	
			DATA	FUNCTION	DATA	FUNCTION
0	76	8,86	0,0922	0,1000	0,0922	0,1000
1	171	15,7	0,0208	0,2330	0,3000	0,3330
2	174	22,6	0,0211	0,1930	0,5110	0,5260
3	132	29,4	0,0160	0,1360	0,6710	0,6620
4	77	36,3	0,0934	0,0933	0,7650	0,7550
5	64	43,1	0,0777	0,0645	0,8420	0,8190
6	24	50,0	0,0291	0,0453	0,8710	0,8650
7	35	56,9	0,0425	0,0324	0,9140	0,897
8	18	63,7	0,0218	0,0235	0,9360	0,9210
9	9	70,6	0,0109	0,0174	0,9470	0,9380
10	11	77,4	0,0133	0,0130	0,9600	0,9510
11	4	84,3	0,0049	0,0099	0,9650	0,961
12	10	91,1	0,0121	0,0076	0,9770	0,9680
13	7	98,0	0,0085	0,0059	0,9850	0,9740
14	2	105,0	0,0024	0,0046	0,9880	0,9790
15	4	119,0	0,0049	0,0029	0,9940	0,9860
16	1	160,0	0,0012	0,0009	0,9990	0,9950
17	1	194,0	0,0012	0,0004	1,0000	0,9970

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Professional Experience and Rewards:

Graduated from Turkish Naval Academy, he worked as Naval Officer on board Turkish Navy ships. He was the commanding officer of TCG Yıldırım and TCG Oruçreis frigates. He was retired from the Navy with the rank of Rear Admiral (UH) in 2012. Currently, he has been working in Yeditepe Üniversity as Secretary General since June 2016.

He has a sufficient background in NATO and international relations including crises management.