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Integrated Energy Efficiency of Shipping

by

Önder Canbulat

A thesis presented in fulfilment of the requirements for the degree of Doctor of Philosophy.

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Signed: __________ Date: 23/04/2021

To Mustafa Kemal Atatürk,

To My Wife Seda,

To My Big Family include Ela, Ali Kutlu,

To all children & all good people who live for humanity, peace, and a greener world with love.

ABSTRACT

Energy is a strength and one of the most indispensable resources for maritime transport activities. There is still a research need on the ship-port interface regarding energy efficiency. These complex logistic chains should comprise port performance to reduce shipping delays to create a better energy-efficient system. Therefore, this research is addressing the following question: How can we produce an integrated analysis for the energy efficiency of the port and ship? The objective of this PhD thesis is to improve our understanding of port and ship operation with a focus on energy efficiency by implementing Bayesian Belief Networks (BBN) and ARENA Discrete Event Simulation (DES) based modelling. A modelling framework is developed to investigate how ports and ships could work together to reduce energy consumption and maximise efficient operation time. This PhD study investigates integrated energy-efficient shipping in a holistic way by focusing on ship-port interface and interoperability to increase energy efficiency. BBN focused on more comprehensive ship port integration, and DES analysed more micro-sized parts of this complex integrated port-ship system for a container port. This study improved the energy efficiency of integrated shipping elements by increasing the interoperability between interdependent shipping system elements. The research is addressing dependability by deploying a BBN technique. ARENA application on a case study showed that considering the integrated system's energy efficiency instead of only port energy efficiency, the whole system's energy consumption and CO_2 pollution have around 6% improvement in the port area. The case study also clearly demonstrates that ship operation is the main contributor and has a more significant effect on the integrated system. Results also prove that port operation and ship operation can be more energy-efficient and need more appropriate analyses. As a result, this thesis creates a solution to analyse the energy efficiency of the ship and port integration which is a gap in the literature.

RESEARCH OUTPUTS

The following publications were generated during the timespan of the PhD studies in relation to this thesis.

Journal papers (SCI / SCI Expanded):

Canbulat, O., Aymelek, M., Turan, O. and Boulougouris, E., 2019. An application of BBN on the integrated energy efficiency of ship–port interface: a dry bulk shipping case. Maritime Policy & Management, 46(7), pp.845-865.

Canbulat, U., Kaya, M., Turan, O. and Boulougouris, E., 2021. Integrated Energy Efficiency of Shipping: ARENA application on container operation. Ocean engineering (In progress).

Book Chapter

Canbulat, O., Aymelek, M., Turan, O. and Boulougouris, E., 2018. A Bayesian Belief Network Model for Integrated Energy Efficiency of Shipping. In Trends and Challenges in Maritime Energy Management (pp. 257-273). Springer, Cham.

Conference papers:

Canbulat, O., Aymelek, M., Turan, O. and Boulougouris, E., 2017, January. A Bayesian belief network model for integrated energy efficiency of shipping. In International Conference on Maritime Energy Management 2017. Malmo, Sweden.

Canbulat, O., Aymelek, M., Kurt, I., Koldemir, B., Turan, O., (2015). Publication Preview Source Green Sustainable Performance Comparison of the Three Biggest Container Terminals in Turkey, Proceeding of International Association of Maritime Economists (IAME) 2015 Conference, Kuala Lumpur, Malesia.

Senss., A., Canbulat, O., Turan, O., and Demirel, Y., K., (2018). Maritime Operation Environmental Sustainability vs. Commercial Practice: Contract Based Ocean Voyage Performance Monitoring & Condition Change Simulation. Europe-Korea Conference on Science and Technology (EKC). Glasgow, UK

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Glasgow, April 2021

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ABBREVIATIONS

CO_2 : Carbon Dioxide (CO2)

BBN : Bayesian Beliefs Network

CAPEX : Capital Expenses

EU : European Union

GHG : Green House Gas

IMO : International Maritime Organisation

MARPOL : International Convention for the Prevention of Pollution from Ships.

OPEX : Operating Expenditures

OPEX : Operational Expenses

PhD : Doctor of Philosophy

QC : Quay Crane

RTG : Rubber-tyred Gantry

SSG : Ship-to-Shore Gantry cranes,

TEU : Twenty-foot Equivalent Unit

TOS : Terminal Operating System

UK : United Kingdom

UNCTAD : United Nationals Conference on Trade and Development

VTS : Vessel Traffic System

YT : Yard Trucks

CHAPTER 1: INTRODUCTION

1.1 Chapter Overview

This chapter starts with providing the general perspectives of the issues studied in this thesis. Following that, the motivations behind each chapter of the thesis will be presented. The main research aims, and objectives will be outlined in section 1.4. Then, novelties and contributions of the thesis to the research field will be provided in section 1.5. Finally, the structure of this thesis will be outlined in section 1.6.

1.2 General Perspectives

Over a million seafarers operate around 50,000 merchant ships trading in the international waters (International Chamber of Shipping, 2021), and they receive service from several thousand ports, which are actively working in the world (VEDP, 2014). The world's total maritime trade tonnage was 2.6 million tonnes in 1970; currently, the shipping industry carries around 11.08 billion tons of cargo (UNCTAD, 2019; UNCTAD, 2020), which is 90% of the total volume of world trade. Shipping industry is one of the significant intercontinental trade players, from the bulk transport of raw materials to manufactured goods. It is a global scale activity linking the supply-demand of global commodities and international manufacturers and consumers. Shipping has been playing a progressively more significant role in the global supply chain due to competitive freight costs compared to the other transport modes (Chen et al., 2013). The shipping business has been growing continuously and has become more sophisticated, efficient, and effective (Cullinane, 2014). The growing efficiency of shipping as a transport mode and increased economic liberalisation assist the shipping industry for further and consistent growth. Based on the third IMO greenhouse gas (GHG) study, maritime transport emits around 940 million tonnes of CO_2 annually and is responsible for about 2.5% of global GHG emissions (IMO, 2014). Therefore, this stable growth in these sectors will have side effects on the environment if no action is taken. On the other hand, the minimisation of energy consumption allows shipping to reduce transportation costs, to minimise the negative influences on climate change, and to prevent environmental pollution. One of the industry's primary goals during the last decade and for the near future is to decrease the emissions generated by shipping, including port operations, while expanding the global marine transport activities (Helfre and Boot 2013).

Shipping is a highly energy-efficient transport mode compared to other modes of transport (Johnson, 2014). However, fuel costs represent as much as 50-60% of total ship related operating costs which is the highest component of the total ship operating cost (Stratiotis, 2018). This is more challenging for some of the oceangoing ships like VLCC because the bunker cost share of freight revenue exceeds 80% (Younevitch and Bowles 2019). To minimise the total operating cost in multimodal transportation, ships, ports, and terminals' integrated operational energy efficiency is becoming increasingly significant. There are several important issues like the proper selection of the ship's size, hull form design and optimal speed selection, optimisation of the engine's short term and long-term performance, efficient cargo handling onboard and port operation performance, and arrangement of communication between ships and the ports (Plessas, 2013; Johnson, 2014; McKinnon, 2014; Sharma, 2014). These challenges should be examined to ensure optimal integrated energy utilisation.

1.3 Motivations Behind This Work

Over-consumption has been one of the most significant problems for humanity. It is a circumstance where resources have been excessively extracted from the ecosystem by humans. The whole world has experienced rapid changes regarding environmental problems due to global warming. One of the crucial concerns about global warming is the excessive use of fossil fuels, which generate $\mathrm{CO_2}$ and other polluting gases. Limiting greenhouse gas release, mainly $\mathrm{CO_2}$, has been proposed as the top priority to reduce global warming in the Paris agreement. Many researchers (Besikci et al., 2015; Besikci et al., 2016; Lindstad, Asbjørnslett and Pedersen, 2012; McKinnon, 2014; Yang, Bai and Schmidhalter, 2011) argue that companies should take action beyond the energy efficiency related regulative enforcement to minimise the emission of greenhouse gases from ships. Some of the significant regulations regarding the greenhouse gas emissions, such as the MARPOL convention and Kyoto Protocol, are directly related to emissions and air pollution (IMO 2014; IMO, 2017). There is a significant relation between $\mathrm{CO_2}$ emissions and energy efficiency for shipping companies as the increased energy efficiency will decrease the $\mathrm{CO_2}$ emissions (Sharma, 2014). Therefore, $\mathrm{CO_2}$ emission from shipping should be analysed and reduced to find an ideal marine transport system compatible with energy efficiency requirements and green shipping.

Moreover, to avoid environmental problems, each part of the supply chain system should control their stakeholder's consumption in a more efficient way for a sustainable future. Waterborne transportation is an important worldwide activity that can play a significant role to eliminate Global warming. As a backbone of international trade, shipping has the potential to minimise energy consumption, which has a dual benefit: profit and environmental friendliness.

Supporting the Global decarbonisation and energy efficiency activities via policies and technologies plays a significant role in reaching the world global warming target. One of the considered solutions is to increase the supporting policies after advanced technological innovations to achieve this target (HM Government, 2021). Energy efficiency has been a vital component to minimise ship operation expenses, yet it has not generally been an actual focus during the ships' design and operation (Banks, Turan and Incecik 2013). Recently, it has been discovered that energy efficiency has a significant role in the shipping industry's sustainability. Some of the predominantly larger companies have applied energy efficiency measures in expectation. However, they mostly focus on cost-saving instead of energy efficiency and alternative fuels to minimise emissions. Therefore, energy efficiency needs to be analysed more scientifically in the shipping industry.

On the other hand, Lu et al. (2014) developed an accurate and practical ship operation performance prediction model that is beneficial to choose the optimal route based on the specific weather forecast and the multi-objective weightings, including the most energy-efficient route option. It also helps to build more efficient systems to manage fleet or fleets. However, the optimal route will not solve the system's problem totally because the logistic chains are long and complicated systems with many dependencies. Individual elements can be developed to maximise the utilisation (days sailing laden, cargo loaded) of the ships. This complicated logistic chain should comprise port performance to reduce unavoidable delays to make an energy-efficient total system. Therefore, ports and fleet can be managed together. This includes the installation of effective port assets as well as good communication and resource managing between all stakeholders involved (Banks, Turan and Incecik 2013).

Moreover, Intertanko and OCIMF (2010) reported the significant waste for ships that steam at full speed in order to dock a harbour where there are known delays in cargo handling and hence no berthing space. The ships may avoid wasting time at anchor awaiting the availability of a port cargo handling facility. Emissions can thus be reduced, congestion can be avoided, and safety can be improved in port areas. For instance, where an inevitable inefficiency is observed (such as a port delay), good communication and management can allow for alternative operational energy-efficient measures to be implemented, such as just in time arrival (Intertanko and OCIMF, 2010). Thus, it is possible to say that communication may be considered a key element of integrated energy efficiency.

1.4 Research Aims & Objectives

The existing academic literature demonstrates that there is a lack of holistic energy efficiency effort in the shipping industry. The research gap leads to this research study to develop a holistic approach to ’integrated energy efficiency shipping’. Specifically, the research aims to focus on ship and port interface and interoperability to increase energy efficiency. The objectives of this study are as follows:

- To review the existing literature on the energy efficiency of shipping, regulations, and measurements of energy efficiency within integrated ship port operation and understanding suitable methodologies, including Bayesian Beliefs Network (BBN) and DES, to analyse this integrated system.

- To investigate and show the usability of energy efficiency within the integrated ship and port operations.

- To capture the real container port operations, including interaction with ships and practical challenges faced by conducting field trips, interviews with port operators and collecting actual port operation data where possible.

- Identification of useful solutions and development of a framework to increase the energy efficiency as a whole system by achieving better interoperability of ship and port services through the application of BBN modelling.

- Application of BBN modelling to identify the integrated system nodes to a better understanding of port and fleet operation integration.

- Performing simulation to understand and optimise the integration of ship and port operation based on the know-how from the developed BBN applications. This will be performed using ARENA software with the aim of improving energy efficiency and our understanding of port and ship integration based on energy efficiency.

- In this research, two different developed methods with BBN and DES will be applied to ship port interface systems to analyse energy efficiency via a case study shipping route and a case study from one of a European container port presented in chapter 5.

1.5 Novelties & Contributions to the Field

The main novelties achieved within this PhD study are given as follows:

- BBN modelling for integrated and energy-efficient port and ship operation: To the best of the author's knowledge, this work is novel as the literature contains no research application in this field. This is due to previous investigators applied this method in other research areas and disciplines like safety.
- Integrated and energy-efficient port and ship operation was achieved by developing a methodological framework in line with the industrial research practice, providing integration of energy efficiency of a ship's journey and its port operations using BBN model validated by a case study, as given in chapter 4. A holistic and integrated operational energy efficiency performance measure is generated by establishing an inter-operability link between ship voyage and port operation aspects.
- DES modelling application of energy efficiency for port ship integration: To the best of the author's knowledge, there are many ARENA simulation applications available for port and ship operation. However, none of them analyses the energy efficiency of the port and ship interface. This is one of the novel approaches which has not been applied to analyse the integrated energy consumption of ship and port operations. Furthermore, a case study of the chosen port with real operational data has not been used before in any related studies to examine the energy efficiency of a container terminal by using simulation modelling.
- The modelling framework, which has achieved this aim, is developed to investigate how a port and ships could work together to reduce energy consumption and maximise efficient operation time. One case study is performed, and the results are analysed in detail in chapter 5. This study also improved our understanding of port and ship operations based on energy efficiency.

1.6 Structure of Thesis

This section summarises the layout of this thesis based on the flow diagram displayed in Figure 1.1. In this thesis, Chapter 1 presents a general introduction to the research topic and generic information about the maritime transport industry. This has been given along with the potential research areas in this sector. Besides, this study's aim has been briefly explained in this chapter with novelties and contributions of the thesis to the research field.

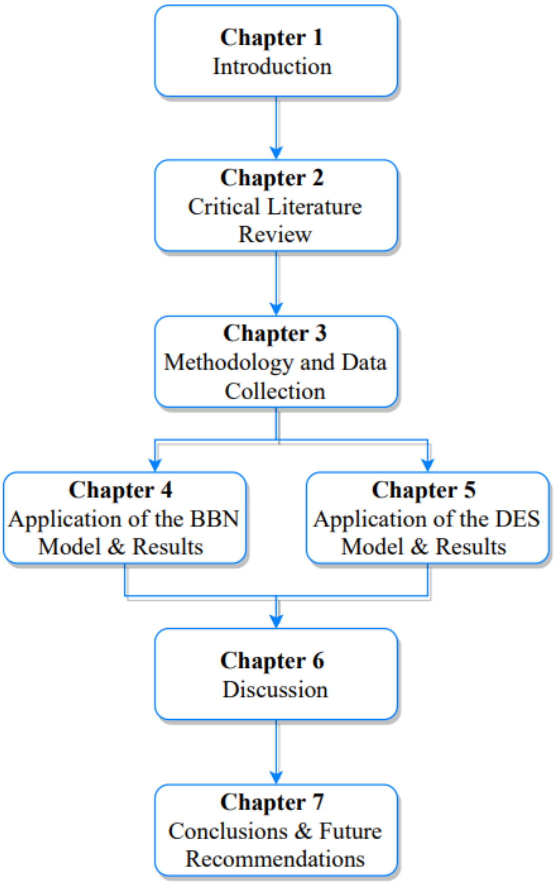


Figure 1.1 Flow diagram of the thesis`s structure.

In Chapter 2, detailed information on the energy efficiency of shipping is presented. A comprehensive literature review has been conducted, and the literature gaps with regards to ship-port interface are reported in this chapter. Moreover, existing studies on simulation-based energy efficiency applications were also reviewed in Chapter 2. BBN and ARENA simulation for container port application were addressed within the same section.

In Chapter 3, the developed methods are examined in detail, generic process, flow charts were created, and port simulation models are developed using the port and fleet process. Moreover, Chapter 3 presents the collection and analyses of the data using the models and demonstrates a framework to design and optimise case ship and port operations.

Chapter 4 and chapter 5 presents the application of the model on an existing port and the results with discussions. This section applied the BBN application within chapter 4 and DES modelling framework within chapter 5 in different case studies to analyse ship port integration based on energy efficiency with results.

Chapter 6 presents a general discussion of the results, and Chapter 7 outlines the conclusions together with future research recommendations.

1.7 Chapter Overview

This chapter has explained the background of the shipping industry and problems and summarised this study's approach, which contributes to solving the energy efficiency problem by using an integrated approach.

CHAPTER 2: CRITICAL LITERATURE REVIEW

2.1 Chapter Overview

A review of existing literature was performed to support the study undertaken in this thesis. The main objective of the chapter is to clarify why energy efficiency in shipping is essential and why there is a need for further research in maritime transport. In recent years, research into energy efficiency measures and energy efficiency regulations have become very popular, and the sections aim to give a comprehensive review of the recent progress in green shipping. The literature review of the fleet and port integration-related activities in connection with energy efficiency is performed. This section also covers the literature review on Bayesian Belief application in shipping and Arena simulation application on container terminals and port. This chapter is constructed in five main sections: chapter overview, energy efficiency role in climate change, energy efficiency regulations, energy efficiency measurements in maritime transportation, simulation-based energy efficiency applications, and chapter summary.

2.2 Energy Efficiency Role in Climate Change

Energy efficiency, also known as efficient energy utilisation, aims to manage the amount of energy consumption to provide goods and services in a sustainable manner. Irrek et al. (2008) reported that delivering more services with the same energy input or the same services with less energy input creates a more energy-efficient system. The aim of energy efficiency should not be just reducing the total usage of energy consumption. Additionally, energy efficiency is a way of managing and restraining Green House Gas (GHG) consumption and lowering carbon emissions to address global warming. Preventing climate change is exceptionally important by minimising the greenhouse gases from various human activities such as energy usage, industrial, agriculture, and logistic activities, including the shipping industry. However, awareness of low carbon shipping has to be increased to eliminate the risk of Climate Change without authorities' sanctions. Therefore, comprehending the background of Climate Change studies and regulations is key for developing an efficient shipping framework.

2.2.1 Climate Change

Human-made activities are the primary reasons causing climate change and pose significant risks for a wide range of human and natural systems (Matson et al., 2010). Neumann (1985) reveals the indirect reference to climatic change, which was found in classical Greek and Roman literature. However, there was no significant evidence of more detrimental changes than climate change in the world or any region (Weart, 2010). The history of the scientific indications of climate change began at the end of the 19th century when the first suspicious natural greenhouse effect was primarily recognised by some scientists like Svante Arrhenius (Weart, 2008) and James Croll (Fleming, 2006). Weart (2010) found that at the begging of the 20th century, a few scientists highlight that human activities may significantly impact the global climate in the long term. In 1938, Guy Stewart Callendar determined that the concentration of the gas had risen by about 10% over the past century, which would lead to global warming (Weart, 2008). At the beginning of the 1980s, a scientific agreement was initiated to create an outline of the change.

The international response to climate change begins with the United Nations Framework Convention on Climate Change (UNFCCC), as seen in Figure 2.1 between 1979 and 2015 (UNFCCC, 2016). According to Herring (2006), despite many initiations to reduce energy use since the beginning of the 1990s, industrial countries' energy consumption has continued to increase. A globally significant Conference was held on 12 June 1992 in Rio de Janeiro, where 154 nations signed the agreement, which came into force to mitigate Global warming (Abood, 2007). It came into force on 21 March 1994 to reduce greenhouse emissions (specifically human-made CO_2) to solve global warming (United Nations, 1998). The governments, which ratified the agreement, committed to reducing greenhouse gases to prevent hazardous anthropogenic gases from interfering with the world's climate system. The Parties meet annually at the Conference of Parties (COP) to evaluate progress regarding climate change. The COP is targeting what they could do to limit Global warming increments and the subsequent environmental change. The Intergovernmental Panel on Climate Change (IPCC), the leading international body for the assessment of climate change, was brought together by the United Nations Energy Program (UNEP) and the World Meteorological Organization (WMO) in 1988 (Kinney, 2008).

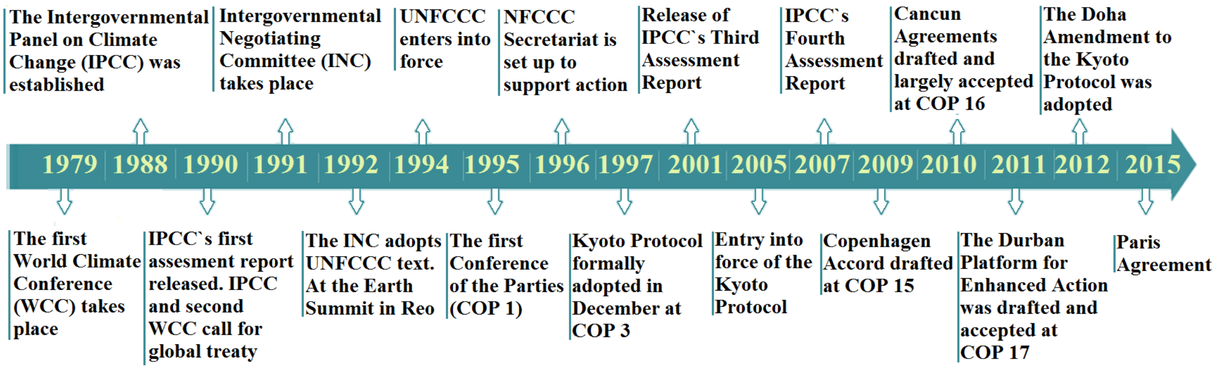


Figure 2.1 Timeline of the international response to climate change between 1979 and 2015

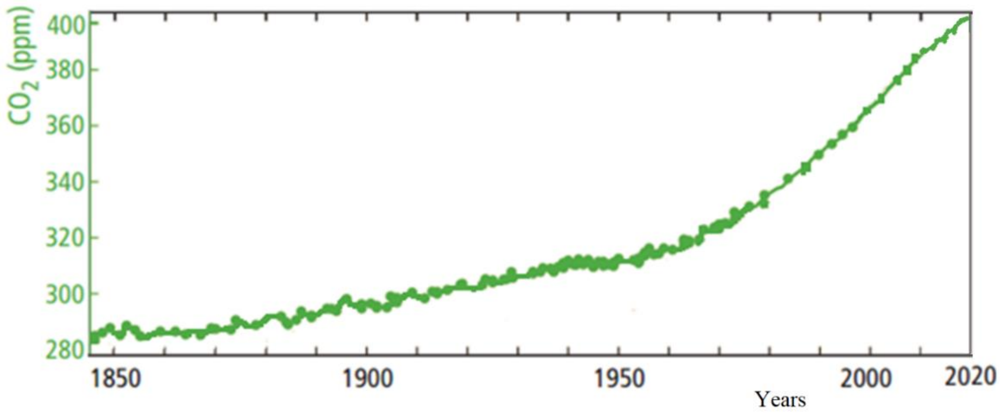


Figure 2.2 Globally average CO_2 emission concentrations (Data collected from Pachauri et al., (2014) NOAA (2016), and Lindsey (2020)).

IPCC found that average concentrations of global CO_2 emissions grow, and the rate of growth has increased rapidly over the last decades (Pachauri et al., 2014), as illustrated in Figure 2.2. Lindsey (2020) recently reported that CO_2 levels are higher than at any point in at least the past 800,000 years by 414 parts per million (ppm for short).

Since the Kyoto protocol, scientists have worked intensely on understanding past and future climate change and have been building theoretical models, and authorities have been making specific laws to protect the world from possible future global changes. By 1997, countries adopted the Kyoto Protocol, and it legally binds developed country Parties to emission reduction targets. The first commitment of the Kyoto Protocol’s began in 2008 and finished in 2012. The second commitment period began on 1 January 2013 and ended in 2020. Currently, there are 197 (196 States and one regional economic integration organisation) Parties to the Convention and 192 Parties to the Kyoto Protocol to improve and apply new regulations. Acceding country of this Protocol monitors and record emissions of their trade to meet required targets (Arslan Besikci and Olcer 2014). UNFCCC was effectively going to reach the deal in 2020, but shipping implications remain unclear in their plan.

Climate change is a long-term issue, and mitigation of this challenge refers to the efforts to reduce or prevent the emission of greenhouse gases which are listed in the Kyoto protocol: Carbon dioxide (CO_2), Matane (CH_4CH4), Nitrous Oxide (N_2O), Hydrochloric carbons (HFCs), Perfluorocarbons (PFCs), Sulphur hexafluoride (SF_6) (NATIONS, 1998). According to Alexander, Simon, and Stocker (Alexander and Simon 2013; Stocker et al., 2014), climate change caused observable and measurable negative impact worldwide. All researchers agree that while Climate Change increases, the quantity of harmful impact is expected to increase further, and the degree of effect increases (Alexander and Simon 2013; Besikci et al., 2015; Besikci et al., 2016; Pachauri et al., 2014; Stocker et al., 2014; NATIONS, 1998). Some of the significant current and future effects contain.

- Effects of weather:
  - Either warmer or cooler regional changes result in more droughts and heatwaves
  - Significant reduction or increase in rainfall in regions, for example, the change in precipitation patterns in Europe.
  - Extreme weather conditions: such as hurricanes, will become stronger, often, and more intensive.
  - Seasonal changes
- Food supply: like frost-free season (and growing season) will lengthen, and it affects harvest times.
- Sea level and ocean temperature rise; seaports could be flooded.
- The unpredictability of future decisions: the Arctic is likely to become ice-free new route will open for shipping and it may become an economically viable shipping route.
- Ecosystem changes: sea animals are affected by ocean water acidification.
- Water resources: increase in some areas whilst the opposite in most other areas (Alexander and Simon 2013; Easterling et al., 2007; Nicholls et al., 2015; Stocker et al., 2014; Solomon et al., 2007; Wheeler and Braun 2013).

Stocker et al. (2014) vehemently claim that urgent action is required to reduce greenhouse gases because the smokes are accumulated in the atmosphere, and it generates the threat of a more than two-degree Celsius temperature increase by 2100. Related results were presented by Pachauri et al. (2014) with regards to the change of global surface temperature. They suggested that the rise will likely be in the range of 0.3 °C to 0.7 °C for 2016–2035, and the temperatures will likely continue to grow for decades and centuries unless greenhouse gas levels do not stabilise. They also indicated that if the world warms up more than 4 °C, there will be a highly possible increase in food demand and water shortage. For several decades, significant effort has been devoted to the study of controlling this issue, especially in the shipping industry. However, more effort is needed to reduce global anthropogenic carbon emissions. This problem will cause challenges to maritime transportation as sea level is expected to rise in the range of 0.26 and 0.55 m between 2016 and 2100 (Pachauri et al., 2014).

There is a relation between shipping and climate change. The first environmental concern in the shipping industry was the United Nations' Conventions on the Law of the Sea (UNCLOS) launched in the middle of the 1950s (United Nations, 1982). Before, the first environmental-related rules were published under the Harbours Act in 1964 (Harbours Act, 1964). After a while, MARPOL 1973/78 (International Convention of the Prevention from Ship was established in 1973 then entered into force in 1983 (Harvey, 2012). In the same year, IMO established a technical committee named Marine Environmental Protection Committee (MEPC) with the idea of controlling environmental pollution from a ship by developing conventions and regulations. In 2015, this subsidiary body announced Annex VI prevention to prevent pollution from ships, decreasing air pollution in seaports (Saxe and Larsen, 2004). After four years, the Second IMO GHG Study published the first broad study on $\mathrm{CO_2}$ emissions from shipping (Buhaug et al., (2009) before the third IOM GHG Study was published in 2014. Additionally, the Third IMO GHG Study's principal strategy is to reduce GHG emissions emitted by the shipping industry, primarily with improved ship design and ship operation. They also calculated that average total shipping emissions were approximately 33,273 million tonnes $\mathrm{CO_2}$ and, for average global shipping and international shipping, $\mathrm{CO_2}$ emissions are estimated to be 1,015 and 846 million tonnes by 3.10% and 2.60% respectively between 2007 and 2012 (IMO, 2014). The studies of IMO statistically show the importance of the air pollution problem created by marine transport. Table 2.1 represents the shipping $\mathrm{CO_2}$ emissions compared to global $\mathrm{CO_2}$ emissions between 2007 and 2015 based on the study by the International Council on Clean Transportation (ICCT) in 2017 (Olmer et al., 2017).

Table 2.1 Shipping CO_2 emissions compared to global CO_2 emissions (Olmer et al., 2017).

	Third IMO GHG Study (million tonnes)						ICCT (million tonnes)		
	2007	2008	2009	2010	2011	2012	2013	2014	2015
Global CO_2 Emissions*	**31,959**	**32,133**	**31,822**	**33,661**	**34,726**	**34,968**	**35,672**	**36,084**	**36,062**
International Shipping	881	916	858	773	853	805	801	813	812
Domestic Shipping	133	139	75	83	110	87	73	78	78
Fishing	86	80	44	58	58	51	36	39	42
Total Shipping % of global	**1,100** 3.5%	**1,135** 3.5%	**977** 3.1%	**914** 2.7%	**1,021** 2.9%	**942** 2.6%	**910** 2.5%	**930** 2.6%	**932** 2.6%

Member of UNFCCC Countries submitted non-binding emission reduction pledges or mitigation action commitment after adaptation of the Copenhagen Accord at COP 15 in December 2009 (UN, 2010). The Accord goal was limiting the global temperature rise below 2 C degrees. Recently, targets agreed during the United Nations' climate change conference in Paris were replaced by a more fundamental new course. This agreed course of action has also confirmed the goal of limiting global temperature increase below 2 degrees Celsius by 120 countries. The conference outcomes did not mention the shipping directly because international transport, including shipping, removed from the final agreed text. However, one of the actions to reach the aim was taking more investment in clean energy research and development in the next five years. Therefore, the shipping industry needs to reduce the CO_2 emissions and keep their sectoral effect on temperature change as low as possible by greening the shipping.

2.2.2 Role of Shipping Energy Efficiency in Climate Change

Growing population, overconsumption and new demand for goods increase the demand for energy. The global shipping capacity increased from 0.67 billion DWT to 1.98 billion DWT between 1980 and 2019, with 92,295 vessels in service (UNCTAD, 2015, UNCTAD, 2019). This significant change causes an increase in total energy usage of the shipping industry. Therefore, energy efficiency is one of the fundamental components and a significant subject of the maritime transportation framework to reduce this rising demand. This increasing trend in demand for energy in seaborne logistic requires further energy to supply the worldwide market. The importance of energy efficiency is taking a stronger position in the sector. The increasing energy demand may generate more significant pressure on all-natural resources globally, and usage of these sources also affects air quality. The 2nd Greenhouse Gas (GHG) studies of IMO have shown one of the good examples of demonstrating the importance of sea transport on climate change. The research projected that shipping would account for between 12% and 18% of global CO_2 emission by 2050 if no actions are taken to reduce shipping emissions (Buhaug et al., 2009). The 3rd Greenhouse Gas (GHG) stressed the challenge at hand, and they highlight the need for more efforts to tackle this problem. GHG emissions from shipping are projected to increase by 50–250% by 2050 within this study (IMO, 2015).

Additionally, the EU aims to reduce GHG emission by at least 80% until 2050 (Böttger et al., 2018). The EU Commission considers cost-efficient ways to create the European economy more climate-friendly and less energy-dependent. Industrial developments increase the energy needs of seaborne logistics. Investigation of the European Commission (2010) undoubtedly clarifies the importance of air pollution and global warming, and they suggested a radical action to minimise the emissions from the transportation sector.

In the literature, the role of shipping energy efficiency on climate change has been regularly reported, and several alternatives have been proposed to address the energy efficiency in the shipping industry.

Some projects receive support from authorities, universities, companies, and non-governmental organisations. In addition, Psaraftis and Kontovas (2010) suggested that Technical measures (efficient ship and port facilities), Market-based instruments (emission trading and carbon tariff schemes) and operational options (mainly optimisations) were three essential methods to reduce GHG emulsions. Academic research commonly focussed on these three areas in detail. For instance, Smith et al. (2014) led one of the impressive projects on `Low Carbon Shipping` from 2010 to 2013, and they investigated five research questions:

- The impact of the energy efficiency on the whole maritime logistic system, and the relationship between transport logistics and future ship designs
- The drivers for shipping demand over other modes of transport
- Future shipping scenarios based on the impacts of technology and policy solutions
- Challenges with implementing low carbon shipping
- Optimisation of environmental gains and best way to measure transport's effects on the environment in an international context

The low Carbon Shipping project produced many articles (Cui et. al. 2018; Halim et al., 2018; Tillig, Mao, and Ringsberg, 2015) which provided a detailed answer to each question.

Singh and Rambarath-Parasram (2019) highlighted that many researchers focus on barriers to emission control, energy efficiency, and the existing regulatory framework's effectiveness. They believe that a more comprehensive study to improve technology is the key to achieve climate change mitigation. Halim et al. (2018) underlined the importance of Low Carbon Shipping, which offers environmental, economic, and futuristic opportunities. They also think that energy-efficient designs and new technologies provide much-sought opportunities in shipping to minimise the environmental effect. Technical improvement is a vital area of energy-efficient shipping. For instance, Seo, Atlar, and Sampson (2012) proposed reducing the required power of ships as the most effective way to decrease fuel consumption and hence carbon emission. The developed propeller system needs about 3.5% less power, and this kind of findings proved to be very important for ship design.

In terms of energy efficiency, the operational study is also a significant area, and speed optimisation is the most popular solution. As an example, Aydin, Mansouri and Lee (2015) focus on speed optimisation in Liner Shipping to determine an optimal speed policy between ports using a non-linear programming model. The study was described as a fixed route to minimise fuel consumption by optimising the port time and vessel speed. The research considered that the miscommunication between the shipping fleet and seaports is a fundamental issue. These researchers reported that waiting time at the port was reduced by around 20% through improved communication between the ships and the port. Another example can be given about the weather routing approach, and Cui (2018) and Cui et. al. (2018) indicated that their advanced weather routing tool could save as much as 10% of fuel consumption for a real case scenario.

Schoyen and Brathen (2015) developed a method to evaluate energy efficiency for feeder type vessels while sailing and in port. The method was based on operational activities. Technical specifications of vessels, cargo loading lists, and voyage report data are used to identify container flows, voyage, and leg of fleet operation. The research applied to two case studies to understand how intra-regional service affects different markets when energy efficiency is taken into account. The study also shows that short sea container shipping may have more potential for energy efficiency than stated in the Third IMO GHG Study (IMO, 2015). The improvement of information sharing between operational stages may help to build more energy-efficient maritime transport.

Table 2.2 Available energy-saving measures and concepts (Adapted from Tillig, Mao, and Ringsberg, 2015).

Concept categories		**Detailed measures**	**Fuel-saving potential**	**Barriers**
New building vessels	Hull form optimisation and propeller configuration	Main dimensions optimisation like slender and larger ships, less ballast water volume.	▓	Policy and regulations
		Ship energy system optimisation based on actual planned operational profiles, fuel price, trade routes, loading conditions etc.	▒	Information adn organisations
		Optimisation of stern bugle, rudder and propeller for inflow considerations (e.g. better skeg design, better propeller blade design).	▒	Information, economic, organisational and technical
		Optimisation of hull shape and bulbous bow	░	Information and technical
		Better design with consideration of added resistance due to wind and waves in the open sea	░	Technical and economic
		Influence from IMO EEDI on ship design	█	Policy and organisation
	Lightweight construction	High strength steel	░	Technical
		Composite materials	▒	Technical and economic
Existing vessels	Machinery system	A waste heat recovery system	▓	Economic, organisation and information
		Altanative feul for power	░	
		Hybrid auxiliary power generation	░	
		Optimum heating and cooling system	░	
		Adaptive pump and power management systems	▒	
	Energy-saving devices	Propulsion improving devices	▒	Technical and information
		Skin friction reduction	▒	Technical and economic
		Wind power and other renewable devices for auxiliary propulsion	▓	Technical, economic and organisation
	Ship operation management and optimisation	Speed reduction	█	Organisation
		Optimise ship maintenance schedule, hull and propeller cleaning	▒	Information and economic
		Autopilot adjustment	░	Technical
		Intelligent engine adjustment according to weather and loading conditions	▒	Information and economic
		Trim, ballast and rudder control optimisation, air lubrication etc.	▒	Technical and information
		Weather routing and voyage optimisation	▓	Technical and information

Fuel-saving up to	2%	5%	10%	≥20%
Marker	░	▒	▓	█

Moreover, Research of Johnson and Styhre (2015) on a port operation in short sea shipping indicates that reduction on the unproductive time of ships is highly possible, and only 4 hours of decrease per port call in the given case study would lead up to 8% efficiency compared to normal operation. Then all operation will be completed with much less energy to produce the same amount of service. Furthermore, an efficient application of IMO EEDI creates a 20 per cent potential average fuel savings for a general ship type, as given in Table 2.2 (Tillig, Mao, and Ringsberg, 2015). Figure 2.1 gives more fuel-saving possibilities for general ship types. This research proves that decreasing energy demand is highly possible in the shipping sector. To sum up, shipping has significant potential to improve energy efficiency by focusing on the entire value chain. The value chain includes decreasing the cost per shipping unit by deploying more prominent or more efficient vessels; effective communication and contract structures;

better flexibility of cargo loading to increase the asset utilisation; developing new technologies to implement them; and operational practices including better integration of port-ship interaction.

2.3 Energy Efficiency Regulations

The international regulations for energy efficiency are represented in more detail to understand the policy response from regulatory bodies, which were briefly mentioned in the previous section.

The IMO's primary purpose is safe, secure, and efficient shipping in clean oceans with 174 Member States, 1 United Nations body, 63 intergovernmental organisations, and 80 NGOs. The IMO developed comprehensive regulations and voluntary or mandatory applications on the energy-efficiency guidelines for commercial shipping. The environmental regulations of IMO, specifically EEDI, SEEMP and EEOI, and European Union (EU) directives on Monitoring, Reporting and Verification (MRV) of CO_2 from Ships are explained in detail throughout this section.

Many researchers (Lindstad, Asbjørnslett and Pedersen, 2012; McKinnon, 2014; Yang, Bai and Schmidhalter, 2011) argued that companies' main reason for taking action on the energy efficiency of ships is the regulative enforcement of the IMO or other international regulations about greenhouse gas emissions generated from ships. The notable regulations controlling greenhouse gas emission levels, such as the MARPOL convention and Kyoto Protocol, are directly related to air pollution. There is a significant logical connection between reducing CO_2 emissions and energy efficiency for shipping companies (Sharma, 2014). Therefore, CO_2 emission could be analysed in detail and reduced to a certain level to create a more sustainable marine transport system, which is compatible with the energy efficiency requirements.

Energy efficiency has been a vital component in reducing the operational cost of ships, yet it has not generally been an actual focus of the industry during the ships' design and operation in its lifetime. Recently, it has been discovered that energy efficiency plays a significant role in the shipping industry's sustainability. IMO energy efficiency regulations came into force on the 1st of January 2013. However, some issues regarding the energy efficiency measures were not very clear for the industry. As a result, some of the predominantly larger companies have applied energy efficiency measures based on expectations (Banks, Turan and Incecik 2013).

Since 2003, 6 years after adopting the Kyoto Protocol, considerable discussions on shipping energy efficiency have been progressed. The IMO's first direct action on emissions was Resolution A.963 (23) under the Annex VI of MARPOL in December 2003. Figure 2.3. illustrates the Marine Environmental Protection Committee (MEPC) and the Working Group Timeline from 1997 to date. And as seen in the graph of the MEPC, the IMO developed a mechanism to minimise or reduce the GHG emissions sourced from shipping (Karim, 2015). The work of IMO had three separate paths towards reducing the emissions from shipping; Technological (Design-mainly applicable to new ships – EEDI), Operational (applicable to all ships in operation with SEEMP and voluntary EEOI), and Market-based Instruments (MBI) (Carbon pricing for shipping, may generate funds). Additionally, A.963 (23) covered the MEPC main tasks; establishment of a schedule, the establishment of the GHG baseline, and development of an advanced CO_2 indexing method for CO_2 emission indexing (IMO, 2016a).

As seen in Figure 2.3 and mentioned previously, the Second IMO GHG Study launched in 2009 presented key written concepts and the policies that the IMO has proposed. It also includes the details of implementation to improve the energy efficiency in the shipping industry by technical ship design and ship operational practices. Karim (2015) addressed the MEPC adopted mandatory energy efficiency measures, as known first compulsory international GHG reduction index, for worldwide shipping on 15 July 2011. Moreover, further amendments were made by MEPC at the 62nd session of the Committee. The Commission adopted the required legal implements and improved the energy efficiency regulations, which became mandatory under Annex VI for vessels from all flags on 1 January 2013. On the other hand, IMO has not fixed an agreement on efficiency calculations or transport work data until 2016 (Wessels, 2016). Further development has been made in MEPC 69, and nearly 1,200 ships have been certified as they fulfilled the updated energy-efficiency design standards (IMO 2016b). In 2016, MEPC 70 adopted amendments, which made the requirement for ships of 5,000 gross tonnages and above (responsible around 85% of GHG emissions from ships) to collect and submit fuel oil consumption data as a mandatory requirement from January 2019. They need to report it to their flag State for collection and then submission required to IMO (IMO 2019). MEPC 72 adopted resolution MEPC.304 (72) in April 2018; the Initial IMO Strategy forced international shipping for the first time to reduce total GHG emissions. IMO' 4 phased plans aimed to reduce the ship's carbon intensity through the implementation of further phases of the energy efficiency design index (EEDI) for new ships (IMO, 2019).

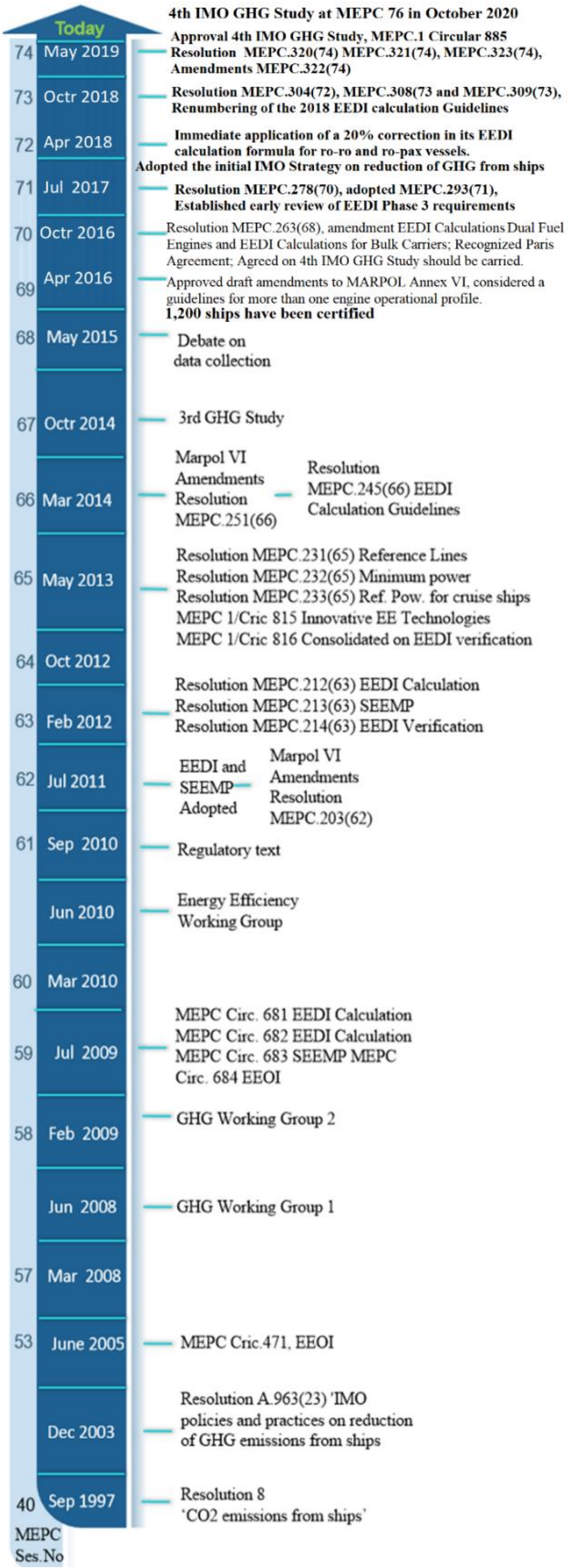


Figure 2.3 IMO MEPC and Working Group Timeline (Data collected from the studies of Lloyd's Register 2015; Lloyd's Register, 2021; ABS, 2019; IMO, 2016a)

The IMO progressed that MEPC 74 in May 2019, where the session adopted amendments to the 2018 Guidelines on the Method of Calculation of the Attained EEDI for New Ships and EEDI Phase 3 in 2022 (from 2025) and increase the reduction factors for specific ship types/sizes (ABS, 2019). They agreed to publish the Fourth IMO GHG Study to show global emissions of GHG emissions and carbon intensity from international shipping between 2012 and 2018, as shown in Figure 2.3.

2.3.1 EEDI – Energy Efficiency Design Index

The innovation of technology and design methods is a critical element for the reduction of emissions. The EEDI is used to evaluate the scenarios of how energy consumption would demonstrate sustainable development in the future. The available Ship design index, the EEDI, targets the physics of energy losses and aims to minimise resistance. It also aims to recover the waste heat and optimise the cargo-carrying capacity, the ship speed, and the propulsive efficiency (El Geneidy et al., 2017). Furthermore, Figure 2.4 gives an example of the possible scenarios with/without EEDI impacts on bunker usage in the shipping industries. The results represent that there is an increasing demand for energy-efficient design, and high potential is available in comparison with today's technologies.

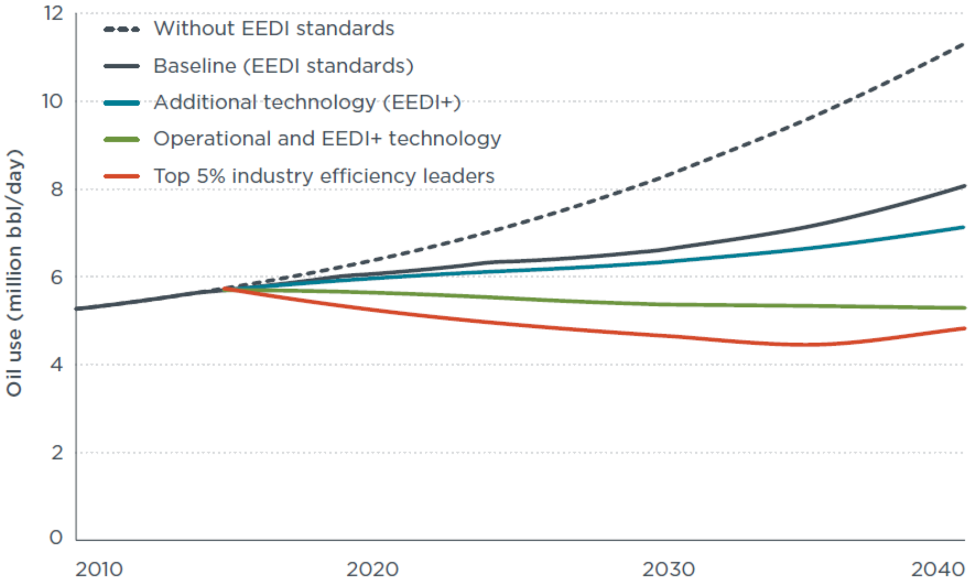


Figure 2.4 Global shipping fleet petroleum use with new ship efficiency standards (Wang and Lutsey, 2013).

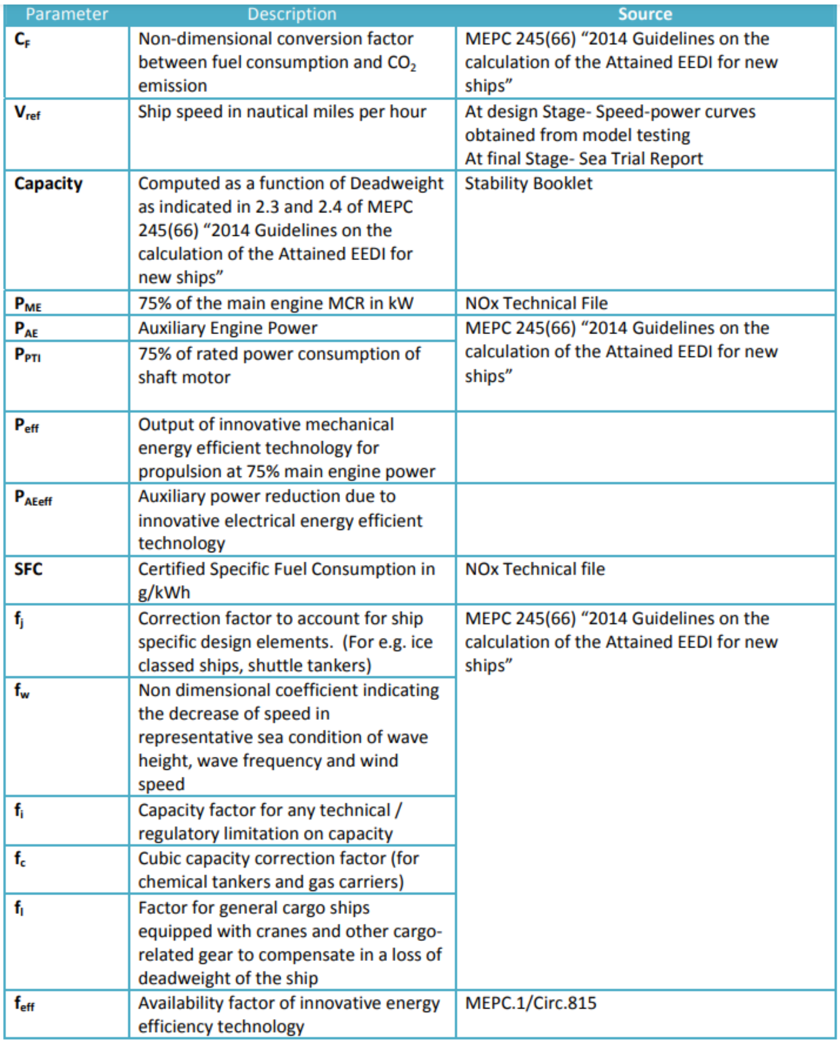
EEDI is an index that measures grams of CO_2 per transport work per tonne-mile (IRCLASS, 2020). It can be formulated as the ratio of "environmental cost" divided by "Benefit for Society" in other words `$CO_2$ Emission` divided by 'Transport Work` as follows equations (*i*) and (*ii*).

$$EEDI = \frac{Impact\ to\ environment}{Brnefit\ for\ society} \qquad (i)$$

$$EEDI = \frac{CO_2\ Emission}{Transport\ Work} \qquad (ii)$$

This measurement is a function of installed power, speed of each vessel, and cargo carried. The theory behind EEDI is that its computing is basic and capable of comprehensive implementation. It promotes the efforts of all participants to mitigate Carbon emission by modelling the energy of a ship. The following full equations (*iii*) and parameters are given based on IRCLASS (2020).

$$\frac{\left(\prod_{j=1}^{M} f_j\right)\left(\sum_{i=1}^{nME} P_{MEi} * C_{FME} * SFC_{ME}\right) + \left(P_{AE} * C_{FAE} * SFC_{AE}\right) + \left(\left(\prod_{j=1}^{M} f_i * \sum_{i=1}^{nPTI} P_{PTI(i)} - \sum_{i=1}^{neff} f_{eff(i)} * P_{AEeff(i)}\right) C_{FAE} * SFC_{AE}\right) - \left(\sum_{i=1}^{neff} f_{eff(i)} * P_{eff(i)} * C_{FME} * SFC_{ME}\right)}{f_i * f_c * f_j * Capacity * f_w * V_{ref}} \qquad (iii)$$



Parameter	Description	Source
C_F	Non-dimensional conversion factor between fuel consumption and CO_2 emission	MEPC 245(66) "2014 Guidelines on the calculation of the Attained EEDI for new ships"
V_{ref}	Ship speed in nautical miles per hour	At design Stage- Speed-power curves obtained from model testing At final Stage- Sea Trial Report
Capacity	Computed as a function of Deadweight as indicated in 2.3 and 2.4 of MEPC 245(66) "2014 Guidelines on the calculation of the Attained EEDI for new ships"	Stability Booklet
P_{ME}	75% of the main engine MCR in kW	NOx Technical File
P_{AE}	Auxiliary Engine Power	MEPC 245(66) "2014 Guidelines on the calculation of the Attained EEDI for new ships"
P_{PTI}	75% of rated power consumption of shaft motor	
P_{eff}	Output of innovative mechanical energy efficient technology for propulsion at 75% main engine power	
P_{AEeff}	Auxiliary power reduction due to innovative electrical energy efficient technology	
SFC	Certified Specific Fuel Consumption in g/kWh	NOx Technical file
f_j	Correction factor to account for ship specific design elements. (For e.g. ice classed ships, shuttle tankers)	MEPC 245(66) "2014 Guidelines on the calculation of the Attained EEDI for new ships"
f_w	Non dimensional coefficient indicating the decrease of speed in representative sea condition of wave height, wave frequency and wind speed	
f_i	Capacity factor for any technical / regulatory limitation on capacity	
f_c	Cubic capacity correction factor (for chemical tankers and gas carriers)	
f_l	Factor for general cargo ships equipped with cranes and other cargo-related gear to compensate in a loss of deadweight of the ship	
f_{eff}	Availability factor of innovative energy efficiency technology	MEPC.1/Circ.815

On the other hand, there is some disagreement and discussion on the paybacks and the applicability of EEDI. For example, Arslan, Besikci and Olcer (2014) argued that the suggested design options might not be as effective as expected in the short term. The reasons for this suggestion were listed as follows:

- Retrofitting is costly and usually needs more dry-docking time, which causes a significant loss of short-term revenue.
- Most innovative technologies take time to be developed, and they require an additional investment load for shipping companies.
- Current new technologies mostly suitable or profitable to implement only on the new build vessels.
- Lack of reliability and uncertainty related to the new technologies causes severe doubts about their potential savings and actual total savings.
- In some cases, technologies provide mixed results.
- Sometimes, complicated and controversial metrics are used as a performance measure (Devanney, 2011).

Although several developing countries had fierce opposition towards EEDI during IMO discussions, the MEPC adopted the EEDI for new ships (Psaraftis, 2012).

When new devices or technologies are installed, they may cause congestion issues with future or new implementations. However, the full potential of a new fleet with innovative technology and design approaches may be realised in a long-term period. Hosseinloo et al. (2015) demonstrate more technology take-up to provide emission reduction in the long-term period.

As illustrated in Table 2.3, the International Council on Clean Transportation (ICCT) summarised the potential of CO_2 and fuel use reduction for each current technology (Wang and Hon, 2011; Wang and Lutsey 2013). Therefore, the EEDI plays a vital role in the shipping sector.

Even though ships' efficiency has been improved with EEDI in recent years, most improvements have been achieved by minimising the amount of energy lost from non-design related issues. Nonetheless, it is possible to further improve the efficiency of the whole system through operational improvements. With this goal, The Ship Energy Efficiency Management Plan (SEEMP) is established as a mechanism to improve the energy efficiency of a ship operating cost-effectively. The SEEMP is entirely linked to a broader corporate energy management policy.

Table 2.3 Some of the ship efficiency measures which can be used to meet the EEDI and their efficiency targets (Wang and Lutsey p.n.9, 2013).

Area	**Technology**	**Potential CO_2 and fuel use reduction**	**Improvements promoted by EEDI standards?**	**Improvements promoted from in-use efficiency policy?**
Engine efficiency	Engine controls	0-1%	+	+
	Engine common rail	0-1%	+	+
	Waste heat recovery	6-8%	+	+
	Design speed reduction*	10-30%	+	+
Thrust efficiency	Propeller polishing	3-8%		+
	Propeller upgrade	1-3%		+
	Rudder	2-6%	+	+
Hydrodynamics	Hull cleaning	1-10%		+
	Hull coating	1-5%		+
	Water flow optimisation	1-4%	+	+
Aerodynamics	Air lubrication	5-15%	+	+
	Wind engine	3-12%	+	+
	Kite	2-10%	+	+
Auxiliary power	Auxiliary engine efficiency	1-2%	+	+
	Efficient pumps, fans	0-1%	+	+
	Efficient lighting	0-1%	+	+
	Solar panels	0-3%	+	+
Operational	Weather routing	1-4%		+
	Autopilot upgrade	1-3%		+
	Operational speed reduction*	10-30%		+

"+" = promotion of the practice/technology

"*" CO_2 and fuel reduction rates are dependent on the ratio of speed reduction and rate of engine design modifications, controls, design score/tuning.

2.3.2 The Ship Energy Efficiency Management Plan (SEEMP)

The second GHG Study led the way for policy dialogue that involved supplementary SEEMP, an operational measure that provides a mechanistic framework to develop a ship's energy efficiency cost-effectively. This goal-based regulation is the second mandatory energy efficiency regulation that came into force for each existing ship on the operation, as well as a new ship built since 1st of January 2013 (IMO, 2014). The 2016 Guidelines for the SEEMP were adopted as mandatory requirements for ships of 5,000 gross tonnages (IMO, 2020). Compared to the EEDI, the purpose of providing a mechanism of SEEMP is to improve in-use efficiency for ship and unit operation (Wang and Lutsey, 2013).

The guideline of the SEEMP provides some steps, as illustrated in Figure 2.5. It is required to improve the energy efficiency of shipping through the four phases listed. The four phases are planning, implementation, monitoring, and self-evaluation and improvement. The planning involves ship specification, company specification, human resource, and goal setting. It mainly determines the current status and expected improvement of ship energy usage and efficiency. Implementation of each measure is more beneficial for self-evaluation. The monitoring part contains continuous and consistent data collection and utilisation of specific tools like EEOI. Self-evaluation and improvement evaluate the understanding of characteristics of a ship's operation and the planned measures in term of effectiveness and implementation. These operational practices require cooperation among different stakeholders.

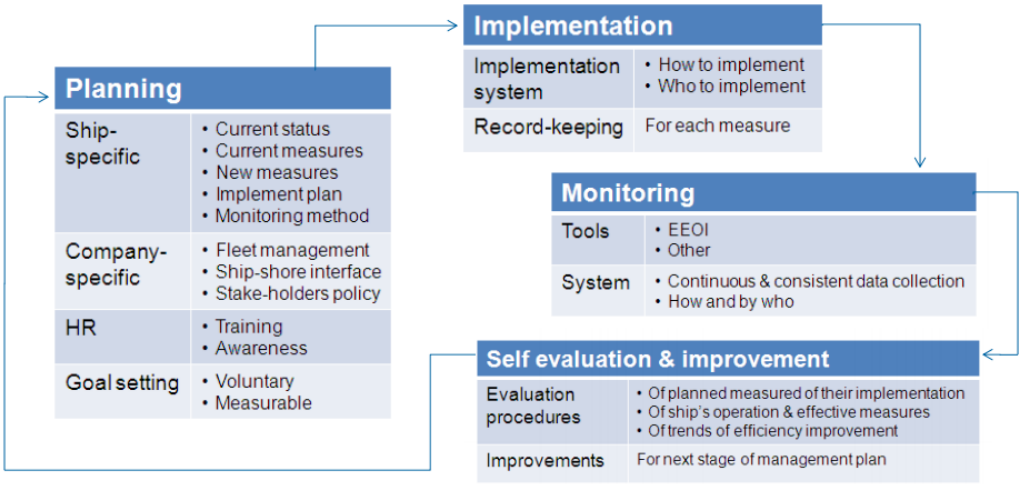


Figure 2.5 Four-step process of SEEMP (Tran, 2019).

The planning stage of SEEMP is the stage before the implementation stage of the continuous reduction of fuel oil consumption and carbon dioxide emissions. All these stages aim to reduce the actual fuel consumption and emissions by operating new technologies and their best innovative practices if ship owner and operator seeking to improve the SEEMP performance of a ship.

The Resolution MEPC.282 (70) of the IMO Guidelines updated the SEEMP at the end of 2016 (IMO, 2016a). This update made the data collection system for fuel oil consumption of ships mandatory and has already entered into force in 2018 (Classnk, 2019). Data collection and reporting are required since 2019. Based on Hansen, Rasmussen and Lutzen (2020), the SEEMP guidelines recommend operational practices such as weather routing, just-in-time arrival, optimal trim and waste heat recovery. However, it is better to mention that some goals are not suitable for all types of vessels; they mainly cover ships of 5,000 gross tonnages and above involved in international voyage.

According to Classnk (2019), the following steps are required related to introducing the concept in Figure 2.5.

- Evaluation of the revised SEEMP by the Administration or Recognized Organization, issuing Confirmation of Compliance and retaining the SEEMP on board
- Identification of the Data and parameters to be collected and monitored

- Aggregation of the collected data and reporting to the Administration or Recognized Organization
- Confirmation of the reported data by the Administration or Recognized Organization and issuance of Statement of Compliance
- Logging the disaggregated data based on the reported data

2.3.3 Energy Efficiency Operational Indicator, EEOI

Managing ship and fleet efficiency performance over time using operational indicators is vital for shipping companies. The IMO introduced a measurement approach under SEEMP, providing the EEOI as a monitoring tool for both new and existing ships during operation. The primary way to define the EEOI is the ratio of the mass of $\mathrm{CO_2}$ (M) emitted per unit of transport work did work unit, e.g., $\mathrm{CO_2}$ [t]/(t/Nm), $\mathrm{CO_2}$ [t]/(TEU/Nm), etc. (Tran, 2017):

$$\text{Indicator (EEOI)} = {}^{\text{Emitted Mass of } \mathrm{CO_2}}\!/_{\text{Transport Work}} \qquad (iv)$$

In other words, the EEOI measures the tons of mass carbon dioxide emitted for a ton of cargo carried over a sea mile (IMO, 2009). The EEOI is the only indicator in Annex VI of MARPOL that signifies the actual transport work's carbon intensity. The EEOI allows ship operators to measure the fuel efficiency of a ship in operation and to measure the effect of any changes in an operation like improved voyage planning or better period arrangement for hull or propeller cleaning (IMO, 2020). Prill and Igielski (2018) stated that the EEOI exemplifies the ship energy efficiency in a specified time. This formula generally used to calculate the energy efficiency per voyage, a year or a specific operational run. To determine the EEOI for a specific period (for a shipment), the MEPC.1/Circ. 684 provided the following equation:

$$EEOI = \frac{\Sigma_j FC_j \times C_{Fj}}{m_{cargo} \times D_j} \qquad (v)$$

Where: j is fuel type; FC_j is a mass of consumed fuel j at voyage; FC_j is fuel mass to $\mathrm{CO_2}$ mass conversion factor for fuel j; m_{cargo} is cargo carried (tonnes), or work is done (TEU or passengers or gross); D is the distance in nautical miles relating to the cargo carried or work done. Intending to calculate the EEOI for a time period like a year, all voyages of the vessel in that period have to be summed up along with those where the vessel did not transport any freight (Prill and Igielski, (2018).

Based on the Kyoto Protocol (1997), the variables that affect a ship's EEOI come from four areas: fuel as energy consumption, fuel type, cargo volume and distance travel. As opposed to being found on fuel utilisation for the designed ship, a genuine fuel utilisation record for every voyage is utilised. This difference provides opportunities to understand the level of operational energy efficiency. For more details of the indicator, the calculation process, and the equations, Appendix 1 is provided. The EEOI estimation is affected by unpredictable parameters such as the wrong speed report, fuel consumption records etc. Therefore, before performing a voyage of the EEOI, all uncertainties must be addressed (Acomi, and Acomi, 2014).

While SEEMP and especially EEOI records, analyses, and compares various aspects of the operational energy efficiency, there are still some interesting and relevant problems to be addressed to measure the fuel efficiency of a ship during the operation. Although the effect of any changes in operation is calculated with EEOI, such as improved voyage planning, the ship owners still need to confirm the accuracy of their fleet's database for all measurable indicators. Studies indicated that the type of charter and size of a ship has an impact on the EEOI ratings (Parker, Raucci and Smith 2015). For instance, owner-operated ships achieved more efficient EEOI ratings than ships leased on time charter due to the contractual time pressure. This situation points out the fact the owner may not be in control of the operation if they leased their ship for time charter, and hence ship energy efficiency may be low due to the charterer's operational decisions. This research has also demonstrated that none of the alternative energy efficiency metrics was a reliable substitute to EEOI.

Arslan, Besikci and Olcer (2014) considered that the EEOI is worth improving further by diminishing fuel utilisation for the same voyages or expanding the measures of payload conveyed and/or using the ship (i.e. decreased time in ballast and port). Numerous unpredictable variables stay with the EEOI, especially with its benchmarking. Thus, it has not been made compulsory and enhanced techniques for measuring operational execution areas still being considered.

Furthermore, EEOI does not have industrial standards for quantifying, analysing and ship performance monitoring, and analysis of the operational data was also not widely established (Banks, 2015). Therefore, further research is needed to clarify the maritime operation sides of energy efficiency in shipping to support policymakers.

2.3.4 MBM (Market based measures)

IMO considered the potential of technical and operational measures, which were not very effective to reduce GHG emissions from international shipping at MEPC 55 in 2006. Therefore, a decision was taken that MBM was necessary to be fulfilled under the IMO GHG regulation. The idea of potential MBMs was to focus on financial incentives in details to serve two main purposes. The first one is to ensure financial encouragement about the reduction of fuel consumption for the shipping industry by putting resources into fuel-efficient ships. This will also assist in providing innovation and operational enhancement in a more energy-efficient way. The second one is offsetting against different sectors for the reduction of ship emissions. This requires further discussions as it was not actively deliberated over past years, and further details possibly will be provided by IMO as proposed in IMO (2016a) study. The 62nd MECP meeting adopted EEDI and SEEMP measures in 2011, and since then, the developing countries were not willing to implement MBMs targeting GHG emissions in the shipping industry. MBM was highlighted at the 63rd MEPC in 2013 as well. This topic was discussed further at MEPC 69 in 2016 when a specific debate took place about the further implementation of measures like MBMs. However, member states were not able to come to any agreement. Ranaraja (2020) mentioned that several studies indicate that MBMs for international shipping will bring harmful economic effects for developing countries, but the effect is expected to be minor. A number of research studies highlighted some possible MBMs, such as fuel taxes, cap & trade and baseline & credits (Ranaraja, 2020).

2.3.5 EU MRV Regulation

The European Union introduced the monitoring, reporting and verification (MRV) of carbon dioxide emission of ships as a scheme for energy-efficient shipping. It came into force on 1st July 2015, and the ships are to be monitored from 2018. Wessels (2016) argued that IMO work would unlikely be satisfactory for the European Council. He expects similar EU and IMO systems. The EU MRV consists of three stages:

"– Phase 1: Implementation of the MRV program to create the nature and quantity of CO_2 *emissions from maritime transport.*
– Phase 2: Establishment of an agreed global energy efficiency standard as part of the regulation.

– Phase 3: Identification of whether the efficiency standards are achieving the EU's desired absolute CO_2 emissions reductions and determine what else should be done, e.g., introduction of a Market Based Measure (MBM) (Lloyd's Register, 2015)."

The MRV regulation applies to every ship above 5000 GT (all flags), which have to report annually CO_2 emission regardless of a flag on all voyages to-from and between EU ports. The MRV gives a chance to calculate fuel consumption for each voyage by using the methods provided. All ships have been submitting a reporting plan for verification for each of their voyages since 31 August 2017; monitoring has started on 1 January 2018. From 2019, by 30 April of each year, verified emission reports must be submitted to EC and the authorities of the flag states. EC is responsible for publishing data by each following June. The efficiency data such as tonne-nm and any related information on CO_2 emissions will be provided in these reports. Moreover, the EU suggests a step toward a "global MRV" system which should be adopted by the IMO (Wessels, 2016). In the last few years, there has been a growing interest to guide energy efficiency issue with regulations. The previous research has demonstrated that MBM and MRV are not applied in developing countries. Therefore, in this research, a novel and easily applicable method of efficient ship operation may allow these countries to participate in these regulations.

Political improvement at COP 21, under UNFCCC, may have had a significant impact on continuing IMO work on data collection of fuel consumption from ships and ship efficiency. The agreement might cause further discussions on the Market Based Measures, but this arrangement may not be practically applicable to EU MRV developments' expected contribution (Wessels, 2016). As illustrated in Figure 2.6, future developments steps are coming up. This process might lead to supportive changes in terms of energy efficiency. Therefore, future research needs to find the right direction for regulators to meet industrial and regulatory targets of CO_2 emissions and energy efficiency. IMO introduced an Energy Efficiency Design Index for existing ships (EEXI) during MEPC 75 in November 2020 (DNVGL, 2021a). The main reason is to reduce ships` CO_2 intensity by 40% within the next decade is 2030. EEXI requirements will come into force in 2023 for all existing vessels above 400 GT falling under MARPOL Annex V (Lloyd's Register, 2021). EEXI is expected to expand for current ships of the new building based EEDI due to limited access to design data of existing vessels (DNVGL, 2021a).

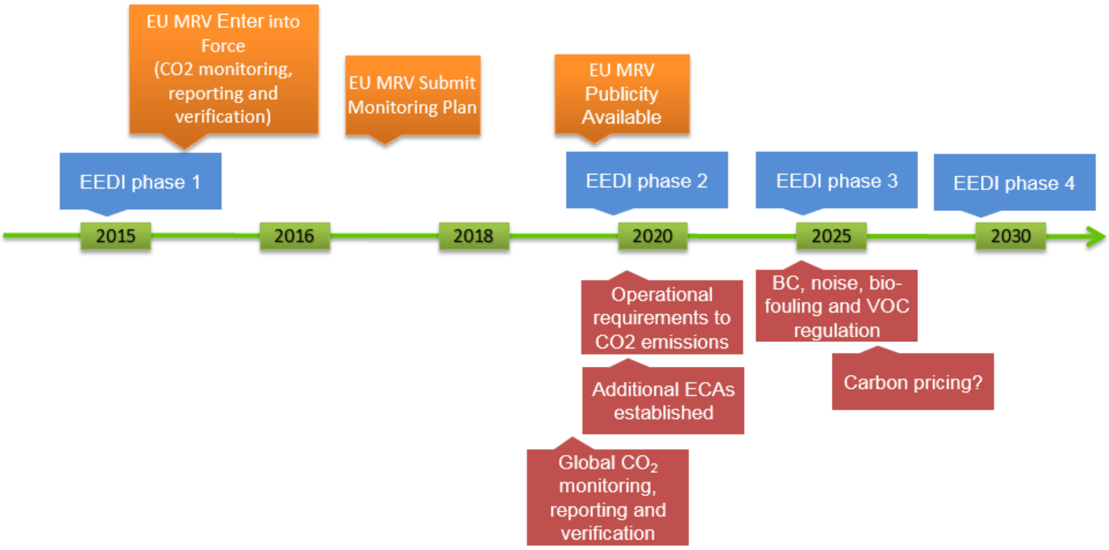


Figure 2.6 Current and upcoming IMO and EU regulations (Wessels, 2016 and DNV GL, 2019).

2.3.6 International Organisation for Standardisation (ISO)

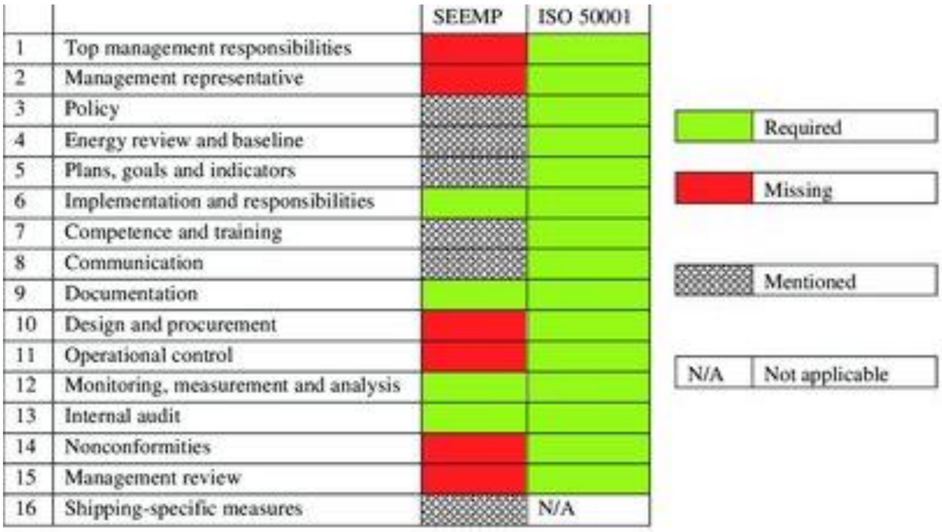
The International Organisation for Standardisation (ISO) is established on 23 February 1947. Currently, this international standard-setting body is composed of representatives from 164 countries' standardisation organisations (ISO, 2020). The ISO provides 50001:2011 Energy Management Systems (EnMS), which is developed based on the management system model's continual improvement. The organisation also used two well-known standards related to energy or environmental issues: the ISO 9001 (Quality Management System) and the ISO 14001 (Environmental Management System). These standards, specifically EnMS, make the integration of energy management easier for organisations. It also assists in understanding their overall efforts to improve quality and environmental management.

Moreover, Johnson et al. (2012) believe that ISO 50001 addresses key features like monitoring, energy auditing, design, and procurement procedures in a wider concept. The framework of the ISO 50001:2011 provided is listed according to requirements of organisations as below:

- Developing a policymaking concept to maximise energy efficiency,
- Setting targets and objectives to meet the requirements of the policymaking,
- Using records in a better way to analyse energy consumption and be in control of energy use,
- Measuring the outcomes quantitatively,
- Reviewing influence of the policy implementations, and
- Improving energy management for the future.

Several topics were established in the ISO 50001 standard but not as depth in the SEEMP, as shown in Table 2.4. This ISO standard's main weakness is the enclosing a management framework of an environmental system without consideration of specific environmental and ship specific performance criteria or measures.

Table 2.4 Comparison of the SEEMP and the ISO 50001 standard (Johnson, 2013).



		SEEMP	ISO 50001
1	Top management responsibilities	🟥	🟩
2	Management representative	🟥	🟩
3	Policy	▨	🟩
4	Energy review and baseline	▨	🟩
5	Plans, goals and indicators	▨	🟩
6	Implementation and responsibilities	🟩	🟩
7	Competence and training	▨	🟩
8	Communication	▨	🟩
9	Documentation	🟩	🟩
10	Design and procurement	🟥	🟩
11	Operational control	🟥	🟩
12	Monitoring, measurement and analysis	🟩	🟩
13	Internal audit	🟩	🟩
14	Nonconformities	🟥	🟩
15	Management review	🟥	🟩
16	Shipping-specific measures	▨	N/A

🟩	Required
🟥	Missing
▨	Mentioned
N/A	Not applicable

2.4 Energy Efficiency Measurements in Maritime Transportation

The marine transport system has significant potential to reduce energy consumption. As discussed earlier, policy and regulations-based solutions have been applied to solve this problem—however, more effort needed for future developments to use the maximum potential of energy efficiency in maritime transport. One of the important challenges in effective maritime management is measuring the performance of energy efficiency. Most of the articles and studies used or developed these measurements for ship or ports. Some of them focused both on a fleet operation. In this sub-part, firstly, critical players of integrated shipping will be analysed briefly. After that, energy efficiency measurements are presented from up-to-date literature under three sections: port-related measurements, ship-related measurements, or their integration. Each of these sections is examined based on their operational, technical and policy relations.

2.4.1 Key Characteristics of Integrated Shipping

Before understanding the energy efficiency measures in the port, on the ship, and fleetwide, it is vital to clarify crucial players and elements in integrated shipping briefly. According to

Notteboom, Pallis., and Rodrigue (2021), four major functional elements characterise the maritime / land interface as a bigger perspective of the ship and port integration. These elements are the port system, transport modes, the hinterland of ports and the foreland. A Port system is defined as the set of intermodal infrastructures serving port operations. This system focuses on gateways granting access to large domains of inland freight operation by using transport modes. Each mode has technical constraints and the potential for serving more effectively to specific inland markets. They are structured as corridors like veins in the human body accessing the hinterland and inland hubs acting as intermodal and transmodal centres. Hinterland is the inland space accessible by a port to maintain commercial relations within that area. The foreland is the waterway providing access to overseas markets by fleet operation from a port. Figures 2.7 presents some of the actors who are involved in various transport modes. Shipping companies are the main actors in managing fleets of their ships. Terminal operators, port operators, and landowners are the main port actors. The Port system provides the hub for goods that are distributed via road, rail, and coastal/fluvial transfers, as illustrated in Figure 2.7. This transportation network enables commodities to reach their destination within the hinterland of the port.

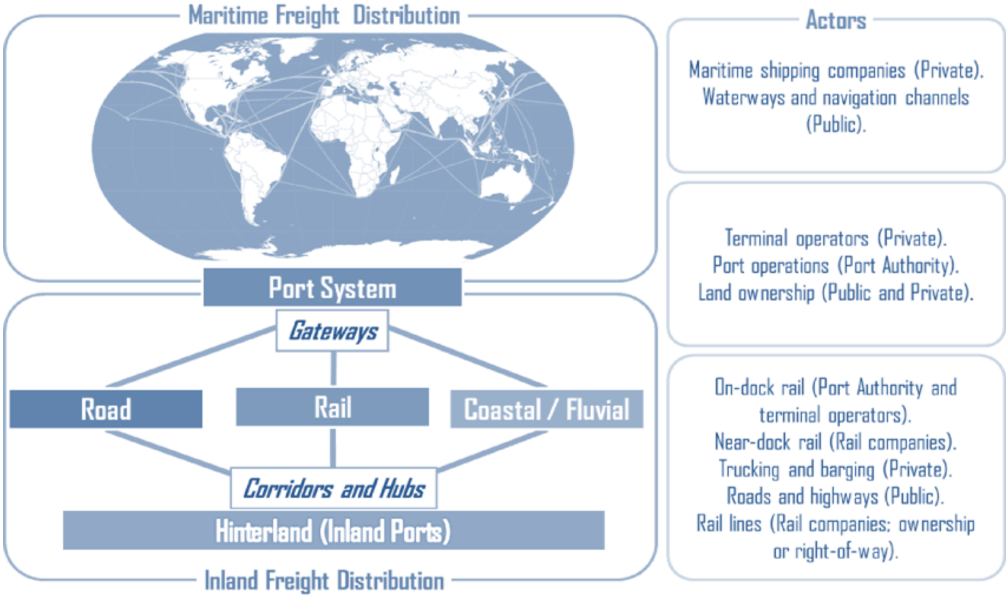


Figure 2.7 The maritime / land interface (Notteboom, Pallis., and Rodrigue 2021).

Ports are operating and facilitating all necessary handling equipment and storage spaces to handle cargo transfer from ships to shore, shore to ships, or ships to ships (Lun, Lai and Cheng, 2010). They also operate berthing or anchoring of ships and providing service and operation for cargos coming from their hinterland via different transports like land and rail. Based on

Export Virginia (VEDP, 2014), several thousand ports are globally active. Just 835 of the most productive ports responsible for 99 per cent of all trade movements. More than half of the global freight traffic is operated by the top 10 ports in 2017 (UNCTAD, 2019). Additionally, shipping facilitates around 90 per cent of global trade, and as trade rates continue to grow, the large ports tend to become larger and more efficient to meet the demand (European Commission, 2020). Ports operated around 11 billion tonnes of cargo in the world in 2018, and more than 70 per cent of the cargo is dry, and around 17 per cent is crude oil and nearly 12 per cent of the other goods transported by tankers in 2018. Nearly 800 million TEUs were handled in container ports across the world in 2018. Therefore, every type of cargo service in ports plays a critical role in delivering highly effective operation. These complex logistic chains should comprise port performance to reduce unavoidable delays to make the system more energy efficient. Leading players and key activities in a port operation need to be identified, clarified, and analysed to understand the operational measures of ports for energy efficiency.

2.4.1.1 Main Players and Activities in A Port

A port is a location where the mode of transportation of the goods varies, shown in Figure 2,8. Ports offer different services to ships, cargo, and passengers. Many ports can have multiple ports and/or terminals under port boundaries. The prominent players in the port are terminal operators, inland transport companies, shippers, agents, forwarders, and freight companies illustrated in Figure 2.8.

A general example of an international port was given in Figure 2.8. The incoming ship operation began with pilotage and tugboat services for arriving ships. Before the handling operation start, the berthing process of the ship began in a terminal. The handling process starts with the unloading cargo until a variety of land operations are carried out in the port to stock or offer value-added facilities such as repacking and CFS. After this, the gate operation is performed. Some service providers have been involved in certain phases, such as shipping agencies, custom brokerage firms and freight forwarders. Figure 2.8. illustrates the management structure of the port operation. While each county has a different layout, this can be taken as a typical example from a port in Turkey. The Port Operators have four major sub-sections; operations, marketing, finance, and other support services, such as human resources. State officials also provide services such as customs, immigration, and quarantine facilities through their state-owned agencies.

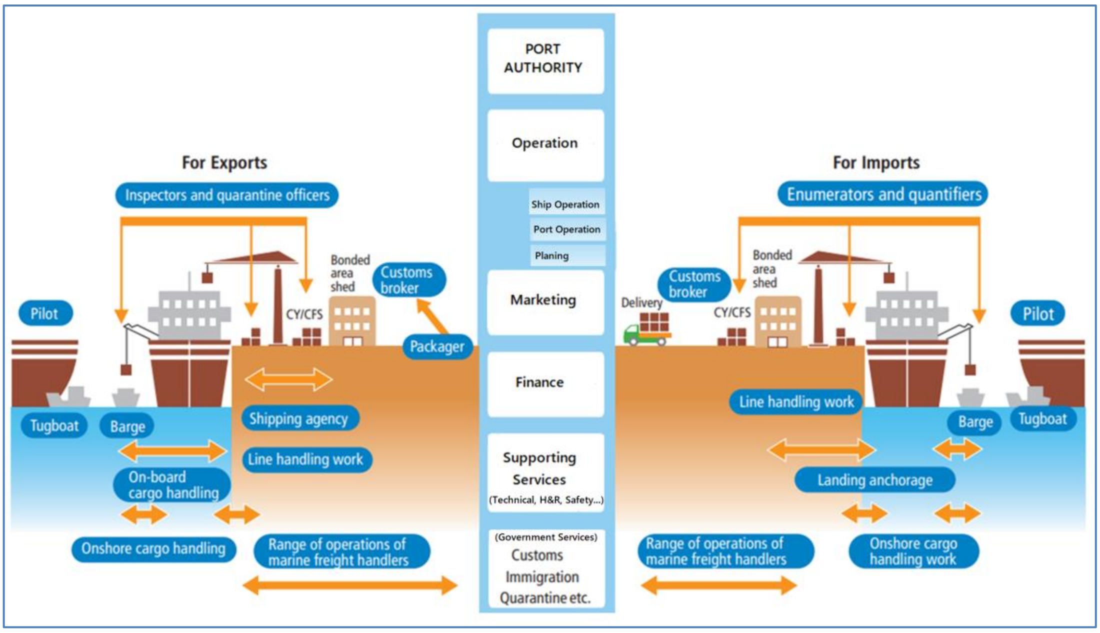


Figure 2.8 Example of an international port (Adapted from MLIT in Japan, 2006, and Esmer 2019).

The port's key role is to move goods between sea transport and inland networks most effectively and securely. Although these excessively complicated logistics operations are carried out by sea, various approaches can be used depending on cargo and container type. Nonetheless, ports' significant operations can be classified based on ship-based activities and associated cargo activities, as seen in Table 2.5. Ship related events described under seven categories. Arrivals and departure operations include pilotage, tugs, mooring, navigation assistance and VTS. Supply services at the port supply water, bunker, and energy to the ships. Energy supply is a value-added activity here that allows making the entire operating system more sustainable.

Table 2.5 Main activities of a port (Inspired from Alderton 2005, Esmer 2019).

Ships related activities	**Cargo related activities**	**Both Cargo & Ship related activities**
-Arrivals and Departure Activities -Pilotage, -Tugs, -Mooring -Navigation aid -VTS - Supplies -Water -Bunker *-Energy (cold ironing)* -Waste disposal -Opening/closing of hatches -Crew services procedures - Shelter (if heavy weather conditions) - Port state control	-Transport to/from storage -Storage/warehousing -Weighting -Dangerous cargo segregation -Safety, surveillance, protection, sanitary measures -Receiving and delivery (road or railway connections) -Tallying, marking, and surveying *-Claiming and preparing cargo* *-Repackaging, labelling, sorting, assembling*	- Loading - Unloading -Ship to Ship Cargo Handling -Repairs -Environmental control -Emergency services -Police, immigration, costume -Telephone, health and medical services *-Setting up a logistic or a marketing place*

While most of the cargo-related activities are listed in Table 2.5, cargo packing, repackaging, tagging, processing, and assembly, which are value-added items for freight, are also offered by some ports within their regular port services to support their primary business by serving their clients. Table 2.5 also presents both ship and cargo related operations, such as loading/unloading.

2.4.2 Port Related Energy Efficiency Applications and Energy Efficiency Measurements

Achieving energy efficiency results in the shipping sector depends on various factors, ranging from numerous commercial, technical, regulatory, and operational factors (Singh and Rambarath-Parasram, 2019). This complex logistic chain should comprise port performance to reduce potential delays to make ports more energy efficient. Therefore, reducing energy consumption in ports has become a key challenge for all port stakeholders (Roos and Neto (2017). Based on the ESPO report (ESPO, 2018), making ports energy efficient is the second most important environmental issue for EU ports after air quality control. This consideration has driven 57 per cent of EU nations to establish energy efficiency schemes and 20 per cent to take steps to directly generate electricity from renewable sources (Martínez-Moya, Vazquez-Paja, and Maldonado, 2019). The Port of Rotterdam, for example, has concentrated on becoming a green port by implementing energy efficiency programs, adopting clean resources and decarbonisation (Lam and Notteboom, 2014). Iris and Lam (2019) believe in a positive correlation between port operation efficiency and port energy efficiency. When the operational efficiency of a port is improved, electricity usage will decrease through energy efficiency (Wilmsmeier and Spengler 2016). Practitioners and researchers provide substantial environmental and energy performance measures, which are more often operational or technical solutions. This subsection of the energy efficiency research will be reviewed based on the technical, operational and energy management measures and their impact on ports, as shown in Table 2.6. The following subsection will provide a detailed review of each section.

Table 2.6 Port related energy efficiency measurements and their applied examples (Faber et al, 2011; European Union, 2011; Fan et al 2019; Hansen, Rasmussen and Lutzen, 2020; Boile et al. 2016; Vaio, Varriale and Alvino 2018; Longo et al., 2015).

Applications	**Application type**	**Example of application**	**Measurement**
Technical Applications	Equipment	Technical specification of port handling equipment and their energy efficiency (like Truck, Crane, SSG, RTG, Forklift, Cargo pumps, Screw conveyors) for each cargo type (Container, General cargo, RORO, Dry bulk, liquid bulk, Special cargo). Fuel conversion potential of port equipment (switch to electric, hydrogen, biofuel and LNG, LPG and their energy-saving calculation, green power options) Equipment automation and their effect of infrastructure technologies on energy consumption of the port	Energy consumption calculation for equipment • Handling volumes • Number of equipment • Engine and fuel types • Operation time • Throughput time • Seasonality • Special equipment instalment • Repairment time The energy supply of port • Energy sources of port electricity • Energy switching possibility. Handling equipment optimisation • Effective working configuration • Upgrading possibility (like switch fuel)
	Cargo related	Cargo storage requirements and their energy consumption • LNG • Reefer containers energy usage • Dry bulk/food • Dangerous cargos	Calculation of energy consumption for cargo heating or cooling (like LNG) Reefer's energy consumption • Waiting time of each container, their required temperature and volume • Type of refers engine
	Port buildings and infrastructure	Technical specification of port facilities and their switching capability (like building energy efficiency and improvements, the terminal lighting, and their upgrades option to lead). Smarter power distribution systems and measures to prevent electric transmission loss. Energy consumption monitoring of the building. • Type of terminals the port has and their physical storage areas, and their energy consumption. Lighting technologies Energy storage devices Port size	Energy consumption calculation for buildings • Availability of smart meter • The heating system and fuel type • Internal lighting • Storage areas energy consumption Electric transmission lost. • Transmission system efficiency • Saving of smart meters • Of peak shaving Lighting energy consumption • Type of light and working hour. • The size of the area needs to be lighted. Performance of energy storage calculation and their capability of energy shaving Cargo capacity calculation and berth length of the port to calculate available capacity
	Ship related	Minimisation of ship energy consumption while her stay at the port Technical capability of efficient/greener energy supply to ship like Cold ironing, LNG	Ship energy consumption during port stay • Port stay time. • Ship waiting time. • Ship engine and fuel type • Availability of cold ironing and LNG • Energy usage of tug bouts
	Others	Staff Awareness, knowledge, and communication Sustainable and environmentally friendly supply (Consider sustainable products to use at the port) (like sustainable tyres)	Soft measurements • Stuff effective working hours • Stuff awareness on energy consumption of port equipment and infrastructure • Effective communications within a team Sustainable supply options for port need • Calculation of their impact on energy
Operational Applications	Shipside Operational Applications	Operational efficiency (Pilotage, Towage, Mooring) Ship supplies efficiency (reducing the time of supply like water, waste, and energy) An operational technique to adjust ship speed and energy consumption before she arrived at the port (reducing ship waiting time on the queue, develop concepts like just in time)	Ship and tag boots operational details • Sailing speed, • Engine specifications • Operation time • Waiting time • Type of fuel they use. • Cold ironing availability while waiting-an operational technique to reduce energy consumption. • Just in time measurements • Weather routing measurements. • Booking system measurements • Chartering the most energy-efficient and available ship for a specific cargo

	Terminal/ landside Operational Applications	Efficiency of Seaside (quay loading–unloading) operation and energy consumption utilisation. The lifecycle management plan of equipment Storage capacity utilisation Gate operation Empty storage (in and off terminal) Port traffic/layout efficiency (Port traffic management and information systems (e.g., ITS, SESAR, ERTMS, SafeSeaNet, RIS)). Maintenance or repair operation Availability of value-added services (like repackaging to reduce transportation of cargo).	The efficiency of assigned equipment for operations • Calculating the operational energy efficiency of each piece of equipment and their possible improvements • Equipment`s waiting times calculation. • Assigning equipment for the best effective operation, and it is calculations. • Land area traffic design • Land area traffic management method • Waiting times at the gate • Waiting time due to information or documentation Waiting due to maintenance or repair • Alternative fuels for internal combustion engines, electric and hydrogen fuel cell vehicles, energy storage systems Value-added service operation. • Calculating the impact and energy benefit of value-added services at the port
	Policy Applications	EEOI Emission standards Design of vessels and infrastructure, Speed limits Targets for the use of renewable energy sources and energy efficiency. Emission standards for ships and ports, Energy efficiency design index (EEDI), Energy efficiency operation index (EEOI), Ship energy efficiency management plan (SEEMP), IMO Fuel oil consumption data reporting	• EEOI Equations and other related studies to improve it is measurements. • Calculation of emission standards • Calculation of subsidies and related supports • Calculation and monitoring of emission targets of ship and ports. • EEDI calculations and their effect on the operation • SEEMP methods and measurements • Calculation of all subsidies or support for possible operational advancement
	Other/soft Applications	Staff awareness-raising activities Administration (PA, customs, etc.)/client services) Availability of renewable energy supply.	Calculating the impact of educated staff on energy efficiency Ease admin works and calculating improvement in the operation. Managing tariffs to get greener energy sources
Energy management	Energy Supply Applications	Fossil related fuel supply Renewable energy Cleaner fuels Cold ironing	Analysis of port energy supply and their variety Alternative energy supply services their impact • Electricity supply (Cold ironing) • Fossil fuel supply • LNG supply
	Energy Demand Applications	Real-time monitoring Electrification of port equipment Refers to containers monitoring. Fossil fuel demand of the port Alternative energy demand	Energy switching possibility and their impact on supply (like swishing from fossil-based fuel to electricity) Optimum demand management like peak shaving
	Smart Grid System/Storage Applications	Smart grid Demand balancing by using energy storage	Loss of energy in the grid or storage. Energy-saving from storage technologies and their efficiency
	Policy Applications	ISO 50001 ISO 14001 Individual port policies	Contribution of policies and their possible impact on positive energy saving.

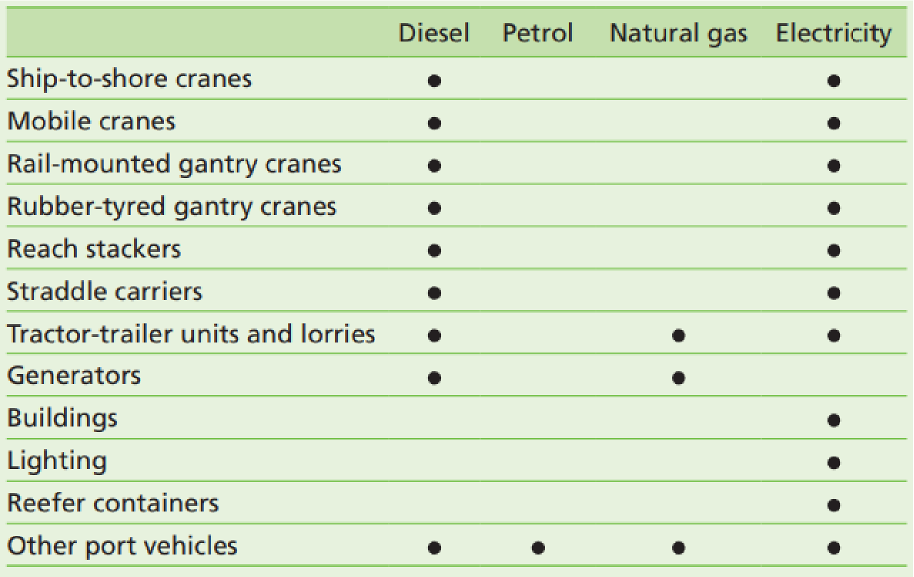
2.4.2.1 Technical Applications

Some of the current literature had analysed port-related energy consumption from a technical perspective (Acciaro et al., 2014, Alamoush, Ballini, Ölçer 2020, Gonzalez-Aregall and Bergqvist 2020, Greencranes, 2012, Longo et al., 2015, Misra et. al., 2017; Innes and Monios, 2018; Van Duin et al., 2018, and Wilmsmeier and Spengler 2016). Technical applications in literature are related to equipment related applications, cargo-related applications, port buildings related applications, ship-related applications, or any other soft applications like staff awareness about energy efficiency, emissions.

2.4.2.1.1 Utilisation of Port Equipment

Ports accommodate equipment based on their available services. As an example, container ports used specialised equipment to handle containers, and they are mainly Truck, Crane, Ship-to-Shore Gantry (SSG) cranes, rail-mounted gantry (RMG) cranes, rubber-tyred gantry (RTG) cranes, reach-stacker (RS) cranes and Forklift etc. Although every technical specification of port equipment is highly sophisticated, all of them used similar parameters to calculate their performance or consumption of the equipment when they try to advance or quantify their specifications. The following terms are used in the literature when calculating the energy consumption of equipment; handling volumes, throughput time, engine and fuel types, operation time, number of equipment, seasonality, particular equipment instalment, and repairment time. Wilmsmeier and Spengler (2016) researched energy consumption in container terminals, as very limited research is available in the literature on this topic. They analysed the energy consumption of the port by following energy activity clusters such as vertical operations (quay cranes), horizontal operations (e.g., SSG cranes, RS cranes, RTG cranes, RMG cranes, etc.), lighting, buildings, and cooling (reefers). While they analysed the port activities under these clusters, further details from a technical perspective of energy consumers in a port are listed in Table 2.7, which shows the most common handling equipment and their common energy consumption types. They also include some infrastructure-related parts as an energy consumer like buildings and lighting. Their study also reported that besides each consumer's technical details, time is also identified as one of the most important factors when energy consumption is measured at the port, as given in Table 2.6. Time changes due to three main reasons: handling volumes and frequency of ship visit, seasonality (mostly effect reefers energy consumption), and port stay times for all types of cargos. Seasonality change energy consumption due to cooling systems at a port like reefers and air conditioning of buildings or vehicles. Alamoush, Ballini and Ölçer (2020) wrote a review paper on ports' technical and operational measures and analysed 214 academic research between 2007 and 2019. Their research, which focused on equipment, indicated the need for physical adjustment or advancement of older pollutant port infrastructure with better and modern energy-efficient technology, e.g., tugs, equipment and lighting, and buildings' air conditioning. The measures can be introduced in various ways, the first one is buying new equipment, the second is by replacing old equipment with better and more efficient equipment, the third is by converting old engines to advanced ones, and the fourth is by renovating that integrates pollution control technologies.

Table 2.7 Type of energy consumption and consumer in a container terminal (Wilmsmeier and Spengler (2016) adapted from Spengler (2015)).



	Diesel	Petrol	Natural gas	Electricity
Ship-to-shore cranes	●			●
Mobile cranes	●			●
Rail-mounted gantry cranes	●			●
Rubber-tyred gantry cranes	●			●
Reach stackers	●			●
Straddle carriers	●			●
Tractor-trailer units and lorries	●		●	●
Generators	●		●	
Buildings				●
Lighting				●
Reefer containers				●
Other port vehicles	●	●	●	●

The fuel conversion potential of port equipment is another equipment related technical application. It means that they switch their energy type from pollutant fuel to electric, hydrogen, biofuel and LNG, LPG. Based on this change, their energy-saving potential can be calculated. Based on the Port Authority of Barcelona's action plans, the port agreed to invest in new infrastructure to encourage the use of alternative fuels for cargo transport (Port of Barcelona, 2020a). The Port of Barcelona (2020b) considers Liquefied Natural Gas (LNG) as the cheapest energy source for marine vessels with stable prices and environmental benefits. The port is swapping diesel-powered vehicles with electric-powered ones, and they are operating a project with yard trucks for container terminal called "RePort" to replace diesel-powered trucks with a dual system with Natural Gas (NG). In terms of port terminal equipment, the port authority plans to improve the usage of electricity and gas for port terminal equipment

(Port of Barcelona, 2020a, Port of Barcelona, 2020b. Port Authority of Barcelona, 2016). Port of Los Angeles developed a reduction program (Acciaro et al., 2014). Energy efficiency is strongly linked to costs at the operational level in a port. Therefore, terminal operators aim to maximise energy efficiency not only by reducing external costs but also by generating large operating cost savings. Therefore, more efficient equipment and technologies are required for port operations to save more energy. However, it is important to remember that the importance of energy conservation achieved by terminal operators presently has put extra pressure on the machinery industry to develop more powerful engines. As a result, the suppliers of RTG machinery for the port industry have increased the cranes' energy efficiency and, in some installations, the fuel usage could be similar to the second alternative without impacting the operating times (Martínez-Moya, Vazquez-Paja, and Maldonado, 2019). It is seen that replacing the original RTGs with the less powerful ones in the port of Valencia increased the energy efficiency of the RTG with 6.06 l/h decrease in fuel consumption and there is overall annual EUR 41000.00 cost savings per unit of RTG. For example, from the manufacturer side, Konecranes (2018) introduced a new crane concept of STS crane using a three-beam concept instead of two-beam concepts, giving a 50% increase in output. On the other hand, Munim (2020) believes that terminals and ports that do not invest effectively in port infrastructure will suffer from long-term service levels. However, ports that invest strategically in equipment based on long-term projections of port productivity maintain a steady technical efficiency and service level. Therefore, the port needs to have a road map and a good understanding of future cargo volume to minimise any side effect of technical efficiency due to their equipment and infrastructure investments.

Equipment automation is a global trend and primarily applied in port container terminals. This technology aims to increase the productivity and energy efficiency of a terminal or a port (Martín-Soberón et al., 2014). Another advantage of automation comes from the energy consumption of equipment which mainly uses electric power sources. This makes automated equipment efficient and reduces consumption, emissions, and noise in a port. Martín-Soberón et al. (2014) believe that implementing automation technologies into a terminal depends on various factors like the status of port development, the subsystem object of automation, and the yard operating system. They also believe that the most suitable automation solution for a given port container terminal needs to be combined with available automating technologies with the process reengineering of the terminal operations. A terminal in the port of Rotterdam, the first automated terminal in the world open in 1993, is the most technologically advanced terminal in the world (Witschge, 2019). Most of their cargo movements are automated; remote-controlled equipment, which carried all cargos from the quayside to the port gate, is powered by renewable energy sources (Icontainers, 2018). The Port operator says that its terminal is operated by a maximum of 15 people every day (Witschge, 2019). Overall, container terminal automation is still at a very early stage; only 46 semi or fully automated container terminals are in operation worldwide (Mongelluzzo, 2019). This automation system has an increasing trend and needs fewer individuals, and the current situation of COVID-19 pandemic may accelerate this trend. Technical and technological capability and advancement of this automated equipment play an essential role in this system because the equipment is powered either by electricity or battery.

2.4.2.1.2 Cargo related applications

Each port and terminals usually are specialised for various cargo types, and Raucci, Smith, and Deyes (2019) believe that the composition of the cargo they handle also differs substantially in ports. Cargo type has a critical impact on the context of electrification of a ship due to ship types and sizes (Frontier Economics, UMAS and CE Delft 2019). Similarly, onshore power's (cold ironing) cost-effectiveness differs among vessel types and sizes, which ensures that the sustainability of the related port facilities can differ (Raucci, Smith, and Deyes 2019). Electrification of port and seaside also influences energy efficiency. Moreover, cargo storage requirements and energy consumption play an essential role in the port’s sustainability and energy efficiency. For example, from container ports, reefers are refrigerated containers widely used to transport perishable products such as beef, fish, dairy products, vegetables, and fruit. Van Duin et al. (2019) found that reefers are currently responsible for 40 % of the overall energy usage at container terminals when connected to the onshore power grid. An EU project (EU-92151-S programme) (Greencranes, 2012) found that reefer containers consumed 43 % and QCs consumed 37 % electricity at the ports of Valencia, Kopfer and Livorno. The remaining 20% of electricity is mainly shared between yard equipment and buildings. Additionally, the energy consumption of cargos in the port depends on many factors like the waiting time of each cargo in the port area, their required temperature and volume in the storage type of engine they used while they were cooling or heating the cargo. Filina-Dawidowicz and Filin (2019) reported that, depending on the temperature of the cargo transported and the existing environmental conditions on the road, the cooling costs might differ between 15 and 50 per cent of the transport costs. A statistical heat-balance model of containers contained in yards was developed by Filina-Dawidowicz and Filin (2019) to quantify the energy savings for their advanced technique. They argued that this system's performance would be highly dependent on the gap between the refrigerated containers in the storage area. The measured reduction in energy consumption was 7.6 % after their reefer container application. In their preferred scenario, this reduction was 23 %, and, in some cases, this reached up to 35–40 %. This indicates that technological advances have reduced the energy consumption of reefer containers enormously.

2.4.2.1.3 Port buildings and infrastructure applications

Architects, planners, and scientists are working on techniques to make cities more sustainable, and people spent 90% of their time indoors (National Geographic, 2017). Therefore, the interest in the design and development of modern, energy-efficient urban buildings has increased during the last decade, and this interest contributed to the advancement of modern, energy-efficient urban buildings, including port buildings (Sdoukopoulos et al., 2019). Ports usually have different buildings for different functions like warehouses and other storage buildings, terminal offices, dining hall, passenger buildings, administration offices, service and repair facilities etc. Port buildings have a variety of technical and technological advancements such as sustainable building shells, energy-saving systems, central or efficient heating or cooling systems, energy-efficient (like led light) indoor lighting, smart building energy management, and renewable energy applications like solar panels on roofs, small wind turbines applications.

One of the futuristic ports, the Port of Antwerp, has specific action plans and has a list of measures to become more energy-efficient and environmentally friendly (Dirkx, 2015). The port operator has carried out an energy audit of about 20% of its own 140 or so buildings (Port of Antwerp, 2012). Steps such as eliminating excessive heating, improving the exterior surface of buildings, and helping people improve their actions resulted in savings of 1,540,000 kWh in 2011 (Port of Antwerp 2012). They continued their progress, and the first time a port was awarded ISO 50001 certificate for the second time in a row, which is an energy management system with the primary purpose of using energy more efficiently in 2015 and 2018, respectively (Port of Antwerp, 2018). Port buildings mostly consumed electricity for their energy need; therefore, the energy source and sustainability play a vital role in port buildings. Sustainability Report of the Port of Antwerp (2019) states that, in recent years, renewable energy usage at the port has risen from 112.6 MWe in 2009 to 262.83 MWe in 2018. Wind energy made the most outstanding contribution (57.0 per cent of installed capacity in 2018), followed by solar energy (21.5 per cent) and biomass (16.6 per cent). Installed renewable energy capacity includes their installed solar panels on some of the Port of Antwerp buildings, as shown in Figure 2.9 (Port of Antwerp, 2019).

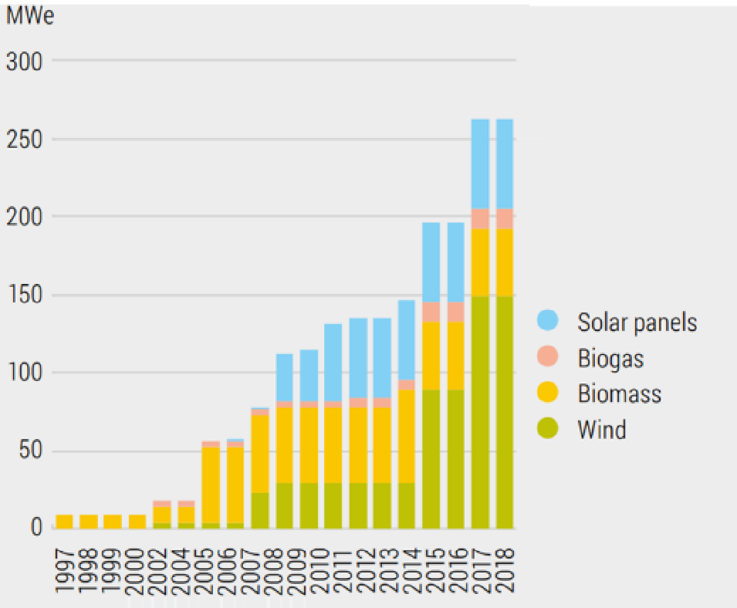


Figure 2.9 Installed renewable energy capacity of the Port of Antwerp (Port of Antwerp, 2019, p. 66).

The technical specification of port facilities and their switching capability (like building energy efficiency and improvements, the lighting of the terminal and their upgrades option to led) is also essential to improve the energy efficiency of port buildings. An office building built in 1970 was renovated and modernised in 2014 at the harbour of Aalborg, where this renovation reduced 95% of energy needs for heating. The port used this perfect result as a reference to do further investments opportunity with passive house standards for all remaining buildings at the port (Hippinen and Federley 2014). An energy-efficient warehouse was built in 2015 in the port of Immingham, United Kingdom. This warehouse includes a solar panel on its roof that produces nearly 156 MWh of power each year, meeting all its energy needs and contributing any surplus energy to the electrical grid. LED lighting has since been used in buildings to reduce energy consumption and expenses with lighting (Baldwin et al., 2015).

In their latest academic work on port energy efficiency, Iris and Lam (2019) stated that energy use assessment and (real-time) monitoring schemes, broader use of green energies and clean fuels and micro-and smart grids are the available technologies and knowledge for ports to increase the energy efficiency of a port including buildings.

2.4.2.1.4 Ship related applications on the port side and other applications

Ships are equipped with technologies as part of energy efficiency measures, as detailed in section 2.4.3. However, there is a strong interaction between a ship and the port as a ship needs to utilise the port facilities to minimise the ship's energy consumption and emissions. This means a port needs to provide the relevant services with the best possible and efficient way to ships. Ship energy consumption during port stay depends on many parameters, including port stay time, ship waiting time, ship engine and fuel type, availability of cold ironing or LNG and energy usage of tugboats etc. Misra et al., 2017 reports that Port of Chennai's total consumption in India is 6.3 million litres of fuel annually. Cranes and tugboats consumed 84.7% of the port's annual fuel consumption, and their share is 59.2% and 25.5%, respectively. Therefore, ship-related consumption involving seaside activities such as tugboats` assistance is vital.

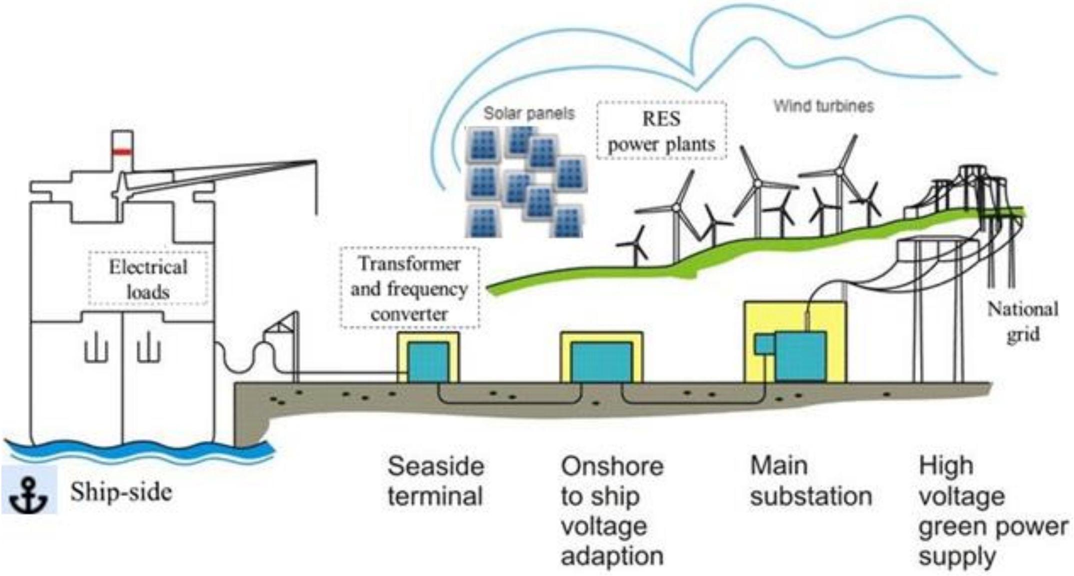
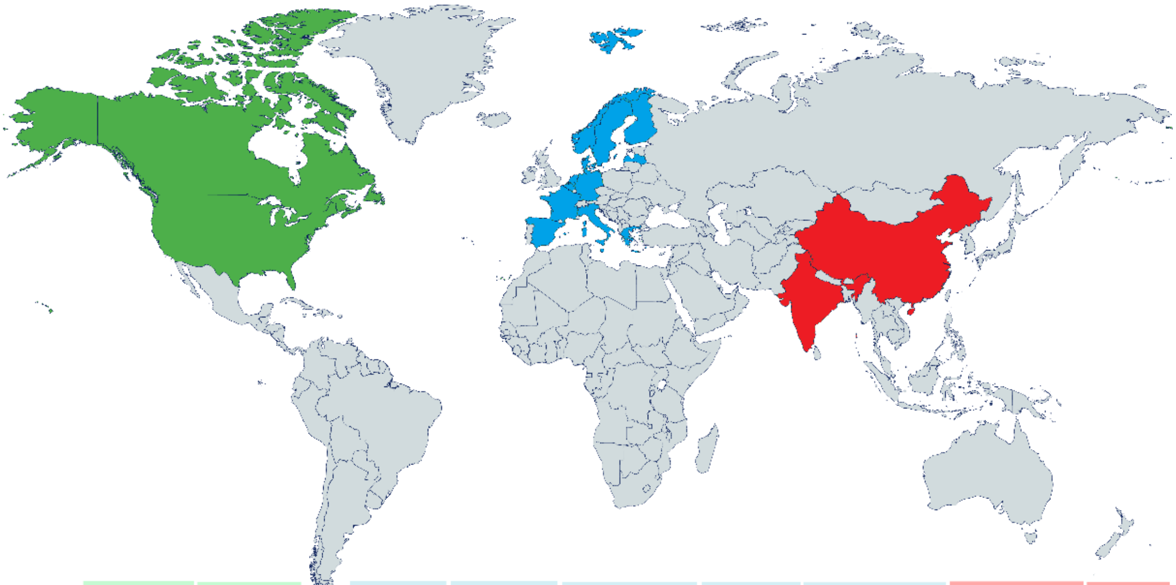


Figure 2.10 Shore to ship power supply (Adapted from ABB cited in Henderson 2012 and Yiğit and Acarkan, 2018).

The ship's electrical power needs are typically generated by onboard auxiliary generators that create noise, vibration, and, most importantly, air pollution and CO_2. Therefore, the onshore power supply (OPS), known as cold-ironing, shore-side power or alternative marine power, as seen in Figure 2.10, will enable ships to use energy from shore. Instead of fossil fuel used by auxiliary generators, they consume electricity from environmentally friendly source by plugging it into the shore-side energy supply. This helps decrease air pollution caused by ship in ports and increase the port's energy efficiency. Besides, energy can be supplied from various sources, such as grid, wind sources, LNG, or other power generation sources. If the source of energy is renewable and efficient, port sustainability can be improved significantly. Cold ironing can be an efficient way to provide greener energy and maximum electrical efficiency to ship when in port. According to Massport (2016), the electrical demand for one cargo vessel is higher than the electrical demand for the entire Boston Logan Airport Terminal. The estimated cost of renovation of OPS for cruise and container vessels is $1 million for each vessel. This is greater in the case of a Port: Halifax Infrastructure Cost is $10 million for One Cruise Berth, and Maintenance Costs of the Port of Long Beach is about $10.3 million for each berth. There is a possibility of a 10% reduction in carbon emissions in ports in the United Kingdom when applying the cold ironing system (Zis et al. 2014). The port of Kaohsiung in Taiwan managed to decrease CO_2 emissions by 57.2 per cent and NOx by 49.2 per cent, and SO2 by 63.2 per cent (Chang and Wang, 2012). In addition to the environmental advantages of OPS, Yiğit and Acarkan (2018) pointed out that there is an economic benefit for countries with an energy price of less than USD 0.19 per kWh. It is possible to reduce electricity usage and maintenance costs by up to 75%. However, the cold ironing's energy efficiency is not yet known based on the IMO (2016a) study. The study also states that cold ironing has more available energy sources and utilises low-carbon or renewable energy sources in a highly productive manner. There were only 12 ports that implemented cold ironing between 2000 and 2010 (WPCI, 2017, cited in Innes and Monios, 2018). Today, 69 ports use cold ironing, as seen in Figure 2.11. Ports in Europe and North America have been the leaders in technology in the world. Over the last decade, more EU countries have implemented this technology, and this trend is going to continue with the ports of Bremen in Germany and the Port of Flam, Norway (Maritime Executive, 2020). The British Ports Association (2019) BPA has released new research showing that none of the ports in the world has implemented cold ironing without public support or subsidies. Analysis undertaken by Arkevista on BPA showed that vessels' overall power consumption at berth in the United Kingdom was more than 641 gigawatt-hours of electricity in 2019-about 0.5 per cent of the total energy demand in the country. Some challenges are listed as uncertain energy planning, possible lack of demand, and high electricity costs (twice that (per kWh) than other countries), making it complicated to compete with marine fuel costs in the UK. Therefore, each port and ship combination in every single county may generate different outcomes. It is important to examine each port type and ship type combination for investment or government support to make the port side operation more efficient and feasible.



USA
Brooklyn
Hueneme
Juneau
Los Angeles
Long Beach
Oakland
San Diego
San Francisco
Seattle
Tacoma

CANADA
Halifax
Montreal
Prince Rupert
Quebec
Vancouver

NORWAY
Agotnes
Bergen
Dusavik
Floro
Kristiansand
Kristiansund
Larvik
Orkanger
Oslo
Sanderfjord
Stord
Trondheim

SWEDEN
Gothenburg
Kapellskär
Karlskrona
Stockholm
Trelleborg
Ystad
Värtahamnen
Visby

GERMANY
Cuxhaven
Hamburg
Kiel
Lubeck

ITALY
Ancona
Civitavecchia
Genoa
Livorno

FINLAND
Kemi
Kotka
Oulu

NETHERLANDS
Amsterdam
Rotterdam
Hoek van Holland

DENMARK
Frederikshavn
Helsingborg
Helsingor

FRANCE
Antibes
Dunkirk
Marseille

LATVIA
Liepaja
Riga

BELGIUM
Antwerp
Zeebrugge

SPAIN
Palma de Mallorca

MALTA
Delimara

GREECE
Killini

CHINA
Guangzhou
Lianyungang
Ningbo Zhoushan
Qingdao
Shanghai
Shenzhen

INDIA
Tuticorin

Figure 2.11 Available cold Ironing facilities in ports around the world in 2020. Data collected from WPCI, 2017, Killiniport (2020), Innes and Monios (2018), World Ports Sustainability Program (2020).

On the other hand, some of the critical challenges to onshore power supply (OPS), it is also called as cold ironing, for ports are availability, cost or technological problems. They are classified based on the work (Zhang, 2016; Ssali, 2018; Sciberras, Zahawi and Atkinson, 2015) and provided below:

- High capital expenditure for port operators to deal with shore structures
- High capital cost for shipowners while retrofitting those vessels may not be financially feasible
- Ships do not have the standardised voltage and frequency specifications. Some ships use a 60 Hz frequency, but most ports are 50 Hz: the US 60Hz grid and the European 50Hz setup
- The price of electricity on the shoreline is greater than the availability of auxiliary engines

- OPS supply is minimal in the world (Ssali, 2018)
- Connectors and cables are not uniform globally
- Policies have not been established properly
- High voltage electricity supply poses health and safety issues and also includes load requirements around ports
- High voltage electricity supply poses health and safety issues and also includes load requirements around ports

Some other organisational issues like staff awareness, knowledge, and communication etc, also play a vital role in energy efficiency. Dewan, Yaakob and Suzana (2018) found that a new type of electronic controlled engines can provide efficiency gains in a port. However, specialized training for the appropriate workers needs to be provided to increase the benefits. Research has shown that the challenges for introducing these cost-free operational measures are mostly common to various stakeholders from all corners of the shipping industry (Dewan, Yaakob and Suzana 2018). However, training people, managing this will require resources and involve cost. The lack of knowledge on the measure, the lack of understanding and expertise of personnel and the challenges in service are as important as technological challenges. Therefore, training people or hiring experienced people can cause an extra cost for the company to have such awareness. Pavlic et al. (2014) performed a case study on the practical implementation of the Green Port principle focusing on the overall enhancement in energy efficiency, implementation, and introduction of energy-efficient technologies in Port of Kope. Their focus was on state-of-the-art technology and developing a pilot program that focused on new energy systems designed to increase fuel efficiency and mitigate emissions of rubber-driven gantry cranes. They found that some soft skills like communication, engagement of staffs and training play a very important role to make the port energy efficient.

Finally, the sustainable and environmentally friendly supply of energy can play a key role in the energy efficiency of a port. For instance, considering the use of sustainable products at the port, like tyres produced in a sustainable manner, have an impact on port energy efficiency and sustainability from a broader perspective of the supply chain. Therefore, the calculation of their impact on port energy system can be beneficial to see the micro impact of this kind of applications.

2.4.2.2 Operational Measures

Most of the existing literature analysed port-related energy consumption from an operation perspective (Bjerkan and Seter 2019; Chang and Jhang, 2016; Chang and Wang, 2012; Cui, Turan, and Boulougouris, 2016; Linder, 2010; López-Aparicio et al., 2017; Lu et al. 2015; Lu et al., 2014; Moon and Woo, 2014; Notley, 2017; IMO, 2016b; Portstrategy, 2011; Styhre et al., 2017; UNCTAD, 2019; Varelas et al. 2013). The operational application covered in literature as ship-side operation includes ship arrivals, terminal or landside operations, policies (analysed in section 2.3 in details), or any other organisational measures like administration as shown in Table 2.6 in section 2.4.2. The following subsection will analyse the operational measures mentioned above and their effectiveness in detail.

2.4.2.2.1 Ship-side Operational Applications

This present section is related to the day-to-day operations of sea-based activities, including ship arrival operations, vessel speed reduction, efficient vessel handling, and other measures listed in Table 2.6. Vessel arrival is one of the main operation legs for ports; information like the vessel's arrival time and the cargo volume that needs to be handled affects the port operations, resource allocation and energy efficiency.

Time is one of the key parameters for operations of ports and shipping fleets in terms of energy efficiency. Often, ships spend more time in port than they require for the activities due to port queues or delays at ports operations. Figure 2.12 demonstrates the analysis of the time of the ship in the port. Here, waiting time applies to the ships which are waiting for the available berth. Manoeuvring time refers to a ship, which manoeuvres in order to reach anchorage or berth or leave. Berthing time refers to the actual time spent at the berth of the ship. It has two parts: proactive time applies to real-time cargo handling activities. Idle time applies to unproductive times in the berth for cargo handling activities when the ship is in the berth (IMO, 2016b).

Several factors impact the time of the ship and the port time. The most significant factors can be listed as:

- The time of the ship on a voyage depends primarily on:
    - The distance between loading and unloading ports,
    - Climate conditions,
    - The volume of the ship and the cargo,

  - Particular ship capabilities and efficiency (such as ship speed and engine types).
- Port time, thus, depends mainly on:
  - The type and volume of the vessel,
  - Type and volume of the shipment and,
  - Available port services (includes Pilotage, Towage, Mooring, the supply of water, waste, and energy like bunkering, cold ironing, handling services etc.) and their quality and usability.

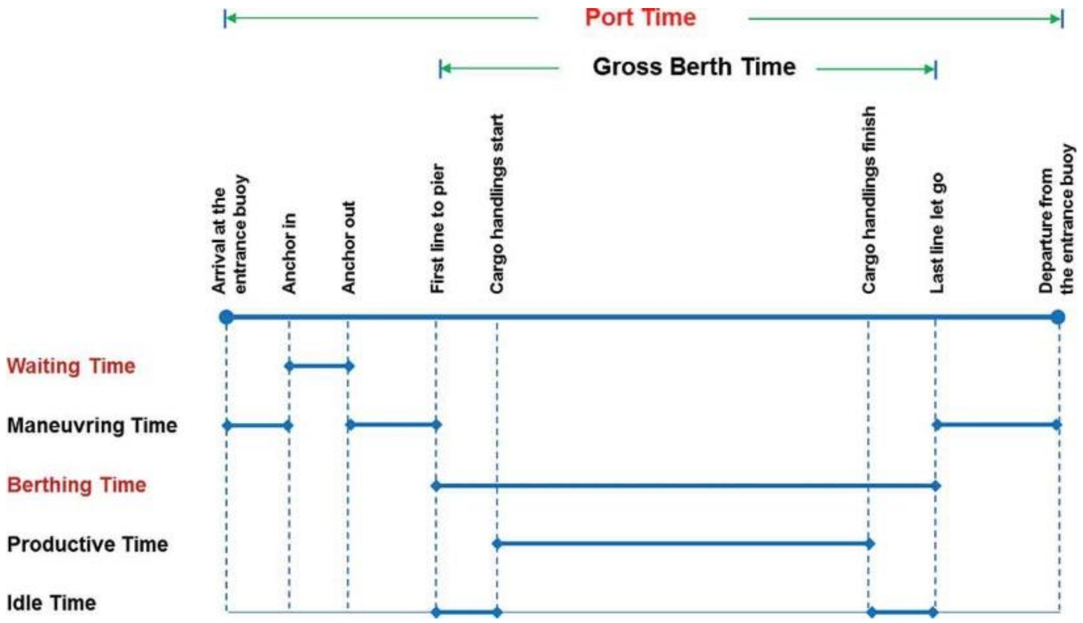


Figure 2.12 Breakdown of ship's time in port (IMO, 2016b).

The time spent by a ship in port affects the vessel's utilisation and hence annual profits, running costs and the energy efficiency of the terminal and the vessel, as provided in Figure 2.13. This figure shows that a ship's voyage time at open sea affects the voyage cost, the fuel efficiency of the ship at sea and the annual cost of the ship's service. Ship port time needs to be properly estimated and acknowledged to make this operation more effective and energy efficient. The decrease in port time also impacts the availability of ships during the year and the ship's speed during its voyage. The ship's speed also impacts the fuel consumption at sea and the volume of CO_2 emissions generated by the ship. The annual running costs and the volume of electricity and CO_2 emissions also may dynamically change due to changes in port time (Moon and Woo, 2014).

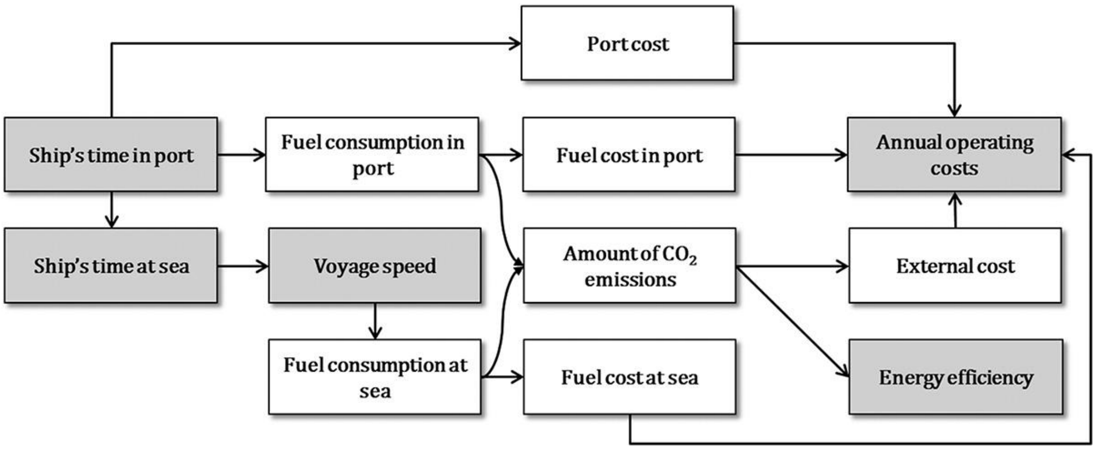


Figure 2.13 The impacts of port time on operating costs and energy efficiency (Moon and Woo, 2014).

Notley (2017) conducted research on a major European port using the port's Vessel Traffic System data. The study found that the average time spent in port by a ship is 42 hours, and the average delay experienced 64 hours per vessel by the 58 vessels out of 245 vessels from a sample of 200 calls over three weeks during the summer of 2017. Each hour of ship time saved in a port benefits ports, carriers, and shippers as the money will be saved on investment in port facilities, ship capital expenditure and inventory of goods (UNCTAD, 2019). Based on UNCTAD analyses, the port turnaround time calculated for dry bulk vessels is the fastest by 2.05 days, followed by liquid bulk with 0.94 days and container ships by 0.7 days and 2018.

Therefore, some studies examined ship arrival time and the arrangement depending on port availability or the best available ship operation route. The studies related to ship arrival are mostly about weather routing, virtual arrival, and queueing related studies like just in time arrival. Several academics developed models or calculate potential emission reduction from slow steaming due to less energy consumption (Chang and Jhang, 2016; Chang and Wang, 2012; Cui, Turan, and Boulougouris, 2016; Ferrari and Parola Tei, 2015; Linder, 2010; López-Aparicio et al., 2017; Lu et al. 2015; Lu et al., 2014; Styhre et al., 2017; Varelas et al. 2013). Cui, Turan, and Boulougouris (2016) indicated a very high potential for energy consumption and CO_2 reduction by applying weather routing. Their tool reduced the use of fuel up to 27.65% compared to the recorded/actual route. Vessel Speed Reduction Program is an excellent example of a voluntary program utilised by a port side at the Ports of Los Angeles and Long Beach, as analysed by Linder (2018). In this program, ocean-going vessels are requested to decrease their speed within a determined distance from the port. Participating vessels benefit from pre-assigned berth labour for handling cargo and possible port fee reductions for the participating shipping companies. Linder (2018) found that well-designed, low-cost, easy programs will likely play a role in vessel speed reduction, impacting energy consumption and air quality improvement. Bjerkan and Seter (2019) surveyed the Ports of Los Angeles program and found that most of the ship operators were involved in this program mainly for financial benefit and improved the public image of the company without regulatory requirement. They discovered the importance of environmental concern is listed after financial one based on their survey, which reveals that operators are keen to use this program for their financial benefit or public image instead of environmental benefit.

Virtual arrival was defined as "a process that involves an agreement to reduce a vessel's speed on a voyage to meet a revised arrival time when there is a known delay at the discharge port. The speed reduction will result in reduced fuel consumption, thereby reducing greenhouse gas (GHG) and other exhaust gas emissions" (Intertanko and OCIMF, 2011).

Virtual arrival is applicable when there is a known delay in the discharge port. A mutual arrangement can be established between the owner/operator of the ship and the charterer on the operation procedures. Other parties may engage in the decision-making process, such as ports, freight receivers and commercial interests. The vessel's speed change should be made to meet the agreed time of arrival. This would reduce the total bunker usage and the realisation of the accurately measured pollution reduction for the voyage. In a case study of Intertanko and OCIMF (2011), 290 tonnes of fuel were saved by increasing a tanker’s sailing time from 15 days to 17 days.

Virtual arrival is a very recent operating model that aims to minimise barriers of JIT service by reducing freight and port delays. 'JIT transport' used for liner transport by Frankel in 1993 and 'just in time' for delivering and handling the goods cited by Lanzara in 2000. This definition has been converted and used at the stage of the ship-port operation. An example of JIT & Virtual Arrival service can be seen in the Newcastle Port of Australia using a slot booking system to prevent longer anchorage waits, which creates significant security and environmental problem for the Great Barrier Reef. This framework generates green gains and operational improvements for the Newcastle Port of Australia (Portstrategy, 2011). JIT refers both to the service of the fleet and to port activities. The fleet optimisation process includes all facets of the planning, execution, tracking and evaluation of the journey. IMO supported the activity of the JIT in the port (IMO, 2016b), which refer to the following key points of JIT:

- Any action that cuts the idle time in ports by minimizing delays:
- Early communication provides a performance increase for JIT.

- Optimum time speed of ship and
- Optimum port operation
- Optimum land transport
- Contribution to the supply chain approach by early notifications

2.4.2.2.2 Terminal/land side - Operational applications

As defined earlier, the seaport operation is described as a cargo handling activity carried out by an organisation, consisting of labourers, equipment, policies, and infrastructure. Energy efficiency is crucial for ports and terminals, aiming to decrease energy consumption and become greener with minimal emission (Iris and Lam 2019). Therefore, the energy efficiency of all types of terminals needs to be enhanced to make them more competitive and profitable while becoming more efficient and greener. Currently, it is challenging to define port energy efficiency and its measurements due to a non-universal concept of what an energy-efficient port means. Wilmsmeier and Spengler (2016) argue that performance measurement in ways beyond conventional efficiency and productivity indicators is an influential agenda. In the case of energy consumption, they believe that there is a direct correlation between the terminal's sustainability, efficiency, competitiveness, and profitability. According to their research, this sustainability/efficiency correlation between energy consumption and productivity is not yet well known and has not been studied in detail. However, some very comprehensive current academic work is available to enhance the knowledge in this situation and research shows that equipment plays an essential role in seaports, especially in container terminals (Iris and Lam 2019; Lirn et al., 2013; Yang and Chang, 2013). Academics found that energy consumption utilisation, sustainable resource usage, and electric powered equipment usage are vital for ports (Cannon, 2008, Hiranandani, 2014, PIANC, 2013, Lirn et al., 2013). The energy efficiency of port equipment is also reviewed in Iris and Lam's (2019) review article. They briefly provided the types of conventional equipment, their specifications, and, consequently, each equipment's energy usage. Electrification and technologies for equipment are analysed in detail. Given the importance and popularity of electrification studies in energy-efficient ports, more research in terms of a technological application is carried out compared to the operational aspects.

According to the maritime technology outlook for 2030 (Marine Digital, 2020), more ships will deliver superior energy efficiency in the future by using clean energy sources resulting in the reduction of fuel usage, toxic pollution, and environmental effects. Steps such as hydrodynamically optimised structure, lightweight materials, and advanced hybrid energy storage devices will be implemented to boost energy efficiency. The report also states that automation will be aided by digitalisation, resulting in the construction of smart ships that will improve protection and environmental efficiency.

They reported that quay cranes (QCs), ship-to-shore gantry cranes (SSG) cranes are mostly used to handle cargoes. Rail-mounted gantry cranes (RMGs) and rubber-tired gantry cranes (RTGs) are employed for container stacking, and yard trucks (YTs) and automated guided vehicle (AGVs) are employed for horizontal transport of containers. SCs and RSs are capable of stacking and transporting full or empty containers (Carlo, Vis and Roodbergen, 2014). Highly automated machinery forms are also in use recently, and they increase operational performance and hence reduce human intervention (Gharehgozli, Roy and De Koster, 2016). Automatic container ports can include devices such as automatic QCs and RMGs. AGVs, automated lifting vehicles (ALVs) and intelligent autonomous vehicles (IAVs), which may be used for horizontal transportation, and automated stacking cranes (ASCs) may be used for loading activities in automatic terminals.

Only a few papers address transport operations and other processes in an integrated way. Cao, Shi, and Lee (2010) integrate the vehicle and storage yard allocation problem to minimise the unloading operation's maximum completion time.

Lifecycle planning provides a rational way of maximising lifecycle aspects, beginning with the original design and installation and culminating with the system's decommissioning and reconstruction after its service life (Frangopol and Soliman 2016). This lifecycle process needs to be analysed for ports, and it is structured especially for port equipment that is consuming a large amount of energy. Zrnić, Bošnjak, and Đorđević (2009) believe that the modern advanced and economical crane solutions have a direct impact on reducing operating and Life Cycle Cost due to low energy consumption. The lifecycle management strategy structure can be divided into four phases, each of which involves engineering assessment and economic analysis in the evaluation (Zhang et al. 2017): 1. Standardised inspection of existing infrastructure status; 2. Determine the remaining operational life of the deteriorating systems and components and forecast future performance; 3. Assess the cost of maintenance work, considering financial, environmental, and social factors; 4. Determine the maintenance methods and identify the right solution depending on the desired factor.

Moreover, a container terminal's capacity is generally calculated in terms of the volume of containers it can handle each year (Güler, 2001). Storage capacity utilisation is any other essential application of terminal/landside operational. Keller (2008) figured out that terminal storage utilisation, cargo sequencing, and improved turn time would be crucial in allowing fleets and terminals to satisfy potential demand. Wilmsmeier and Spengler (2016) show a strong link between some types of terminal operations and the scale of terminals. Small terminals with less than 100,000 box movements a year tend to use more than twice as much electricity a box as terminals processing more than 500,000 box movements. Some supporting technologies like operations and information technologies allow managers to expand capability without adding physical infrastructure (Gordon, Lee, and Lucas, 2005). His research discovered that the Port of Singapore created several man-made facilities to support and improve its natural resources include energy as a protected port. This research also found that capacity increment success depends on the interaction of multiple port resources instead of one resource improvement. Therefore, other terminals/landside applications like gate operation, port traffic/layout and empty storage (in and off terminal) availability and efficiency also were studied in the literature Kulkarni et al. 2017; Cubas Briceno-Garmendia, and Bofinger, 2015; and Pires et al. 2011). Kulkarni et al. (2017) argue that berths, yards, and gates are the three primary infrastructural resources that play a role in port capacity. They developed an application of simulation techniques in examining the performance of gate operations with any possible restriction for each truck type for any gate or road line used in a port in Asia. They managed to reduce waiting times at the gate. However, their study did not investigate any energy-related case or scenario for the gate operation.

In addition to these, the availability of value-added services creates benefits for a port by attracting port users and retaining them (Andersson and Roso 2016; Okorie, Tipi, and Hubbard 2016). Bichou and Gray (2004) support this strategy of value-adding logistics activities to create financial benefits for the port's business. Pettit and Beresford (2009) believe that very uniques value-added services within a port have become vital to the port's overall effectiveness within the entire supply chain. Okorie, Tipi, and Hubbard (2016) listed some of the primary value-added services in port as very sophisticated transport services for port hinterland area, warehousing, packaging, consultancy, and commercial support, assembly of cargo, canteen /catering, cold storage, and water supplies. They found that the most readily available and accessible value-added services are transport followed by warehousing and water supplies. Their research shows there is room for improvements for other services. Andersson and Roso

(2016) believe that exploitation (efficiency) and exploration (innovation) are two primary value-adding mechanisms.

According to an ESPO (European Sea Ports Organisation) (2013) report and ESPO (2020), port characteristics could change gradually as 79 ports of 21 European Maritime States issued environmental evidence showing that air pollution has been the most important concern since 2013. In 2013, garbage and port waste were placed in 2nd, energy consumption was ranked third, and noise was placed in fourth place. Then energy consumption became the second critical criteria between 2014 and 2019 (ESPO, 2020). However, in 2009, noise pollution was ranked fifth, followed by poor air quality, garbage/port waste, and dredging operations. It implies that the significance of the parameters which change with time and policies related to the subject (Chiu, Lin and Ting, 2014; Hiranandani, 2014; ESPO, 2013; Klopott, 2013; PIANC, 2013; Yang, Bai, and Schmidhalter, 2013; Lirn, Lin and Shang, 2013; Yang and Lin, 2013; Yang and Chang, 2013a; Park and Yeo 2012; Cannon, 2008; Darbra et al., 2005; Peris-Mora et al., 2005; Bailey and Solomon, 2004; Saxe and Larsen, 2004).

Also, the recent ESPO (2020) Environmental Report first time used “energy efficiency” instead of “energy consumption” as an environmental monitoring indicator. Energy efficiency is listed as the third most essential parameter of ports’ environmental priorities after air quality and climate change. Another critical perspective of the greener container terminal is the energy-related criteria which usually contains energy consumption, sustainable resource usage, and electric powered equipment usage (Cannon, 2008; Hiranandani, 2014; PIANC, 2013; Lirn et al., 2013). It is found that energy consumption plays a primary role in greener container terminals. PIANC (2013) states about the importance of energy efficiency and the energy transition from fossil towards clean fossil and currently towards renewable energy) for a sustainable port concept. Moreover, Yang and Chang (2013) consider that the main requirement of the green container terminals is to reduce energy consumption by using automated container terminal equipment. This equipment assists to reduce the greenhouse emissions of the ports. The ports can reduce energy consumption and be more eco-friendly by supplying energy from sustainable resources such as solar panels and wind turbine, and waste heat recovery (Port of Antwerp, 2021). Electric-powered vehicles are used to reduce emissions and energy cost (ESPO, 2013; Park and Yeo, 2012).

Consequently, research studies encourage container ports to invest in electric vehicles for more eco-friendly operations. Furthermore, noise pollution in the container terminals could be reduced by using these electric vehicles (Chiu et al., 2014; Yang et al., 2013; Yang and Chang, 2013). Therefore, the electric-powered equipment could be beneficial for the sustainability targets. For instance, fuel cells or “cold ironing” in-ports (which provides electric supply to ships from shore sources) reduce air pollution significantly (Psaraftis and Kontovas, 2010). Additionally, PIANC (2013) believe in the importance of energy efficiency and energy transition (from fossil towards clean fossil and towards renewable energy) for the sustainable port.

2.4.2.2.3 Policy and Other/soft Applications

As described earlier, all available policies indirectly contribute to the calculation of energy consumption of ship or ports to analyse CO_2 emission. Therefore, calculation and monitoring of ship and ports' emission targets may play an important role in energy consumption and efficiency of port-related operations. Besides EEDI, SEEMP methods and measurements, although energy regulations, which include EEDI, EEOI, SEEMP for energy-efficient shipping, is presented in detail in section 2.3, emission standards and other non-technical applications are provided in this subsection. Emission standards are controlled by policies. Saharidis and Konstantzos (2018) highlight the insufficient information available for upcoming vehicle emission standards, such as the new vehicle technologies at Euro VI Heavy-Duty Vehicle (HDV) generated GHG emissions during container transport in ports. The existing literature has focused on the interaction between port charges, freight demand, and volume expansion, but emission policies for ports have generated awareness only very recently (Basso and Zhang, 2007; De Borger, Proost and Van Dender, 2008; Park, Chang, and Zou, 2018). The research of Park, Chang and Zou (2018) introduces a scientific method to examine optimal port emission standards in a duopoly port environment. Their research found that the government will lower its emission standard as the maximum reservation price for shipping operators rises. If the unit cost of environmental damage at a port rises, the port would be required to meet higher emission standards. Their research indicates that the emission standards cause extra fuel cost to shipping companies which is costlier than a tax for congestion as well as emissions.

Education, training, and staff awareness-raising activities play a crucial role in the port business, and they are crucial for advances in a port's green profile (Burns and McDonnell, 2019; MarEd, 2019; Sisawo, 2018) believes that the training should emphasise energy-saving measures through the use of new technologies while also allowing for/inviting input from staff and stakeholders. His research states that in-house training, short but well organised educational activities, and symposiums with keynote speakers and technical experts from industries universities should all be considered. Moreover, MarEd (2020) is very recent and an excellent example of such an effort to fill the gap of education and training by developing a tool to train both shore and ship-based teams. In order to address energy skills gaps and barriers within the education system of seafarers and shore-based staff, the MarEd project has included such training for the proper implementation of global regulations for ship energy efficiency. The project team also believe that measures are not always well applied due to the poor education of staff/ lack of knowledge and application challenges of energy efficiency. Understanding how controlling the port and ship activities will help ship and ports be energy efficient is crucial. Any suitably designed awareness-raising activities can be advantageous for the port and ship staff. These activities may help staff to contribute to the entire system. For example, easing admin work in an organisation and devising improvement in operation can lead to improvement in energy efficiency. Having a specific procedure and administration relating to a port call contributes to the operational performance of liner shipping (UNECLAC, 2013). Careful logistic arrangements and including long-term cooperation can contribute to the increased sustainability and operability of the system.

The availability of renewable energy supply also impacts on CO_2 emission of the seaport and ports, as energy consumers can choose their supplies from more renewable energy sources to reach the green port target. Therefore, managing their energy tariffs to use energy sources with low emissions can play an essential role in port energy efficiency and CO_2 intensity per unit of cargo they serve. Besides these possible sources, governments play an essential role in converting their energy mix to greener sources and investing in better infrastructure around the port area to make them greener. The UK recently announced to make their electricity carbon-free until 2050 and invest £160 million to upgrade ports and infrastructure across communities, including Teesside and Humber in Northern England (Gov UK 2020a). On the other hand, Figure 2.14 shows the emission intensity of the power sector in the G20 countries in 2018, where the UK has a %55 decrease compared to the rate in 2013. This shows the country’s significant effort, and this is a great opportunity for seaports, which can obtain cleaner electricity and decrease their carbon footprint. The statistics show that some developing countries like Indonesia and Turkey's electricity emissions grown dramatically in 2018 due to coal-generated power increasing is faster than renewable. Turkey changed this trend in 2020 by tripling its renewable energy capacity in the last three years (IEA 2021). In the G20, South Africa continues to have the highest emission levels. In 2018, France, Brazil, and the United

Kingdom all reduced their power sector emissions significantly. Although France and the United Kingdom, along with Canada and Italy, get a 1.5°C compatible coal phase-out programme, Brazil and Germany have been the only two G20 nations with long-term clean energy plans.

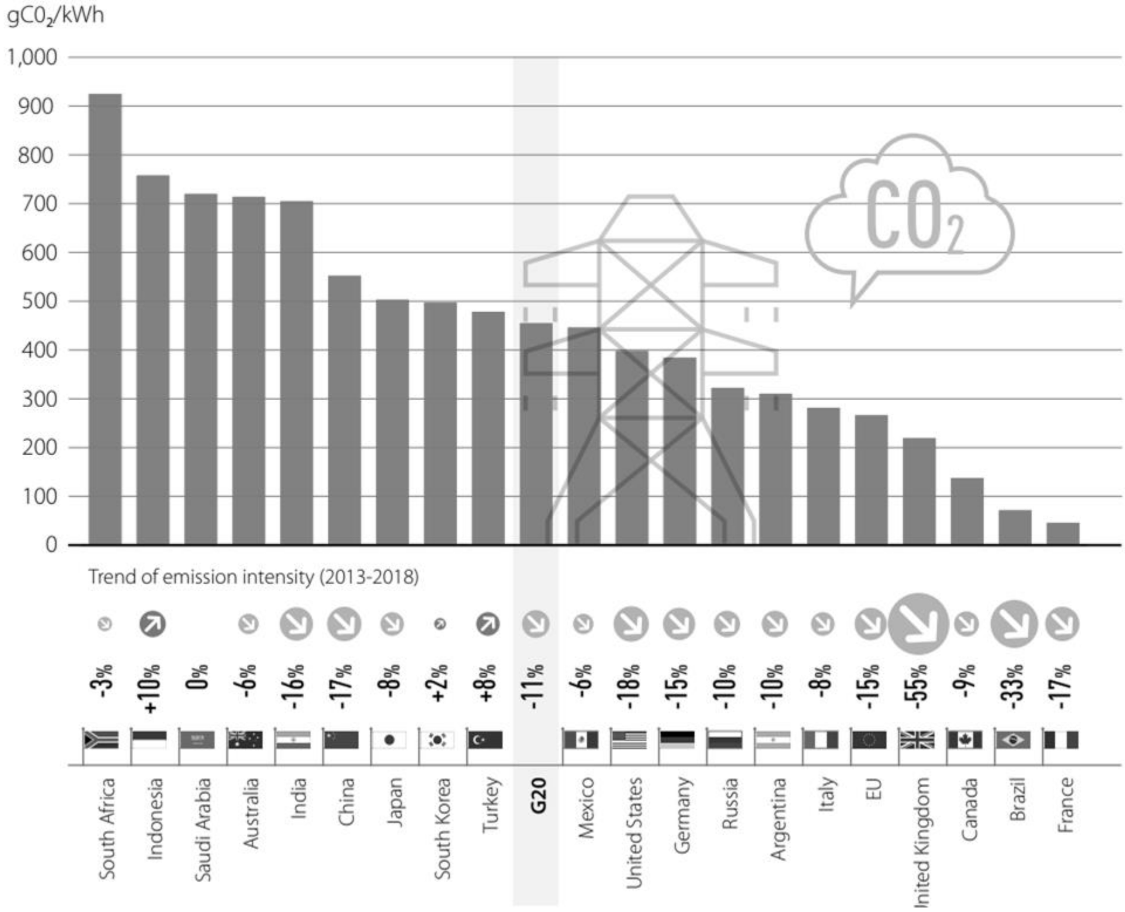


Figure 2.14 Emission intensity of the power sector in the G20 in 2018 (Climate Transparency, 2019).

2.4.2.3 Energy management

Recognising and managing the energy-related activities near or within the port has become more important in recent years due to the growing importance of emission control, energy trades, corporate environmental responsibility, and business focus on energy efficiency (Acciaro, Ghiara and Cusano, 2014). On the other hand, a few port authorities have successfully adopted energy efficiency policies to support the efforts towards greening the shipping activities. Seven port authorities in five Mediterranean countries (Italy, Slovenia, Montenegro, Albania, and Greece) are working together to establish a port energy management plan covering various zones (Mazzarino and Rubini 2018). Acciaro et al. (2014) suggested that for future ports, effective energy management will deliver significant productivity benefits and lead to the growth of new alternative revenue streams, increasing the port's competitive position. Their study uses examples from Hamburg and Genoa ports, which have already managed to arrange and rationalise their energy needs. However, both port energy management plans are based on city strategies. Sdoukopoulos et al. (2019) state that European port authorities have been working hard to develop effective strategies to generate green ports in recent years. They support developing targeted action plans and set up adequate management process structures. Their research is based on the vision that an energy management framework is a necessary approach for gaining a clearer understanding of the ports' energy profile and efficiency as well as evaluating any relative improvement made over time. Such solutions may have a broad reach, such as monitoring many installations, processes, and port locations. They can have a more specific focus, such as real-time energy consumption of any building or equipment.

2.4.2.3.1 Energy Supply and Demand

There is little prospect of shipping switching to low carbon energy sources in the short to medium term. Energy management strategies bring ports into the centre of a dynamic network of energy flows, and in order to effectively enforce those strategies, terminal owners and port authorities must understand how energy is used in the port and where it comes from (Acciaro, 2014; Wilmsmeier and Spengler, 2016).

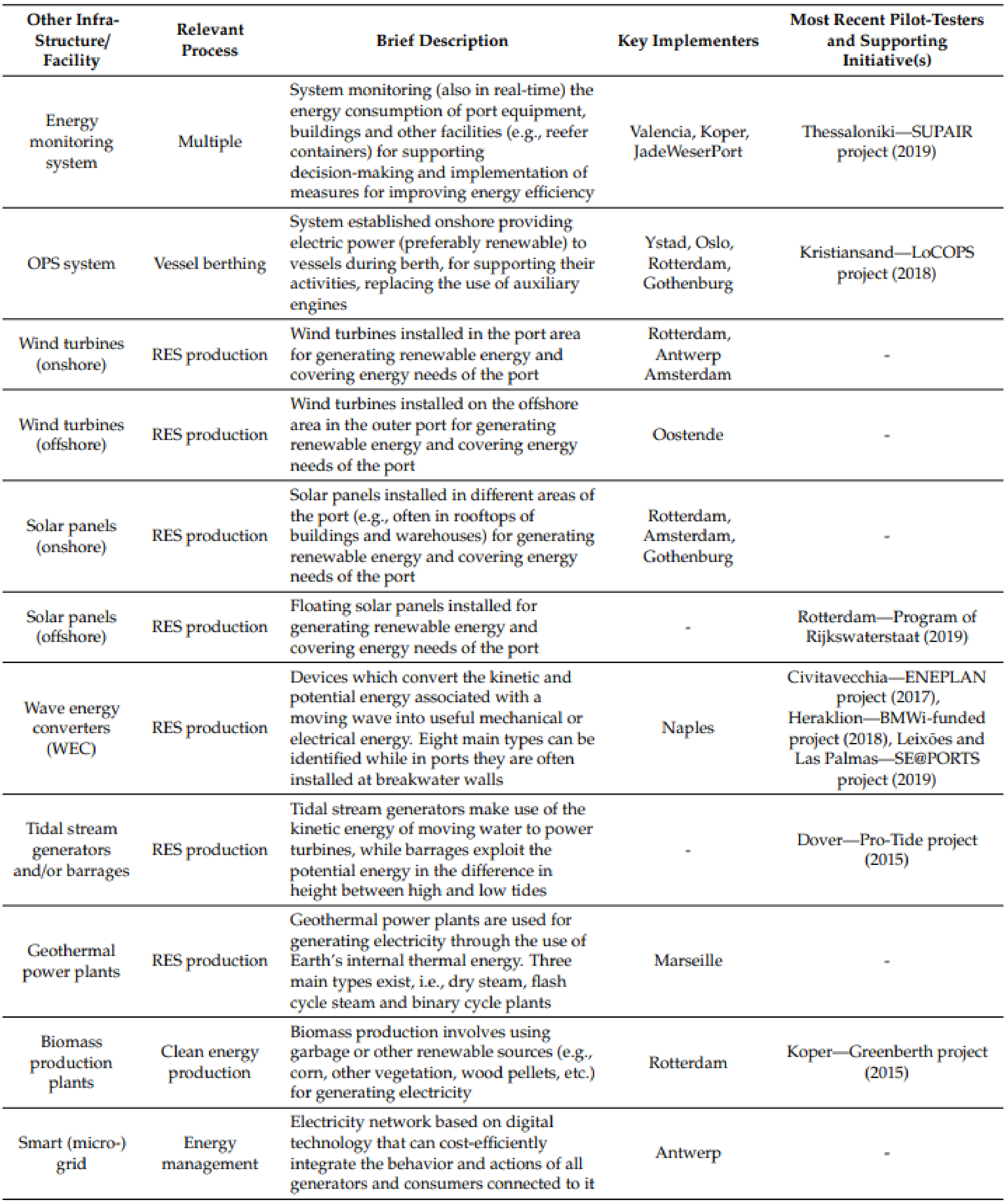
Energy consumption can be in the form of electricity or fuel. In recent years, Iris and Lam (2019) report that there has been a shift in energy consumption of ports from fuel to electricity. They believe that electrification of equipment and the usage of electricity produced in a port from renewable energy sources are the driving forces behind these shifts, as the public expects such change from the land-based businesses. Electrification often substitutes diesel as a source of electricity for ships when docked. Other alternative fuels (such as biodiesel, LNG, and hydrogen) are now growing rapidly as an alternative to fossil fuels as a source of power for a variety of appliances. Though the IMO Strategy suggests an indicative framework of measures to be introduced in short- (2018–2023), medium- (2023–2030) and long-term (after 2030), the impact of such measures is not expected within the next few years. Therefore, IMO will introduce additional and stricter emission regulations in the coming years (Serra and Fancello, 2020).

A decade ago, DNV (2012) predicted minor changes until around 2020, when a significant shift from bunker fuel (HFO) and marine diesel oil (MDO) to renewable and LNG was observed to meet much tighter emission requirements. Today, this prediction is proven, and LNG and renewable sources are getting more popular and replacing some of the world fleet bunkers as a competitive option for the shipping industry's current fossil fuel options. Almost 200 ships are powered by liquid natural gas (LNG) in early 2021, and this will be doubled by the end of 2023 (Evans, 2021). Shell plans to have fourteen LNG-fuelled ships, and all of them will consume 20% less fuel than the current lower-emissions LNG vessels. This movement will have a significant effect on port structures and energy supply and demand. Besides this, McKinnon (2014) argues that the use of wind and solar panels on ships is unlikely to have a substantial impact for many decades, and cold ironing (the method of running ships in port with shore-side electricity) would be limited to a small number of ports for the near future. However, as mentioned earlier, cold ironing facilities have increased more than expected. Wind technologies (like sailing rotors and wind turbines) became more applicable technology for ship and port area (Mason, 2020; Junqueira et al., 2021). Therefore, the energy supply and demand of port and ships are not static and should be monitored and managed to get the best possible outcome. Very recent news state that a new ship powered only by lithium-ion batteries is coming to Japan's coastline by the end of 2022 (Gallucci, 2021). This development shows that battery systems and renewable energy technologies seem to change the energy demand and supply for both port and ship sides. The port of Durres is a real example of an energy supply change in a port. The port of Durres evaluates the sustainability of possible investments for the implementation of sustainable and alternative energy sources in the port (Mazzarino and Rubini 2018). It investigates solar PV construction, the transformation of terminal vehicles and facilities from diesel to electric, introducing a cold ironing system, and investing in LNG supply structure (Danas, 2020; Mazzarino and Rubini, 2018).

Table 2.8 shows energy monitoring and onshore power supply projects, as well as smart energy grids and other applications, which are all being used by the ports to maximise various sources of renewable and clean energy (Sdoukopoulos et al., 2019).

Real-time monitoring of energy demand is vital for all ports, and Table 2.8 shows that the port of Valencia considers real-time monitoring to improve its energy efficiency. This gives a chance to analyse and respond to the port's energy consumption faster to address the overall and individual energy performance of port equipment and infrastructures.

Table 2.8 Measures taken to improve the energy efficiency of other port infrastructure and facilities (Sdoukopoulos et al., 2019).



Other Infra-Structure/ Facility	Relevant Process	Brief Description	Key Implementers	Most Recent Pilot-Testers and Supporting Initiative(s)
Energy monitoring system	Multiple	System monitoring (also in real-time) the energy consumption of port equipment, buildings and other facilities (e.g., reefer containers) for supporting decision-making and implementation of measures for improving energy efficiency	Valencia, Koper, JadeWeserPort	Thessaloniki—SUPAIR project (2019)
OPS system	Vessel berthing	System established onshore providing electric power (preferably renewable) to vessels during berth, for supporting their activities, replacing the use of auxiliary engines	Ystad, Oslo, Rotterdam, Gothenburg	Kristiansand—LoCOPS project (2018)
Wind turbines (onshore)	RES production	Wind turbines installed in the port area for generating renewable energy and covering energy needs of the port	Rotterdam, Antwerp Amsterdam	-
Wind turbines (offshore)	RES production	Wind turbines installed on the offshore area in the outer port for generating renewable energy and covering energy needs of the port	Oostende	-
Solar panels (onshore)	RES production	Solar panels installed in different areas of the port (e.g., often in rooftops of buildings and warehouses) for generating renewable energy and covering energy needs of the port	Rotterdam, Amsterdam, Gothenburg	-
Solar panels (offshore)	RES production	Floating solar panels installed for generating renewable energy and covering energy needs of the port	-	Rotterdam—Program of Rijkswaterstaat (2019)
Wave energy converters (WEC)	RES production	Devices which convert the kinetic and potential energy associated with a moving wave into useful mechanical or electrical energy. Eight main types can be identified while in ports they are often installed at breakwater walls	Naples	Civitavecchia—ENEPLAN project (2017), Heraklion—BMWi-funded project (2018), Leixões and Las Palmas—SE@PORTS project (2019)
Tidal stream generators and/or barrages	RES production	Tidal stream generators make use of the kinetic energy of moving water to power turbines, while barrages exploit the potential energy in the difference in height between high and low tides	-	Dover—Pro-Tide project (2015)
Geothermal power plants	RES production	Geothermal power plants are used for generating electricity through the use of Earth's internal thermal energy. Three main types exist, i.e., dry steam, flash cycle steam and binary cycle plants	Marseille	-
Biomass production plants	Clean energy production	Biomass production involves using garbage or other renewable sources (e.g., corn, other vegetation, wood pellets, etc.) for generating electricity	Rotterdam	Koper—Greenberth project (2015)
Smart (micro-) grid	Energy management	Electricity network based on digital technology that can cost-efficiently integrate the behavior and actions of all generators and consumers connected to it	Antwerp	-

Demand and supply balance of energy at the port is also vital where peak shaving reduces peak energy consumption to increase sustainable and cheaper energy usage. Container terminals aim to lower the costs of handling containerships as a result of this, giving them a competitive advantage. Geerlings, Heij, and van Duin (2018) investigated the possibility of reducing the peak demand of ship-to-shore cranes at container terminals by enforcing operational guidelines. The findings reveal that the peak demand (and peak-related costs) can be reduced by nearly 50% by increasing containership handling time by less than half a minute per hour.

Van Duin et al., (2019) also figure out that peak shaving techniques are promising ways to reduce peak energy usage in reefers.

2.4.2.3.2 Smart Grid System/Storage Applications

A smart grid (SG) improves the power grid and power utilisation. Traditional power grids are typically used to distribute electricity from a few central generators to many consumers or customers (Fang et al., 2011). However, SG creates an automated and distributed advanced energy distribution to the network using two-way power and knowledge flows. Smart grid technology can be characterised as self-sufficient networks that can easily identify solutions to challenges in an available infrastructure, reduce the workforce, and ensure that all port consumers and suppliers have access to renewable, efficient, secure, and sufficient power (Bayindir et al., 2016).

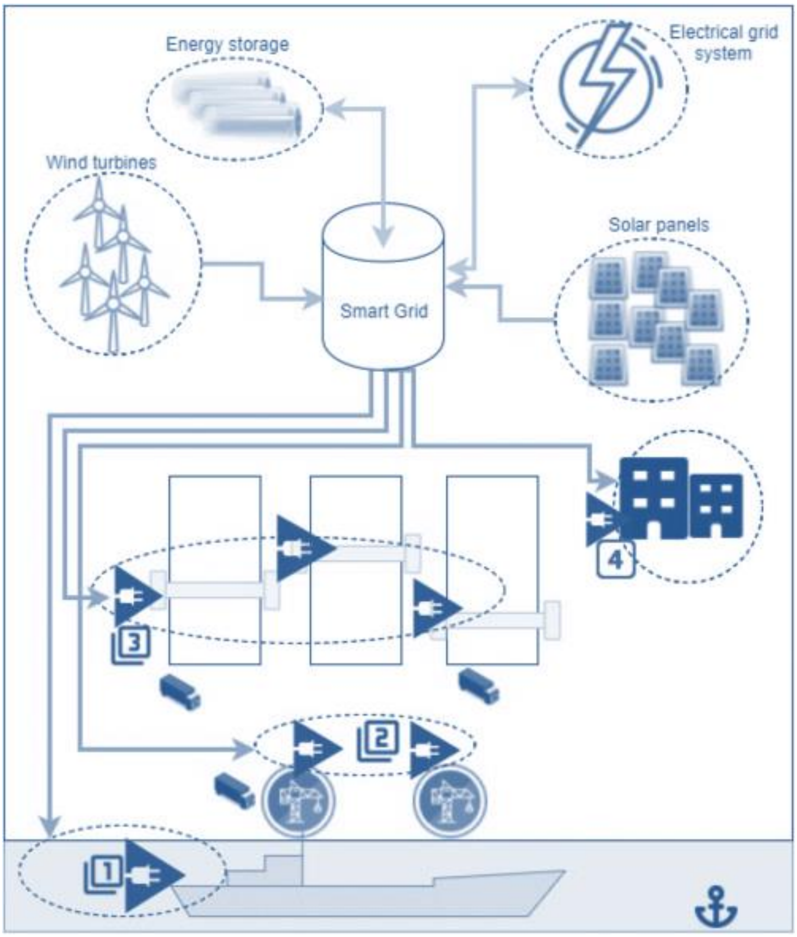


Figure 2.15 An example of a smart grid at a port or container terminal: (1) onshore electricity supplies, (2) quay cranes, (3) Rail Mounted Gantry Cranes, (4) buildings, warehouses, and the reefer field (Iris and Lam, 2019).

Components and relationships within the smart grid for a simplified seaport is shown in Figure 2.15. This consist of (1) onshore electricity supplies, (2) Quay Cranes, (3) Rail Mounted Gantry

Cranes, (4) Buildings, Warehouses, and the Reefer field (Iris and Lam). Parise et al., (2016) show a smart grid system used in large container port systems is capable of using mostly renewable sources to supply all the energy required.

Energy storage systems (ESS) offer a "buffer" zone between supply and demand when there is high demand or supply of energy (Safak and Devetsikiotis, 2021). In addition, to manage the sudden energy demand or store any possible unused supply like wind energy curtailment, energy stores have become a common approach (Canbulat et al., 2021; Canbulat, 2018; Canbulat, Balci and Canbulat 2020). ESS may help manage generation schedules if a seaport has any renewable energy sources. ESS also decreases imbalanced charges and prevents fines for not meeting deadlines. ESS may have a possible capacity to use at port for peak demand shaving. Additionally, on-site ESS could contribute to ancillary services like frequency support, reactive power provisioning, and black start during outage periods (Windeurope, 2017). Canbulat et al. (2021) show that onside energy storage technologies can increase the energy efficiency of ports if they suffer from their wind energy curtailments. This can create additional help for the entire port's energy efficiency. Technological advancements in power generation, transmission, supply, storage, and use have a significant impact on energy efficiency (Parise et al. 2016). Energy efficiency is also supported by technological advancements. Ports will benefit from the development of the latest fuel-efficient engines and fuel cells in the near future.

2.4.2.4 Policy

Energy efficiency is a broad concept that cannot be described by a single, clear quantitative metric; rather, a set of metrics has been created to monitor improvements in energy efficiency (Di Vaio, Varriale and Alvino, 2018). While some studies and publications mention "management success indicators" for environmental protection and energy conservation in the port sector, they are quickly linked to the review and assessment of particular environmental or energy programmes and activities, such as strategies, reports, records, policies within the port organisation. Most of the policies are discussed in earlier sections. One of the most mentioned ones is the reaction of the International Maritime Organization (IMO), including the Air Pollution Annex (VI) in the MARPOL Convention as more attention has been given to the harmful effects of shipping pollutants (Endresen et al., 2007; Dalsøren et al., 2007) and harbour environments (Isakson et al., 2001; Yang et al., 2007). Academics and operators, especially international organisations like the IMO, are actively promoting improved energy management by introducing mandatory SEEMPs for ships (Di Vaio, Varriale and Alvino, 2018). However, it may have an impact on the policy of port operation.

As one specific example, Martínez-Moya, Vazquez-Paja, and Maldonado (2019) identify the polluting equipment in the port before engaging with the port authority and policymakers to reduce energy usage or adjust the fuel alternative. Their research discovered that retrofitting RTG cranes and replacing fuel-powered terminal tractors with new LNG tractors could be a workaround for the Port of Valencia. However, there is a need for policy and safety measures to be identified. Boile et al., (2016) produced a port energy management plan (EMP) that identifies the most pressing concerns and problems. They formulated several standards for evaluating energy-efficient solutions and technologies, which they extended to several Italian ports to determine port energy needs, improvement measures, and alternatives. Their research proves that efficiency can be calculated in accordance with the environmental issues since they do not specify how the measurements are performed.

2.4.3 Ship Related Energy Efficiency Measurements

As part of the global target to GHG, the industry must operate and run lower emissions-higher energy-efficient ships. Therefore, shipping academics, companies, and regulatory authorities create ship-related energy efficiency measurements to understand the results of any advancements or policy changes. As mentioned earlier in the policy section, IMO introduced mandatory standards on most newly built vessels' energy efficiency (EEDI). They plan additional regulations, which are expected to be introduced for ship types not already covered by the current regulations. EEOI and the SEEMP have been adopted for existing ships in an attempt to monitor EEOI and advance their energy efficiency. When policies highlighted the importance of environmental challenges, many shipping companies have invested and ordered environmentally friendly vessels that are commonly known as a new generation of eco-friendly and fuel-efficient ships (Psaraftis et al., 2019). This sectoral reaction to regulations is also encouraged by academic researchers. Many research studies attempt to analyse ship-related advancement to achieve the best applications to reduce or use the energy most efficiently. The most popular examples of energy-saving measures for ships are listed in Table 2.9. These measures can be listed under three main groups except for policies; technical applications, operational applications, and their integration for ships energy efficiency.

Ship design-related energy efficiency measures provided a total contribution to reducing energy usage by ships, as reported by Faber et al. (2011). In their research, the design-related energy efficiency measures and their potentials are differentiated for each advancement, and they can reach up to 20% improvement once applied. Therefore, design-related studies are one of the primary technical measures to improve the energy efficiency of ships, and they focused on hull-related improvements like hull-propeller interactions, bow optimisation, hull coating, and air lubrication which provide different forms of energy efficiency potential. Based on Johnson (2013) review, hull bow optimisation has the potential of 10%, and hull coating has a 5% potential. Faber et al. (2011) and Johnson (2013) stated that hull coating has up to 5% potential energy reduction capability.

Table 2.9 Ship related energy efficiency measurements and their applied examples (Psaraftis et. al., 2019; Winkel, Bos and Weddige, 2015; Dimopoulos and Kakalis, 2014; Faber et al, 2011; European Union, 2011, Hansen, Rasmussen and Lutzen, 2020; Uzun et al, 2019; Sezen et al., 2021)

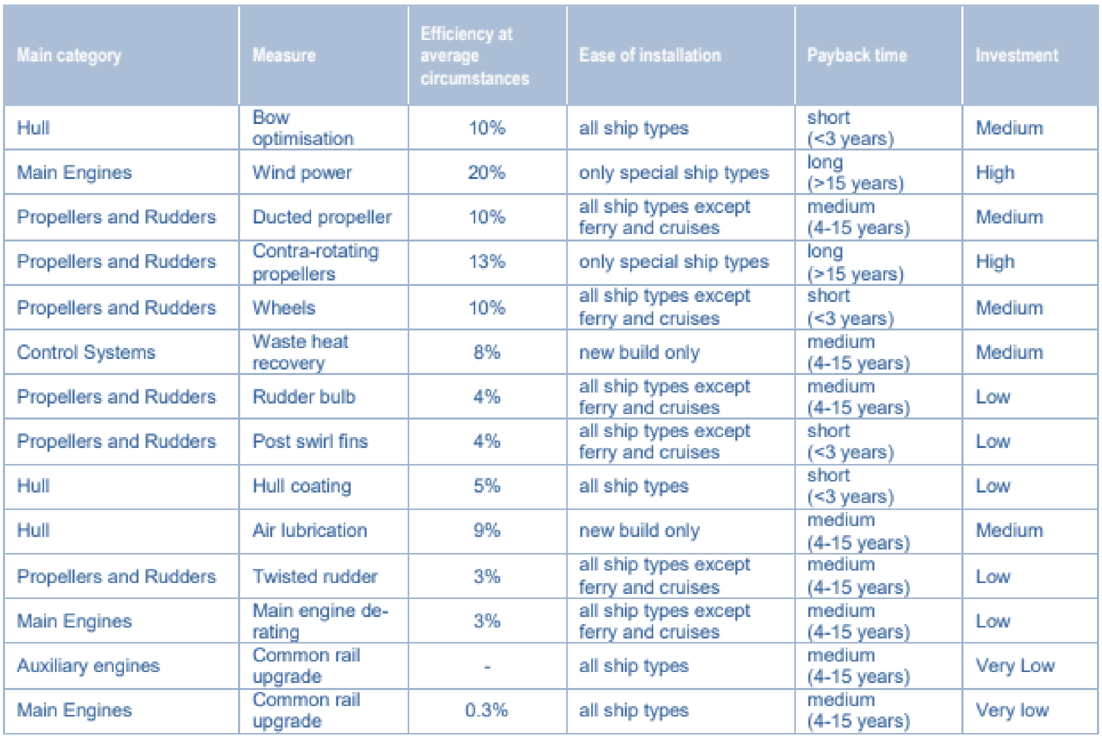
Applications	**Application Types**	**Example of measures and actions**
Technical measurements	Design	Hull Related Optimisation - Better aerodynamics to improve fuel efficiency, Optimising hull form or dimension, aft waterline extension, Hull coating, Biofouling resistance, Low profile hull opening, optimising water flow of hull openings, optimising skeg shape, interceptor trim plates, air lubrication Material Related Advancement - Lightweight construction, Antifouling paint technologies, new materials Propulsion Related Design - Engine design, propeller design, machinery part design The internal design of the ship - Leaving areas design, Lighting design, engine room design, Electrification and DC grid design
	Machinery, Propeller and equipment Technologies	Main and auxiliary engine optimisations - Common rail technology, main engine tuning, coordination of machinery parts Propeller Related Optimisation -Propeller – rudder upgrade (nozzle, winglets etc.), Propeller boss caps with fins, contra-rotating propellers, -Optimum speed reduction due to new or advanced machinery and propeller technologies Optimizing ship`s equipment like boiler and lighting
	Fuel-related measures	Ship fuel types Alternative marine fuels - Cleaner fuels, cleaner-burning engines, improved vehicle and propulsion technology: hybrid fuel cell auxiliary power, diesel electric propulsion, solar power. Energy Saving devices - waste heat recovery, Towing kite, flattener rotors, low energy lighting, heating, efficiency of ventilation and air conditioning (HVAC), speed control of pumps and fans, fuel efficient boilers, Propulsion efficiency devices.
Operational measurements	Voyage distance optimisation	-Speed optimisation - Slow steaming -Just in time arrival Plan and organize routings and scheduling to reduce empty mileage and optimize operations
	Cargo volume optimisation	-Trim optimisation - Manoeuvring optimisation - Stability optimisation - Stakeholders involvement
	Contract terms optimisation	- Arranging ship contract to arrange/rearrange delivery or discharge dates
	Communication	Increasing communication between operation legs like ports and ship agency
	Other	Operational evenness of crew Accurate reporting like the logbook
Regulatory measurements	IMO Ship Energy Efficiency Regulations	EEDI Emission standards, design of vessels and infrastructure, speed limits, targets for the use of renewable energy sources, targets for energy efficiency, emission and noise standards for ships and ports, Energy efficiency design index (EEDI), Energy efficiency operation index (EEOI), Ship energy efficiency management plan (SEEMP), IMO Fuel oil consumption Data reporting
	EU MRV Mechanism and Other policies or regulations	Carbon emission market mechanism Emission standards, design of vessels and infrastructure, speed limits, targets for the use of renewable energy sources, targets for energy efficiency, emission and noise standards for ships and ports

Researchers use various software and programs like; Computer-Aided Drawing (CAD) to design 3D models or Computational Fluid Dynamics (CFD) for further analyses o to reach the best design options for each ship or ship sections. Machinery parts and propeller technologies are the other areas investigated by academics. Propeller Related optimisation studies focus on propeller – rudder upgrade (nozzle, winglets etc.) and propeller boss caps with fins, contra-rotating propellers etc. Main and auxiliary engine optimisations focus on areas like main engine tuning and coordination of machinery parts (Fanning, 2016).

Fuel-related measures are also available in the literature, and alternative marine fuels and fuel energy saving devices are analysed, and their details are given in the previous table (Percic, Vladimir and Fan, 2020 and Mandic et al 2021). Ships have profited from the latest innovations such as a Becker Twisted Fin, which increases the propeller's efficiency helping for an actual reduction in the energy cost and minimise CO_2 pollution by around 6.3% (Guiard and Leonard, 2013). New-generation engines substantially decrease oil usage (25 per cent) with an overall CO_2 emissions loss of 3 per cent (Psaraftis et. al., 2019). Recently, the Rotor Sails technology has achieved 8.2% fuel redaction by using wind energy during ship sailing. The rotor was installed onboard Maersk Pelican in August 2018 saved 8.2% fuel from 1 September 2018 to 1 September 2019 based on Norsepower and Maersk Tanker (2019) press release.

Family-owned ship manufacturer Ulstein realised their first application of a battery hybrid vessel for the offshore wind industry in 2019 (Ulstein, 2020). They revealed their plans on 3 June 2020 to scale the use of hydrogen as a marine fuel. Although a fuel cell has high efficiency, today's technology and hydrogen infrastructure only allow operations of 4 to 5 days in zero-emission mode (Wingrove, 2020). On the other hand, Michala and Lazakis (2016) investigate wireless condition monitoring system for ship machinery and equipment to have better and safer fleet management. They developed a new method under INCASS (Inspection Capabilities for Enhanced Ship Safety) EU FP7 project (Michala and Lazakis 2016). They also realised that condition-based maintenance provides better fleet management, energy efficiency, effective decision-making, and emission reduction. The report of Winkel, Bos and Weddige (2015) focused on energy efficiency technologies for ships, summarised the most critical technologies regarding efficiency improvement and their potentials of saving as detailed in Table 2.10 below.

Table 2.10 Energy Efficiency Measures for ships (Winkel, Bos and Weddige, 2015).



Main category	Measure	Efficiency at average circumstances	Ease of installation	Payback time	Investment
Hull	Bow optimisation	10%	all ship types	short (<3 years)	Medium
Main Engines	Wind power	20%	only special ship types	long (>15 years)	High
Propellers and Rudders	Ducted propeller	10%	all ship types except ferry and cruises	medium (4-15 years)	Medium
Propellers and Rudders	Contra-rotating propellers	13%	only special ship types	long (>15 years)	High
Propellers and Rudders	Wheels	10%	all ship types except ferry and cruises	short (<3 years)	Medium
Control Systems	Waste heat recovery	8%	new build only	medium (4-15 years)	Medium
Propellers and Rudders	Rudder bulb	4%	all ship types except ferry and cruises	medium (4-15 years)	Low
Propellers and Rudders	Post swirl fins	4%	all ship types except ferry and cruises	short (<3 years)	Low
Hull	Hull coating	5%	all ship types	short (<3 years)	Low
Hull	Air lubrication	9%	new build only	medium (4-15 years)	Medium
Propellers and Rudders	Twisted rudder	3%	all ship types except ferry and cruises	medium (4-15 years)	Low
Main Engines	Main engine de-rating	3%	all ship types except ferry and cruises	medium (4-15 years)	Low
Auxiliary engines	Common rail upgrade	-	all ship types	medium (4-15 years)	Very Low
Main Engines	Common rail upgrade	0.3%	all ship types	medium (4-15 years)	Very low

Table 2.10 summarises most of the energy efficiency measures and their energy efficiency potentials. The table shows that the main engines have up to 20% energy saving potential, followed by propeller and rudder applications. Their payback period is also analysed in the table to support investment decisions. It indicates that standard technologies are accessible to achieve high-efficiency improvements. There is a potential to save 35% of fuel when only some improvements made. Their payback period is 15 years to save this significant amount of energy. Some of these investments require a high amount of initial capital investment, like contra-rotating propellers and wind power, but they bring the highest savings of between 13% and 20%. The medium investments and low investments also have the capability of energy efficiency improvements between 5-10% and less than 5%, respectively. Ship design-related energy efficiency measurements provided a total contribution to a reduction in inefficient energy usage. However, manufacturers usually express these energy efficiency gains after applying or testing on one or certain ship types. Their validation from different sources can be required to avoid any misleading results. Therefore, these technologies need scientific validation to compare in-service data with model testes or CFD under valid method and realistic conditions (Mfame, 2018).

Operational applications can be listed under two generic groups for ships. They are ship operational measures and other/soft measures. Academic and industrial studies have attempted to advance ship operation by applying speed optimisation like slow steaming, just in time arrival and trim optimisation. Port or ship related logistic optimisation also available in the literature. As an example, Cui, Turan, and Boulougouris (2016) established a ship weather routing optimisation approach considering both times of arrival and fuel consumption. Varelas et al. (2013) have created an innovative toolkit for ship routing optimisation. Improving voyage planning is one of the popular ones in the literature. Lu et al. (2014) developed an accurate and practical ship operational performance prediction model that is beneficial for selecting the optimal route to the specific weather forecast and the multi-objective weightings, including the most energy-efficient route option. It also assists in building a more efficient system to manage a fleet.

Furthermore, Lu et al. (2015) created a method that can precisely forecast the operating efficiency of the vessel for a particular commercial vessel under different designs, at differing speeds and direction of waves, and then allows the operator to examine the relationship between fuel consumption and the various sea states and directions that the vessel may encounter during its voyage. Using the operational performance prediction model and real-time climatological data, different options for the ship's navigation course can be evaluated according to several objectives, including increasing safety and reducing fuel consumption and voyage time. This allows the user to analyse the relationship between fuel consumption and the various sea conditions. However, the only optimal route could not be capable of solving the problems of the system. Complex maritime logistics require more developments to manage all the objectives as an integrated system. Individual elements can be developed to maximise the utilisation (days sailing laden, cargo loaded) of the ships. Voyage optimisation is a practice to select the optimum route for the ship operators to increase energy efficiency and reduce the GHG release from the shipping industry while delivering the goods on time.

Additionally, Yuan et al. (2019) compared the following advancements in their research; speed reduction, trim optimisation, autopilot adjustment, weather routing, and speed control of pumps and fans. They find that speed reduction has the highest energy savings potential of up to 10% and is considered as the top option among the mitigation measures analysed. However, none of these academic research studies considered the ship's time at the port or possible changes with port operations. However, Sun et al. (2020) believe the reducing engine revolution will increase EEOI explicitly. They believe that slow steaming may bring less environmental benefit if the life cycle assessment result is involved (Sun et al. 2020).

Fan et al. (2019) carried out a comprehensive review in their research and mentioned the factors affecting the ship operational energy efficiency. Based on this research, the factors influencing the operational energy efficiency are summarised, and these factors are even further evaluated. The results are presented from the microcosmic and macroscopic point of view in Figure 2.16. These influencing factors are used to calculate most of the results with regards to the ship operational energy measures as mentioned above. They have four critical sections under micro factors: operations, ship efficiency, ship type, and environmental factors. They may be grouped into two main subsections as operation and ship-related factors. However, this study gave a more detailed perspective to understand the factors involved in ship-related energy efficiency measurements.

Ship related parameters are listed under four subgroups; standard ship hull parameters (e.g. ship length, ship width, weight, displacement, block coefficient, midship coefficient, prismatic coefficient, water level coefficient, buoyancy location and superstructure wind area); power system parameters (e.g. primary engine size, rated capacity, rated speed, specific fuel oil consumption); propulsion system parameters (e.g. propeller diameter); parameters of other fuel consuming equipment (such as the auxiliary engine, boiler, and incinerator); and electrical equipment parameters.

Operating parameters primarily include:

- the ship working parameters (e.g., speed of the ship, main engine speed),
- loading parameters of the cargo (e.g., loading rate - draft, floatation - trim angle),
- a degree of the vessel fouling,
- Ship sailing line and type of fuel.

Parameters of natural environments primarily include current, wind speed and direction, water level, wave height, and many more. Ship efficiency primarily includes thermal efficiency (e.g., main engine thermal, thermal auxiliary engine efficiency), combustion performance of the system (e.g., propeller performance, shaft movement effectiveness, hull efficiency, gearbox efficiency). The mentioned parameters can significantly affect the energy efficiency level of a ship, but if the entire fleet is to be addressed, the energy efficiency variables at the company level should also include some macro variables. One of these factors is linked to the management of a shipping company, in particular, raising employee awareness on energy efficiency, a fuel-saving opportunity for crews, the on-board introduction of emerging technology to energy saving and emission reduction (ESER). The shipping market environment is another factor that mainly involves the shipment price of the cargo, global oil price, shipping prosperity index. Policies and regulations on ESER in the shipping industry are the last factors. It primarily covers the global and local compulsory ship emission policies and regulations like IMO ship energy efficiency regulation and the EU MRV policies, and the CO_2 emissions market mechanism.

IMO developed a ‘Train the Trainer’ course on energy-efficient ship operation in 2016 (IMO, 2016b). In this material, they state that improving energy efficiency awareness among the core personnel and seafarers through the course will result in a change in attitude that reduces shipboard energy usage and fuel consumption. They believe that it is important to increase visibility and provide the necessary support for all shore-based and shipboard staff to enforce the company's energy management strategy successfully. Their course module also states that daily onboard meetings with the entire crew should be held to assess the shipboard energy efficiency plan's efficacy. Ideas for best practice obtained from seafarers should be registered and passed back to shore to be tested for use on other vessels and possibly included in an energy efficiency report for the entire company.

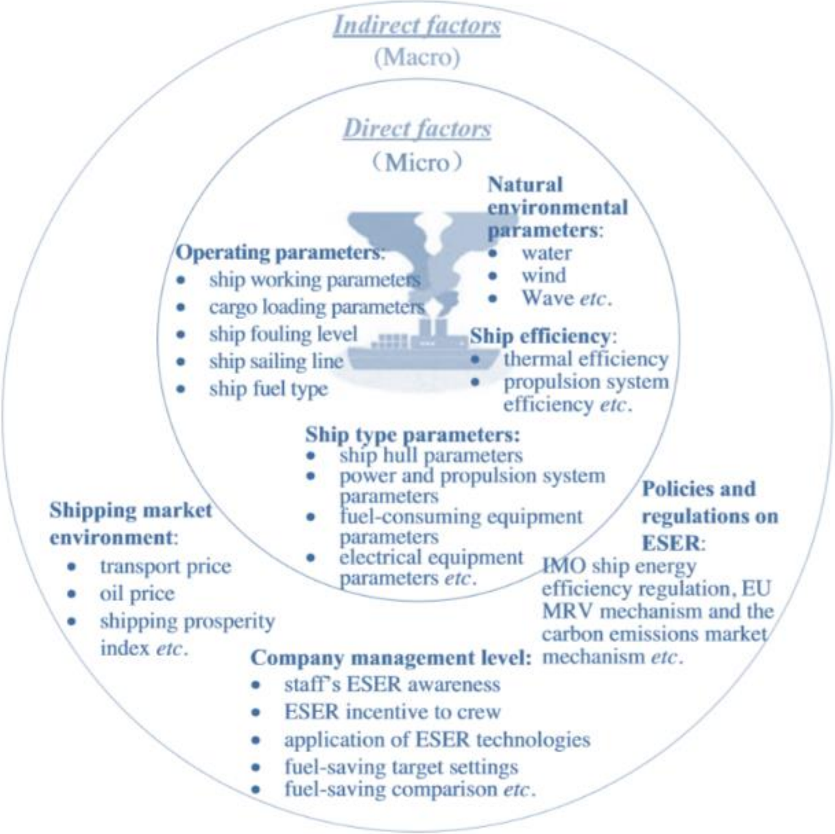


Figure 2.16 Categorisation of the aspects affecting the ship operational energy efficiency (energy saving and emission reduction (ESER)) (Fan et al 2019).

Armstrong and Banks (2016) also emphasized that technical solutions alone are unsuccessful in achieving real energy efficiency upgrades without any efforts like training. Changing personnel may be a barrier for energy management due to the loss of the experienced crew on energy management unless correct measures and records can be collected to use as a reference for future energy managers (Jafarzadeh and Utne, 2014). Therefore, new managers may seek guidance or training to manage the best possible energy-efficient ship operations. On the other hand, small businesses often have a small team that may interact with various topics, and they do not have time to respond to energy issues due to time limitation (Thollander, Danestig and Rohdin, 2007). Therefore, short and effective methods may need to be implemented for staff training. On the other hand, the crew onboard needs real-time data and incentives to prepare for fuel-saving operations, resulting in more energy-efficient freight (Schøyen and Bråthen, 2015). This suggests that to make better decisions on how to run their shipping company more flexible and energy-efficiently, ship managers may need to provide more coordinated effort between ship and shore-based workers.

2.4.4 Energy Efficiency Measurements for Fleet Operation

A fleet is a group of ships operated by shipping companies by using a fleet management technique. Shipowners or charterers always aim to maximize their income from ships while they are at sea. They usually use signed contracts with fleet management companies that manage the day-to-day operations of ships, including crewing, maintenance, etc., bunkering, while ship owners concentrate more on cargo securing activities. Ships need to be ready in the best possible technical and operational condition to be energy efficient. Some new smart energy efficiency management methods developed by private companies like Wärtsilä, DNVGL and Maersk also assist fleets and ships in saving energy. Also, as mentioned earlier, measures like EU MRV (Monitoring, Reporting and Verification) directive and IMO DCS (Data Collection System) are forcing shipping companies to adopt strategies and efforts to fulfil the regulations and improve the environmental performance of their ships.

Very few private companies share very limited information about their measures to enhance their ship’s environmental performances. They explain their straightforward methods, results, and the data they collected. As an example, Wärtsilä has developed a fleet performance-monitoring tool called SkyLight in 2016. The tool offers a cost-effective fuel performance-monitoring solution and optimizes vessel operations for vessel owners, operators, or charterers (Wartsila, 2020). Their tool combines the collected data about the ship’s movements via satellite, the vessel's noon reports and enriched with meteorological data, sea state and currents to model the vessel's speed and fuel performance. They use this data to calculate an accurate fuel-speed curve for all ships to analyse ships' performances. Their method is presented in Figure 2.17.

D.N.V. G.L. is another company that offers service of energy efficiency applications for ships and shipping companies (DNVGL, 2021b). They provide various services like effective fleet performance management. However, they do not publicly reveal which tools and calculation they used while they provide solutions. However, it seems they consider SEEMP, EEDI, EEOI and ISO 50001 energy management system. Most companies follow these international policies and applications as a backbone of their system while they calculate or implement their systems. Therefore, understanding these policies or measures can be beneficial to understand the energy efficiency measures in shipping. Like any other effort, the "eco voyage" of Maersk Line is a shipping software tool that can help plan a ship journey to reduce fuel expenses while minimizing fuel consumption; and the eco-sailing system of Mitsui O.S.K. Lines (M.O.L.) includes the latest 20,000 TEU-class container ships fitted with modern, efficient technologies (Psaraftis et. al., 2019).

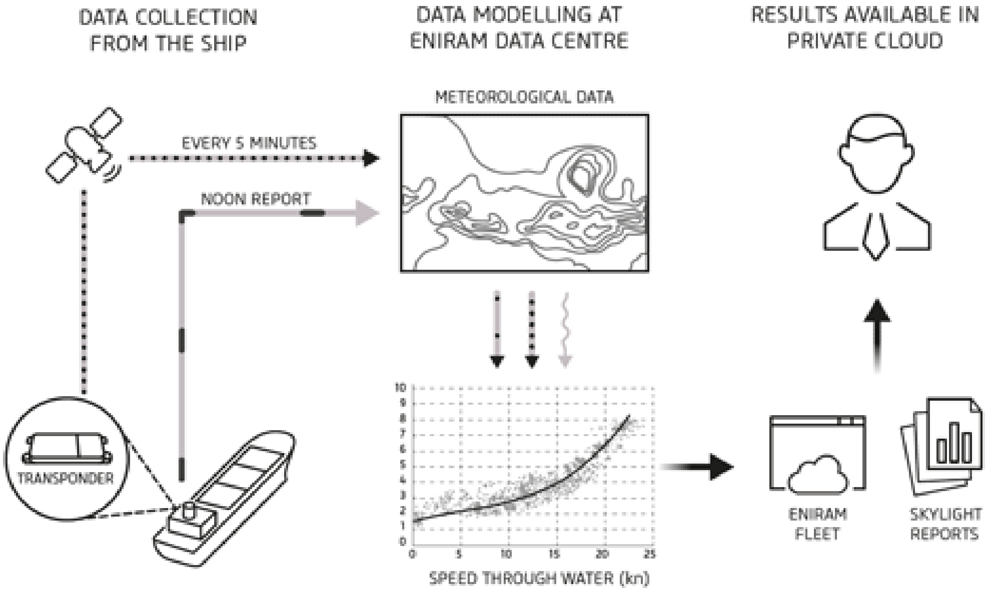


Figure 2.17 Concept of SkyLight and Ship's movements data and noon data collection (Wartsila, 2020).

On the other hand, Armstrong, and Banks (2015) demonstrate that a range of potential measures for improving energy efficiency is beneficial and available in the shipping sector. These measures mentioned in their study contain advanced fleet planning (weather routing/routing for just-in-time), speed and power optimisation, optimised ship handling (ballast/trim/use of rudder and autopilot), advanced fleet management, improved cargo handling and better energy management. These listed measures cover most of the fleet operational measures adopted by several shipping companies. These parameters need to be used in the actual application more carefully to build an energy-efficient and sustainable fleet. Johnson (2013) also focused on operational measures, and the research mentioned that the high potential of advancement is available in this sector. Bazari and Longva (2011) assessed that a 30% reduction would be possible by applying the operational measures enabled by the SEEMP only. Based on Faber et al. (2011) research, up to 10% of energy-saving comes from voyage optimisation. A significant contribution to scientific literature has been provided by Eide et al. (2009) and Longva, Eide, and Skjong (2010). Eide et al. (2011) constructed a model to project future CO_2 emissions from shipping, considering global fleet expansion and various measures. They also highlighted fleet optimisation in their research to tackle the emission problems of the world fleet. Besides macro analyses, some local efforts also are also implemented, like the Barcelona Port Authority, which has a method for measuring CO_2 emissions and a transport path, which is connecting Europe and the entire world through the Port of Barcelona. ECOcalculator is the name of this instrument (Barcelona Port Authority, 2017). This service provides their customers with a visualised idea and awareness to manage their CO_2 consumption.

2.4.5 Integrated Energy Efficiency Measurements

One of the well-known indicators for an integrated system can be the Key Performance Indicators (KPI). Started by InterManager in cooperation with the Research Council of Norway, MARINTEK and Wilhelmsen ASA, the Shipping KPI Project has developed standard tools for measuring both companies' and ships' performance. Now founded as the independent, not-for-profit KPI Association Ltd, the project works with a wide range of industry stakeholders and aims to develop industry-wide standards for vessel performance measurement. KPI is a standard based on 64 different performance indicators to allow for a detailed and accurate ship performance comparison and, they explain all details in their document KPI (2020). The system is originally developed to define, measure and report information on the operational performance of shipping.

This KPI expresses the ship's energy efficiency by comparing the emitted mass of CO_2 to the vessel's total transportation work. The definition gives the emitted mass of CO_2 per ton of cargo transported one mile. As the Performance Indicator (PI) Value' Emitted Mass $\mathrm{CO_2}$ is to be given in tons, the figure is multiplied by 1 million to get the $\mathrm{KPI_{Value}}$ in g/transport work (ton-mile, passenger mile, TEU-mile, etc.). KPI referenced IMO's Energy Efficiency Operating Index, and calculation showed below:

A: Emitted mass of $\mathrm{CO_2}$ [tonne]

B: Transport work [tonne mile]

$$\mathrm{KPI_{Value}} = \frac{A}{B} x10^6 \qquad (vi)$$

$$\mathrm{KPI_{Rating}} = \frac{\mathrm{KPI_{Value}} - \mathrm{KPI_{MinReq}}}{\mathrm{KPI_{Target}} - \mathrm{KPI_{MinReq}}} x10^6 \qquad (vi)$$

Where $\mathrm{KPI_{MinReq}}$ refers to the minimum requirement of the key performance indicator for the chosen indicator in that ship or operation. $\mathrm{KPI_{Target}}$ refers to the targeted key performance for the chosen indicator for that ship or operation.

More than 20 shipping associated firms and organizations have utilised Shipping Performance Indexes (SPI), Key Performance Indicators (KPI) and Performance Indicators (PI). SPI gives external stakeholders information about the overall performance of a ship as a weighted average of related KPI Ratings on a range between 0 and 100. KPIs ratings will form the basis for the Shipping Performance Index (SPI) score. PIs are the building blocks giving the basis for KPI Value calculations. The KPIs can be expressed in two ways; a KPI Value which is a mathematical combination of relevant Performance Indicators Values, and a KPI Rating which is an expression of the KPI Value on a scale between 0 and 100 where a high rating (100) is a result of high/excellent performance. PIs are directly observable parameters recorded (measures) for each ship under management, e.g., the number of the dismissed crew or fire incidents.

The fact that there are many factors involved complicates the topic of energy quality. The commercial operator is responsible for making the best use of the ship's power, which influences the transportation work. Competition is another major element in transportation work. The hull design, engine type (and, to some degree, age) of the ship, as well as the load factor for each voyage, all influence the amount of $\mathrm{CO_2}$ emitted mass (KPI, 2017) by the ship.

Based on the Author's previous publications (Canbulat et al 2017, Canbulat et al 2018, Canbulat et al 2019), ports and fleet energy efficiency can be managed together to determine the combined impact of the system on the energy efficiency of the shipping. These studies used the first BBN based analyses to capture this complex interaction between ship and port, integrated operation and their energy efficiency relation. Banks, Turan and Incecik (2013) also stated that integration of ship and port operation might include installing sufficient port assets and proper resource management between all the stakeholders involved to generate a positive impact on energy efficiency. Moreover, Intertanko and OCIMF (2010) reported the wasted energy for ships, which steam at full speed in order to dock at a harbour where there are known delays in cargo handling. Ships can avoid wasting time at anchor waiting for port cargo handling when such ship-port integration takes place and is monitored effectively. Emissions can thus be reduced, congestion can be avoided, and safety can be improved in port areas. For instance, where an inevitable inefficiency is observed (such as a port delay), proper communication between fleet and port stakeholders can allow for alternative operational measures to be implemented, such as just in time arrival (Intertanko and OCIMF 2010).

2.5 Simulation Based Energy Efficiency Applications

Various methods and models are available and have the capability to apply to forecast and monitor the energy consumption of ship and ports in isolation. However, no particular model or system has been used to improve the energy efficiency of a vessel or port or their integration (Tillig, Mao and Ringsberg, 2015). Different probabilistic methods and simulation tools and models are used to analyse energy efficiency in the maritime transport sector. However, BBN and ARENA described in the following subsection, are used to examine integrated port and ship operation's energy efficiency for the first time in the literature.

2.5.1 Bayesian Belief

Over the last decade, research focussed on dependability/inter-operability of marine transport systems, including port and ship sub-systems, to enhance their reliability, safety, efficiency, and environmental performance (Mansouri et al., 2009). Numerous diverse sets of studies and schemes attempted to emphasise the issues related to dependability difficulties between Ships and ports. Some researchers (Cao, Coutts, and Lui, 2013; Haser 2013; Neil and Littlewood 1996; Yuqing and Tong 2008) indicate that the BBN which Thomas Bayes introduced in the eighteenth century led to researchers using his approach, which provides the most suitable method to investigate the challenges mentioned above. Although BBN were mainly applied to maritime safety risk, maritime design risk and financial risk management, it is possible to adapt it to any probabilistic analysis and measure to assess the performance of the marine transport systems. Due to the interoperability nature of the marine transport systems, BBN may provide a useful tool to measure the IEE of ships and ports, especially for ships working on liner service, consecutive voyage chartering and time chartering. Canbulat et al. (2019) found that primary energy efficiency variables influence marine transport's holistic energy efficiency on both ship and port. They present an integrated method to increase energy effectiveness, enhance cost-effectiveness, and mitigate $\mathrm{CO_2}$ releases, which are attributable to the activities of vessels and ports. A holistic course of action is required to measure energy efficiency and emission of ships deployed in liner services and under consecutive voyage or time charter conditions more comprehensively by considering both the ship's voyage and port operations. Their research proposed a holistic inter-operability framework comprised of shore-side and vessel operating activities by utilising probability-based BBN. The developed structure quantifies the energy efficiency performance of a particular port regarding a specific shore-based marine transport operation more holistically, considering both ship voyage and port operation aspects. Canbulat et al. (2017) and Canbulat et al. (2019) BBN analysed the port and ship operation's integrated system using BBN, providing a probabilistic result. These research studies then highlight the need to investigate this system with a simulation tool. The following subsection will present a review of the simulation tools and the chosen tool to develop energy efficiency analyses.

2.5.2 DES Application

2.5.2.1 Introduction

A discrete event simulation is a modelling approach broadly used in decision support tools for shipping, logistics and supply chain management (Seay and You, 2016). Literature is quite rich for the simulation studies in the shipping industry. In shipping, one of the early works was presented by Legato and Mazza (2001) developed a simulation model for berth planning and resources optimisation at a container terminal via discrete event simulation. Woo and Oh summarised the application areas of simulation in the shipbuilding industry (Woo and Oh, 2018). Gunbeyaz, Kurt and Turan presented one of the first research on designing efficient shipyards by applying DES. Caprace et al. (2011) first reviewed available DES software to find the best option using an analytical hierarchy process and using the same number of resources; 18% of the decrease in lead time was achieved. Muñoz-Villamizar et al., (2021) very recently published a research article on the environmental impact of fast shipping. They applied DES and figure out that fast shipping raises total CO2 to 15%. Many simulation software and techniques are used in DES, like Simul8, AutoMod, and Arena (Wales and AbouRizk, 1996). However, Cosgrove (2008) and Dragović et al. (2017) believe that the Arena simulation software package is one of the modern and most applicable simulation software used for containers port application. Therefore, this research continued to focus on DES Arena simulation while carrying out this research.

This part of the research carried out a detailed review of the published literature on simulation models applied to ports by using ARENA simulation software. The research reviews the journal, conference, and academic workshop publications between 1998 and 2019. The researchers identified the increased usage of the ARENA software in academic publications with regards to seaports, especially container terminals, over the past 21 years. Most of the available research focused on the operational challenges, specifically on the transfer and storage equipment, planning an evaluation such as performance, and comparisons of models and integration such as SM and OM integration. Although the ARENA has the capability to analyse the energy efficiency of the port systems by optimising the port operations, none of them specifically addressed energy efficiency in the container port operation (Arena, 2014; Arena, 2021; Simulation Modelling, 2016). This review part shows that most of the publications have taken place in the last decades. Additionally, some of the journals, such as Simulation Modelling Practice and Theory and Winter Simulation Conference series, become a platform to deliver and publish relevant literature in that period.

The first section presented is the brief background of the Arena simulation applications on container port and terminals, followed by the section, which is demonstrating the selection of the reviewed research and their groupings. The flowing section delivers detailed examinations and critical analyses of literature review findings before the conclusion.

2.5.2.2 Background of the Arena Simulation Applications on Container Port and Terminals

Advancement of the information technologies and the invention of programming with the computer had a considerable impact on simulation modelling. Application of simulation and computer systems on simulation modelling started with Steer and Page (1961) and Beattie at el. (1971) in the third quarter of the 20th century (Dragović et al., 2017). At the end of the century, the ARENA simulation tool was developed, which used an object-oriented model for graphical design techniques released in 1993 (Takus and Profozich 1997). Many simulation software and techniques are used in simulating natural systems like Monte Carlo Simulation, Simul8, AutoMod, and Arena (Wales and AbouRizk, 1996). The Arena simulation software package is one of the most popular, advanced and modern simulation software used in business, especially in container port application (Cosgrove, 2008; Dragović et al., 2017).

Among the literature review papers, Dragović et al. (2017) carried out the most informative research. This is the most recent journal paper which has a comprehensive literature review, useful guidance for port simulation review and covers all relevant literature journal papers, including Vis and de Koster. 2003; Steenken et al. 2004; Gunther and Kim, 2006; Stahlbock and Voss, 2008; Angeloudis and Bell, 2011; Luo et al. 2011; Rashidi and Tsang, 2013; Carlo et al. 2014a; Carlo et al. 2014b; Carlo et al. 2015. However, this paper focused on all kinds of simulation tools applied in container port terminals instead of focusing on only the ARENA. They figured out ARENA is the most commonly applied software to analyse container ports for different purposes such as operations, optimisations, planning and evaluation. The research analysed the 41 journals, which used ARENA software to simulate the container terminals between the 1990s and 2015. The total reviewed academic research publications increased from 41 to 97 since 2015, as shown in Table A3.1 in Appendix 3.

One of the significant contributions of the research presented in this thesis is the comprehensive analyses of the literature review of ARENA applications in container port and terminals. Additionally, this research used tables and figures to give readers a clear insight to find a brief and detailed understanding of the research. Each research listed and evaluated with the following details: Application area (and subareas) of the research, authors, Year, Publication type, Publisher, case port if there is any, country of origin of the research, keywords used by authors, and the main future of the arena model which have been used in the publication. Moreover, this part of the research is the first detailed review in this subject, and this is essential for identifying the research needs and gaps in energy efficiency application of the ARENA simulation tool for container port operation and its integration with ship operations.

2.5.2.3 Review methodology

A total of 97 pieces of research outputs were analysed in this literature review part which contains 85 research papers and 12 theses, and one technical report and all of the database is presented in Table A3.1 in Appendix 3. The collated research papers consist of 65 journal papers, 18 conference papers and two workshop papers. One of the journals is a literature review paper. All the journal papers used in the previous literature review mentioned earlier are included in this research as well.

In order to review all relevant literature on ARENA simulation application on container terminals and ports, a broad literature examination was carried out in web-based research. Besides webpages of publishers like Elsevier and Science Direct, the leading research platform used in this research was Google Scholar, a freely accessible online search engine that indexes the complete manuscript or metadata of academic literature collection of publishing formats and discipline. The keywords used in this research are a container, port, container terminal, arena simulation and modelling, from which only Arena simulation-based research studies were selected. More than 500 research abstracts have been skimmed and scanned before detail analysed of 150 publications. In order to make the review reliable and inclusive, all academic publications are considered, including thesis and conference papers. These 97 academic and international researches have been analysed and screened. Two hundred ten researchers shared the authorship of reviewed publications—the average number of authors per research publication is 2.16. Simultaneously, 76 (78.5%) of all publications written with co-authors and only 21 (21.5%) of them were written by single authors. Affiliations of the first authors' locations also analysed. Only 26 countries published at least one paper, two-third of all publications completed in 6 countries which are 24 from the USA, ten from China, ten from Turkey, eight from Korea, seven from Italy and five from the Netherlands. Most of the publication published in Europa by 39 (40.2%) and followed with Asia by 28 publications, and America by 26 publications.

Various journals, conferences and institutions have published container port simulation literature. Therefore, each publication's review is started to classify them based on their scope of research and application area by considering their title, keywords and abstract. After that, each of them was analysed in detail by reading the conclusion and application of the Arena, methodology and their research contributions. The review results are condensed based on the following areas: area of the applications to container port process and their contribution to the research field, main features of the ARENA applications and case port if the study is used, and analyses of publications and their year of publication.

2.5.2.4 Findings and critical analysis of the review

2.5.2.4.1 Analysis of the area of the applications, their published year and publishers

The structure in Figure 2.18 presents the schematic grouping of the available ARENA applications in the literature. Figure 2.19 show the distribution of main application areas using the ARENA simulations. Eighty-three (86.5%) papers with regards to the ARENA simulation has on the container terminal simulations in the operation sector. It is followed by the port traffic application with (11 publications, 11.3%), and only three publications are on the general application about the ports. This review did not cover other ARENA application on other port types, and applications like Ro-Ro and bulk cargo as the focus is on container ports and their integration with port traffic and general logistic applications. However, there is only a limited number of publications available in the literature for arena application on other types of ports.

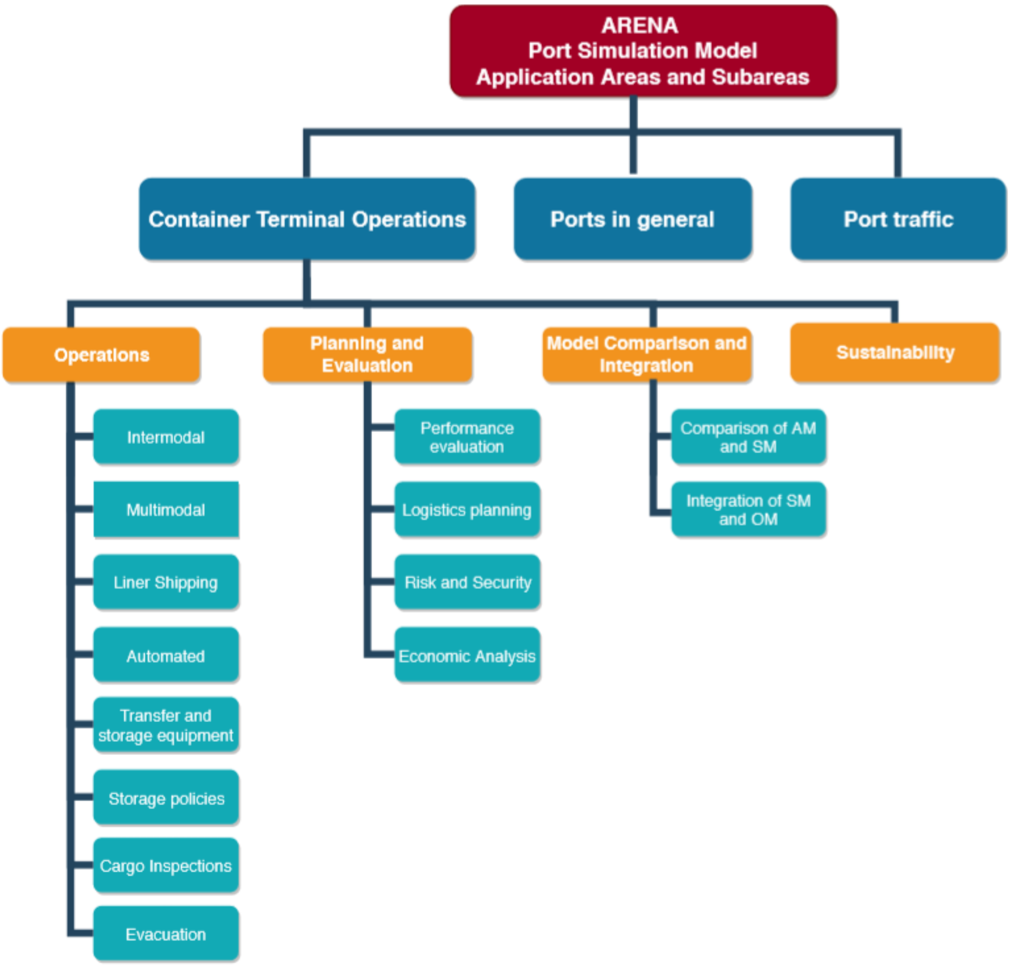


Figure 2.18 Structure of ARENA Port Simulation Application Areas and Subareas, and Number of Publications.

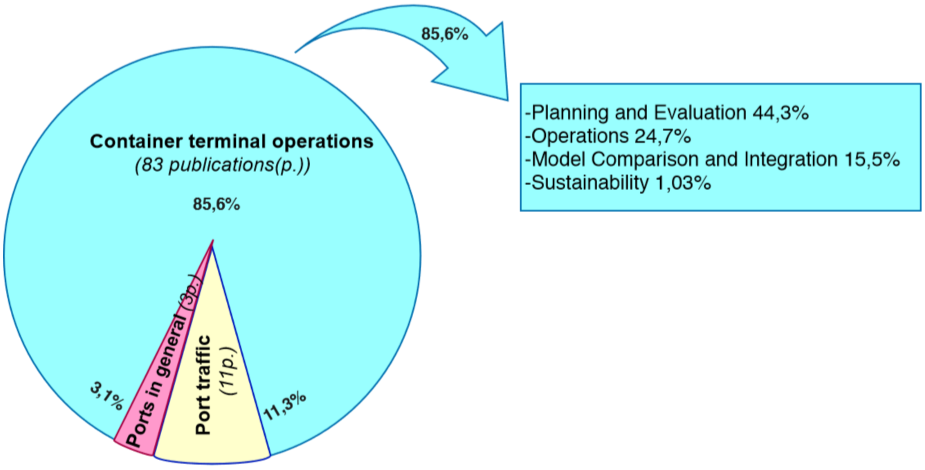


Figure 2.19 Distribution of main application areas and their share on ARENA simulation applications.

As demonstrated in Figure 20, ARENA Applications on container port simulation were divided into four sub-groups which are planning and evaluation (43 publications), operations (24 publications), model comparison and integration (15 publications), and sustainability (only one publication). The analyses demonstrated that performance evaluation is the most popular application area of the Arena in container ports, with 22 publication by 26.5% in container port application. It followed by logistics planning by 18.1%, integration of Arena simulation modelling and operational modelling by 16.9%, transfer and storage equipment applications by 12.1%, intermodal by 7.2% and risk and security by 4.8%. The rest of the sub-areas have only 1 or 2 publications shown by %1.2. and 2.4% respectively.

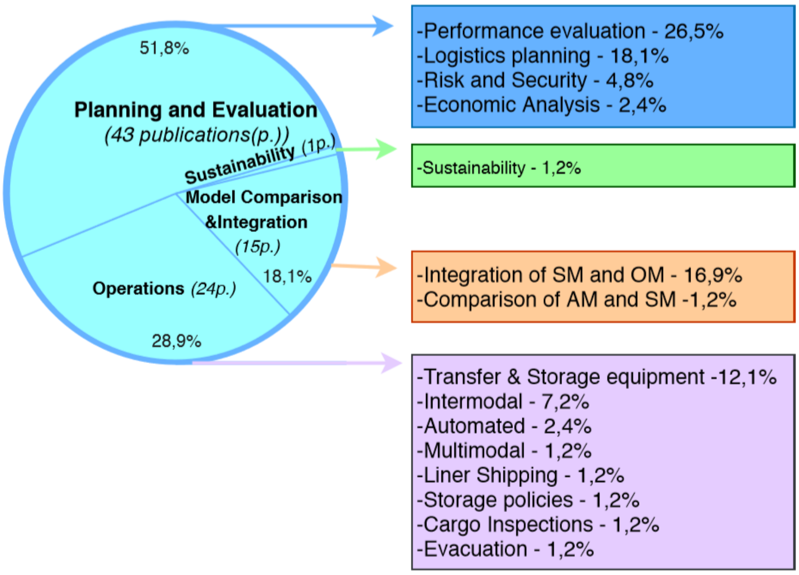


Figure 2.20 Distribution of ARENA Simulation Applications on Container Port according to main application areas in the current literature.

Temporal distribution of publications covers 5 research papers from 1993 to 1999 and 21 pieces of research from 2000-2009, which are considerably lower than the 61 publications in the period of 2010-2019. Figure 21 indicates a better understanding of the trend by analysing it in 5 years periods. The publication numbers in this field had risen since 1995s except for the last period, 2015-2019, when the number stayed the same as between 2010-2014 with 30 publications in total. Table A3.2 in Appendix 3 has shown more details with exact numbers of publications for each year, and It is seen that the first application of the Arena in container ports published five years after the software was released in 1993. The number of publications fluctuated between 1998 and 2006, illustrated in Table A3.2 in Appendix 3, but more publications became available in total.

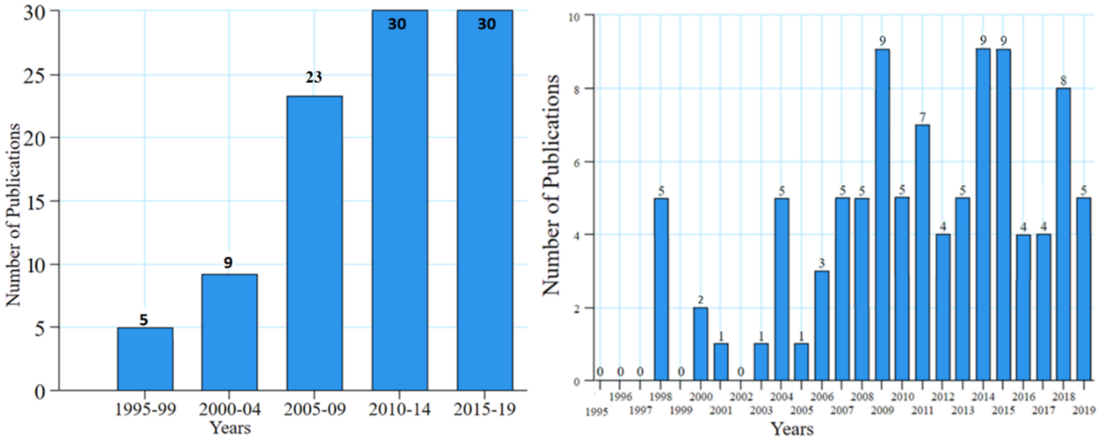


Figure 2.21 Distribution and number of publications according to their publication period between 1995 and 2019.

2.5.2.4.2 Main features of the ARENA applications

To have a better understanding and perform better analysis, the following table is used to distinguish the existence of Arena application in all publications and cases. Dragovi et al. l (2015) applied that table and analysed various simulation techniques and their differentiation. They defined it by the six binary variables A, B, C, D, E and F (see Table A3.2 in Appendix 3). Each binary variable is provided as a guide of an arena simulation feature. For instance, C = 0 shows that the arena application did not have any port and terminal layout. If it is equal to 1 (C=1), the arena application has a port and terminal layout. All variables are given in the table below.

Variable	Explanation – Condition	Condition	Value
A	Is there any flow diagram of the SM?	Yes	1
		No	0
B	Is there any screen or code of the models and sub models?	Yes	1
		No	0
C	Is there any port and terminal layout?	Yes	1
		No	0
D	Is there any simulation graphics and animations?	Yes	1
		No	0
E	Is there any integration among terminal subsystems?	Yes	1
		No	0
F	Is there any sensitivity analysis?	Yes	1
		No	0

As shown in Table A3.2 in Appendix 3, the most used future is A. In other words, two-third of the publications provided use with a flow diagram in their research. The least used future among the mentioned was D and followed by E with 29 and 39% respectively. Additionally, 63 publications used a case port and only 53 of them provided port or terminal layouts. More than half of the researchers did not perform sensitivity analysis. Just more than half of the studies has given a screen or code of the models and sub-models. These figures demonstrate that a very limited number of studies used or provided all mentioned futures of the simulation method.

2.5.2.4.3 Analyses of publications with their contributions

Roop and Koster (1998) aimed to develop a general simulation model of ship-to-rail intermodal container movements, which tried to provide analytical support for the port operations. They developed an Arena model and applied it to three different scenarios which are used to analyse the phase of the port, capacity studies and crane utilisation for an intermodal port. Due to the limited technical availability, their analyses were a straightforward application of the ARENA software.

Kozan (2006) investigated delays of trains for different service configurations and developed an Arena model to find an optimum cost of train delays with optimum service in a small intermodal container transfer terminal.

Three articles from Wadhwa (2000), Cigolini et al. (2013) and Yuan et al. (2010) are about bulk operations. Wadhwa (2000) aims to find the best approach for a new situation by using one ship loader, resulting in an excessive ship waiting times and a high level of demurrage. Using two ship loaders continuously resulted in inefficiency and high running costs. His research outlines a method for designing a plan that considers a trade-off between the cost of waiting for a ship and the cost of launching an extra ship loader, resulting in the most efficient use of resources. Simulation, scenario development, and economic fundamentals are all part of the plan. The applicability of this method is shown using an actual bulk export terminal in Australia. Cigolini et al. (2013) build a new model that allows service providers to optimise their transhipment system using simulation. He tested the model and applied 2 cases to carry out a practical cost analysis of a floating barge terminal. However, both of them only consider the economic output and not mentioned the energy efficiency of bulk operations. With Arena tools, Yuan et al. (2010) investigated the logistic operation of the raw material terminal at an iron and steel company’s industrial port. Their paper developed a simulation model focused on an overview of the existing state of the raw material terminal, logistic environment, and optimization steps such as blending proportion optimization and ships' berthing optimization. Their simulation findings indicate that optimization measures improved the previously unbalanced problems. On the other hand, the logistics scheme of the raw material terminal is far more complex, and since many parameters affect the system, the issue of imbalance must be thoroughly addressed.

Feng et al. (2015) developed an Arena simulation model for the Ningbo-Zhoushan Port's crude oil terminal. Their study focused on terminal operations to see how the cost of logistics per tonne of oil varies with seasonal crude oil throughput, including costs shared by both the port and the carrier (i.e., the holding cost). They ran various simulations and discovered that upgrade of the unloading equipment would result in a substantial decrease in the average cost per tonne of crude oil unloaded. When there is a strong demand for crude oil, for example, installing a new berth and updating equipment will decrease unit logistics costs by 17%.

Bruzzone et al. (1998) and Fanti et al. (2015) carried out their research on general port application. Bruzzone et al. (1998) provided an outline of various methods for reproducing and analysing ship handling in harbours; in particular, the potential of Web-Based modelling has been considered as an inventive and valuable method for efficient distribution simulations within the user community; the implementation results in terms of productivity and validation ability were satisfactory. Fanti et al. (2015) developed a decision support system for logistics management by using Arena. They applied their simulation on Trieste port and ran the freights' export flows between a dry port and a seaport. Their integrated approach used both simulation and optimisation modules. Their simulations identified the worst-case scenarios when the number of transportation units is doubled and when the average operational level is deployed; the complete decision process took 33 min 32 minutes, respectively.

Thiers and Janssens (1988), Khatiashvili Bakeev and, Fidler (2006), Almaz and Altiok (2012), Shahpanah et al. (2014), and Hang et al. (2015) used Arena software to analyse port traffic. Thiers and Janssens (1988) built a simulation model for Port of Antwerp to investigate the port's river quay's hindrance. There is a comprehensive simulation of the river's traffic, including navigation dynamics, tides, and lock schedule. The model created as a phase of this effort has evolved into a port planning tool applicable to any other port traffic planning. In order to predict the ferry activities, Arena modelling software was used by Khatiashvili, Bakeev and Fidler (2006) to construct a virtual model of the Eastern Docks at Port of Dover. Following that, the simulation model was used as a research instrument to observe and measure the impact of changes in port operating procedures and traffic volumes. External considerations such as marginal or restricting weather conditions were also considered as part of the project's scope.

When environmental conditions are taken into account, the model shows that the appropriate amount of ferry movements in the manoeuvring region off the Eastern Docks will decrease from 2024 to 2004. Almaz and Altiok (2012) applied Arena simulation modelling of the vessel traffic in the Delaware River and Bay in the USA to analyse the port traffic impact on port performance. Shahpanah et al. (2014) used the tool to improve the queuing to reduce waiting time at the berthing area of the container terminal. Hang et al. (2015) modelled the ship traffic in the Three Gorges area to help decision-makers with the area's current navigation, traffic flow feature and the behaviour of ships sailing across the lock.

Performance evaluation examined by various scholars with Arena tool includes Rusca et al. (2018). Nasution (2019) Kotachi et al (2016) and Shu and Zhang (2011). Rusca et al. (2018) examined the berthing capacity at the initial planning period of a container terminal or during the operational planning stage of the terminal's logistic processes. Nasution (2019) examined the port terminal's service preparation structure and the mechanism of landside operations to propose possible scenarios for resolving the terminal's congestion challenge. The simulations suggested a Truck Appointment System (TAS), which was shown to decrease the average total time in the system by 76% and average total operation time in peak days by 88 per cent, from 151.5 minutes to 38.4 minutes per vehicle. The TAS was also shown to cut queue length by 97%, from 162 trucks to 5. Kotachi et al. (2016) created an Arena simulation for the newly built container terminal in Hamad's in Qatar. The framework illustrates the movement of ships, containers, external trucks, and critical infrastructures such as cranes, Yard Trucks, and RTGs. Simulation results show that the modest decrease in resources has little effect on vessel turnaround time because the port has more resources than are available for current demand levels and in consideration of potential demand increases. However, reducing the number of Yard Trucks would have a direct effect on vessel turnover time. However, in order to fully comprehend the case, this study should have tested more comprehensive procedures. Shu and Zhang (2011) used Arena modelling tools combined with a loading and unloading process in the port Logistics Park to define all port services, including berths, containers, ships, yards, cranes, transportation equipment, bridges, parking areas, cars, and other employees. The simulation results helped fine-tune the parameters so that waiting times and volumes are reduced, facility performance rates are high, and the system's net cost is minimal.

In his research, Islam (2018) used Arena to analyse and evaluate truck-sharing benefits for reducing empty trips and achieving port sustainability. Islam (2018) aimed to create simulation models for the current truck arrival process in a seaport and the concept of truck-sharing. The simulation results show that the truck-sharing concept improves port transport flexibility and can effectively accommodate future truck volumes. Reduced pollution from vehicles in the port area can also be attributed to the truck-sharing concept.

Sislioglu et al. (2019) used an Arena simulation to investigate terminal productivity and improve container terminal productivity through investment options. The proposed simulation model included 16 different investment scenarios as well as 10-months’ worth of operational data. The simulations identified one of the proposed scenarios (current total length of quays ranging from 1.560 to 2.000 metres) as the most feasible investment option under the actual situation. The method is also thought to help with container terminals' investment decisions, and the developed framework could be applied to other transport systems.

2.6 Chapter Summary

In this literature review, almost all energy and CO_2 related regulations, technological advancements, applications, associated methods, measurements about port and ship are addressed. This detailed literature was used to develop a novel way to establish the research methodology to achieve the aims and objectives of the PhD. More details of the methodological applications were mentioned in the methodology part.

CHAPTER 3: METHODOLOGY AND DATA COLLECTION

3.1 Chapter Overview

This chapter introduces the approach adopted to carry out the research presented in this thesis and provides the introduction of the workflow between the modules. The methodology for the BBN and DES system is described from the perspective of each module. Moreover, this chapter aims to describe the data collection strategy and clarify the approach taken for data collection work. Further details of the methodology are provided in this chapter as well. The method of data analysis was presented in this chapter, as well. Moreover, chapter 3 explains the primary and secondary data collection process and discusses the potential limitations of the methods adopted. This chapter further clarifies how the validity and reliability of the results are achieved in this research. Lastly, the limitations of the research and ethical issues are introduced and discussed.

3.2 Methodology

Appropriate methods and selected approaches are provided in each chapter. However, in chapter 3, the general methodology of this thesis is provided to show the whole study together with connections between the chapters. Figure 3.1 illustrates the general methodology followed in this thesis. It indicates the interactions between different steps to reach the final simulation results.

As shown in figure 3.1, the literature review of this study is the starting point to understand the BBN. Then literature review and expert opinions are used to shape the BBN application into ship-port integration. Then, the BBN port model was developed by utilising data, which is collected through a comprehensive data collection trip. Expert views and raw data collected from companies during the field data collection activities are combined with different primary and secondary sources.

These inputs are also used to predict conditional probabilities in nodes in BBN. After that, the model is utilised to generate results with GeNIe Modeller, a software used for BBN. This model helps to investigate different cases under different assumptions. Following the simulations, the results and data obtained are analysed to understand the importance of each node on energy consumption and CO_2 emissions. All the details of these methods are explained and applied in the BBN section of Chapter 4. After that, the system produces the first results, which require simulation programming to analyse further details of the system to calculate energy consumption and CO_2 emission.

After the BBN results, the chosen part of the system was analysed using a suitable simulation tool (Arena) to investigate various conditions analytically. After selecting the case studies and simulation model with the literature review, new data sets are required to build up for simulation applications. In this thesis applied BBN and DES and GeNIe 2.1 and ARENA software was used. This part of the method creates possible analyses of highly complex cases and situations. Cases and tool identification of operation process take place before creating activity diagrams of the chosen port and ship operations.

The model is built in ARENA software, and databases are used to create accurate simulation models. After testing the model, validation is carried out with real data supplied from the chosen seaport. Next, case scenarios are decided. In this application, cases are chosen by identifying the most relevant port activities, available systems and needs of the port after a meeting with the case seaport. After a small adjustment, the simulations are performed for the cases, and the results are generated for the analyses. Based on simulation results, further analyses and calculations are carried out to determine the energy consumption and CO_2 emissions of the case seaport for different conditions and assumption. The details of the relevant processes and all detailed information are provided in the ARENA part of Chapter 4. The final step is to understand and discuss simulation results to create the most suitable measures for ship and port integration, considering the energy efficiency and the CO_2 emission.

A novel BBN model which enables predicting energy consumption and CO_2 pollution from ship and port interface is proposed and developed. Noon data, sea trials, real weather datasets are obtained from a shipping company. Vessel tracking and marine traffic data sets are purchased from Fleetmon, a third-party data provider company. Expert views are obtained from one-to-one meetings with experienced engineers, academics, and port operation managers. Secondary sources from literature like ship engines figures are also used in this model. This thesis, basically, deployed all data sets mentioned above to predict an accurate prediction from the simulations.

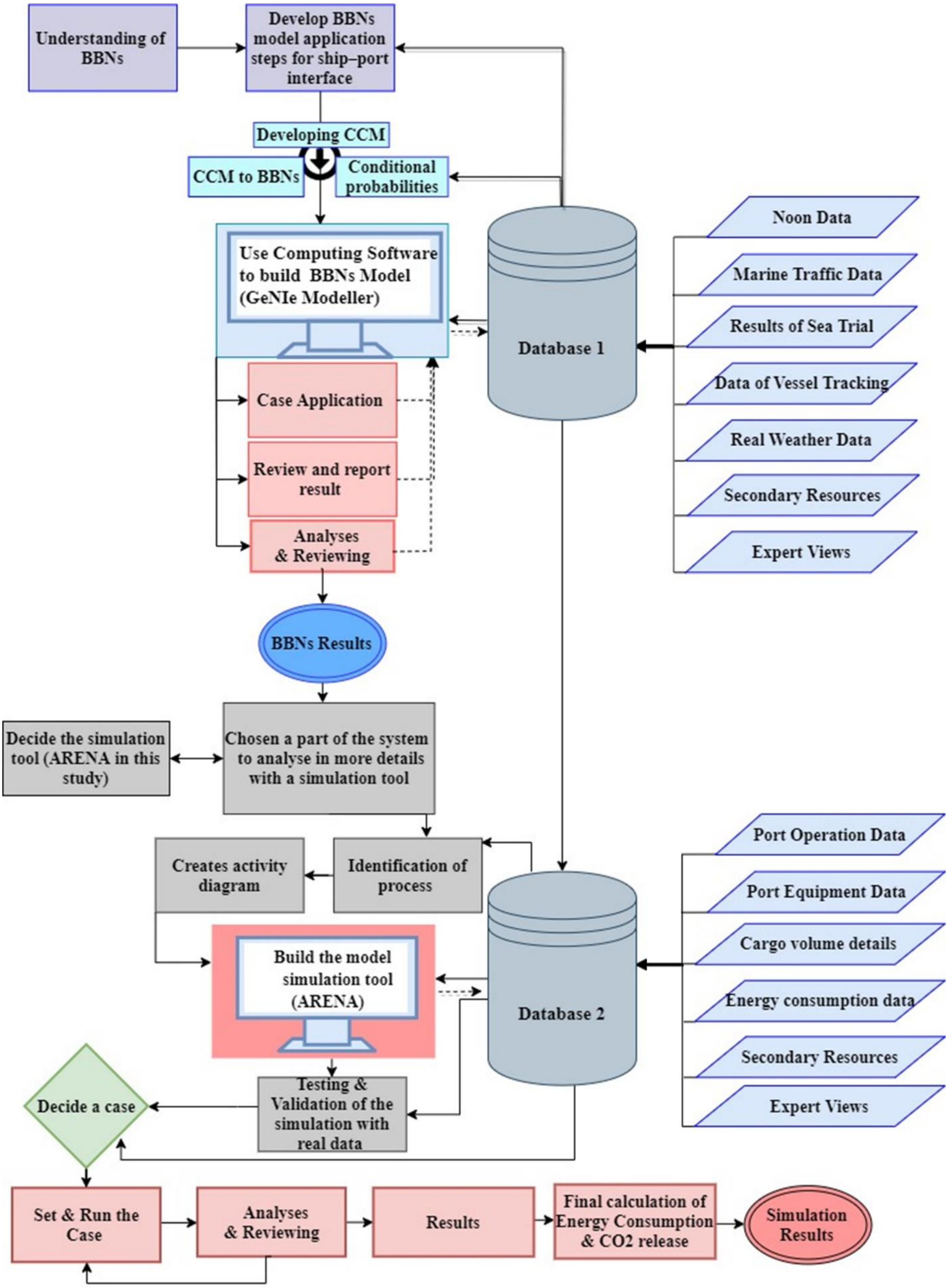


Figure 3.1 The general methodology followed in this thesis.

After obtaining BBN results for the selected ports and ship interface relations with a probabilistic outcome, the research continued with a simulation (Arena) to carry out detailed simulations with high complexity. Results of BBN creates an understanding of the structure and relation of the entire integrated system. After that, this knowledge and understanding are used to design and build an Arena simulation.

DES Arena simulation part of the model is briefly presented in figure 3.1. All other details of modules and their descriptions are provided in Chapter 4. The model was tested by using the real case data provided by the case port. The validation of the model is performed in two stages. In the first stage, case data of ship operations and their technical information are reviewed to apply in the simulation. Then, simulation results are compared with the real values obtained from the port to validate the accuracy of the model.

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ARENA tool is used to perform a series of calculations to calculate port and ship energy consumption and CO_2 pollution. A method developed by Trozzi and Vaccaro (2010) was used to calculate the energy consumption of the ships. This method is also explained further in Chapter 4. It is important to note that the scope of this thesis and novelty and contribution have partly been presented with results in Chapter 5, and more details and discussions of results are given in Chapter 4 and Chapter 5. Port data set, equipment data sets with cargo volumes and energy consumption of port equipment are obtained from several field trips and meetings with the case study port. Due to the sensitivity of data sets, the research case port was changed once, and this situation caused at least nine months delay to obtain any other data sets from a new case port. Expert views are obtained from one to one, focused group meetings and interviews with experienced engineers, academics, and port operation managers. The developed BBN and Arena application have the capability to use any ship and port operation as a case study. However, some data sets like ship trial data, noon data of the ships or port operation details are not easy to obtain. Therefore, case studies are chosen from ships and port with detailed, accessible data sets.

3.2.1 BBN and ARENA

The following subsection will give a brief description of used models based on Bayesian Belief Networks (BBN) and ARENA modelling, and further details provided next section when they are applied in a case study.

3.2.1.1 Bayesian Belief Networks (BBN) Application

The dependability of marine systems is a growing area of interest, and researchers may improve the dependability/interoperability of this system in order to make them more efficient. Many different standards and models aim to address the dependability challenges (Neil, Littlewood, and Fenton, 1996). Researchers (Cao, Coutts and Lui 2013; Neil, Littlewood and Fenton, 1996; Yuqing and Tong, 2008) recommended that the most capable approach to support this kind of argumentation is Bayesian Belief Networks (BBN) (invented by Thomas Bayes in 1763). A Bayesian Network (also called Bayesian belief network, belief network, Bayesian net, BBN, BN, graphical probability model, graphical probability networks, causal probabilistic networks, causal nets, and probabilistic influence diagrams) is a model for reasoning about uncertainty. Based on the foundations of the centuries-old Bayesian probability theory, the subject has been given a lease of life in recent years due to advances in algorithms and philosophy (Neil, Littlewood, and Fenton, 1996; Yuqing and Tong, 2008). The interoperability/dependability analysis of marine transport is a complicated approach to make commercial shipping more efficient. There are many operational details, and each operational relation should be examined, such as vessel speeds, port performance, and communication challenges, clauses of the charter agreements, and ships types or sizes. This research is going to apply BBN to marine transport systems. This kind of approach may provide both the details on the availability of information during operation as well as the possible operational influence of any determined deficiencies. Cao, Coutts and Lui (2013) developed the stages of this approach. A BBN model may be abstracted to Surveillance and Reconnaissance, which also helps to build a new methodology based on BBN. This may require the following actions:

- Developing a Causal Concept Map (CCM).
- Converting the Causal Concept Map to a BBN Model.
- Eliciting Conditional Probabilities.
- Analysing the results of BBN.

With the development of computer technology, interoperability is increasing its actuality in academia. Firstly, it focuses on interoperability on the Operating System level; but now, it emphasises more on other issues. BNNs has helped us analyse interrelationships and interdependencies between integrated shipping system elements and create a software-based tool to improve energy efficiency as a whole in the marine transport chain. In other words, a developed method based on BBN aims to specifically focus on the inter-operability of different management systems of the ship-port interface to increase energy efficiency more holistically. The primary objectives of this study are as follows:

- Applying BBN modelling to identify the integrated system's nodes to understand the inter-operability of port and fleet operations in a more coherent way.
- Obtaining analytical solutions and creating an interdependency framework in order to increase energy efficiency as a whole in the marine transport system.
- Improving the resource efficiency of integrated coordination between port and fleet management and optimising the energy consumption of the integrated marine transport system by utilisation of the BBN.

3.2.1.2 DES Simulation Application

The advancement of information technologies and the invention of programming with computers had a considerable impact on simulation modelling. Many simulation software and techniques are used DES like Simul8, AutoMod, and Arena (Wales and AbouRizk, 1996). The Arena simulation software package is one of the most popular, advanced, and modern simulation software used in business, especially in container port application (Cosgrove, 2008; Dragović et al., 2017).

The complex logistic chain ought to comprise port performance to reduce unavoidable delays to make a better energy-efficient system. A comprehensive tool can help to improve energy efficiency and our understanding of port and ship operation based on energy efficiency. Therefore, a modelling framework is developed to investigate how ports and ships could work together to reduce energy consumption and maximise efficient operation time. According to the integrated concept of shipping, the system is analysed to create a case study application of a container port using ARENA software, which is capable to analyse the fleet and port integration. ARENA is one of the effective tools used for DES application to simulate real cases like port operation. However, this tool has not been applied to use for energy efficiency calculation for port and ship interface.

3.3 Understanding of the Data Requirements

It is well known that there are many research methods, but we can classify them into two main categories, which are quantitative and qualitative approaches (Berg and Lune, 2004; Creswell 2013). Mainly, the quantitative method is adopted in this research, and its brief details are given in this chapter. However, this research also includes expert opinions, which is a qualitative way of analysing inputs. Therefore, it can be beneficial to explain the differences between these two main methods as it creates more comprehensive datasets. Quantitative research involves a deductive approach that emphasises the quantification of numerical data to test hypotheses/theories. In general, it is used to test theories; theory and hypothesis drive the data collection process (Bell and Bryman, 2007). However, due to limited numerical data in some parts of the research, limited qualitative data collection has been adopted for this study. Qualitative research involves an inductive approach, which emphasises the generation of theory.

Moreover, qualitative research is related more to words rather than numbers (Bell and Bryman, 2007). This technique is much better in understanding the participants' points of view and providing a better contextual understanding. As remarked by Saunders, Lewis, and Thornhill (2009), qualitative research highlights words, sentences, and meanings rather than figures and calculations to gain a comprehensive understanding of the research topic and builds a strong relationship between research and the phenomenon under investigation. Therefore, this research used a combined method to get all datasets possible to consider while applying the BBN and ARENA parts of the approach.

3.3.1 Data Collection

The various sources of data are collected in the forms of primary and secondary data for this study. In the second chapter of this thesis, extensive literature reviews were used to build a better understanding of and data needs of this study. After the developed method, the most appropriate data collection is deployed in that particular part of the research. Primary and secondary data are used to build the models for this study, and descriptions are given in this chapter and Chapter 4.

Primary data provide raw information and first-hand evidence. The thesis's primary data sources are noon data, marine traffic data, vessel tracking data, real weather data, port operation data, port equipment data, cargo volume details, energy consumption data, and expert views, as shown in figure 3.2. All data are explained in more details and given while they used in Chapter 4. These two databases are used in different stages of the thesis.

While this research is carried out, secondary data collection took place as well. Secondary data means "studies made by others for their purposes" (Blumberg, Cooper, and Schindler, 2008). In this thesis, research-related documents were compiled from books, academic journals, ship data providers (like Fleet-moon and Marine traffic), sectorial reports, and the University of Strathclyde library web sources. These sources provided useful information about the subject in hand, i.e., loading conditions of ship and machinery and related system performance, which helped build a simulation framework in BBN. During fuel consumptions calculations of ship engines, as explained in Chapter 4, some secondary data from the published research (Wilmsmeier, 2015) was used to calculate the fuel consumption for reefer containers. Questions asked during post visits and expert views collated were also utilised together with the information/data obtained from the literature.

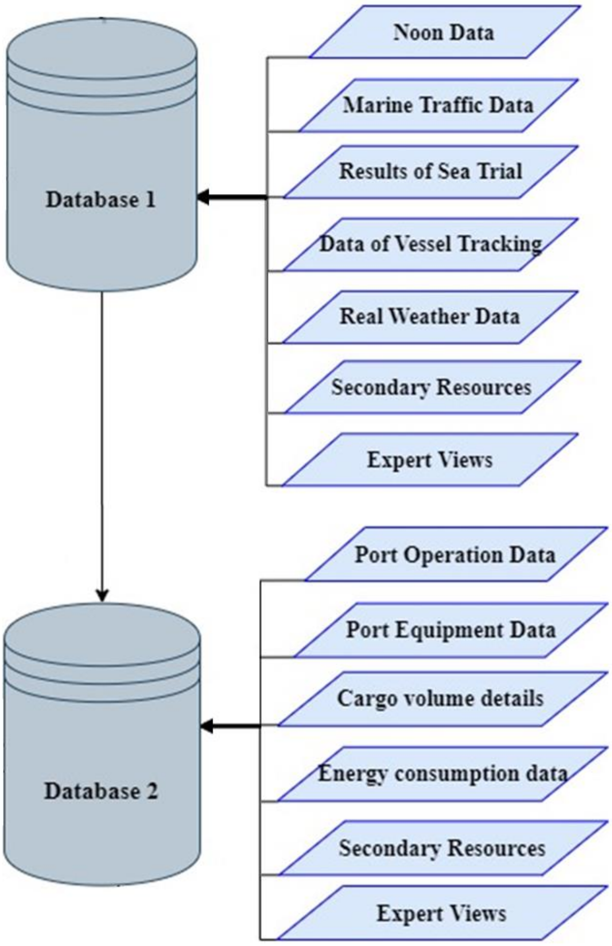


Figure 3.2 Databases and their datasets

3.3.1.1 Primary Data

The collection of primary data is of paramount importance due to the nature of this research. It is described by Hussey and Eagan (2007) that primary data is original data collected at source. As outlined in Chapter 5, the data of the first data set was obtained from operational measurements, including data from ships and ports, recorded meteorological data, as well as previously published data. The study by Cui, Turan, and Boulougouris (2016) helped calculate the CPTs of route planning and energy consumption nodes, using optimum route data with minimum fuel consumption for this case study. Publicly available data is utilised to obtain port weather condition data (Wunder 2016).

The second primary data set was provided by the case port operator as raw data. The port provided almost all requested raw data after a face-to-face meeting/interviews with the port operator at their local port headquarter on 28 February 2018. During the visit, the author of this thesis also visited the port, used it as a case study in this research and observed the operations. The data set was from the whole year of 2017 and the first four months of 2018. After that, communication continued via e-mail, and one more physical visit took place on 17 August 2018. All the remaining requested raw data and details were provided a few weeks after that meeting.

Some data were also collected via face-to-face interviews during these visits, and some were recorded as voice records. The process was continued with e-mail communications to collect missing minor but essential data. Data from interviewees were collated, transcribed into readable word text; the interviews were undertaken in a local language or English language. Due to data confidentiality, not all but some of these unique records are provided in Appendix 4. Table 3.1 shows a list of sensitive and necessary data collected from port visits. Their explanations and some details displayed in the same table. These data sets used in the DES application presented in Chapter 5. Some of these primary data is presented in Chapter 5, where the data such as equipment consumption figures used while building and running the DES Arena application. Moreover, Appendix 4 provides the following data: Cargo and ship volume of the case container port for DES Arena Application on table A4.1; real data collected for each ship and their operations on table A4.2; capacity utilisation of SSG, careens and trucks the port based on real data on table A4.3; distribution of hip LOA, total/full/empty container for ship loading (TEU) and total container for ship unloading for arena application shown on figure A4.1, A4.2, A4.3, A4.4, A4.5 respective.

Table 3.3.1 The List of Data Collected from the Case Port

Data Source	**Details**
Port layout map	Accurate and highly detailed port layout map
Port layout technical details	Capacity and types of each storage areas, possible port traffic flow, location of reefers containers, each port equipment locations
Port equipment details	Technical details of all port handling equipment include numbers and technical features (models, brands, engine specifications and average fuel consumption.
All details of a completed ship operation for each berth	Details of the ship, cargo and port layout actively used equipment for each operation and their operational details like the number of hours and movements they completed. Planned arrival time of the ship, the planned start time of the operation, the planned end time of the operation, the actual arrival time of the ship to the port, the time of the actual start of the operation, the actual end time of the operation. (If the planned berth and the actual berth are different, ship waiting time in a queue). The number of containers that each screening equipment (SSG, RTG, YT) loads and unloads. The starting and finishing times of each sifting equipment (jib crane, field crane, truck) and the amount of break, if any The locations of the stacking blocks assigned for each ship and the stacking plan of the unloading and loading containers.
Details of port energy sources	Details of renewable energy source or technology used in the port, if any. The port's electricity source. Model and tour of Generator in use.
Operational data for each terminal	One year of operational data for each terminal. Ships details Operation starts and end times. Equipment information for each operation
Fuel consumption details	Total fuel consumption and total operating time of each equipment per year. Total annual energy consumption and types of the port (such as electricity, gasoline, diesel oil, heating fuel)
One complete operation detail	It is for a validation
Port capacity details	Capacity of all port facilities and equipment like storage areas and equipment
Average performance and consumption details of port equipment from real operations	Recorded and analysed data sets.
The waiting time of containers in the port area	Container spent time in port area.
Operational details	Operational priorities and their details

3.3.1.2 Design of the Interview questions

The development of the interview questions has substantial importance to achieve the research aim and objectives. As the questions are more relevant to the research objectives, more valuable data is created for the research. According to Saunders, Lewis, and Thornhill (2009), questions help researchers convey variables such as opinions, behaviours, and attributes. In this research, the interview questions are carefully designed to attain as reliable information as possible from the respondents. Primarily questions are prepared and later revised by the expert group. After the experts` input, the last adjustments were made before the interviews with participants are carried out.

3.3.1.3 Semi-Structured Interviews

There are three main types of interviews: structured, semi-structured, and unstructured (Saunders, Lewis, and Thornhill, 2009). This study adopted unstructured and semi-structured interviews. As highlighted by Saunders, Lewis, and Thornhill (2009), the researcher prepares a list of questions to be covered, but the selection of the questions could be modified for each interview, depending on the context for semi-structured interviews. In this way, it is easy to have greater depth and attain fewer unanswered questions from the survey. Semi-structured interviews will be containing both closed and open-ended questions to capture ideas not previously considered.

3.3.2 Interview Design

Interviewing is usually seen as a flexible way of data collection. The interviewer adapts and responds to the interviewee; there is a great interest in the respondent's perspective (Bell and Bryman, 2007). All the questions are designed to meet the research's aim and objectives, and the list of the interview questions is presented in Table 3.1. Questions are appropriately translated from English to the local language before interviews.

3.3.3 Respondent Selection and Data Collection

The respondent selection allows the generation of a wide variety of ideas correlated to the particular matter that is researched and offers the opportunity to get a deep understanding of why respondents have this view (Bell and Bryman, 2007). All the participants for this study were experts in port operation. All participants have more than ten years of experience. This interview follows the study of Bell and Bryman (2007) to avoid any bias and distortion in the participants' replies.

The author visited the case port on 28 February 2018; 3 meetings took place in the port:

1. The author met with the assistant manager of the port operation.
2. The author visited all parts of the port operation area with the assistant manager. After that, an interview took place to collect some more data for the port application.
3. The author met with the port's operation manager to collect more data about operational difficulties and energy consumption challenges in the case port.
4. The author met with the general operation director of the case port and got more data.

Table 3.3.2 Questions of the semi statured interview..

Name: .... Company: ....

Title: .... Department: ....

How many year experiences do you have? ....

1. How do you assign a container ship for berthing?
   Do you have any major criteria for this?
   Are trucking distance and dock productivity important? What are the main factors that influence your decision like this?
2. Is there a single main queue, or is there a separate queue for each terminal?
3. Is the length of the ship or the suitability of the berth is the main criteria for ship terminal allocation?
4. According to your perception, which situations do cause the most waiting time for ships arriving at your port? Which kind of most common problems can you list?
5. What are the LOA and draft constraints for your port?
6. Is there any very important criterion for your harbour to provide docking at arrival? Do you have any special practice for any ship or companies?
7. What is the average move per vessel hour (MPH) and how does it change with ship sizes?
8. What is the average and max mph for a ship for cranes? Which operation condition let a crane reach optimum operation speed?
9. Do you use a mobile crane for every ship operation? How do you assign them for each operation?
10. Which Blocks are generally used for Import, Export, Transit vs. Empty and Reefer?
11. Is there a significant change in the port map that has affected the operation in the last few years?
12. Details of the renewable energy source or technology used in the port. The electrical source of the port. Do you use any generator? If yes, what are their details?
13. What is the time difference between the ship's berthing and the start of the operation in general? Which parameters affect this?
14. Would you like to mention any common operational problems which cause delays and more energy consumption?

The author visited the port general headquarters on 8 March 2018. He met with a senior specialist of port group reporting and consolidation and port group internal audit, reporting, and consolidation director. The author gave information about the application and progress of the research and requested more port data. They agreed to share all relevant data of the case port. They also agreed to share the port data of four other container ports.

Another port visit took place on 17 August 2018, where the author shares early results with the port authority to convince them for further collaboration. The case port authority is satisfied with the results and given some vital feedback. It was a productive unstructured meeting where the author took some notes regarding their comments/feedback.

After the first port visit, the author communicated with the port's assistant manager clarified all the required data and requested more details. The assistant manager of the case port provided all the requested data for the case port covering the operations for 2017 (690 ships) and the first four months of 2018 (234 ships). The data includes many details, including ship name, pilot start time, time berthed, operation completion time, the quantity of the container loaded and unloaded. Based on this data, the simulation model developed in ARENA software became highly advanced and accurate.

3.3.4 Data Analysis

One of the most common methods used for analysing the collected data is a content analysis of the qualitative data sets, where the researcher examines in depth what the interviewers refer to most and how relevant their responses are to each other (Radcliff, 2010). In this study, the following steps were undertaken within the concept of the content analysis technique:

- The recorded interviews were transcribed from local language to English if required to make sure that nothing was missed or misunderstood.

- After the transcription, answers were grouped and discussed separately for each question for the researcher to gain a more in-depth insight.

- The categorised data were compared to relevant ideas presented in the literature review part for further check.

3.3.5 Reliability and Validity

The validity and reliability of the collected data and the responses attained depends to no small extent on the design of the questions, the structure of the interview, and comprehensive pilot testing (Saunders, Lewis, and Thornhill, 2003). In this survey, qualitative research's validity and reliability of the findings depend on the researcher's analytic capability, which was gained through this research and from the research work he has undertaken in the past.

3.3.6 Ethical Consideration

As required in every research, the author has taken time to identify the relevant ethical issues that may arise during the research activities and will satisfy them. According to Bell and Bryman (2007), ethics concerns the data's privacy during the research must be considered. This research's ethical consideration was based on the code of ethics published by the University of Strathclyde, University Ethics Committee. The following processes were undertaken to adopt the main ethical concerns and ensure that none of the respondents' rights was violated. The participants accepted to be part of the interview after accepting the participant information sheet, which they appended their permission before conducting data collection. All respondents were made aware of this research's voluntary nature and the purpose of the data collection and assured that collected data would be used only for academic purposes and their results will be published only in this research. The following statements underline the process followed during the collection of all primary raw data and interviews:

- The author got appropriate permission where needed from companies and people to conduct research involving them.
- Interviews and questionnaires were structured, and words were chosen not to cause physical or emotional harm to the participants.
- The author has given fair consideration to all sides involved in the research and makes sure that the researcher maintains the law of objectivity.
- In the case of anonymity, the author would let the subjects know whether the research results will be anonymous or not.
- The author chooses participants based on who will provide the maximum benefit to the research and not because they are easy to access.
- The author accurately represented what the author observed and what researchers told during the study.

3.3.7 Research Limitations

This research methodology has some limitations. During the application of BBN, all limitations are explained in Chapter 4. A 35,600 DWT Bulk Carrier data is obtained within this case study to implement a simplified model evolved with BBN. Some vessel specifications are given in Chapter 4. The Port of New York (USNYC) and the Port of Southampton (GBSOU), one of the UK's major ports, have been respectively selected as the outward and inward ports for this case study.

The voyage information and visualisation is also implemented in Chapter 4. Departure day from USNYC is 01.05.2014, and the arrival day in GBSOU is 10.05.2014. The capacity of discharging/loading cargo type is obtained from port specifications and operations for port operation performance (PO) nodes based on Fleet-moon data and based on expert Views. Node descriptions, states, and data collection sources of the study given in Chapter 5. Performance of port storage system is employed to investigate the nodes of storage performance (SP). Due to the data limitation and partly available port data, the Fleetmon data are also used together with expert opinions. Nodes of equipment performance (EP) were considered based on the original port handling equipment for the case port in the BBN section. Due to the data limitation, only primary port equipment performance is considered with limited secondary data sets for the first case in BBN.

During the ARENA application, the author assumed that 16 months of port data set of the case port from 2017 and 2018 represents the cargo and operation volume of the port. LOA of the ship is 274 m, load is 1473 TEU. The author used real ship 'Ship S` data for validation. Cargo handling and all other operation details are presented in Chapter 5. Moreover, Trozzi and Vaccaro (2010) method was applied to the model to calculate energy consumption and CO_2 emissions. While calculating energy consumption and CO_2 from different sources, some assumptions were made, like grid emission factor is taken as 0.481 kg CO_2 / kWh, all equipment powered by electricity used this conversion factor to calculate their CO_2 pollution. All types of energy consumed were converted to tonne(s) of oil equivalent, abbreviated as a toe, a generic energy unit. All other conversion details are given in Chapter 5, while the calculation is made in sequences. 53 kW/24 hours is taken as an average consumption per reefer container per day for this calculation (Wilmsmeier, 2015). When the author calculated the trucks' energy consumption, it is understood that real data set results are not the same as the theoretical figures both given by the port authority. After that, the author contacted the port and discussed the reason, and it was agreed and considered that each truck's consumption was 6,27 LT per hour. These figures are validated with unique real data provided by the port authority.

The other limitations are related to the primary data collection and the limited number of interviewees. Despite the limited number of participants, interviews were conducted with the most expert people in this field in the case port. Therefore, interviews provided all possibly relevant data and insights. Finally, interviewer bias is another concern as a limitation; participants might feel uncomfortable bringing out their thoughts while performing. Moreover, respondents might have been influenced by the researcher's words, actions, or the recording device's presence. However, this was attempted to put to a minimum, and the researcher has been aware of this risk of qualitative research and remained impartial in asking questions to the participants. Therefore, minimal data collected based on interviews were applied to design the ARENA process like the actual queuing system of the upcoming ships. Mostly raw numeric data was used in this research. The researcher has learned that awareness of situations in conducting interviews has helped him improve the research quality.

3.4 Chapter Summary

This chapter provided the details of the methodology with data collection to perform the research, together with the structured workflow. This chapter shows the combination of BBN and the ARENA system, and it is integration. This chapter also focused on the data collection and briefly the importance of the methodology for data collection applied in this research. This chapter explains how the data was collected through this quantitative research and the minor qualitative data collection through interviews. The research has adopted an inductive approach with the use of questionnaires. In the next chapter, the findings of the research with a detailed explanation and background were presented. The following chapters provide more details when the method is applied through case studies.

CHAPTER 4: APPLICATION OF MODEL & RESULTS - BBN

4.1 Chapter Overview

It is known that energy efficiency is one of the new challenges in maritime transportation and operation. There is no doubt that port operation and ship operation can be more energy-efficient and need more appropriate analyses and regulations. Knowing that current studies are not enough, energy efficiency studies and its' effect on ship and port interface should be thoroughly and systematically investigated to have a better understanding and to have methodical and practical answers for ship and port operators to help them sustain energy-efficient integrated ship and port operations.

This research had two applications to examine the energy efficiency in the ship and port interface. The first application in this thesis is based on a BBN application, and it is applied for different ship case studies to investigate the simplified model which was published in Maritime Policy & Management in 2019 and Trends and Challenges in Maritime Energy Management in 2018 after presented in Conference of MARENER 2017 in Malmö (Canbulat et al. 2017; Canbulat et al. 2018; Canbulat et al. 2019). This theoretical concept is generated to measure holistic energy efficiency in shipping operations as a detailed concept. The primary purpose of the model is to identify nodes of the integrated ship-port energy efficiency framework and develop a probabilistic approach, which can help increase energy efficiency and reduce CO_2 emissions for shipping companies. The second application is developed as an ARENA model applied to one of the European ports to see possible energy efficiency improvement and reduction in CO_2 release in a port operation and ship activities near port using different simulation scenarios will presented in Chapter 5. This application attempts to understand a much smaller part of the integrated system compared to BBN application, like a single yard truck's impact on the system's energy consumption. This chapter will explain the theoretical concept of BBN application and simulation application of DES application will deliver in Chapter 5 in detail with their case study applications.

4.2 Applications of the Models

4.2.1 BBN Application

An application of inter-operability/ dependability examination on marine transport can be an analytical way of assisting commercial shipping to become more energy-efficient and environmentally friendly. The BBN allow this opportunity to understand complex systems' interactions in a probabilistic manner (Neil, Littlewood, and Fenton, 1996; Yuqing and Tong, 2008, Sutrisnowati, Bae, and Park, 2014). The ship-port interface model with BBN regarding the energy efficiency interactions demonstrates interoperability by utilising the interdependency of ship and port operations (Canbulat et al., 2018). This model will also provide integration between port and ship operations by considering various parameters, including weather conditions, ship characteristics, primary engine efficiency, and ship speed planning and port efficiency. This section of Chapter 4 introduced the application of BBN and adaptation of BBN approach to ship-port interface regarding the energy efficiency and CO_2 emission interactions.

4.2.1.1 Bayesian Belief Networks (BBN)

Bayesian Theorem (BT) applies the prior and the probability functions to address the background knowledge in reversing conditional probability observations. BT also includes a statistical inference technique called Bayesian Inference. This is a statistical inference technique that aids BT to enhance the probability of a hypothesis based on the increasing availability of information. BT theorem can be described as follows (Bedford and Cooke, 2001):

X partition is a group of independent and identically distributed events with unknown distribution $X_1,\ldots,X_n \subset n \subset \Omega$ like that $X_i \cap X_j = \emptyset$ whenever $i \neq j$, and $X_1 \cup,\ldots, \cup X_n \subset n \subset \Omega$, Ω is a sample space, which is a set for all possible outcomes. Assuming that Y is an event and if it has $X_1,\ldots,X_n$ a partition, especially $Pr(Y) \neq 0$ *with* $Pr(Y) > 0$. At that time,

$$\Pr(X_\iota|Y) = \frac{Pr(Y|X_i)\,Pr\,(X_i)}{\sum_{j=1}^{n} Pr\,(Y|X_j)Pr\,(X_j)} \tag{1}$$

By using the definition of conditional probability, we can write the following formula:

$$\Pr(X_\iota|Y) = \frac{\Pr(Y|X_i)\Pr\,(X_i)}{\Pr\,(Y)} \tag{2}$$

The evidence of the aforementioned description regarding conditional probability can be presented as undermentioned:

$$Pr(Y) = \sum_{j=1}^{n} Pr\left(Y \cap X_j\right) \tag{3}$$

It continues to extend *the Pr(Y)* term. Law of Total Probability states undermentioned:

$$Pr(Y) = \sum_{j=1}^{n} Pr\left(Y|X_j\right)P\left(X_j\right) \tag{4}$$

Where:

$Pr\left(X_j\right)$, the initial probability is named as the prior probability.

$Pr(X_i|Y)$, the updated probability is named as the posterior probability.

$Pr(Y|X_i)$ is named as the likelihood.

$Pr(Xi|Y)$, the probability of Y for a given X as formulated in equation 5.

$$\mathrm{Pr}(X_\iota|Y) = Pr(Y|X_i)P(\,X_\iota) \tag{5}$$

Then $1/\sum_{j=1}^{n} Pr\left(Y\middle|X_j\right)P(\,X_j)$ is the constant of proportionality required to ensure that the total probability equals 1.

The BBN can be defined as a graphic modelling method. It presents a directed acyclic graph (DAG) in which the network nodes characterise stochastic variables (Yuan and Druzdzell 2006). Moreover, the relations between nodes are directed with arrows or arcs to represent probabilistic dependencies.

The BBN enciphers the distribution of joint probability between a set of variables $\{\mathrm{X_i}, \dots, \mathrm{X_n}\}$where n is subject to limitations and divides it into an outcome of dependent probability distributions across all individual variables connected to its parent nodes. In the case of nodes with parents, the prior probability is practised. The joint probability distribution across $\{\mathrm{X_i}, \dots, \mathrm{X_n}\}$ can be attained by using the output of each of these priors where; $\{\mathrm{X_i}, \dots, \mathrm{X_n}\}$ where n is a finite number and divides the joint probability into an outcome of dependent probability distributions through all individual variables that appoint its parents. When nodes obtain parents, the prior probability is computed. The distribution of joint likelihood across $\{\mathrm{X_i}, \dots, \mathrm{X_n}\}$ can be performed by utilising the outcome of every single prior where:

$$Pr(X_i, \dots, X_n) = \prod_{i=1}^{n} \Pr(X_i \middle| P(X_i)) \tag{6}$$

4.2.1.2 Stages to apply the BBN model

A usual BBN model requires four significant steps to be followed (Cao, Coutts, and Lui 2013). Creating a Causal Concept Map (CCM) is a significant first step before transforming the CCM into a BBN Model structure (step 2). CCMs are cognitive maps that reflect a subject's causal information in a particular area (Nadkarni and Shenoy 2001). CCM (also known as cognitive maps, cause maps, casual maps) are visual representations of important causes, experience, and situations that influence the system. Then computation of the conditional probabilities needs to be completed (step 3) before analysing the results of the BBN (step 4). As it is illustrated in Figure 4.1, in this study, 16 processes were developed to cover these four significant steps. This detailed model requires mainly the structure nodes and connections for developing CCM. The BBN connected by an arc are regularly named parent or child, subject to the arc direction.

The BBN method gives the flexibility of using various data sources and knowledge, including small or incomplete datasets and specialists' knowledge (Uusitalo 2007). As illustrated in Figure 4.1, nodes of BBN may adapt to remove the data subject to experts' opinion sets at different stages. Therefore, chains on the data set with experts' touch may have an influence on the probability distributions. However, the BBN helps to use all available or accessible data to obtain the probabilities.

The BNNs is applicable to visual analyses of inter-operability and inter-dependencies among the defined integrated shipping energy efficiency system's nodes. In this study, the GeNIe Modeller software tool is utilised to visually illustrate BBN and the results of the mathematical calculations (GeNIe Modeler. 2017).

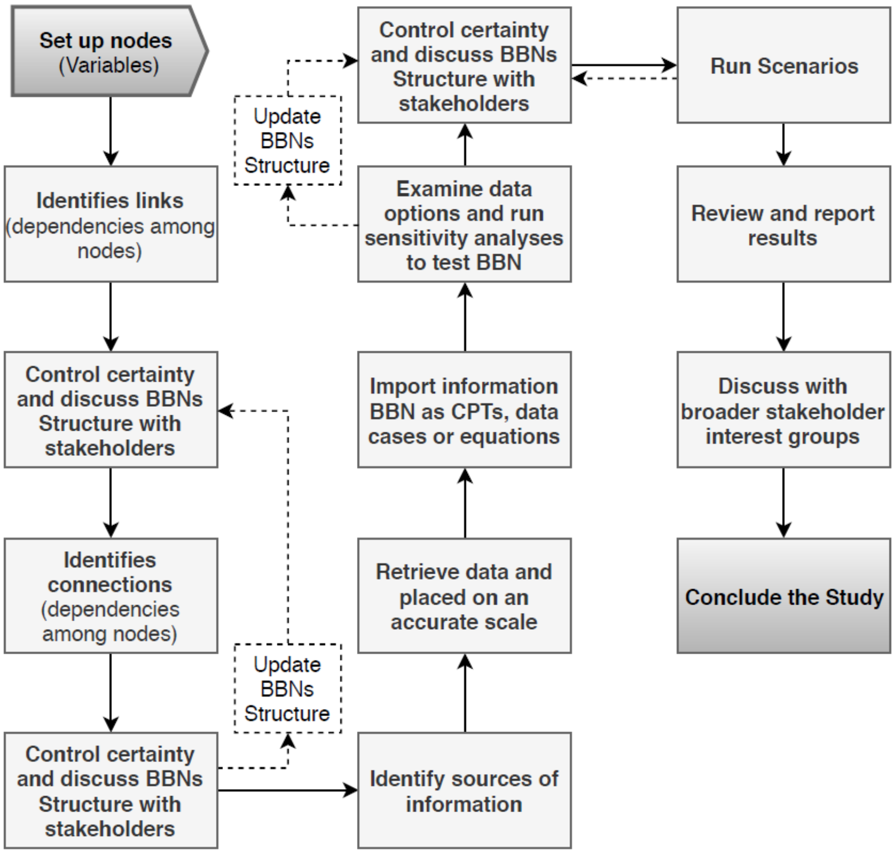


Figure 4.1 The flow chart representing important stages to develop and apply the BBN model (Inspired from Smith, Madsen, and Barton, 2015).

4.2.1.3 The BBN model of the integrated energy efficiency of ship-port interface

By applying BBN methodology on ship-port interface regarding the energy consumption and CO_2 emissions, the interoperability framework of systems is established. Expert opinions are utilised in the identification and development of parent-child hierarchy relationships of the nodes. According to the model developed in this study, the port performance consists of port operation performance, port traffic and weather-related conditions. On the other hand, ship operation performance consists of ship resistance and machinery and related systems performance. Based on the model, port and ship's operational performance outcomes influence slow steaming and route planning decisions, influencing energy consumption and CO_2 emissions. This methodological adaptation provides significant benefits for industrial practices, including:

- To identify energy efficiency interdependencies of ship and port operations.
- To clarify parameters influencing ship speed arrangement and route planning more holistically, considering both ship and port aspects.

- To measure energy efficiency performance of a ship working on liner service, time charter on a specific voyage, or consecutive voyage charter between two ports.
- To know where to improve nodes' performances based on different scenarios to get the best outcomes.

When the following chart, presented in Figure 4.1, is applied to create the BBN model, the application of the developed BBN model is visualised, as shown in Figure 4.2. To create a better understanding of the methodology and reduce the complexity of this first application, it is assumed that each of these variables in the BBN is designed for 2 or 3 different states in the study.

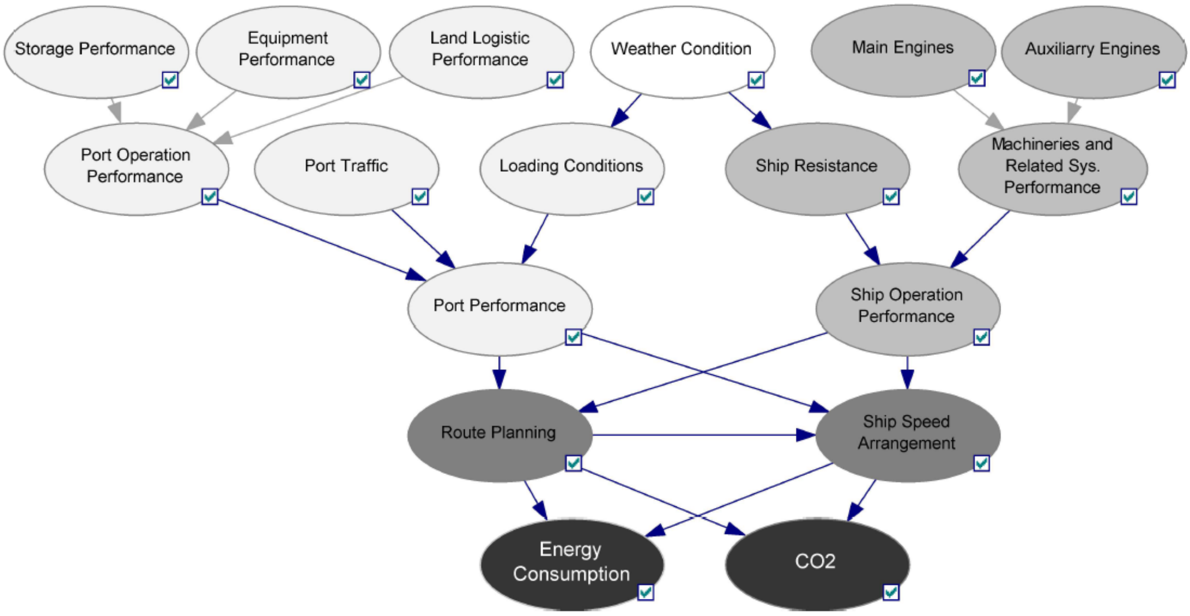


Figure 4.2 The BBN model for the integrated energy efficiency of ship-port interface.

In order to clarify the node hierarchy of the developed BBN model in Figure 4.2, the following part provides a detailed explanation:

Weather Condition (WC) refers to the weather condition of the ship's actual simulated voyage, which is attained from historical weather data. The probabilistic distribution of the recorded data is considered and divided into three sea state categories. They are considered based on Beaufort Numbers 0-3, 4-6, and 7-12.

Port Operation Performance (PO) refers to the discharging performance of the port. It is measured according to Expert opinions based on a specific case port and for a specific ship operation. `Mean Value` indicates the port operation performance average for similar ships based on internet-based commercial data statistics.

Port Traffic (PT) refers to the existence of queuing density of a particular time based on marine traffic data. This section is divided into two stages; `Busy` or 'Not Busy' to understand the queue in the port for that particular time.

Loading Conditions (LC) refers to the difficulty of the loading or unloading conditions at the port. This is mainly caused by operational uncertainties, which may occur due to the frequency of operational disruption. "Moderate_Lower_Difficulties" or "Heavy_Difficulties" are used as stages based on the perspective of experts within this field.

Ship Resistance (SR) indicates ship's total resistance in laden(loaded) condition, including the weather influence. It is computed according to the study of Y. J. Kwon and R. Lotensin theory cited in Kwon (2008). "Higher _Mean" or "Lower_Mean" are used by taking account of expert knowledge.

Machinery and Related System Performance (MP): The efficiency of machinery components, including the shaft, based on current ship data. "Higher _Mean", or "Lower_Mean" are used as stages. The 'Mean Value' is computed regarding the research of Shao (2013) and Cui (2018), which calculate the mean of sea trial performance.

Port Performance (SP): Performance of the entire port operation with various aspects generated according to existing port studies. “Higher _Mean (hm)” or “Lower_Mean (lm)” are used as stages. The `Mean Value` is taken based on port performance data of internet-based commercial data statistics.

Ship Operation Performance (SO): This indicates the ship's performance based only on actual data regarding energy consumption. The 'Mean Value' is computed as the mean of the sea trial energy consumption concerning the study by Shao (2013).

Route Planning (RP): Possible efficient route options are vital here, and "Fuel_Efficient_ Route" or "Not_Fuel_Efficient_ Route" are used as stages. Data on the research of Cui (2018) is used as reference data.

Ship Speed Arrangement (SS): The total energy utilisation of the vessel regarding current vessel data and the study of Cui (2018) are used as reference calculation. “Slow_Steaming_Speed” or “Other_Speed” are used as stages.

Energy Consumption (EC): The total energy utilisation of the vessel established on current ship data and calculations based on research by Cui (2018) “Higher _Mean (hm)” or “Lower_Mean (lm)” are used as stages. The `Mean Value` refers to the average energy consumption of the ship's possible scenarios of energy consumption.

CO_2 (CO): Total CO_2 emission of the ship based on existing ship data and ship consumption calculation based on ship trial data. Only ship energy consumption is considered. “Higher _Mean” or “Lower_ Mean” are used as stages.

(Port) Storage Performance (SP): The performance of the port storage system is used for analysis. Due to the lack of port data availability, commercial data statistics is also used together with expert opinions.

Equipment Performance (EP): Performance of port equipment based on existing port terminal handling equipment. Due to the lack of available data, only port equipment performance is considered. User performances are excluded.

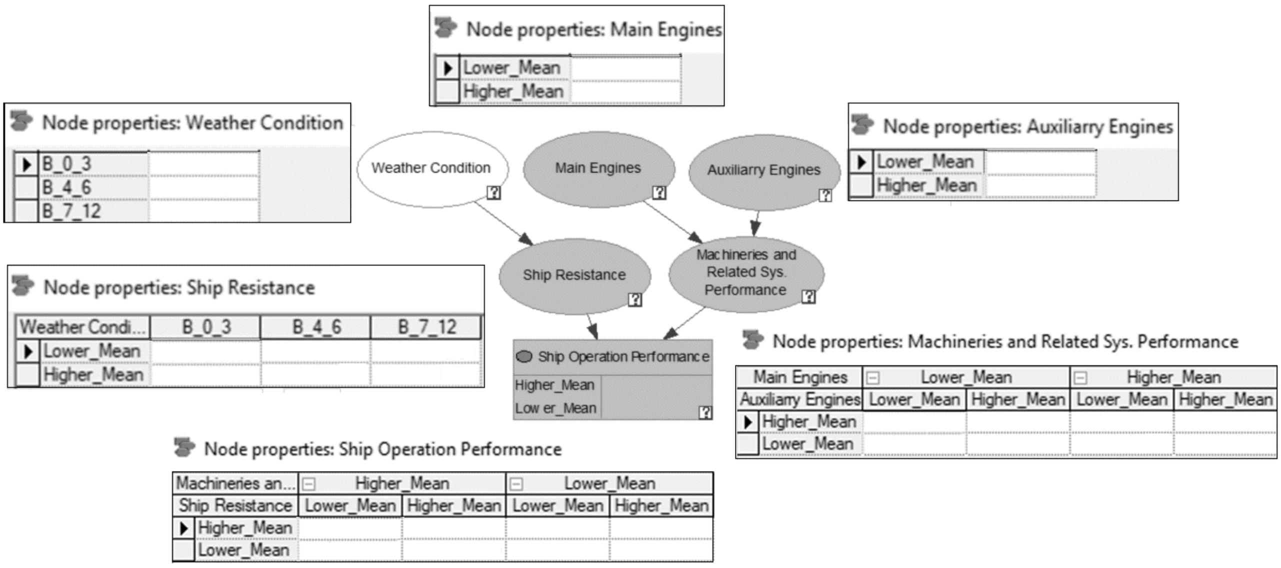
Land Logistic Performance (LL): Performance of land logistic based on expert opinions are used.

Main Engines (ME): Performance of the vessel's main engine by using recorded vessel data. The `Mean Value` is computed as the mean of the sea trail capability established on specialist knowledge by taking in to account the research from Shao (2013).

Auxiliary Engines (AE): Similarly, to the primary engine, the ship's auxiliary engine performance according to recorded vessel data is used. The `Mean Value` is calculated as the mean of the computed sea trial performance drives expert knowledge by considering the research from Shao (2013).

Every node requires a probability table in the BBN model. These tables can have conditions on their parental nodes' situations or marginal over the states if the node has not had any parental nodes. This is usually needed to perform parameterisation of the model using conditional probability tables (CPTs), which are determined by utilising data or any other available facts regarding the case or issue, expert opinion, or real data sets. CPT tables are illustrated in Figure 4.3 as part of the model.

Each CPT is represented by conditional probabilities Pr (X | Y), where; X is the child node, and Y is the parent node. In the BBN probability allocation, the outcome of the conditional probabilities of all individual variables of a node is established only on its parental nodes. This characteristic of BNs explains that all marginal prior and posterior probabilities can be acquired by marginalising and conditioning. Thus, an understanding of one or more variables can be amended as new knowledge or proof about other variables is gained.



Node properties: Main Engines

Lower_Mean	
Higher_Mean	

Node properties: Weather Condition

B_0_3	
B_4_6	
B_7_12	

Node properties: Auxiliarry Engines

Lower_Mean	
Higher_Mean	

Node properties: Ship Resistance

Weather Condi...	B_0_3	B_4_6	B_7_12
Lower_Mean			
Higher_Mean			

Node properties: Machineries and Related Sys. Performance

Main Engines	Lower_Mean		Higher_Mean	
Auxiliary Engines	Lower_Mean	Higher_Mean	Lower_Mean	Higher_Mean
Higher_Mean				
Lower_Mean				

Node properties: Ship Operation Performance

Machineries an...	Higher_Mean		Lower_Mean	
Ship Resistance	Lower_Mean	Higher_Mean	Lower_Mean	Higher_Mean
Higher_Mean				
Lower_Mean				

Figure 4.3 CPTs illustration example in the BBN model application of the study.

After the development of the BBN model the formula of the Energy consumption calculation under condition lower mean consumption (lm) of (EC) can be given, as shown in equation 7 by using GeNIe:

$$\Pr(EC = lm) = \sum_{PP,SO,RP,SS} P(PP = pp_i, SO = so_i, RP = rp_i, SS = ss_i\ EC = lm) = P(PP = hm, SO = hm, RP = fe, SS = os, EC = lm) + P(PP = hm, SO = hm, RP = fe, SS = ss, EC = lm) + P(PP = hm, SO = hm, RP = nf, SS = os, EC = lm) + P(PP = hm, SO = lm, RP = fe, SS = os, EC = lm) + P(PP = lm, SO = hm, RP = fe, SS = os, EC = lm) + P(PP = hm, SO = hm, RP = nf, SS = ss, EC = lm) + P(PP = hm, SO = lm, RP = fe, SS = ss, EC = lm) + P(PP = lm, SO = hm, RP = fe, SS = ss, EC = lm) + P(PP = hm, SO = lm, RP = nf, SS = os, EC = lm) + P(PP = lm, SO = hm, RP = nf, SS = os, EC = lm) + P(PP = lm, SO = lm, RP = fe, SS = os, EC = lm) + P(PP = hm, SO = lm, RP = nf, SS = ss, EC = lm) + P(PP = lm, SO = hm, RP = nf, SS = ss, EC = lm) + P(PP = lm, SO = lm, RP = fe, SS = ss, EC = lm) + P(PP = lm, SO = lm, RP = nf, SS = os, EC = lm) + P(PP = lm, SO = lm, RP = nf, SS = ss, EC = lm) \quad (7)$$

Where:

EC: Energy Consumption
PP: Port Performance
RP: Route Planning
SO: Ship Operation Performance
SS: Ship Speed Arrangement
hm: Higher Mean
lm: Lower Mean

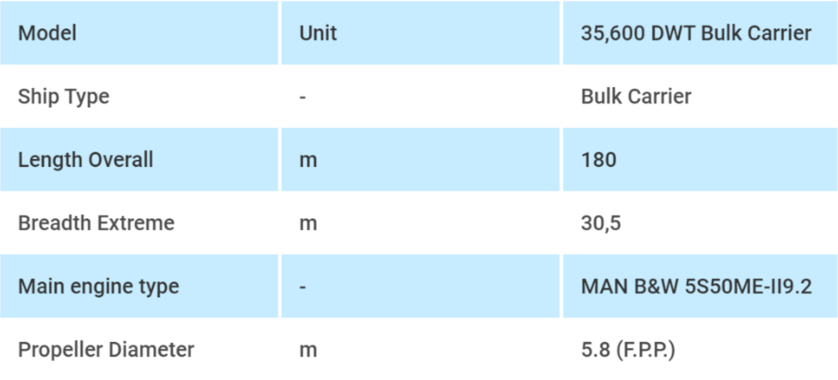
The following formula shows EC under the condition, which has a higher probability than a mean value (*hm*) of a typical operation:

$$\Pr(EC = hm) = (1 - \Pr(EC = lm) \tag{8}$$

4.2.1.4 Case Study

Within this case study, 35,600DWT Bulk Carrier data is used to implement a simplified model of BBN. Some vessel specifications are illustrated in Table 4.1. The Port of New York (USNYC) and the Port of Southampton (GBSOU), one of the UK's major ports, have been respectively selected as the outward and inward ports for this case study. A map illustration of the voyage is shown in Figure 4.4. Departure day from USNYC is 01.05.2014, and the arrival day in GBSOU is 10.05.2014.

Table 4.1 Specifications of the ship utilised in the case study.



Model	Unit	35,600 DWT Bulk Carrier
Ship Type	-	Bulk Carrier
Length Overall	m	180
Breadth Extreme	m	30,5
Main engine type	-	MAN B&W 5S50ME-II9.2
Propeller Diameter	m	5.8 (F.P.P.)

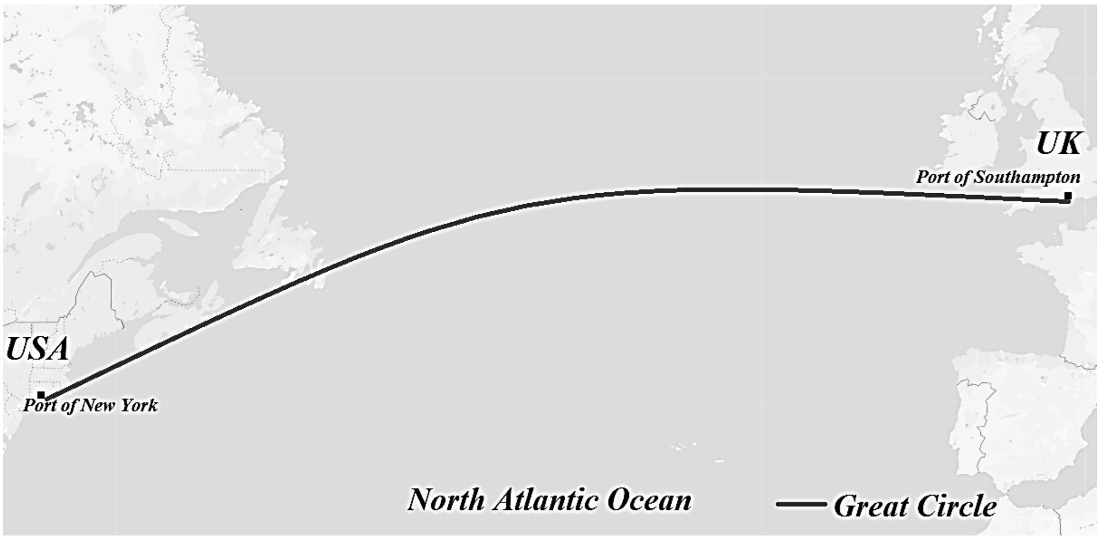


Figure 4.4 Origin and destination ports of the case study.

The quantitative hierarchal probabilistic interactions between the case study variables are illustrated in Figure 4.5, thanks to the facilitation of the Bayesian network. By implementing the BBN practice stages, as thoroughly described in the preceding section, it is possible to display each variable as a node. The energy efficiency interface between the port and ship following the BBN model's implementation is indicated in Figure 4.5. The distinct format (nodes and interconnections) of the model is evolving from existing research and specialist opinions (Hansen, 2012). The joint probability distribution of the considered variables is exhibited analytically in the BBN model. The data highlighted in Table 4.2 has been utilised to consider the precise distribution of the probabilistic independencies amidst the modelled nodes. All nodes are individually characterised by a conditional probability interaction on their parent node. For example, the nodes given in Figure 4.5 illustrate all CBTs by the prior probability interactions across results displayed in Table 4.2. The Node 'Loading Conditions' was depicted by a likelihood distribution over its results (Low/Moderate Traffic and Heavy Traffic), and its contingent relationship on the results of its parent node (hub Weather Condition, results from 0-3, 4-6, and 7-12). Specialist judgement assisted to evoke the structure and numerical parameters of the BBN model. As outlined in Table 4.2, the data was obtained from operational measurements, including data from ships and ports, recorded meteorological data, as well as previously published data. The study by Cui, Turan, and Boulougouris (2016) helped calculate the CPTs of route planning and energy consumption nodes, using optimum route data with minimum fuel consumption for this case study. Data, which was publicly available, was utilised to obtain port weather condition data (Wunder 2016).

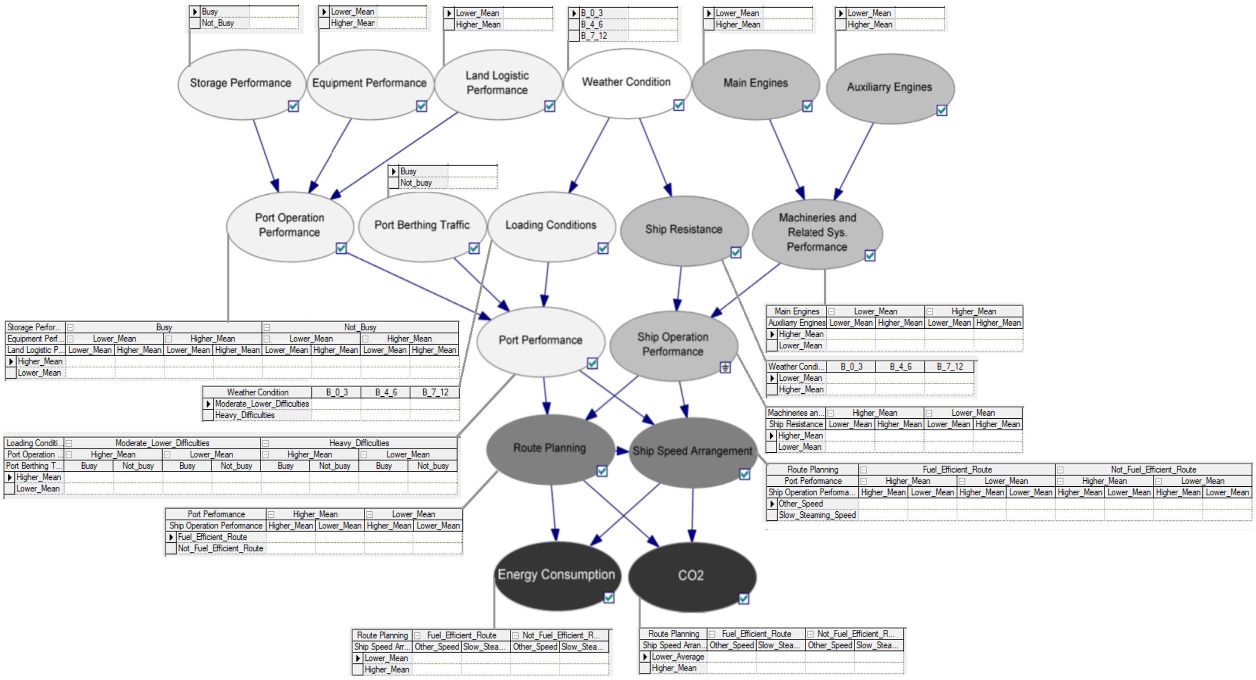


Figure 4.5 The Integrated Ship-Port Energy Efficiency Model data matrixes.

Table 4.2 Node descriptions, states and data collection sources of the study..

Input node	Description	States	Data Type
Weather Condition (WC)	Weather data based on Beaufort Numbers obtained from verified weather data. Sea state condition is considered based on Beaufort Numbers frequency. As an example, all noon data analysed for the case study and average Beaufort Numbers are considered and compared with optimum weather rooting results of that route.	0-3 4-6 7-12	Noon Data and Real Weather Data
Port Operation Performance (PO)	The capacity of the discharging/loading cargo type is obtained from port specifications and operations. Due to the data limitation, assumptions are used. It is assumed based on Expert Views. `Mean Value` refers to the mean of port operation performance.	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Secondary Resources and Expert Views
Port Traffic (PT)	Marine traffic Fleetmoon data are used to assume the actual traffic of the port. `Busy` means that the possibility of having a queue in the port when the ship arrives at the port. Marine Traffic and Fleetmoon Statistic are used for the selected port case.	“Busy (bu)” or “Not_Busy (nb)”	Marine Traffic Data
Loading Conditions (LC)	Difficulties in reaching the real loading conditions are made based on port operation research and weather data. It is calculated based on the frequency of loading/discharging operation breaks due to operational problems such as heavy weather. Secondary sources and expert opinions are used for estimation.	“Moderate_Lower_ Difficulties (ld)” or “Heavy_Difficulties (hd)”	Secondary Resources and Expert Views
Ship Resistance (SR)	It refers to the total resistance of the ship. Weather effect calculation is made based on Y. J. Kwon and R. L.Townsin theory cited in Kwon (2008). Ship sea trail results compared with operational one based on Kwon (2008).	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Real Results of Sea Trial, Secondary Resources and Noon Data
Machinery and Related System Performance (MP)	It is the performance of all machinery parts, including shaft, of ship based on the ship data. The `Mean Value` is calculated as the mean of the calculated sea trail performance based on the available data set using Shao (2013) studies and Cui, Turan, and Boulougouris (2016).	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Real Results of Sea Trial and Noon Data and Secondary Resources
Port Performance (PP)	Performance of whole port operation based on actual port research. “Higher _Mean (hm)” or “Lower_Mean (lm)” are used as stages. The `Mean Value` is based on port performance data of Fleetmoon.	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Secondary Resources and Expert Views
Ship Operation Performance (SO)	This refers only performance of the ship based on energy consumption from actual data. The `Mean Value` is calculated as the mean of the calculated sea trail energy consumption based on the study of Shao (2013).	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Real Results of Sea Trial and Noon Data and Secondary Resources
Route Planning (RP)	Possible efficient route options are vital here, and “Fuel_Efficient_ Route” or “Not_Fuel_Efficient_ Route” are used as stages. Research of Cui (2018) is used as a reference for calculation.	“Fuel_Efficient_ Route (fe)+” or “Not_Fuel_Efficient_ Route (nf)”	Secondary Resources and Expert Views
Ship Speed Arrangement (SS)	Total energy consumption of ship based on actual ship data and study of Cui (2018) is used as reference calculation. “Slow_Steaming_Speed” or “Other_Speed” are used as stages.	“Slow_Steaming_Speed (SSS)” or “Other_Speed (OS)”	Noon Data
Energy Consumption (EC)	Total energy consumption of ship based on actual ship data and calculation is based on Cui (2018). “Higher _Mean (hm)” or “Lower_Mean (lm)” are used as stages. The `Mean Value` refers to the average energy consumption of the possible ship energy consumption scenarios.	“Lower_Mean” or “Higher_Mean”	Noon data, Secondary Resources and Expert Views
CO_2 (CO)	It refers to the total CO_2 emission of ship based on actual ship data and ship consumption calculation based on ship trial data. Only ship energy consumption is considered. “Higher _Mean”, or “Lower_Mean” are used as stages	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Noon data, Secondary Resources and Expert Views
(Port) Storage Performance (SP)	Performance of port storage system is used to analyse. Due to the data limitation partly available port data, the Fleet-moon data are also used together with expert views.	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Secondary Resources, and Expert Views and Fleetmoon Data.
Equipment Performance (EP)	It refers to the performance of port equipment based on actual port handling equipment. Due to the data limitation, only port equipment performance is considered.	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Fleetmoon Data, Secondary Resources and Expert Views
Land Logistic Performance (LL)	Performance of land logistic based on expert views is used.	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Secondary Resources and Expert Views
Main Engines (ME)	Performance of the main engine of ship based on actual ship data is used. The `Mean Value` is calculated as the main of the calculated sea trail performance based on expert knowledge by taking into account the research from Shao (2013).	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Real Results of Sea Trial Noon data, Secondary Resources and Expert Views
Auxiliary Engines (AE)	Performance of the auxiliary engine of ship based on actual ship data is used. The `Mean Value` is calculated as the main of the calculated sea trail performance based on expert knowledge by taking into account the research from Shao (2013).	“Higher _Mean (hm)” or “Lower_Mean (lm)”	Real Results of Sea Trial Noon data, Secondary Resources and Expert Views

4.2.1.5 Results and Discussion

The results are generated by applying the GeNIe version 2.1 for the chosen case after applying the model of BBN. Outcomes are shown in Figure 4.6 as a value of nodes` outcome for Energy Consumption and CO_2. The model application of this integrated system is expected to be energy efficient by 58% and CO_2 efficient by 61%, respectively, in comparison to the mean of previously recorded data when we consider them as an indicator.

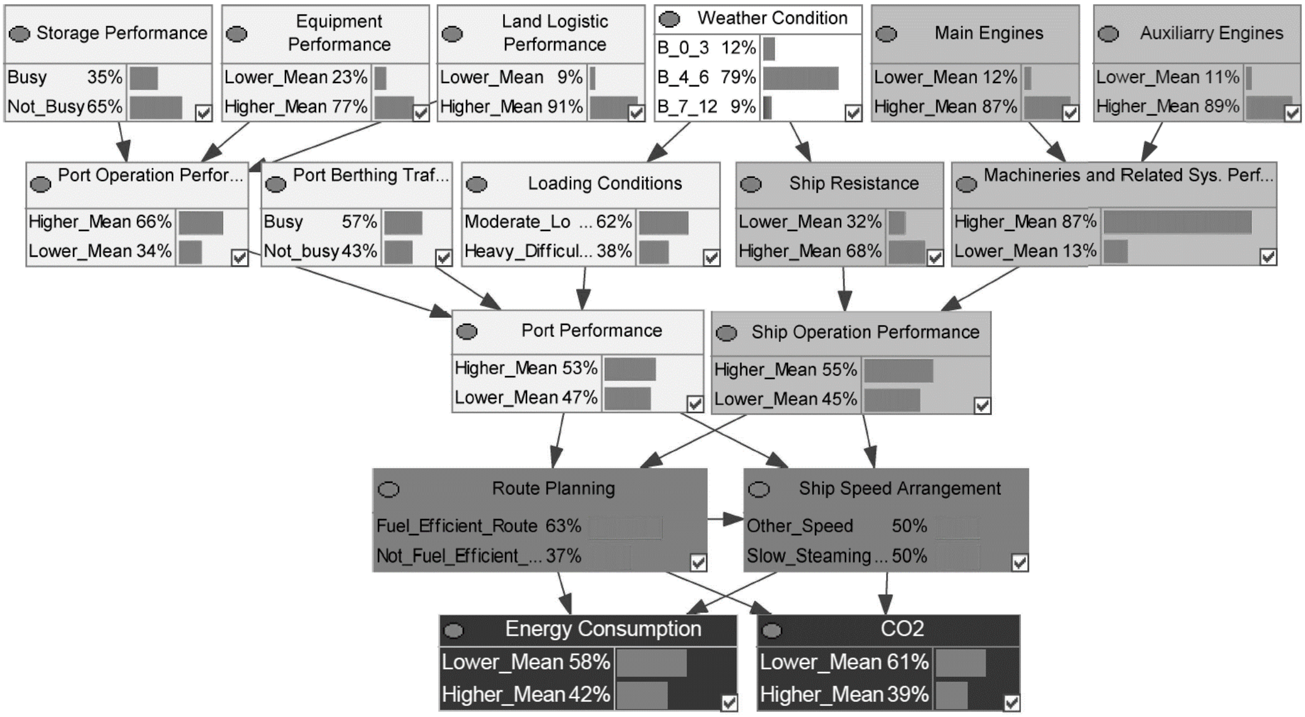


Figure 4.6 Real Results of the case study application.

On the other hand, there is still a higher probability of having lower energy consumption than the average performance in comparison to similar ship voyages and port operations. When exact information about higher port performance than the mean value is known, the ship has better energy efficiency probability, in comparison to results previously given in Figure 4.7. Similarly, when the ship operation performance is predicted to be higher than the mean value, relating to energy efficiency, the likelihood of being CO_2 and energy-efficient rapidly increases, as displayed in Figure 4.8.

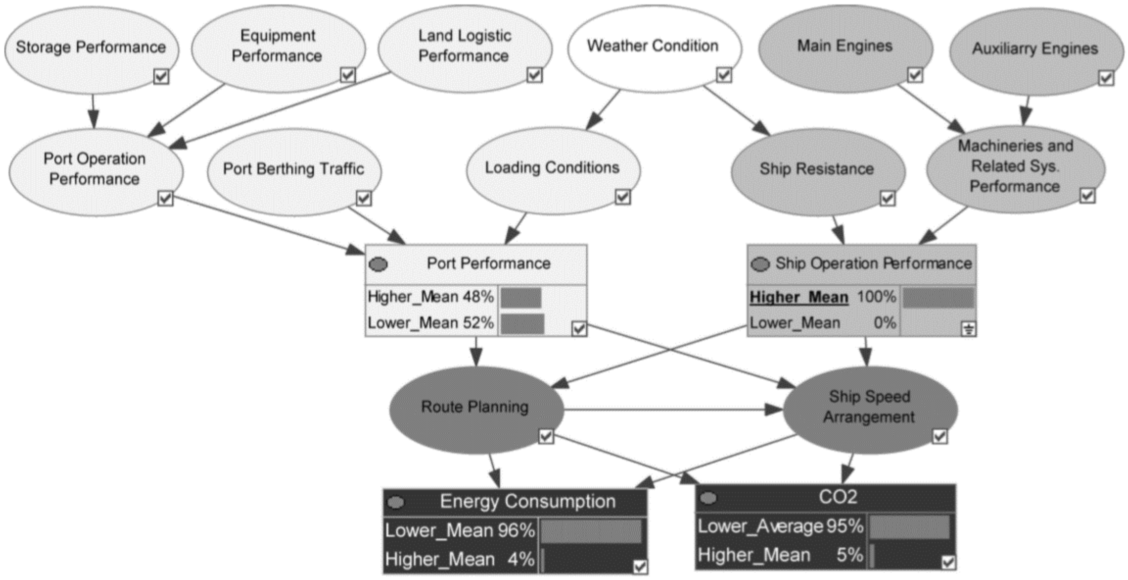


Figure 4.7 Results of the case study for best ship performance scenario.

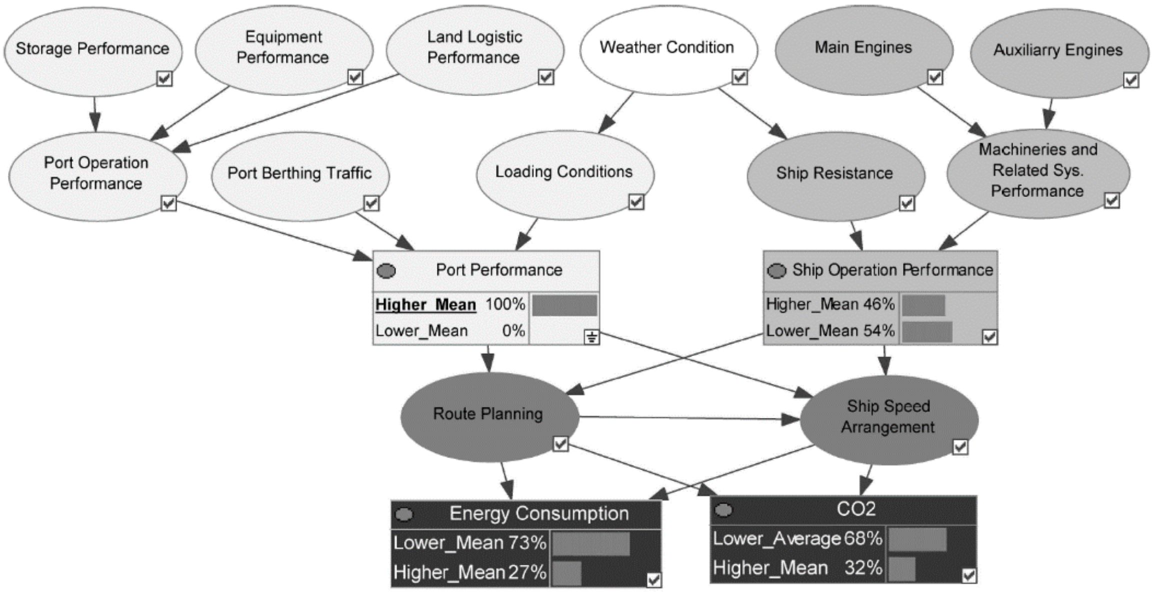


Figure 4.8 Results of the case study for the best port performance scenario.

Assuming the ideal ship operation performance, the likelihood of consuming less energy, in comparison to the mean value, rises from 58% to 86%. This shows that if the industry makes ships fully energy efficient, they can have such a high increase in the energy efficiency of the integrated system. Likewise, the possibility of less CO_2 emission, in comparison to the mean value, increases from 61% to 85%. The result primarily determines that positive adjustments in ship operation related nodes have a greater impact on energy consumption and CO_2 emission than port-related ones. However, both port performance and ship operation needed to be coordinated to reach the possibility of having a 100% energy and CO_2 efficient system in comparison to previously recorded data of ship working on time charter or consecutive voyage charter. It certainly clarifies that the port performance and ship operation performance complete each other to run a much better energy-efficient operation.

Table 4.3 Comparison of real probabilistic value results with different scenario results.

Node Names	**State**	**1. Real Result (%)**	**2. Scenario 1 (%)**	**3. Scenario 2 (%)**	**4. Scenario 3 (%)**	**5. Scenario 4 (%)**	**6. Scenario 5 (%)**	**7. Scenario 6 (%)**
Weather Condition (WC)	*B_0_3*	12	18	5	14	19	10	3
	B_4_6	79	75	83	78	74	80	85
	B_7_12	9	7	12	8	6	10	12
(Port) Storage Performance (SP)	*Busy*	35	33	38	30	35	41	35
	Not _Busy	65	67	62	70	65	59	65
Equipment Performance (EP)	*Lower_Mean*	23	20	28	14	23	33	23
	Higher_Mean	77	80	72	86	77	67	77
Land Logistic Performance (LL)	*Lower_Mean*	9	9	9	8	9	10	9
	Higher_Mean	91	91	91	92	91	90	91
Main Engines (ME)	*Lower_Mean*	13	5	21	13	2	12	2
	Higher_Mean	87	95	79	87	98	88	25
Auxiliary Engines (AE)	*Lower_Mean*	11	10	12	11	10	11	12
	Higher_Mean	89	90	88	89	90	89	88
Port Operation Performance (PO)	*Higher_Mean*	66	74	56	87	66	44	34
	Lower_Mean	34	26	44	13	34	56	66
Port Berthing Traffic (PT)	*Busy*	57	52	65	42	57	74	34
	Not _Busy	43	48	35	58	43	26	57
Loading Conditions (LC)	*Moderate_Lower_*	62	68	54	72	66	51	43
	Heavy_Difficulties	38	32	46	28	34	49	58
Ship Resistance (SR)	*Lower_Mean*	32	46	14	33	51	30	42
	Higher_Mean	68	54	86	67	49	70	92
Machinery and Related System Performance (MP)	*Higher_Mean*	87	96	76	87	99	87	72
	Lower_Mean	13	4	24	13	1	13	28
Port Performance (PP)	*Higher_Mean*	53	70	27	**100**	53	**0**	52
	Lower_Mean	47	30	73	**0**	47	**100**	48
Ship Operation Performance (SO)	*Higher_Mean*	55	88	15	56	**100**	54	**0**
	Lower_Mean	45	12	85	44	**0**	46	**100**
Route Planning (RP)	*Fuel_Efficient_Rout*	63	95	18	89	53	35	39
	*Not_Fuel_Efficient_*	37	5	82	11	47	65	61
Ship Speed Arrangement (SS)	*Slow_Steaming_Sp*	50	91	4	62	84	62	93
	Other_Speed	50	9	96	38	16	38	7
Energy Consumption (EC)	*Lower_Mean*	58	**100**	0	77	86	38	25
	Higher_Mean	42	0	**100**	23	14	62	75
CO_2 (CO)	*Lower_Mean*	61	**100**	0	74	85	46	31
	Higher_Mean	39	0	**100**	26	15	54	69

1. Real Results refers to the actual outcome of the case study.
2. Assumption 1 refers to them when the EC and CO are known as lower than the mean value.
3. Assumption 2 refers to when the EC and CO are known as higher than the mean value.
4. Assumption 3 refers to when the only PP is known as higher than the mean value.
5. Assumption 4 refers to them when the only SO known as higher than the mean value.
6. Assumption 5 refers to when the only PP is known as lower than the mean value.
7. Assumption 6 refers to them when the only SO known as lower than the mean value.

Table 4.4 Experiment matrix of scenario

Node Names	**Scenario 1**	**Scenario 2**	**Scenario 3**	**Scenario 4**	**Scenario 5**	**Scenario 6**
CO_2 (CO)	%100 LM	%100 HM	-	-	-	-
Energy Consumption (EC)	%100 LM	%100 HM	-	-	-	-
Ship Operation Performance (SO)	-	-		%100 HM		%100 LM
Port Performance (PP)	-	-	%100 HM	-	%100 LM	-
LM: *Lower_Mean* *HM: Higher_Mean*						

Table 4.3 illustrates the results of each state under six different assumptions and actual situations shown in experiment matrix Table 4.4. These results allow a comparison of the impact of each scenario and provide the possibility to analyse the impact of each node on others. For instance, a comparison between real results and scenario 1 illustrates some improvements needed to be carried out to reach total energy and CO_2 efficient operation. Some possible actions are required to increase the performance level, e.g., machinery performance needs to increase by 9%, and the main engine and port performance need to increase by 8%. Besides, the table demonstrates that there is a big gap between scenario one and real results. However, this gap indicates the possible probabilistic limits of an efficient system and the differences between these two situations. To be able to reach 100% port efficiency, some vital developments are required for enhanced port operation performance. Energy consumption of the integrated system should be enhanced by 27%, and some minor variations should be made for port berthing traffic by 5% without any change with loading conditions.

Scenario 2 represents the worst state as the absolute value of not being energy and CO_2 efficient system. The impact of port performance on results when the port performance is known exactly is lower than the mean value. It increases the CO_2 emission by 19% and energy consumption by 13% without any change to the ship's engine or resistance.

Table 4.3 provides the detailed results for scenario 4 and 5 for the same assumptions made in Figure 4.7 and Figure 4.8 regarding port and ship operation performances that are higher than the average values. Table 4.3 also shows the results for scenarios 6 and 7 for the opposite assumptions regarding port and ship operation performances, which are lower than the average values. The comparison of these last four scenarios emphasises that CO_2 consumption decreases much slower than energy consumption decreases when the performance of port activities is improved. Moreover, these results show that slight changes create a substantial impact on the same nodes when any of the absolute values are changed by conditional probability.

As mentioned in the table, the second scenario referred to the known low energy consumption and CO_2 released. When the actual results are compared to the results of the second scenario, the results underline the following points:

- Port performance needs to be 17% better than the actual situation. However, ship operation performance needs to be 33% better than it is actual performance. This can show that ships performance needs to be advanced more than port performance to achieve less energy consumption and carbon release in the given case.
- When the Route Planning figures are compared, the system requires at least 95% fuel-efficient route to operate the ship to reach the lower energy consumption and carbon pollution. This means that there is a possible improvement need of around 32% for the actual case.
- The most significant improvement and change that appear for the ship speed arrangement is 41% for the same purpose. This shows us that ship speed can be one of the notable effects on the system for that case ship.

- However, port berthing traffic does not require more than 5% improvements to contribute to the system, and this followed by ships' auxiliary engines performance and port storage performance improvements by 1% and 2%, respectively.

4.3 Chapter Conclusion

This research introduced a methodological framework to demonstrate the influence of integrated ship-port operations regarding ship energy efficiency. The methodology is in line with BBN on the ship-port interface by utilising the interdependencies among port and ship operations in terms of the ship's energy consumption and CO_2 emissions. Therefore, by establishing an inter-operability link between ship voyage and port operation aspects, a more holistic and integrated operational energy efficiency performance measure is generated.

In this paper, different research efforts, including port operation, weather routing and slow steaming studies, were integrated under one probabilistic methodology. The Port-ship integration energy efficiency framework was established based on the conditional probability theory and was practically applied to the given case study. The study's case application also gave a chance to understand the probabilistic relation between all nodes in practice. Therefore, the results of different scenarios show that the integrated energy efficiency may be achievable with some improvements in different nodes described in Table 4.2. Each of the possible assumption results gives a chance to understand the impact of these potential changes on the ship-port interface's integrated energy efficiency.

This research has the potential to build more understanding and create more opportunities around the idea of probabilistic modelling, with the aim of enhancing energy efficiency for specific operations for a range of ship types. The findings of this case study have several important implications for future practice. Firstly, it will be possible to develop a commercial software application with coding based on probabilistic BBN methodology. Furthermore, the study may create opportunities to publish new studies on self–organisation of port operations to adapt to the changing energy efficiency requirements regarding vessels. Moreover, this research offers to quantify the integrated energy efficiency of ship operation and determine and eliminate barriers causing an energy efficiency gap. Results of the models indicate where the operators need to focus most. The results of the scenarios indicate which nodes of the case study have more room for improvements that can be realised by the operators. Lastly, a new understanding of this research will generate the application of similar methodologies in different engineering and operation management problems where efficiency with interoperability is needed.

4.4 Chapter Summary

This chapter summarises the research goals and objectives obtained by applying BBN, as well as a general discussion of the limitations, assumptions, and challenges encountered during the PhD review. New concepts and contributions were also clearly highlighted.

CHAPTER 5: APPLICATION OF MODEL & RESULTS – DES ARENA

5.1 Chapter Overview

As stated in both Chapter 2 and Chapter 4, there is a need to better understand the ship and port operators to help them sustain energy-efficient integrated ship and port operations. This research had two applications to examine the energy efficiency in the ship and port interface. The first application in this thesis is based on a BBN application presented in Chapter 4. This theoretical concept is generated to measure holistic energy efficiency in shipping operations as a clear concept and develop a probabilistic approach, which can help increase energy efficiency and reduce CO_2 emissions for shipping companies. The second application is designed as a DES Arena model applied to one of the leading European container ports. This part aims to see possible energy efficiency improvement and decrease in CO_2 release in a port operation and ship activities near port using different simulation scenarios presented in this chapter. This application attempts to understand a much smaller part of the integrated system than the BBN application, like a single yard truck's impact on the system's energy consumption. This chapter will explain the simulation application of DES by using ARENA software in detail with their case study applications.

5.2 ARENA Application

Simulation is one of the most powerful tools and problem-solving techniques available to analyse complex systems like port and ship operation (Kelton, Sadwoski, and Sadwoski, 2007). Simulation methods can be used to simulate a wide variety of operations while at the same time allowing for their related randomness and uncertainty. ARENA is one of the accurate modelling tools, and this software is used to develop a model in this section to have a quick and detailed investigation for port operation and ship arrival integration in terms of energy efficiency. Simulation of a container port in Europe has been developed, and all processes and steps were explained in detail, and then they are validated with real data obtained from the case study port. After building the model, the results have been presented with discussions in this subsection.

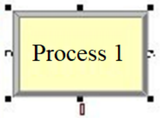
5.2.1 Identification of Modules in ARENA

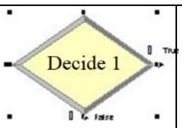
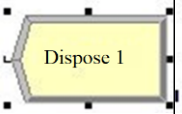
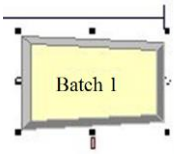
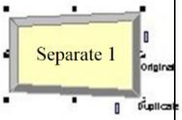
The Arena is built on SIMAN language constructs, and it is a simulation environment that consists of module templates (Altiok and Melamed, 2007). Here the main concept and modules of ARENA simulation are presented to understand the model developed in this research. More descriptions can be found in Kelton, Sadowski, and Sturrock (2004) and Altiok and Melamed (2007). Two types of objects are available in SIMAN language, and these are blocks and elements. In detail, blocks are simple logic structures that represent operations like the SEIZE block models, including the seize of a service facility by the transaction (used in ARENA as "entity"), while the RELEASE reverses the function (Altiok and Melamed, 2007, Rossetti, 2015). Commonly used Arena modules in the developed model and frequent applications are detailly described based on Guide's book of ARENA (2010) in Table 5.1. The table also gives possible applications for a port application for each module.

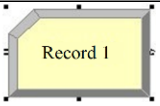
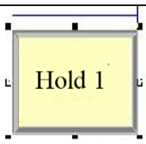
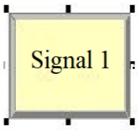
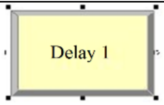
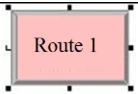
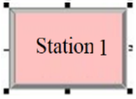
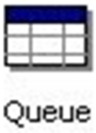
Arena develops a programming framework that integrates visual and text programming. The standard Arena process has several activities (Altiok and Melamed, 2007):

1. Choose the module/block symbols from the template panel and put them on the Visual model canvas (by drag and drop).
2. Visually linking modules to represent the actual flow paths of transactions and/or the logical flow paths of control.
3. Using a text editor to make parallelised modules or elements.
4. Writing snippets of code in modules using a text editor.

Table 5.1 Arena modules and their details (Adapted from ARENA, 2010).

Module	Symbol	Description	Examples
Create		This is the starting point for any simulation model consist of entities` flow the model. Each entity is created by our supplied timing information. Entities then leave the module to begin processing through the model. The entity type is specified in this module. This module assists in a specified entity type.	• The start of cargo packaging in a logistic hub. • A cargo arrival (like container, bulk cargo) into a port operation. • A ship`s arrival to ports area (like anchoring area, terminal).
Process		This module is the primary processing method in the simulation. This provides optional resource constraints for seizing and releasing. There is also a possibility to use a "submodel" and identify hierarchical user-defined logic. The processing time is assigned to the entity and may be value-added, non-value-added, transfer, wait, or other. There is a possibility to add associated costs for a suitable category.	• Reviewing a document (like cargo or ship documents) for completeness. • Fulfilling orders. • Serving a ship, truck, or customer. • Machining a part. • Handling a cargo.

Decide		This module allows users to make decisions based on one or more conditions (e.g., if entity type is an export container) or based on one or more probabilities (e.g., 60% full; 40% empty). This module also creates a decision regarding attribute values (e.g., Preference), variable values (e.g., number Rejected), the entity type, or an expression (e.g., NQ (ProcessC.Queue)). This module provides two exit points based on the Decide module when its specific type is either 2-way Chance or 2-way Condition. It also has "true "false" differentiation for entities and multiple exit points by N-way Chance or Condition type for each condition or probability and a single "else" exit.	• Branching accepted or rejected checks (like ships documents). • Sending priority customers to a dedicated process (like separating certain ship to give priority. • Deciding to use a service or not (like tugboat). • Dispatching a damaged container for different process.
Dispose		Entity flow always starts with a Create module and terminates with a Dispose module. Therefore, this module is intended as the ending point for entities in a simulation model when their processing is complete. This module is capable of record statistics before the entity is disposed of.	• Parts leaving the modelled facility. • The termination of a business process • Customers departing the store.
Batch		This module is intended as a grouping feature in the simulation model. A batch of individuals can be permanently or temporarily batched together. Then, temporary batches must be separated using the Separate Module. Batches can be generated for any set amount of entering entities or may be matched together based on an attribute. Entities arriving at the Batch Module may also be put in a queue before the appropriate number of entities has accrued. A new representative entity is produced after it has been accumulated.	• Collect several entities (like 20 TEU container) before starting processing. • Reassemble previously separated copies of a form. • Bring together a patient and his record before commencing an appointment (make 40 TEU containers from 20 TEU ones).
Separate		This module can copy an incoming entity into multiple entities or separate an already batched entity. The principles for assigning duplicate costs and times are described. Rules for assigning attributes to member entities are also described. As the previous batches are separated, the temporary representative entity that was formed is disposed of, and the initial entities that formed the group are recovered. The individuals continue consecutively from the module in the same order they were initially added to the batch. When duplicating entities, the required number of copies shall be made and sent from the module. The initially received entity also leaves the module.	• Send different entities to represent boxes removed from a container. • Send a container both to exit the port from a gate by a truck and billing for parallel processing. • Separate a previously batched set of documents or countries (40 TEU to 2 times 20 TEU).
Assign		A new value to variables (like entity attributes, entity types, entity images, or other systems) can be added by using these module variables. Multi assignments can be rendered using a single Assign module.	• Set priority for the consumer. • Set entity images to any entity like Ship/Container. • Adjust the type of individual to indicate the consumer copy of a multi-page form

Record		This module is for gathering and recording various types of statistics in the build model. Some of these statistics are time (between exits through the module or for any entity), expenses, observation, count type of statistic and interval statistics like time stamp to the current simulation time.	• Record the number of handling completed each hour. • Count how many ships have been late being operated. • Record the time spent storing reefer containers.
Hold		This module will keep an entity in a queue either to wait for a signal, to wait for the defined state to become true (scan), or to keep it indefinitely (to later be removed with the Remove module).	• Holding containers/trucks for a signal.
Signal		If the module is keeping an entity, the Signal Module would be used to allow the entity to pass to the next module. If the entity keeps for a defined condition to be true, the entity will stay in the module queue until the condition(s) becomes true. When an entity is in an infinite hold, the Remove Module can be used to enable the entity to move to the next process.	• Giving a signal for trucks to start operation.
Delay		The Delay Module can delay an entity by a given period of time. The time is then allocated to the entity’s value-added, non-value-added, transfer, wait, or other time. Delay related expenses are also measured and assigned.	• Delay berthing of a ship.
Route **Station**	 	The Route block moves an entity in the Duration of time units to the arrival destination identified by the assigned a `Destination` module.	• Creatin a route for ship or trucks
Entity		This data module describes the different types of entities and their input images in a simulation. Actual costing and holding costs are also specified for the entity.	• Products to be manufactured or assembled (parts, pallets). • Documents (forms, e-mails, faxes, reports). • Individuals who move into the process (customers, callers).
Queue		This data module can be used to adjust the ranking rule for the given queue. The standard ranking rule for all queues is First In, First Out, unless it is stated in this module. There is already an optional field to enable the queue to be specified as shared.	• Stack of tasks pending for a resource in the Process Module. • A holding area is waiting for paper works to be processed in a batch module.
Resource		This data module describes the resources of the simulation framework, like costing details and supply of resources. Resources with a set capability do not change during a simulation run or may function on a scheduled basis.	• Equipment like machinery, trucks, cranes, tugboats. • People like operators, captain, officers, order agents.
Variable		This data module is used to describe the dimension and the initial value of the variable(s), which can be referenced in other modules (like a Decide module). A new variable	• Number of containers handled per day. • Serial number to allocate to parts for unique ID. • Place available in a storage.

		can be reassigned to the Assign module, which can be applied in any expression.	
Schedule	Schedule	This data module can be used in combination with the resource module to define a resource operating schedule or the Create module to establish an arrival schedule. Besides, a schedule can be used to link to the delays of factor time dependent on the simulation time.	• The work schedule for workers, including break times. • Breakdown patterns for port equipment. • The volume of ship or cargo arriving in port.
Set	Set	This data module identifies various set types, including resource, counter, count, entity form, and entity image. The resource sets are also found in the Process modules.	• Crain that can perform the same operations in a port. • Shipping workers, receptionists in an office • Set images for each entity.
Attribute		Data modules are a list of objects in the model spreadsheet view that describe different process components' characteristics, such as resources and queues. This data module is used to describe the dimension, data form, and initial value of the attribute (s). An attribute is a characteristic of all entities, but it has a particular meaning that can vary from one entity to another. Attributes can be referenced in other modules (e.g., the Decide module), a new value can be reassigned to the Assign module, which can be included in any expression. Attribute values are unique for each entity compared to variables that are universal to the simulation module.	• The delivery date of a cargo arrival (entity). • A priority of cargo or order (entity). • Colour of a part (entity).

Overall, ARENA offers an effective simulation environment to model almost every situation involving the flow of transactions across various processes, including port operation. Although the user builds the model interactively in both graphical and textual modes, ARENA records reverting in SIMAN code. It checks the model for syntactic errors (graphic and textual), a significant amount of initial testing takes place automatically (Altiok and Melamed, 2007). Figure 5.1 demonstrates the interface of an application of Arena for a simple example of a queueing theory as the M/M/1 (Kleinrock, 1975) queue before to shows the build model in AREAN for a complex port application.

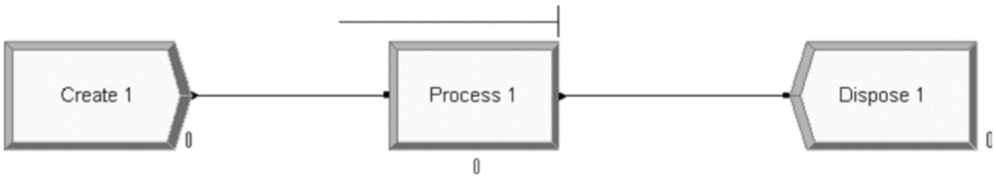


Figure 5.1 simple Arena model of an M/M/1 queue (Altiok and Melamed, 2007).

5.2.2 *Building Arena Process for the model*

5.2.2.1 Identification of port process

As detailed in section 2.4.1.1, the leading players and activities of a port depend on port types. Due to the complexity of the operation and data availability, a container port is chosen to analyse and investigate the energy efficiency between port and ship operation as integrated operations with the aim of energy efficiency. The primary operations at port are shown in Figure 5.2. They can be listed as berth operation, yard operation, and gate operation in a container port. These activities start with ship arrival and then continue with cargo handling and their transfer to a storage area in the yard before the final stage of gate processing. This process is analysed comprehensively in the model developed in the ARENA simulation tool.

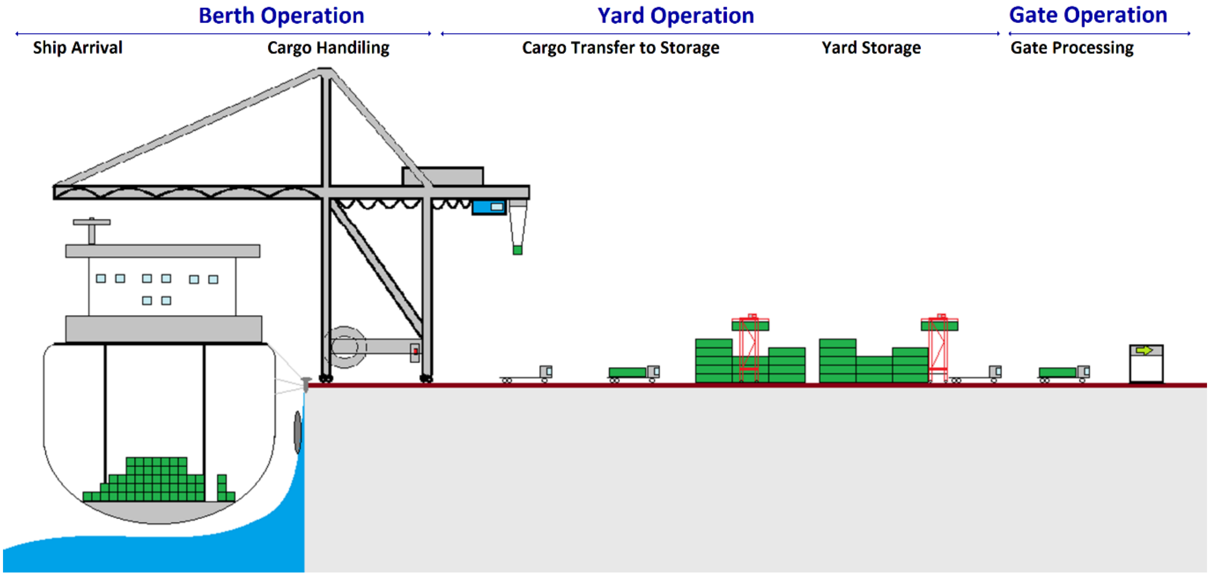


Figure 5.2 The main operations in a container port.

One of the European container ports has been chosen for the ARENA modelling application to analyse the energy efficiency of the integrated operations. The container movements at the port have three main directions, which can be listed as import, export, and transit containers, as shown in Figure 5.3. Import container operation starts with unloading a container from ship to yard and then continuing to store in yard area or directly goes to the gate to deliver a discharge point outside the port by an external truck.

Ports also give service for partial services for any partial shipments. Transit operation helps containers to reach their destination by changing their ship. Port store transit containers on the yard until they are loaded onto the next ship. Import container operation is basically the loading operation of the containers to the ship from the hinterland of the port.

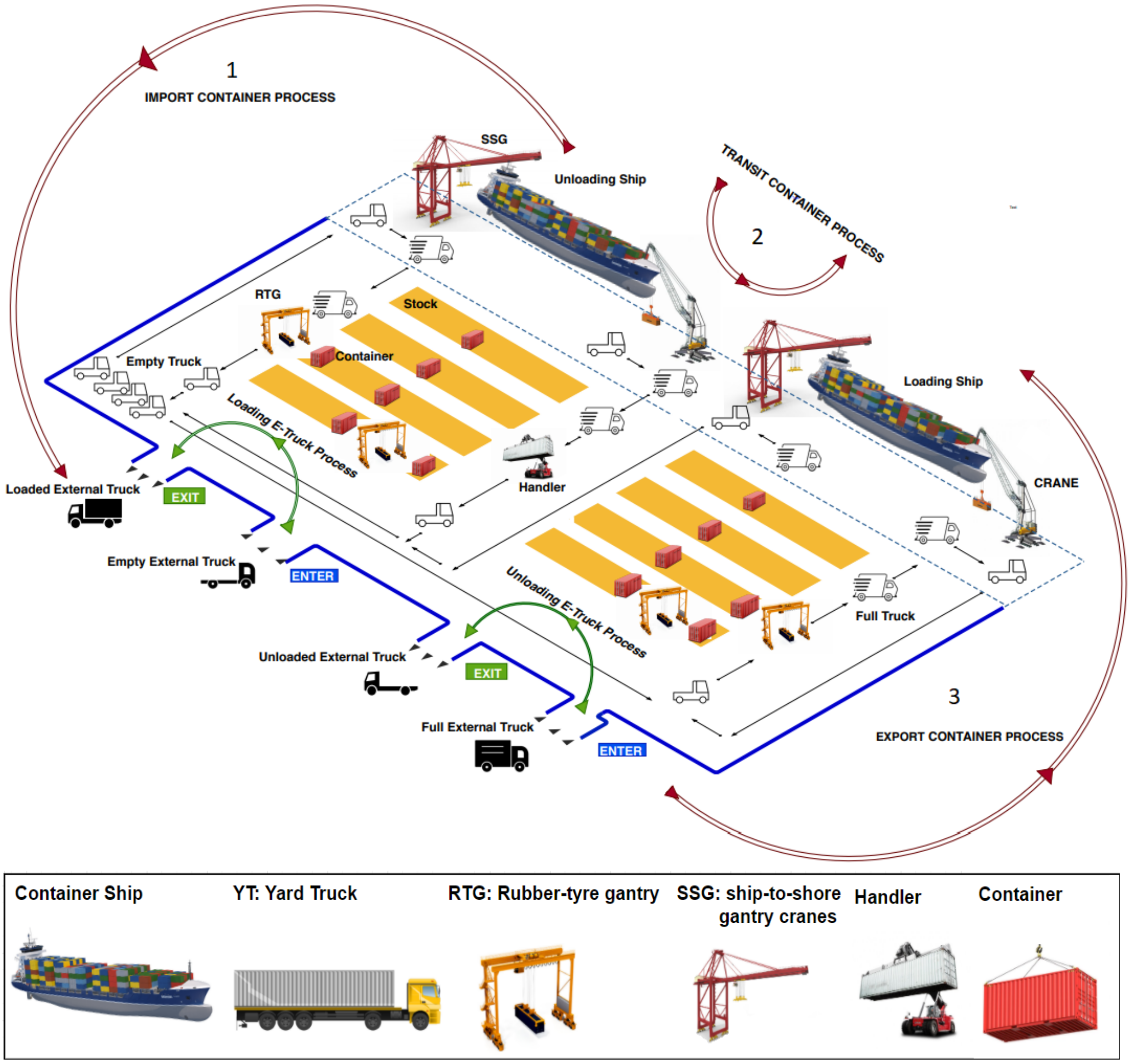


Figure 5.3 Container movements in container ports.

The layout of storage depends on each port due to physical limitations, container, port traffic, and available services in the port area. Figure 5.4 shows the highly simplified version of the port layout applied in the ARENA application. In the figure, each colour represents a storage area of different container types. The red area is for the full export containers; the blue area is full import containers; the green area is for empty containers.

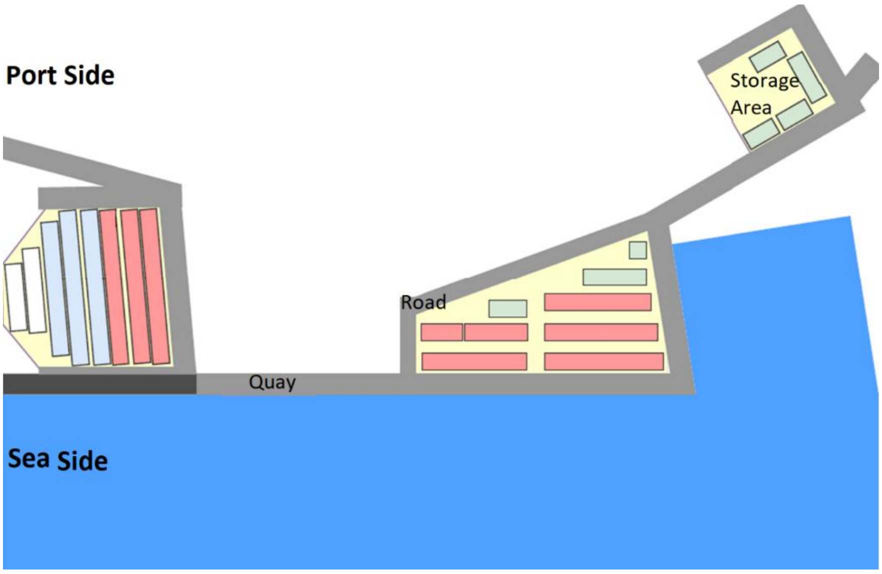


Figure 5.4 The layout of storage for the chosen port (Red: Export, Blue: Import, Green: Empty).

A detailed loading activity diagram from a container port is given in Figure 5.5. First of all, the ship arrives at the port and waiting for an available berth. When there is a suitable berth, a berthing operation takes place. When dockside cranes (DC) ready for handling, discharge operation stars for the ship. In the meantime, DC calls a yard truck (YT); when it starts, it is operated to handle the container on the truck. Then YT starts carrying containers from the berth to the storage areas in the port yard. After that, the discharging of the container on YT conducted by an available RTG. Finally, RTG can call any other available YT to store the following container in a storage area. This process continues until the last container on the ship is discharged at this port. In most of the ports, loading activity starts after discharge is completed. However, some ports and equipment can do both operations together to shorten handling time.

Figure 5.6 illustrates a loading activity diagram with all flow processes to complete a container ship's loading. Loading operation physically starts with RTG movement to handle a chosen container from a storage area to on an YT. If there is an access problem in the RTG storage area, usually handlers help with the operation. When the YT (known as YTT as well) arrives at the quayside, an available DC can handle the container to load onto the ship. The loading process is not complete until all required containers are loaded to the ship. In this port model, 77 handling equipment are actively used. These equipment are 4 SSG, 3 Cranes, 19 RTG, 7 Kalmar, and 31 YT. Their details and typical consumption figures are provided in Table 5.2. Further consumption details will be provided in the next section while building the ARENA model.

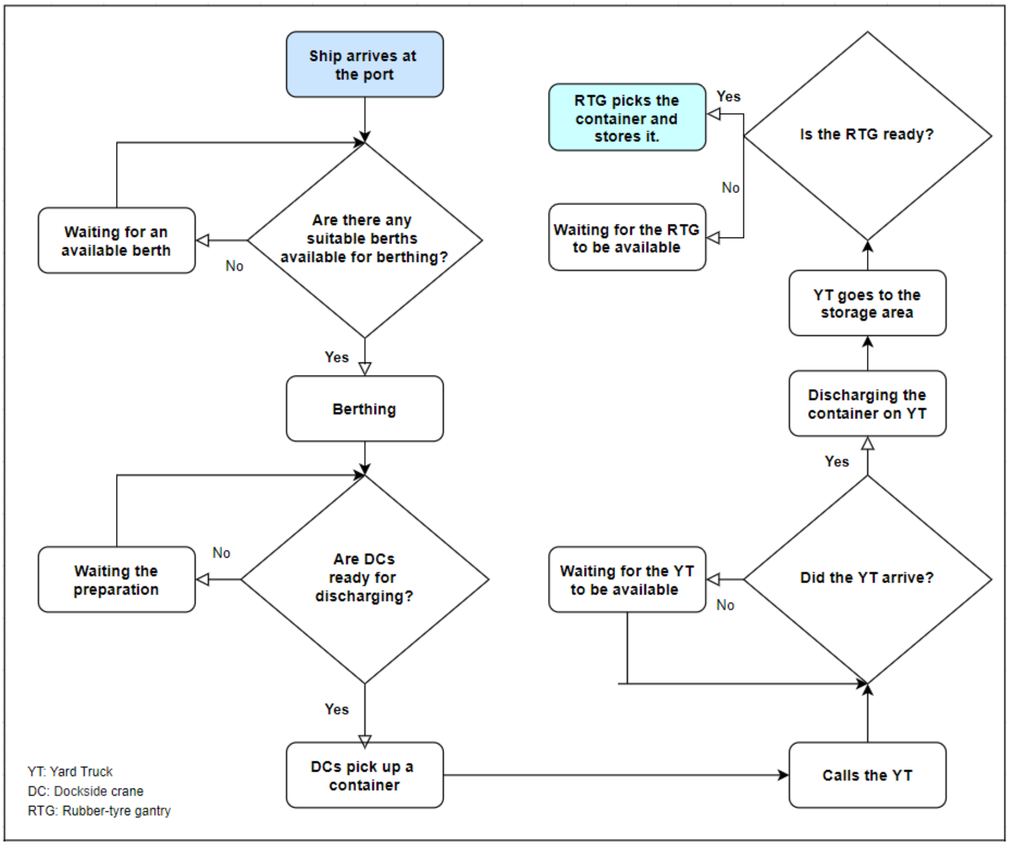


Figure 5.5 Discharging Activity Diagram.

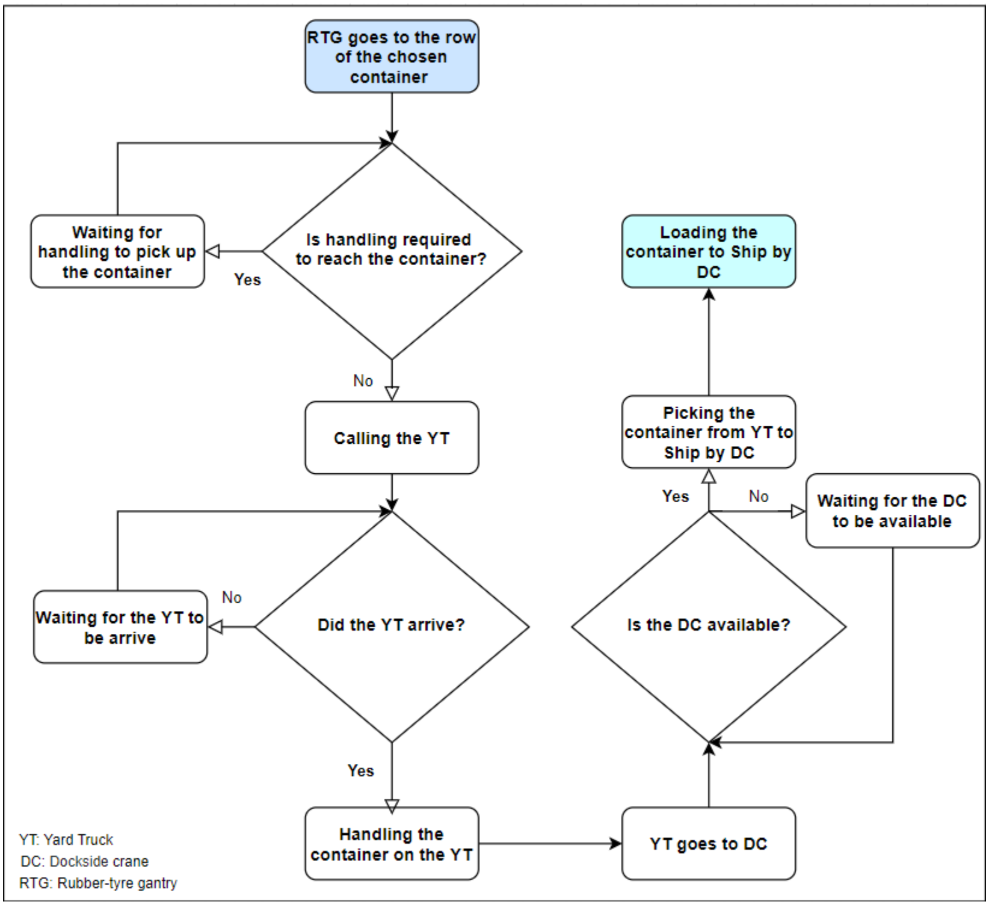


Figure 5.6 Loading Activity Diagram.

Table 5.2 Specification and consumption figures for the handling equipment.

Equipment No	Group	Code	Brand	Engine	Fuel	Fuel Cons/h
1-3	4 SSG	SSG 1- 4	Mitsui Paceco	-	-	235 KW/H
4	3 Crane	Crane 8	Liebherr	LHM 500	48.80 LT	195 KW/H
5		Crane 9	Liebherr	LHM 500	45.80 LT	195 KW/H
6		Crane 10	Gottwald	G-HMK 7408	50 LT	170 KW/H
7-12	24 RTG	RTG 1-6	Kalmar	Scania	13,89 LT	30 KW/H
13-25		RTG 7-19	Mitsui Paceco	Deutz	-	24 KW/H
26-27	7 Kalmar	DCF 80-45E6	Kalmar	Volvo	9,8 LT	-
28-29		DRF 450-65S5	Kalmar	Volvo	14 LT	-
30-31		DRF 450-65S5	Fantuzzi	Volvo Penta	15.2 LT	-
32		Hyster Stacker	Hyster	RS45-31	13 LT	-
33-41	31 YTT	YTT09 -16	Terberg	Cummins Isb.	5,8 LT	-
42-47		YTT17-22	Kalmar Ottawa	Cummins Inc.	6,3 LT	-
48		YTT23	Terberg	Mercedes	-	-
49-64		YTT 30-45	Terberg	Cummins Inc.	5,5 LT	-

5.2.2.2 Building an Arena Process for the Chosen Port

The two-dimensional interface of the model developed by advanced ARENA software is shown in Figure 5.7. Due to the complexity of the system, the model was built under four main sections. Their details will be provided under relevant sections. They are as follows.

A: Arrival of ships to port and their transfer; this part defines ships' arrival to the port, and it is departure after the operation is completed.

B: Assignments of Ships and discharge of ships; this part involves the berthing and handling operation of each ship, and it is detailed.

C: Assignment of SSG to ships that are berthing; this part is built for shore-side cranes and their operation.

D: Container Storages Area and Truck Logic: This subsection builds storage area operation for RTG and other handlers and truck operation in the port.

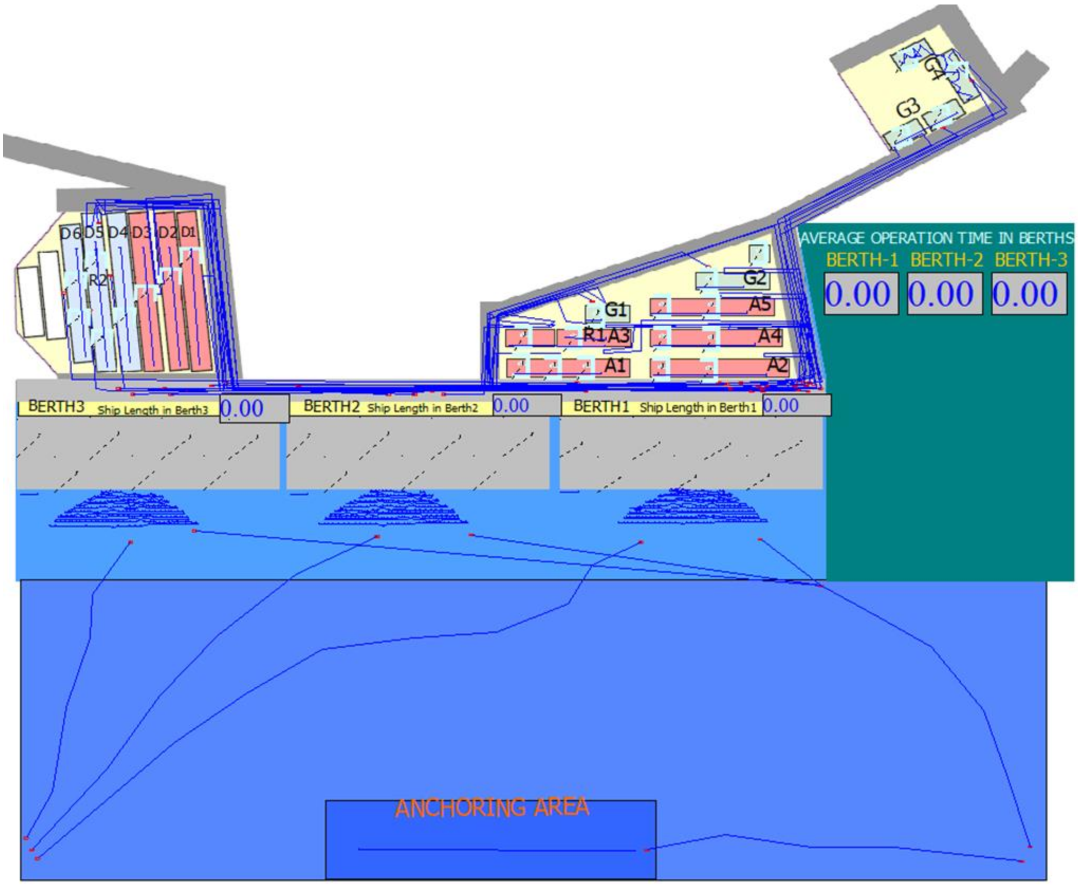


Figure 5.7 Two-dimensional (2D) interface of the model.

5.2.2.2.1 A: Arrival of Ships to Port and Their Transfer

This part introduces operations of arrival and departure of ships at the port. This submodule of the simulation has 43 ARENA modules, as shown in Figure 5.8. Explanations of all modules are given in Table 5.3 in the order of Figure 5.9.

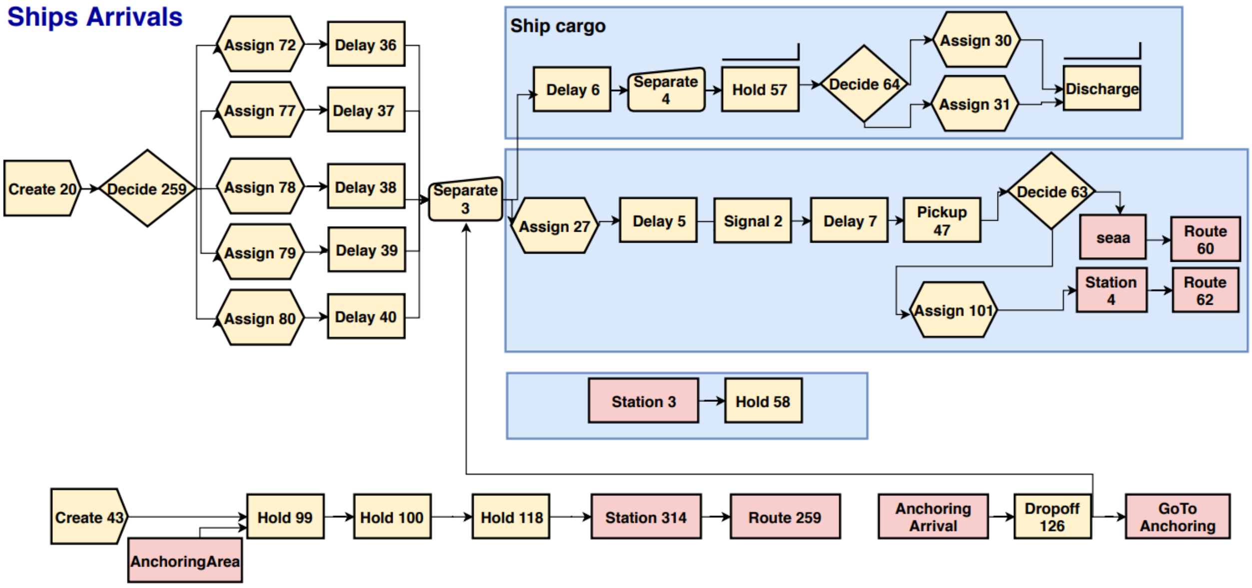


Figure 5.8 Submodule of Ship Arrivals to Port.

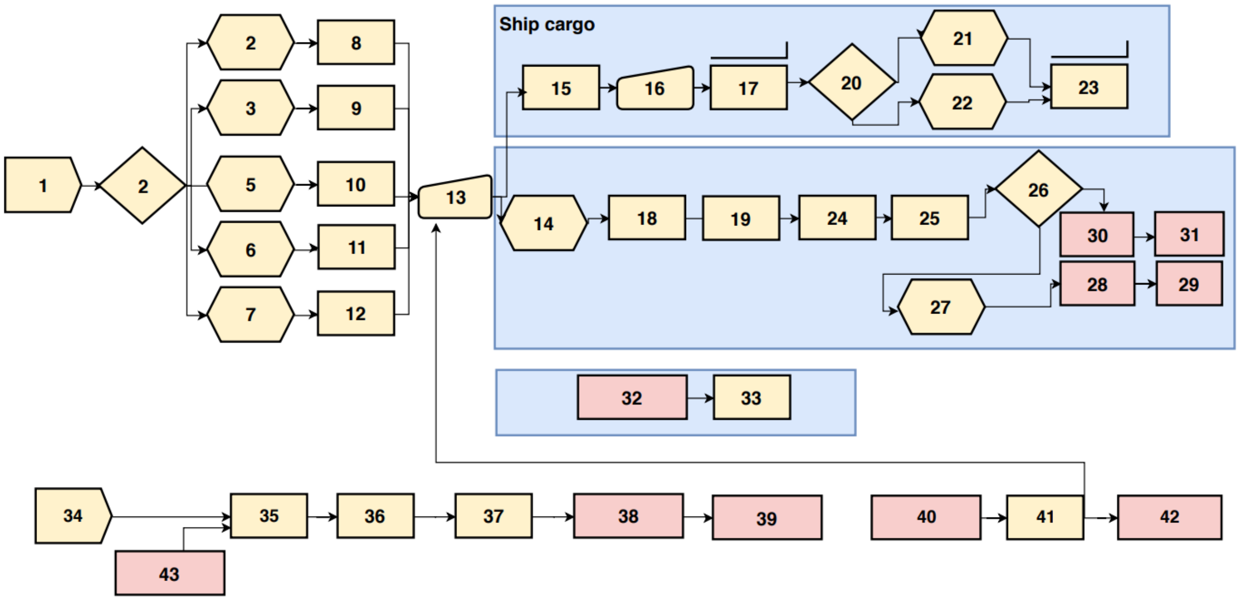


Figure 5.9 Ship Arrivals to Port in order.

The port has one actual queue for upcoming ships, and first come and first serve have been applied for this simulation. Create 20 creates `ships` entity and define the arrival of ships. The module also set ship arrival frequency based on the real data provided from the port and analysed in the ARENA input data tool. The next step is to use ‘decide and assign modules’ to check the availability of berths for vessel arrivals. After the delay modules (Delay 36-40), it helps the simulation's decision to regulate the berthing of ships in the port. These delays are set to avoid and identify the ships arriving simultaneously, and a waiting period has been set. This time does not affect the system’s performance. Then Separate is used to copy incoming entities to identify loads of incoming ships. Assign 27 assigned the ship's length, numbers of full and empty containers to be discharged for each ship. Entity picture for a ship is also assigned here for 2D visualisation of the model. All other modules and their contribution to the model have been explained in detail in Table 5.3. Therefore, some essential steps are enough to explain further steps. In this submodule following sets have been made; definitions for empty and full containers, allocate the cargo for each ship, counting the number of ships that go to berth, arrange the queuing and the anchoring of ships.

Table 5.3 Ship Arrivals Modules Explanations in details

	Module number	Module Type	Module Name	Definition	Properties and Function
ARRIVALS OF SHIPS and THEIR TRANSFER and DEFINITIONS	1	Create	Create 20	Define the arrival of ships	It creates `ships` entity, 1 entity per arrivals an expression is -0.001 + 81 * BETA (1.1,5.82), unit is days
	2	Decide	Decide 259	Checks the berthing possibility of vessels to port	N-way by condition which are (aa <= bb) && (aa <= cc) && (aa <= dd) && (aa <= ee); (bb <= cc) && (bb <= dd) && (bb <= ee); (cc <= dd) && (cc <= ee); (dd <= ee)
	3	Assign	Assign 72		Variable is aa; New value will be aa+1
	4	Assign	Assign 77		Variable is bb, New value will be bb+1
	5	Assign	Assign 78		Variable is cc, New value will be cc+1
	6	Assign	Assign 79		Variable is dd, New value will be dd+1
	7	Assign	Assign 80		Variable is ee, New value will be ee+1
	8	Delay	Delay 36	It is part of the decision system that controls the berthing of ships to the port. To identify the ships arriving at the same time, a waiting period has been set. This time does not affect system performance	5 minutes delay
	9	Delay	Delay 37		10 minutes delay
	10	Delay	Delay 38		15 minutes delay
	11	Delay	Delay 39		20 minutes delay
	12	Delay	Delay 40		25 minutes delay
	13	Separate	Separate 3	The incoming entity is copied to identify loads of incoming ships.	Duplicate Original, 50% cost to duplicates: 1 of duplicates
	14	Assign	Assign 27	This module defines the length, load, and number of full and empty containers to be loaded.	Assignments: Attribute, shipLOA, MN (300, (135 + 165 *BETA (0.487,0.552))); Attribute shipLOA ANINT(0.999 + 912 * BETA(0.607, 0.866)); Attribute, fullcontainertoloadship, ANINT(0.999 + 890 * BETA(0.641, 0.92)), Attribute, emptycontainertoloadship,ANINT(-0.001 + LOGN(25.1, 75.6));Entity Picture: Picture Boat
	15	Delay	Delay 6	The vessel's information, as defined in Assign 27, is stored until the ship has been identified.	Delay time: 2 seconds, Allocation: Other
	16	Separate	Separate 4	In Delay 6, the waiting entity is replicated as far as the ship's load. Here the amount of load is created up to the entity.	Percent Cost to Duplicates:50; Type; Duplicate Original: # of Duplicate; ANINT (NORM (467,64.4))-1
	17	Hold	Hold 57	After the ship loadings are reproduced, they are waited here for identification within the ship.	Type: wait for the signal, Wait for Value 1: Queue Type; Queue: Queue Name; Hold57.Queue
	18	Delay	Delay 5	Ships are stored in this module while the ship loadings are multiplied in Separate 4.	Allocation: Other, Delay Time, 2 seconds
	19	Signal	Signal 2	It sends a signal to release the cargoes in the Hold 57 module.	Signal Value 1
	20	Decide	Decide 64	Once the ship loadings have been replicated, it is decided whether the containers are full or empty based on actual statistical data.	Type: 2 way by chance: Percent True; 72.3
	21	Assign	Assign 30	Makes necessary definitions for empty containers.	Assignments: Attribute, emptycontainer,1; Attribute, tracsporttime,1.7; Attribute, emptycontainer, emptycontainer+1; Antitiy Picture: Blue Ball
	22	Assign	Assign 31	Make necessary definitions for full containers.	Assignments: Attribute, fullcontainer, 1; Attribute c.tracsporttime,2.4; Attribute, CONTAINER; Attribute, fullcontainer, fullcontainer +1;Antitiy Picture: Red Ball
	23	Hold	Discharge	The defined full and empty containers are kept there for identification in vessels.	Type, infinite Hold: Queue Type; Queue: Queue Name; discharging.Queue
	24	Delay	Delay 7	The vessels are kept here until full and empty containers are identified and come to hold module named `Discharge`	Allocation: Other, Delay Time, 1 second
	25	Pickup	Pickup 47	Containers are kept inside the ships with this module.	Quantity; NQ (discharging.Queue): Queue Type; Queue; Queue Name; discharging.Queue
	26	Decide	Decide 63	This module decides which berth will be berthed or kept in the anchoring area	type: 2 way by chance: if Expression, ((berth1 + berth2 + berth3) >= 3) || (totalshipLOA > 765) && (#ofShipInBerths < 3)
	27	Assign	Assign 101	Counts the number of ships to go to the berth.	Assignments; Variable, #ofShipInBerths, #ofShipInBerths+1
	28	Station	Station 4	Station module to send the ship to the berth.	Station Name: Station 4
	29	Route	Route 62	Ships from station 4 to the berths.	Route time: 58 minutes, Destination Type, Station; Station Name: berth
	30	Station	sea	This module is the station for ships to go to the anchoring area	Station Name: Sea
	31	Route	Route 60	With this module, ships go to the ship area.	Route Time: 15 Minutes, Destination Type Station, Station Name; Station 3
	32	Station	Station 3	This station is in the anchoring area.	Station Name, Station 3;
	33	Hold	Hold 58	Ships in the anchoring area are kept with this module.	Type, Infinite Hold: Queue Type; Queue: Queue Name; Hold 58. Queue
	34	Create	Create 43	Defines the entity that will take the ship in the anchorage area to the berth	Entity Type; Entity 1: Time Between Arrivals, Type Random (Expo), Value, 1: Units: Seconds: Entities per Arrival, 1: Max Arrivals, 1: First Creation, 0.0
	35	Hold	Hold 99	Keeps the ship in the anchorage area until the ship leaves any of these 3 berths.	type: Wait for signal: Wait for Value, 12: Queue Type; Queue: Queue Name, Hold 99. Queue
	36	Hold	Hold 100	If there is no ship in the anchorage area after one of the berths is empty, the boat that takes the ships to the dock waits here.	type: scan for condition: condition: NQ (Hold 58.Queue) > 0: Queue Type; Queue: Queue Name, Hold 100.Queue
	37	Pickup	Pickup 118	It takes this module to take the ship in the anchorage area to the berth.	Quantity; 1: QueueType; Queue: Queue Name; Hold 58 Queue
	38	Station	Station 314	Station leading to the berth area	Station Name: Station 314
	39	Route	Route 259	Defines the path that leads to the berth area.	Route Time, 1 Hour: Destination Type, Station: Station Name, AnchoringArrival
	40	Station	AnchoringArrival	Station leading the ship to the berth area	AnchoringArrival Station
	41	Dropoff	Dropoff 126	It allows the boat to leave the ship to the berth area and leave.	Dropoff starting Rank is 1; quantity is 1
	42	Route	GoToAnchoring	It carries the ship from the anchoring area to the berth, the ship anchor, after leaving the arrival queue.	Route time: 0, Station Name: AnchoringArea
	43	Station	AnchoringArea	It is the station where the ship will arrive to the anchorage area.	Station Name, AnchoringArea

5.2.2.2.2 B: Assignments of Ships and Discharge of Ships

This part sets the berthing and handling operation of each ship. This sub-module of the simulation has 110 ARENA modules. Each module is illustrated in Figure 5.10. Their orders are given in Figure 5.11, and Table 5.4 explains all details of these modules. This subpart starts with `berth`, which is a station where the incoming ships enter the berth. The following modules assign the incoming ships to the berths if the port has any available berth. The simulation checks this availability every second from the availability of berths and cargo operations of the ship at the port. The cargo operations of the ship are based on loading/unloading rates for the full/empty container on the ship. Whether the container is a full or empty container is a vital decision parameter. Because berth one and berth two are closer to the red and green storage area than berth three, as shown earlier in Figure 5.4. Blue areas are stores for the full imported containers, and green ones are for the empty containers. Berth 3 is close to the blue area, which is for the full imported containers. Therefore, the model sends the ship to the most appropriate berth to start the handling operation. When a ship needs to discharge more imported full imported containers than all other export and empty container, simulation tries to send the ship to berth three first. When a ship has more full /empty export containers to be loaded than imported full containers to be discharged, simulation firstly tries to send it to berth 1. In other words, the module decides the berth for the ship based on full/empty cargo quantity and their direction, whether they are for import or export. Therefore berth 2 is an optional berth, and ships are first arriving berth 1 (near export storage area) or berth 3 (near import storage area). After that, the ship is held in this Hold module until the cargo is unloaded. While handling taking place, unloaded 20` and 40` containers from the ships are handled by SSG as 40`. They combine 40` by transporting two pieces of 20`. All the signalling process for equipment activation also settled in the module with signal modules. After unloading the cargo on board, it indicates the ship's condition and a berth in the system. A signal comes from the Signal modules after the ship is loaded and the vessel moves to leave the port. The loaded ship sends a signal for the anchoring area; if there is a ship in the anchoring area, it leads them to a berth. Stations help at the end with 2D visualisations, which show the route where the ships are sailing to the exit the simulation using ‘dispose of modules’. Before ‘dispose of modules’ finalises the submodule, function ‘Assign 224-226’ gives the sum of the ships' waiting time at the berth. This helps the simulation to record total operation time in each berth in the port. This will help us to do further calculations.

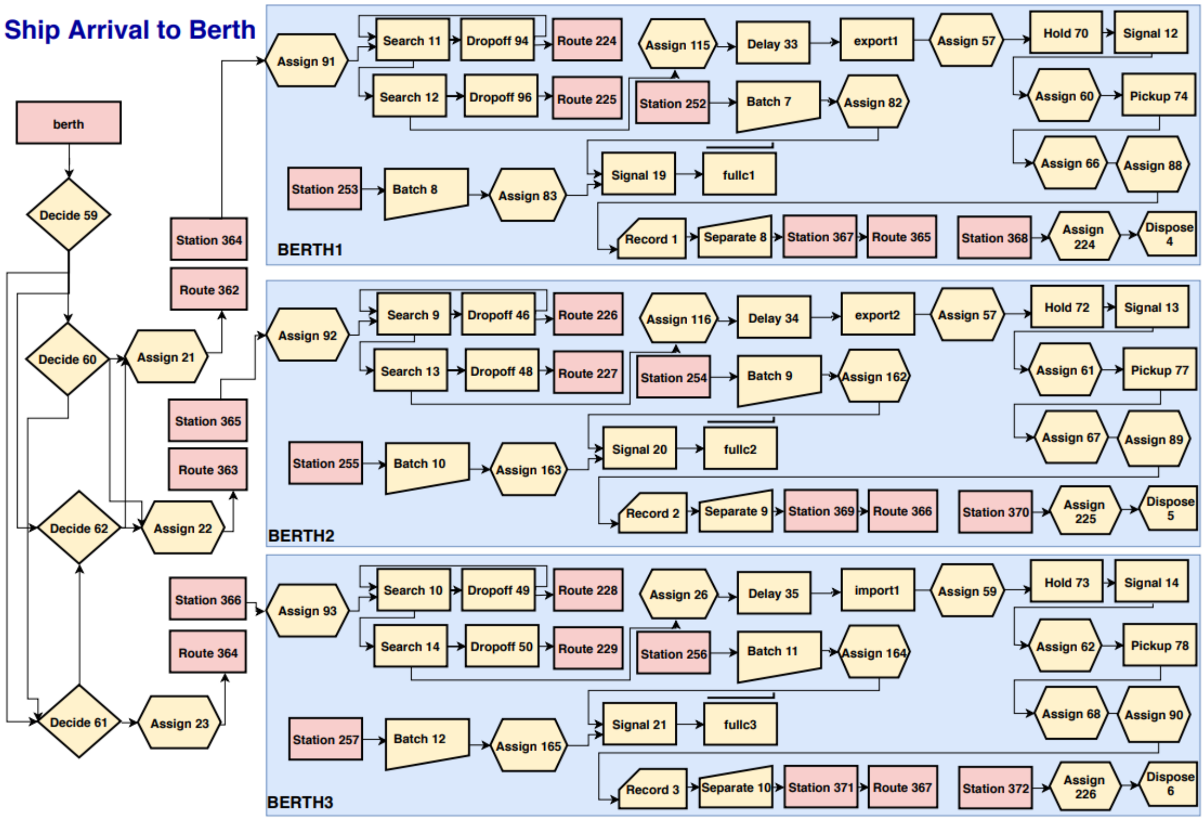


Figure 5.10 Submodule of Ship Arrivals to Berth.

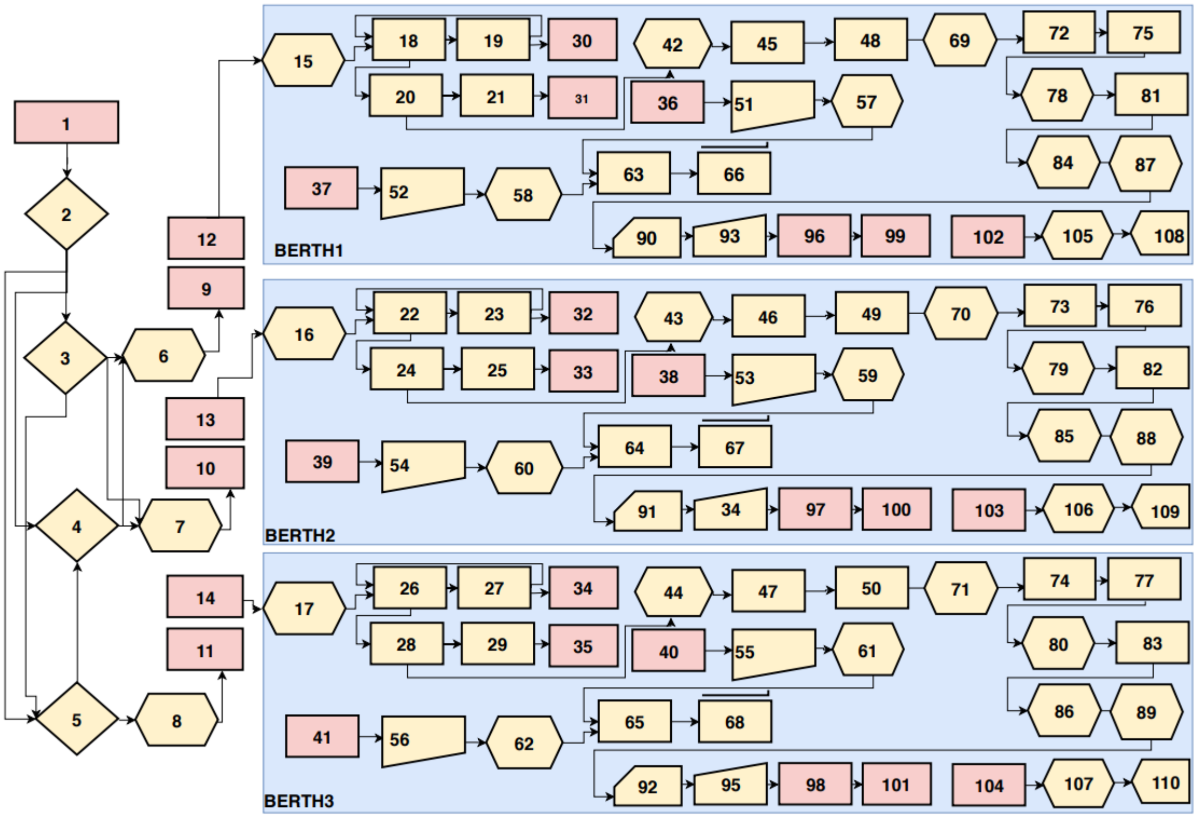


Figure 5.11 Ship Arrivals to Berth in an order.

Table 5.4 Ship Arrivals to Berth in an Order

	Number	Module Name	Definition	Properties and Function
ASSIGNMENT OF SHIPS AND DISCHARGE OF SHIPS	1	Berth - Station	The station where the incoming ships go to the berth.	Station Type: Station Station Name: rihtim
	2	Decide 59	It is the module that assigns the incoming ships to the berths according to the rules. In these rules, full / empty container load rates on the ship and the suitability of the berths are considered.	N way by Conditior, Conditions: if `expression` (emptycontainer + emptycontainertoloadship + fullcontainertoloadship) >= fullcontainer; end of list
	3	Decide 60		N way by Conditior, Conditions: if `expression` berth1 == 0 ; berth2 == 0; end of list
	4	Decide 62		2-way by Condition: if `expression` berth2 == 0
	5	Decide 61		N way by Conditior, Conditions: if `expression` berth3 == 0 ; end of list
	6	Assign 21	The loading information of the assigned ships to the berth is registered here.	Assignments: `Variable, Variable Name; berth1shipLOA, New Value; shipLOA`, `Variable, Variable Name; – numberoffullcontainertoloadship1, New  Value; fullcontainertoloadship`, `Variable, Variable Name; Gemi1eYüklenecekToplamKont, New  Value;  emptycontainertoloadship + fullcontainertoloadship`, end of list
	7	Assign 22		Assignments: `Variable, Variable Name; berth2shipLOA, New Value; shipLOA`, `Variable, Variable Name; numberoffullcontainertoloadship2, New  Value; fullcontainertoloadship `, `Variable, Variable Name; totalcontainertoloadship2, New  Value; emptycontainertoloadship + fullcontainertoloadship`, end of list
	8	Assign 23		Assignments: `Variable, Variable Name; berth3shipLOA, New Value; shipLOA`, `Variable, Variable Name; numberoffullcontainertoloadship3, New  Value; fullcontainertoloadship`, `Variable, Variable Name; totalcontainertoloadship3, New  Value; emptycontainertoloadship + fullcontainertoloadship`, end of list
	9	Route 362	The ships arriving in the port are directed to their berth	Route Time: 2, Unites: Minutes, Destination Type: Station, Station Name, Station 364
	10	Route 363		Route Time: 2, Unites: Minutes, Destination Type: Station, Station Name, Station 365
	11	Route 364		Route Time: 2, Unites: Minutes, Destination Type: Station, Station Name, Station 366
	12	Station 364	It is the entrance part of the ships to the berths.	Station Type: Station Station Name: station 364
	13	Station 365		Station Type: Station Station Name: station 365
	14	Station 366		Station Type: Station Station Name: station 366
	15	Assign 91	After the ships enter the berths, the definition of some variables in the berths is done here.	Assignments: `Type; Variable, Variable Name; berth1; New Value; 1`, `Type; Variable, Variable Name; Berth1Status; New Value; 0`, end of list
	16	Assign 92		Assignments: `Type; Variable, Variable Name; berth2; New Value; 1`, `Type; Variable, Variable Name; Berth2Status; New Value; 0`, end of list
	17	Assign 93		Assignments: `Type; Variable, Variable Name; berth3; New Value; 1`, `Type; Variable, Variable Name; Berth3Status; New Value; 0`, end of list
	18	Search 11	They are used to unload pre-defined full containers from the ship for identification at the berth. Find the full container with Search and drop it off with the Dropoff.	Name: Search 11, Type: Search a Batch, Starting Value:1, Ending Value: NG, Search Condition: Container==1
	19	Dropoff 94		Quantity:1, Starting Rank: J, Member Attributes, Take Specific Representative Values, Attributes, Entity Station, End of list
	20	Search 12		Name: Search 12, Type: Search a Batch, Starting Value:1, Ending Value: NG, Search Condition: Container==0
	21	Dropoff 96		Quantity:1, Starting Rank: J, Member Attributes, Take Specific Representative Values, Attributes, Entity Station, End of list
	22	Search 9		Name: Search 9, Type: Search a Batch, Starting Value:1, Ending Value: NG, Search Condition: Container==1
	23	Dropoff 46		Quantity:1, Starting Rank: J, Member Attributes, Take Specific Representative Values, Attributes, Entity Station, End of list
	24	Search 13		Name: Search 13, Type: Search a Batch, Starting Value:1, Ending Value: NG, Search Condition: Container==0
	25	Dropoff 48		Quantity:1, Starting Rank: J, Member Attributes, Take Specific Representative Values, Attributes, Entity Station, End of list
	26	Search 10		Name: Search 10, Type: Search a Batch, Starting Value:1, Ending Value: NG, Search Condition: Container==1
	27	Dropoff 49		Quantity:1, Starting Rank: J, Member Attributes, Take Specific Representative Values, Attributes, Entity Station, End of list
	28	Search 14		Name: Search 14, Type: Search a Batch, Starting Value:1, Ending Value: NG, Search Condition: Container==0
	29	Dropoff 50		Quantity:1, Starting Rank: J, Member Attributes, Take Specific Representative Values, Attributes, Entity Station, End of list
	30	Route 224	This module determines the unloading direction when loading full and empty containers from the ship	Route time:0, Unites: Hours, Destination Type: Station, Station Name: Station 252
	31	Route 225		Route time:0, Unites: Hours, Destination Type: Station, Station Name: Station 253
	32	Route 226		Route time:0, Unites: Hours, Destination Type: Station, Station Name: Station 254
	33	Route 227		Route time:0, Unites: Hours, Destination Type: Station, Station Name: Station 255
	34	Route 228		Route time:0, Unites: Hours, Destination Type: Station, Station Name: Station 256
	35	Route 229		Route time:0, Unites: Hours, Destination Type: Station, Station Name: Station 257
	36	Station 252	This module determines the unloading station when loading full and empty containers from the ship	Station Type: Station, Station Name: station 252
	37	Station 253		Station Type: Station, Station Name: station 253
	38	Station 254		Station Type: Station, Station Name: station 254
	39	Station 255		Station Type: Station, Station Name: station 255
	40	Station 256		Station Type: Station, Station Name: station 256
	41	Station 257		Station Type: Station, Station Name: station 257
	42	Assign 115	This module indicates the condition of the ship in the system after it is unloaded from the ship.	Assignments: Type: Entry Picture, Entity Picture: Picture.fullShip; Type: Attribute, Attribute Name: OperStart1, New Value: TNOW, End of list
	43	Assign 116		Assignments: Type: Entry Picture, Entity Picture: Picture.fullShip; Type: Attribute, Attribute Name: OperStart2, New Value: TNOW, End of list
	44	Assign 26		Assignments: Type: Entry Picture, Entity Picture: Picture.fullShip; Type: Attribute, Attribute Name: OperStart3, New Value: TNOW, End of list
	45	Delay 33	Specifies the ship's waiting position when cargo is unloaded from the ship.	delay time 1 second
	46	Delay 34		delay time 1 second
	47	Delay 35		delay time 1 second
	48	export1	The ship is held in this Hold module until the cargo are unloaded from the ship.	Type: Scan for Condition, Condition: (NQ(fullc1.Queue) <= 5) && (NQ(gemi1.Queue) < 35), Queue Type: Queue, Queue Name: export1.Queue
	49	export2		Type: Scan for Condition, Condition: (NQ(fullc2.Queue) <= 5) && (NQ(gemi2.Queue) < 35), Queue Type: Queue, Queue Name: export2.Queue
	50	import1		Type: Scan for Condition, Condition: (NQ(fullc3.Queue) <= 5) && (NQ(gemi3.Queue) < 35), Queue Type: Queue, Queue Name: import1.Queue
	51	Batch 7	Unloaded 20" and 40" containers from the ships, containers handle by SSG as 40". They combine 40" as two pieces of 20" as a TEU.	Type: Permanent, Batch Size:2, Save Criterion: Product, Rule: Any Entity
	52	Batch 8		Type: Permanent, Batch Size:2, Save Criterion: Last, Rule:Any Entity
	53	Batch 9		Type: Permanent, Batch Size:2, Save Criterion: Last, Rule:Any Entity
	54	Batch 10		Type: Permanent, Batch Size:2, Save Criterion: Last, Rule:Any Entity
	55	Batch 11		Type: Permanent, Batch Size:2, Save Criterion: Last, Rule: Any Entity

56	Batch 12		Type: Permanent, Batch Size:2, Save Criterion: Last, Rule: Any Entity
57	Assign 82	It was used to redefine full and empty containers.	Assignments: Type :Attribute, Attribute Name: CONTAINER, New Value:1; End of List
58	Assign 83		Assignments: Type: Attribute, Attribute Name: CONTAINER, New Value:0; End of List
59	Assign 162		Assignments: Type: Attribute, Attribute Name: CONTAINER, New Value:1; End of List
60	Assign 163		Assignments: Type: Attribute, Attribute Name: CONTAINER, New Value:0; End of List
61	Assign 164		Assignments: Type: Attribute, Attribute Name: CONTAINER, New Value:1; End of List
62	Assign 165		Assignments: Type: Attribute, Attribute Name: CONTAINER, New Value:0; End of List
63	Signal 19	Activates SSG and Cranes when containers unloaded.	Signal Value:19
64	Signal 20		Signal Value:19
65	Signal 21		Signal Value:19
66	fullc1	It is a place where the defined cargo of berth holds on the quay	Type: Infinite Hold, Queue Type: Queue, Queue Name: fullc1.Queue
67	fullc2		Type :Infinite Hold, Queue Type: Queue, Queue Name: fullc2.Queue
68	fullc3		Type: Infinite Hold, Queue Type: Queue, Queue Name: fullc3.Queue
69	Assign 57	After unloading the cargo on board, it indicates the condition of the ship and berth in the system.	Assignments: Type: Variable, Variable Name:Berth1Status, New Value:1; Entity Picture: Picture.emptyShip; End of List
70	Assign 58		Assignments: Type: Variable, Variable Name:Berth2Status, New Value:1; Entity Picture: Picture.emptyShip; End of List
71	Assign 59		Assignments: Type: Variable, Variable Name:Berth3Status, New Value:1; Entity Picture: Picture.emptyShip; End of List
72	Hold 70	These are hold modules that hold the ship which is waiting to load after the cargo is unloaded. The signal comes from the Signal modules after the ship is loaded and the vessel moves to leave the port.	Type: Wait for Signal; Wait for Value 7; Queue Type: Queue; Queue Name: Hold 70.Queue
73	Hold 72		Type: Wait for Signal; Wait for Value 8; Queue Type: Queue; Queue Name: Hold 72.Queue
74	Hold 73		Type: Wait for Signal; Wait for Value 9; Queue Type: Queue; Queue Name: Hold 73.Queue
75	Signal 12	The loaded ship sends a signal for the anchoring area; if there is a ship in the anchoring area, it helps to lead them to a berth.	Signal Value:12
76	Signal 13		Signal Value:12
77	Signal 14		Signal Value:12
78	Assign 60	When a ship is leaving the berth, the ship changes the status of the berth to be work.	Assignments: Type: Variable, Variable Name:Berth1Status, New Value:5; End of List
79	Assign 61		Assignments: Type: Variable, Variable Name:Berth2Status, New Value:5; End of List
80	Assign 62		Assignments: Type: Variable, Variable Name:Berth3Status, New Value:5; End of List
81	Pickup 74	This module is used to determine the load on the ship.	Quantity:1, Queue Type: Queue, Starting Rank: 1 Queue Name: Hold 78.Queue
82	Pickup 77		Quantity:1, Queue Type: Queue, Starting Rank: 1 Queue Name: Hold 79.Queue
83	Pickup 78		Quantity:1, Queue Type: Queue, Starting Rank: 1 Queue Name: Hold 80.Queue
84	Assign 66	The ship redefines some of the variables in the system while leaving the berth.	Assignments: Type: Variable, Variable Name:berth1, New Value:0; Type: Variable, Variable Name:gemidolulugu1, New Value:0; End of List
85	Assign 67		Assignments: Type: Variable, Variable Name:berth2, New Value:0; Type: Variable, Variable Name:gemidolulugu2, New Value:0; End of List
86	Assign 68		Assignments: Type: Variable, Variable Name:berth3, New Value:0; Type: Variable, Variable Name:gemidolulugu3, New Value:0; End of List
87	Assign 88		Assignments: Type: Variable, Variable Name:berth1shipLOA, New Value:0; Type: Variable, Variable Name: numberoffullcontainertoloadship1, New Value:0; Type: Variable, Variable Name: totalcontainertoloadship1, New Value:0; Type: Variable, Variable Name:#ofShipInBerths, New Value:#ofShipInBerths-1; Type: Entity Picture: Picture.fullShip; End of List
88	Assign 89		Assignments: Type: Variable, Variable Name:berth2shipLOA, New Value:0; Type: Variable, Variable Name: numberoffullcontainertoloadship2, New Value:0; Type: Variable, Variable Name: totalcontainertoloadship2, New Value:0; Type: Variable, Variable Name:#ofShipInBerths, New Value:#ofShipInBerths-1; Type: Entity Picture:Picture.fullShip; End of List
89	Assign 90		Assignments: Type: Variable, Variable Name:berth3shipLOA, New Value:0; Type: Variable, Variable Name: numberoffullcontainertoloadship3, New Value:0; Teype:Variable, Variable Name: totalcontainertoloadship3, New Value:0; Type: Variable, Variable Name:#ofShipInBerths, New Value:#ofShipInBerths-1; Type: Entity Picture:Picture.fullShip; End of List
90	Record 1	Recodes the total operation time of the vessels in the unloading and loading operations	Statistic Definitions: Type: Time Interval, Attribute Name:OperStart1, Tally Name:Op_Timein_Berth1; End of List
91	Record 2		Statistic Definitions: Type: Time Interval, Attribute Name:OperStart2, Tally Name:Op_Timein_Berth2; End of List
92	Record 3		Statistic Definitions: Type: Time Interval, Attribute Name:OperStart3, Tally Name:Op_Timein_Berth3; End of List
93	Separate 8	System requires to separate all batched containers as 40" for allowing to leave the system.	Type: Split Existing Batch, Member Attributes: Retain Original Entity Values
94	Separate 9		Type: Split Existing Batch, Member Attributes: Retain Original Entity Values
95	Separate 10		Type: Split Existing Batch, Member Attributes: Retain Original Entity Values
96	Station 367	Stations are used for the departure of ships from the system	Station Type: Station, Station Name: Station 367
97	Station 369		Station Type: Station, Station Name: Station 369
98	Station 371		Station Type: Station, Station Name: Station 371
99	Route 365	Determine the exit route of the ships	Route Time:20 Unite: Minutes, Destination Type: Station. Station Name: Station 368
100	Route 366		Route Time:20 Unite: Minutes, Destination Type: Station. Station Name: Station 370
101	Route 367		Route Time:20 Unite: Minutes, Destination Type: Station. Station Name: Station 372
102	Station 368	It shows the station where the ships are sailing.	Station Type: Station, Station Name: Station 368
103	Station 370		Station Type: Station, Station Name: Station 370
104	Station 372		Station Type: Station, Station Name: Station 372
105	Assign 224	It gives the sum of the waiting times for the ships at the berth.	Assignments: Type; Variables, Variables Name;Total_Op_Timein_Berth1, New Value; Total_Op_Timein_Berth1 + TVALUE(Op_Timein_Berth1); End of List
106	Assign 225		Assignments: Type; Variables, Variables Name;Total_Op_Timein_Berth2, New Value; Total_Op_Timein_Berth2 + TVALUE(Op_Timein_Berth2); End of List
107	Assign 226		Assignments: Type; Variables, Variables Name;Total_Op_Timein_Berth3, New Value; Total_Op_Timein_Berth3 + TVALUE(Op_Timein_Berth3); End of List
108	Dispose 4	It is the module where the ships depart from the simulation.	Dispose
109	Dispose 5		Dispose
110	Dispose 6		Dispose

5.2.2.2.3 C: Assignment of SSG and Cranes to ships;

This part sets shore side cranes and their operation for the simulation. This sub-module of the simulation has 454 ARENA modules. Each module is illustrated in Figures 5.12, 5.13, 5.14, and 5.12. Their orders are given in Table A5.1 in Appendix 5 explains all details of these modules. This part gives some of the essential modules and rests given in the appendix. This submodule defines SSGs and dock cranes in the model and provides their access to the system under the entity name SSG1, SSG2, SSG3, SSG4, Crane 1, Crane 2, and Crane 3. The holding module helps the SSG and the Cranes in the quay until the ships come. Then they discharge and load cargos under a logic developed for this model based on the port operator’s guidance.

Assignment of SSGs to ships at berths depends on the ship LOA and the total number of ships at the berth. Because this port has three berths (berth1, bert2, berth3 with a full length of 765 meters), the port tries to give the best possible service to all ships with limited resources. The following assignment logic explains that when there is a ship in berth 1, SSG 1 directly goes to berth 1. When there is a ship in berth 3, SSG 4 goes to berth 3. As the previous submodel explained, berth 2 is not the priority berths for ships; therefore, SSGs logic was designed based on this fact derived from the operational data provided by the port. Therefore, when there is a ship in berth 2, SSG3 works for that berth. When less than 90 meters ship visits this berth, crane/s services them, however, such a case occurs very rarely in this port, but simulation is capable of modelling it. Cranes join the system in different cases when SSGS is not capable of loading or discharging. Although they are not as efficient as SSGs, this port needs them to provide the best possible service to reduce the ship’s port time. Cranes’ appointment is complicated; their details are given below after SSGs. Their appointment depends on ships' length and the numbers of ships at berths. Crane or cranes mainly join/s the system when there is a big ship like more than 300 meters, or more than two ships need handling, but SSGs cannot do it at an optimum time. In this submodule, all other necessary adjustments and actions are set by modules, and details are given in Table A5.1 in Appendix 5, and the assignment` logic of SSGs to ship is given in Appendix 6. All necessary statistics to analyse the system, like the working times of SSGs and Cranes, are recorded.

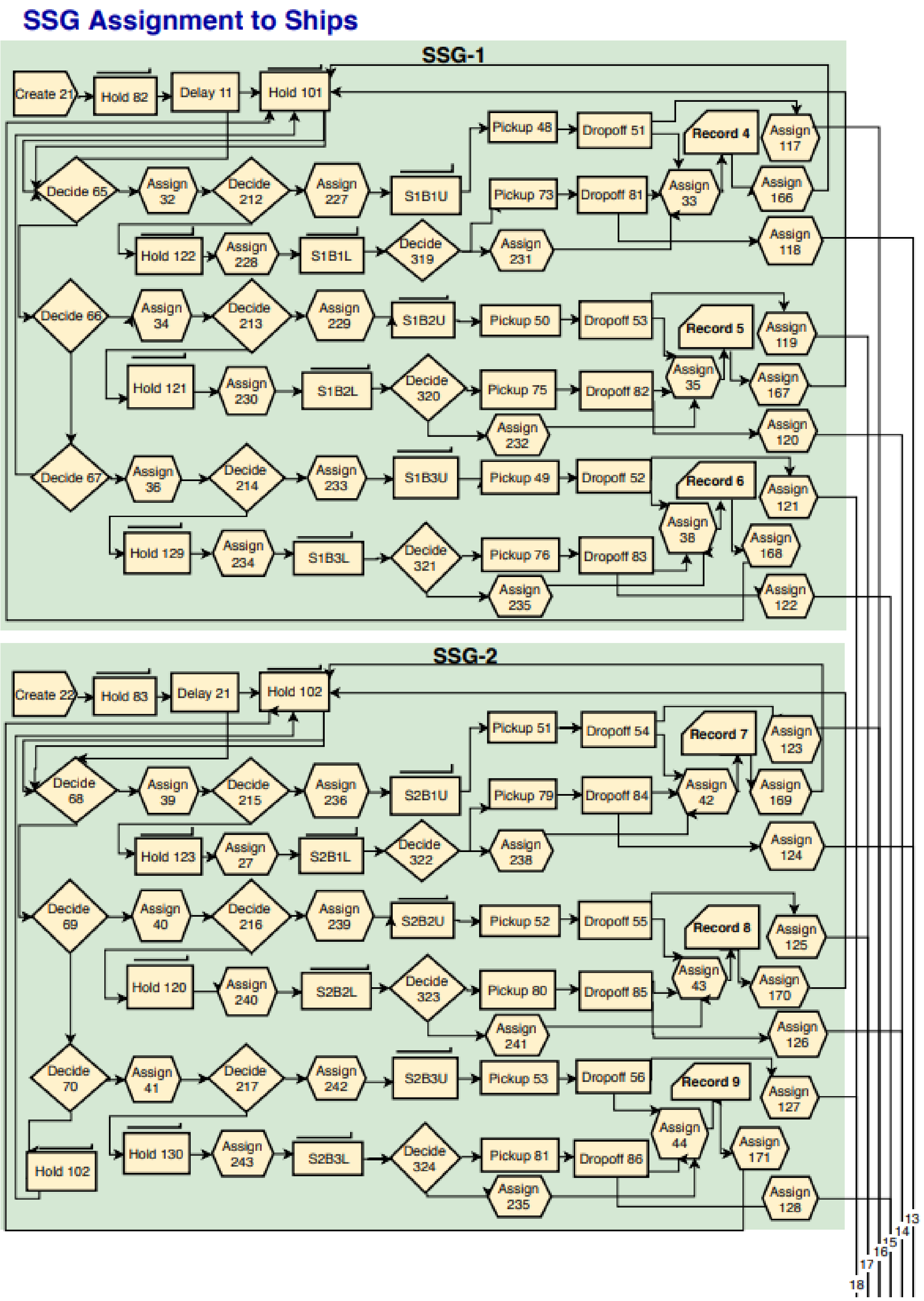


Figure 5.12 Assignment of SSG-1 & SSG-2 to ships.

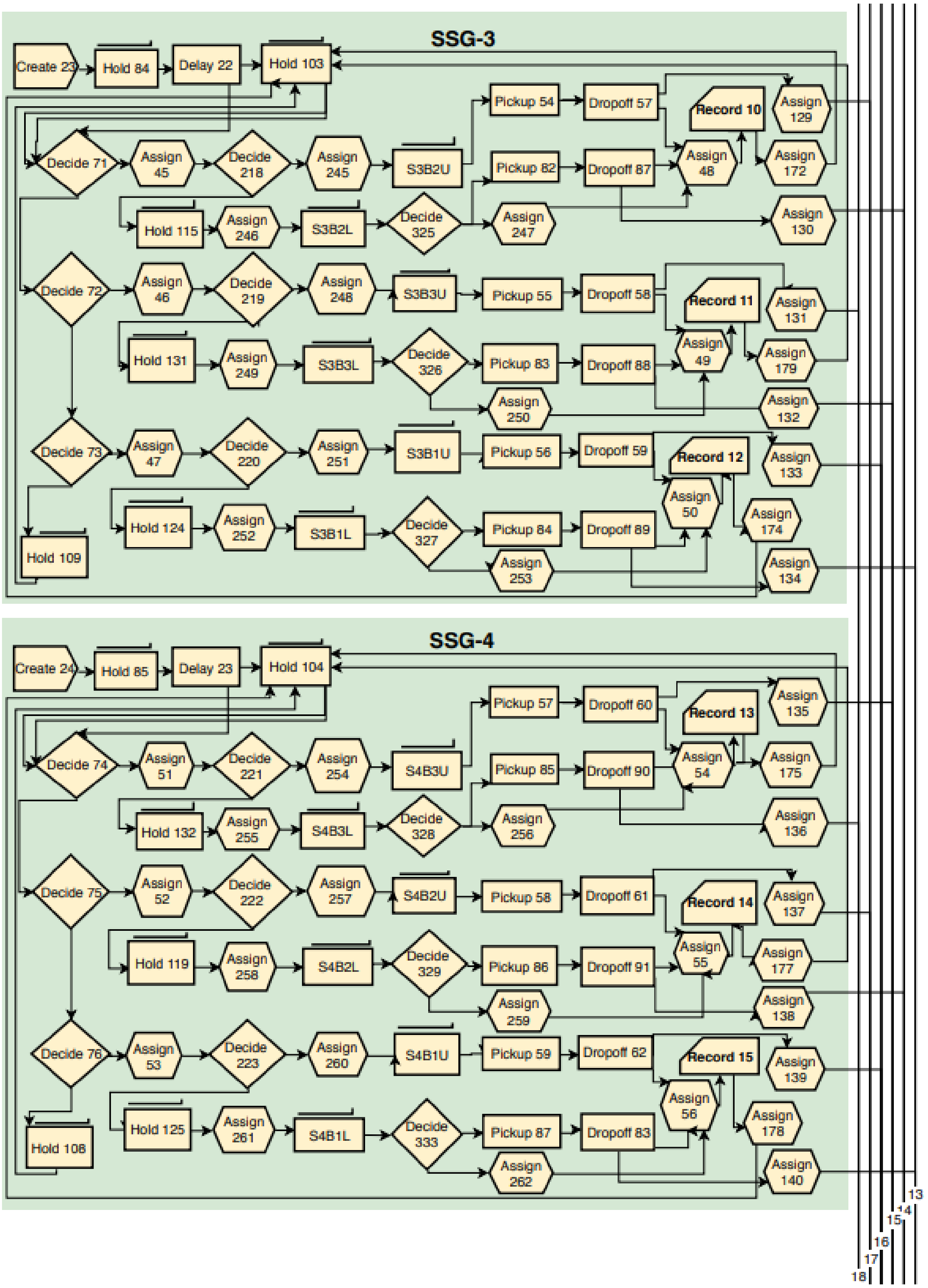


Figure 5.13 Assignment of SSG-3 & SSG-4 to ships.

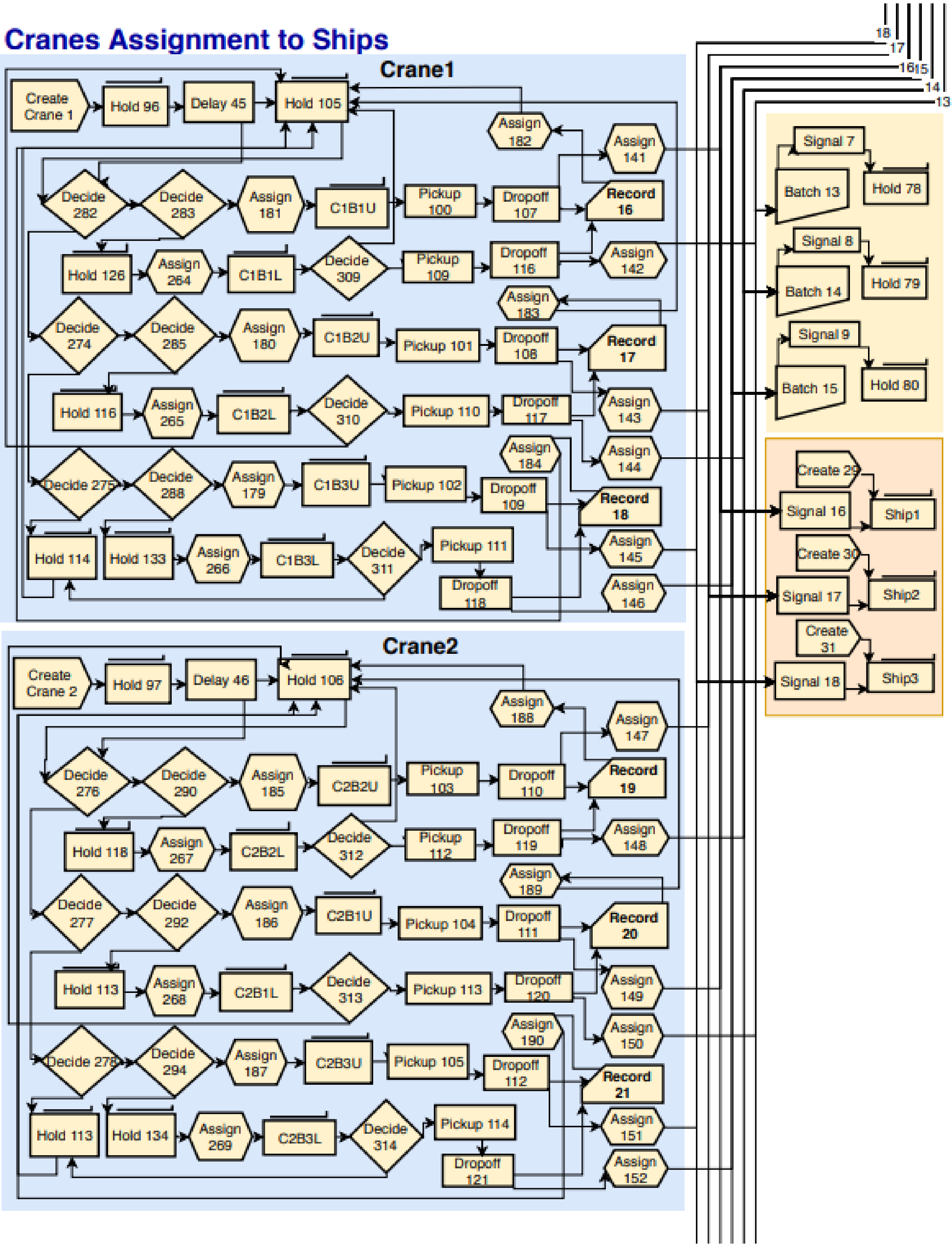


Figure 5.14 Assignment of Cranes 1&2 to ships.

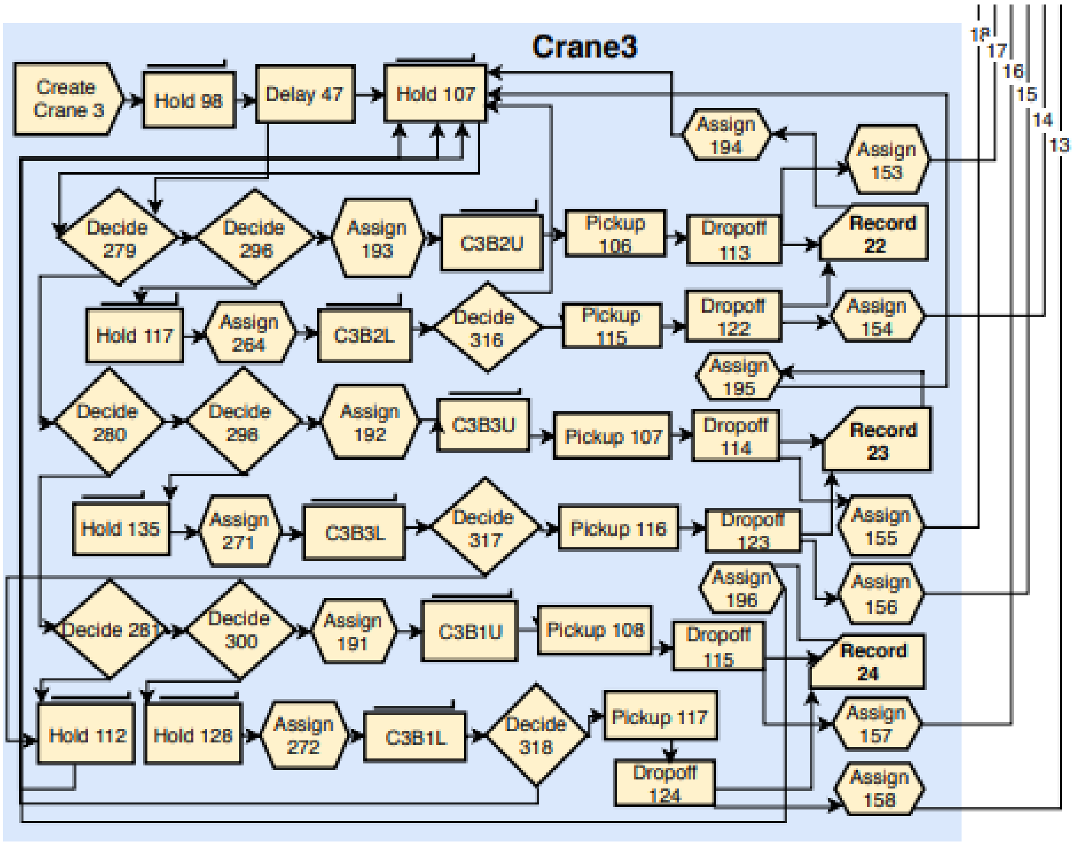


Figure 5.15 Assignment of Crane 3 to ships.

5.2.2.2.4 D: Container Storages Areas and Truck Logic

This subsection builds all storage area operations, including blocks, handlers, and trucks in the port. This sub-module of the simulation has 405 ARENA modules. Their orders given in Table A7.1 in Appendix *7* explains all details of these modules. This complicated part was developed based on container storage area, rubber-tired gantry crane (RTG), Yard Trucks (YTT), and Stackers (Kalmar) operation, and their simplified illustration are shown in Figure 5.16.

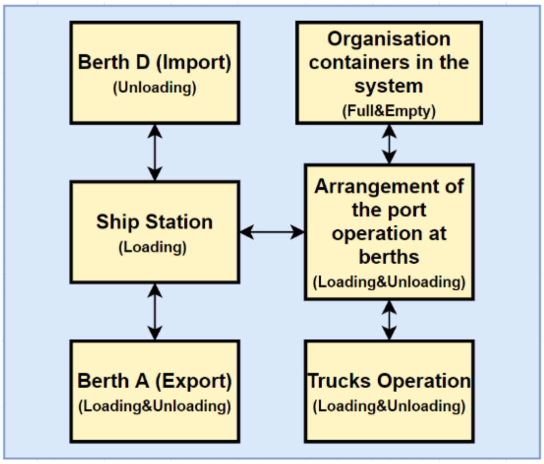


Figure 5.16 Container Storages Areas and Truck Logic.

Container Storage Area: These parts represent the storage areas at the port. This port mainly has export, Import, and empty containers. The case port designed its port storage blocks and storage locations mainly based on these container types. Some ports also include a separate area for transit containers, but this port does not have a transit port area because the case study port is not the kind of a port with a significant volume of transit containers. As a result of this, storage areas are grouped as follows, and their locations are shown in Figure 5.17.

> **Import**: When the unloading activities are taking place, containers are loaded to the Import blocks. Blocks D4, D5, D6 are for the imported full containers in the ARENA model.
>
> **Export**: When the loading activities are taking place, containers are unloaded from the Export blocks, which are A1, A2, A3, A4, A5, D1, D2 and D3.
>
> **Empty**: All empty containers stored in empty blocks are shown as G1, G2. G3 and G4 in Figure 5.17.

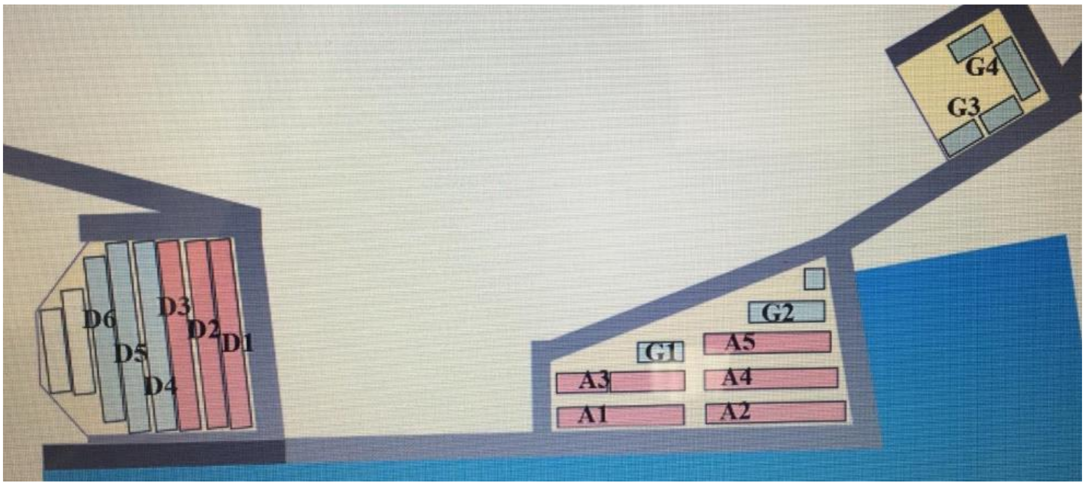


Figure 5.17 Container Storage layout and container blocks: A1-5, D1-6, G1- 4.

RTG: RTG rubber-tired gantry crane loads, unloads, and transits the containers in the yard. In other words, RTGs help to stack containers in this port. This submodel is set in here due to the integration of yard blocks and trucks. RTGs are utilised in Export and Import areas shown as A and D in Figure 5.17. A total of 24 RTGs are used in the model.

Stackers: It refers to a reach stacker, a vehicle used for handling intermodal cargo containers in small terminals or medium-sized ports. Reach stackers can transport a container short distances very quickly and pile them in various rows depending on its access. In this model, Kalmars are the stackers, and 7 Kalmars worked in the model for empty container blocks.

Yard Tractors (Trucks or YTT): They are the main terminal tractors which are semi-tractor intended to move semi-trailers within a cargo yard, warehouse facility, or intermodal facility, much like a switcher locomotive is used to position railcars. It is also known as YTT, and 31-yard trucks are used in the model. All ports get containers from their hinterland and send stored containers to their logistic destination by trucks, which come from the outside the port, such as a private trailer. All these upcoming and outgoing containers work in this model, but their consumption figures are not recorded due to a lack of consumption data. Therefore, YTT is the only trucks that work in the model.

5.2.2.2.5 E: Some main modules and their details

There are many modules used in this submodel, but some significant ones are explained here. The first module in this submodule is Create 44, which creates Truck entries into the system. This module creates all of the 31 trucks and their roads shown in figure 5.18. Furthermore, Hold 159 holds all trucks in the Hold Module unit until the ship berthed quay and started unloading. This module controls all queues of ships and berths to start the operation. This condition is provided in the model as NQ (ship1.Queue) > 0) || (NQ (ship2.Queue) > 0) || (NQ (ship3.Queue) > 0) || (Berth1Status == 1) || (Berth2Status == 1) || (Berth3Status == 1). Decide 460 help to dice whether trucks are going to unload or not by using Type: 2-way by Condition. Decide 336 decides which quay the trucks will go to during operation. This Decide module used N way conditions to direct the trucks to the right queues.

\`EmptyDecide\` decides which area of the port field will be suitable for empty unloaded containers by using trucks. This used N-way conditions based on empty container blocks (G1, G1, G3, and G4) queues. Decide modules like 338 determines where the full containers will be transported in the port field by trucks. This used N-way conditions based on empty blocks (all A and D blocks like A1 and D1) queues. Moreover, Route modules direct trucks to station points (like Station 52) based on unformal time distribution (UNIF (10,14.5). All truck routes are shown in Figure 4.26, with dark blue lines in the berth and the storage area based on the port traffic map. Decide 461, Decide 462 and Decide 463 determines whether containers loaded into trucks are full (72.3%) or empty (27.7%). Decide 430 distinguishes reefer containers as 1% of full containers. Assign modules between 197 and 219 record the number of containers handled for each block. For instance, assign 200 records StorageA1 for blocks A1, assign 207 records StorageD1 for blocks D1, assign 209 records StorageR1 for reefer containers, Assign 216 StorageG1 records for blocks G1. G1process, G2process, G3process, and G4process modules defined KALMAR, which unloads trucks from outside of the port with the cargo by using Kalmar resources with an operation time of 1.71 hours per move.

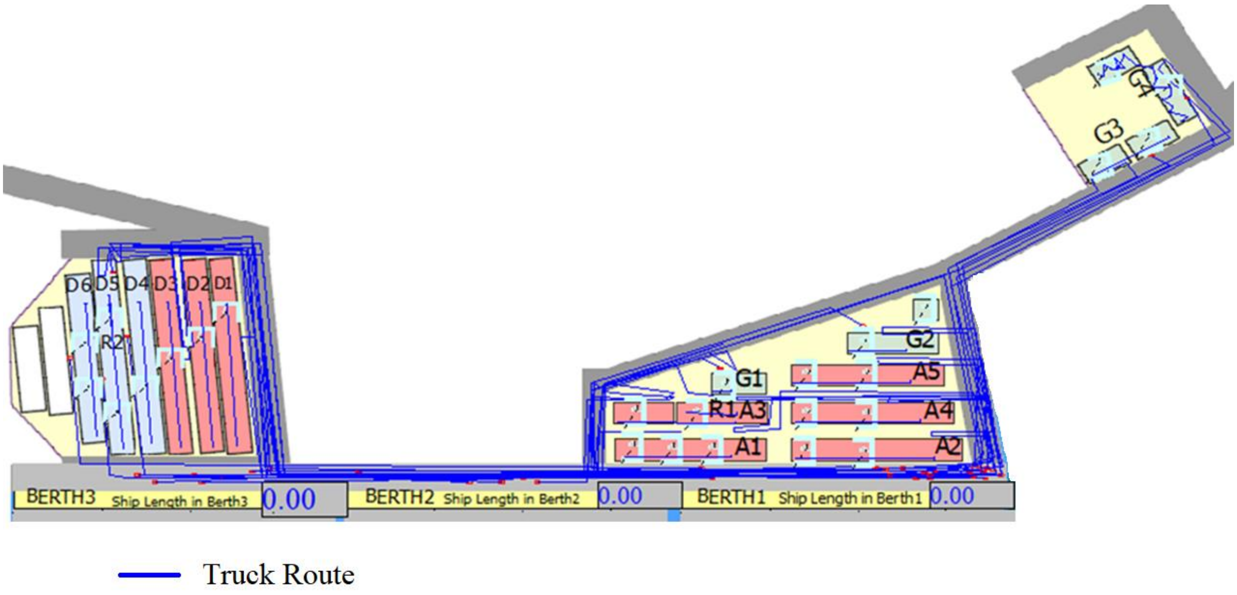


Figure 5.18 Truck Routes.

This simulation model keeps records of all necessary times to use in energy consumption calculation for the port operation, although ARENA has the capability to convert time values to consumption, time, and handling operations as TEU recorded in this model. The main reason behind this record is the validation which is much easier when the system records data as time per movement or operation and TEU handling per equipment. Table 5.5 listed 25 desired statistical data as a result of the simulation. Total handling time for each SSG, Cranes, and other equipment like trucks, handled containers quantity as TEU are also recorded for each quay and storage areas. We know which RTGs and Kalmars work in each stock's area. Therefore, the system is able to identify the handling time and quantity of each RTG and Kalmar operation. More details will be provided in the validation and early results section.

5.2.3 Identification of Energy Consumption and CO_2 pollution Calculation

After calculating the operation time of each type of equipment with ARENA simulation, the following formula is applied in the equation used within the arena to reach the consumption results.

Table 5.5 Desired statistical data as a result of simulation.

	Module	**Definition**	**Properties and Function**
Desired statistical data as a result of simulation	Total_HandlingofSSG1	Gives the number of containers handled by SSG1 for all berths	SSG1inBerth1 + SSG1inBerth2 + SSG1inBerth3
	Total_HandlingTimeofSSG1	Gives the total handling time of SSG1 for all berths.	TotalTimeIntervalSSG1Berth1 + TotalTimeIntervalSSG1Berth2 + TotalTimeIntervalSSG1Berth3
	Total_HandlingofSSG2	Gives the number of containers handled by SSG2 for all berths	SSG2inBerth1 + SSG2inBerth2 + SSG2inBerth3
	Total_HandlingTimeofSSG2	Gives the total handling time of SSG2 for all berths.	TotalTimeIntervalSSG2Berth1 + TotalTimeIntervalSSG2Berth2 + TotalTimeIntervalSSG2Berth3
	Total_HandlingofSSG3	Gives the number of containers handled by SSG3 for all berths	SSG3inBerth1 + SSG3inBerth2 + SSG3inBerth3
	Total_HandlingofSSG4	Gives the number of containers handled by SSG4 for all berths	SSG4inBerth1 + SSG4inBerth2 + SSG4inBerth3
	Total_HandlingTimeofSSG3	Gives the total handling time of SSG3 for all berths.	TotalTimeIntervalSSG3Berth1 + TotalTimeIntervalSSG3Berth2 + TotalTimeIntervalSSG3Berth3
	Total_HandlingTimeofSSG4	Gives the total handling time of SSG4 for all berths.	TotalTimeIntervalSSG4Berth1 + TotalTimeIntervalSSG4Berth2 + TotalTimeIntervalSSG4Berth3
	Total_HandlingofCrane1	Gives the number of containers handled by Crane1 for all berths	Crane1inBerth1 + Crane1inBerth2 + Crane1inBerth3
	Total_HandlingTimeofCrane1	Gives the total handling time of Crane1 for all berths.	TotalTimeIntervalCrane1Berth1 + TotalTimeIntervalCrane1Berth2 + TotalTimeIntervalCrane1Berth3
	Total_HandlingofCrane2	Gives the number of containers handled by Crane2 for all berths	Crane2inBerth1 + Crane2inBerth2 + Crane2inBerth3
	Total_HandlingTimeofCrane2	Gives the total handling time of Crane2 for all berths.	TotalTimeIntervalCrane2Berth1 + TotalTimeIntervalCrane2Berth2 + TotalTimeIntervalCrane2Berth3
	Total_HandlingofCrane3	Gives the number of containers handled by Crane3 for all berths	Crane3inBerth1 + Crane3inBerth2 + Crane3inBerth3
	Total_HandlingTimeofCrane3	Gives the total handling time of Crane3 for all berths.	TotalTimeIntervalCrane3Berth1 + TotalTimeIntervalCrane3Berth2 + TotalTimeIntervalCrane3Berth3
	Total_All_HandlingInSSG_Crane	Gives the total number of handling for all SSGs and Cranes	Total_HandlingofCrane1 + Total_HandlingofCrane2 + Total_HandlingofCrane3 + Total_HandlingofSSG1 + Total_HandlingofSSG2 + Total_HandlingofSSG3 + Total_HandlingofSSG4
	Total_All_HandlingInSTORAGES	Gives the total number of handling operations for each block (all operations between ship and blocks)	StorageA1 + StorageA2 + StorageA3 + StorageA4 + StorageA5 + StorageD1 + StorageD2 + StorageD3 + StorageD4 + StorageD5 + StorageD6 + StorageG1 + StorageG2 + StorageG3 + StorageG4 + StorageR1 + StorageR2
	Total_HandlingTIMEInSTORAGE	It gives the total handling time for all operation for storage blocks (Calculates the working time of RTGs and KALMARs)	(StorageA1 + StorageA2 + StorageA3 + StorageA4 + StorageA5 + StorageD1 + StorageD2 + StorageD3 + StorageD4 + StorageD5 + StorageD6 + StorageR1 + StorageR2) * 3 + (StorageG1 + StorageG2 + StorageG3 + StorageG4) * 1.71
	UnloadedContainers_Berth1	Total number of containers discharged from 1st quay	ContainersFromBerth1
	UnloadedContainers_Berth2	Total number of containers discharged from 2nd quay	ContainersFromBerth2
	UnloadedContainers_Berth3	Total number of containers discharged from 1rd quay	ContainersFromBerth3
	Total_Unloaded_Containers	The total number of discharged containers. The total number of loads from outside of port to port	ContainersFromBerth1 + ContainersFromBerth2 + ContainersFromBerth3
	TruckTime_Loading	Total trucks time for the loading process	TotalLoadingTruckTime
	TruckTime_Unloading	Total trucks time for the unloading process	TotalUnloadingTruckTime
	TotalTruckTime	Total run time of trucks	TruckTime_Unloading + TruckTime_Loading
	Total_Operation_Time_in_Berths	Total waiting time of ships on berths	Total_Op_Timein_Berth1 + Total_Op_Timein_Berth2 + Total_Op_Timein_Berth3

5.2.3.1 Energy Consumption

The primary energy consumers at container ports are equipment, storage of referring containers, and other port buildings and infrastructures. This module does not consider the port buildings and infrastructures in the model calculation. This subsection introduces the basic concept of energy consumption from port equipment and reefer area as initial energy consumers of a container port.

5.2.3.1.1 Port Equipment Energy Consumption

SSG: Total Energy Consumption of SSGs for a ship operation (TEC_{SSG})

$$TEC_{SSG} = \sum_{a=1}^{a=n} (EC_{SSG_a} * OT_{SSG_a})$$

EC_{SSG} : Energy Consumption of an SSG

OT_{SSG} : Operation time of an SSG

n: number of the SSGs work for ship operation at the port.

Crane: Total Energy Consumption of Cranes for a ship operation (TEC_{Cr})

$$TEC_{Cr} = \sum_{a=1}^{a=n} (EC_{Cr_a} * OT_{Cr_a})$$

EC_{Cr} : Energy Consumption of a Crane

OT_{Cr} : Operation time of a Crane

n: number of the cranes worked for ship operation at the port.

Truck: Total Energy Consumption of Yard Trucks for a ship operation (TEC_{YT})

$$TEC_{YT} = \sum_{a=1}^{a=n} (EC_{YT_a} * OT_{YT_a})$$

EC_{YT} : Energy Consumption of a yard truck

OT_{YT} : Operation time of a yard truck

n: number of the yard tracts work for ship operation at the port.

RTG: Total Energy Consumption of RTG for a ship operation (TEC_{RTG})

$$TEC_{RTG} = \sum_{a=1}^{a=n} (EC_{RTG_a} * OT_{RTG_a})$$

EC_{RTG} : Energy Consumption of an RTG

OT_{RTG} : Operation time of an RTG

n: number of the RTGs work for ship operation at the port.

Container Handlers (Kalmar, top picks and side picks)

Total Energy Consumption of Container Handlers for a ship operation (TEC_{CH})

$$TEC_{CH} = \sum_{a=1}^{a=n} (EC_{CH_a} * OT_{CH_a})$$

EC_{CH} : Energy Consumption of a Container Handler

OT_{CH} : Operation time of a Container Handler

n: number of the container handlers worked for ship operation at the port.

Total Port Equipment Energy Consumption for a year (TEC_{PE})

$$(TEC_{PE}) = \sum_{a=1}^{a=m} (TEC_{YT_m} + TEC_{RTG_m} + TEC_{CH_m} + TEC_{SSG_m} + TEC_{Cr_m})$$

m: a number of ship operations in a year. Each piece of equipment's actual energy consumption is given in Table 5.6 with all details of engines and their models. Some figures in the table are updated based on their actual records given by the port operator instead of engine figures given earlier.

Table 5.6 Port equipment technical details and consumption figures.

Equipment No	**Group**	**Equipment Code**	**Equipment Brand**	**Fuel Consumption (Litter/Hour)**	**Electricity Consumption (KW/Hour)**
1-3	4 SSG	SSG 1 SSG 2 SSG 3 SSG 4	Mitsui Paceco	___	235 KW/H
4	3 Crane	Crane 1	Liebherr	48.80 LT	195 KW/H
5		Crane 2	Liebherr	45.80 LT	195 KW/H
6		Crane 3	Gottwald	50 LT	170 KW/H
7-12	24 RTG	RTG 1 RTG 2 … RTG 6	Kalmar	13,89 LT	30 KW/H
13-25		RTG 7 … RTG 19	Mitsui Paceco	___	24 KW/H
26-27	7 Kalmar	Kalmar 1 Kalmar 2	Kalmar	9 LT	___
28-29		Kalmar 3 Kalmar 4	Kalmar	17 LT	
30-31		Kalmar 5 Kalmar 6	Fantuzzi	16 LT	
32		Kalmar 7	Hyster	15 LT	___
33-41	31 YTT	YTT 1 YTT 2 … YTT 9	Terberg	6,27 LT	___
42-47		YTT10 … YTT 15	Kalmar Ottawa	6,27 LT	___
48		YTT 16	Terberg	6,27 LT	___
49-64		YTT 17 … YTT 31	Terberg	6,27 LT	___

5.2.3.1.2 Total Reefer Energy consumption

Total Energy Consumption of Reefer Containers for a ship operation (TEC_{RC})

$$TEC_{RC} = \sum_{a=1}^{a=n} (EC_{RC_a} * OT_{RC_a})$$

EC_{RC} : Energy Consumption of a reefer

OT_{RC} : Operation time of a reefer

n: number of the reefer container used for ship operation at the port.

5.2.3.1.3 Ship Energy Consumption while waiting

Ship's energy consumption is highly dependent on ship engines' consumption, and it is load and operation conditions when they enter the port area. A method developed by Trozzi and Vaccaro (1998) was used to calculate the energy consumption of the ships which visited the port during the simulation time. Trozzi and Vaccaro introduced the method in 1998, and they revised it in 2006 and 2010 (Trozzi and Vaccaro, 1998, Trozzi and Vaccaro, 2006, Trozzi and Vaccaro, 2010). This method is used for all types of the ship, and it is recently used in Ülker et al. (2021). The method offers the formulas presented in the following Equations to calculate CO_2 pollution and energy consumption. Consumption (C) at full power (t/day) as a function of gross tonnage (GT) for container ship is as follow.

$$C_{jk} = 8.0552 \ + \ 0.00235 \times \mathrm{GT}$$

Where:

j is the fuel type,

k is the ship class and,

GT is the gross tongue of the ship.

Effective fuel consumption can be obtained in the simplified methodology as:

$$S_{ik}(GT) = C_{jk}(\mathrm{GT}) * 0.8$$

and in the detailed methodology as:

$$S_{jkm}(GT) = C_{jk}(\mathrm{GT}) * pm$$

Where:

$\boldsymbol{S_{ik}(GT)}$ is the daily consumption of fuel ***j i***n ship class ***k*** as a function of gross tonnage,

$\boldsymbol{C_{jk}(\mathrm{GT})}$ is the daily consumption at full power of fuel ***j*** in ship class ***k*** as a function of gross tonnage,

$\boldsymbol{S_{jkm}}$ is the daily consumption of fuel $\boldsymbol{j}$ in ship class $\boldsymbol{k}$ in mode m as a function of gross tonnage.

$\boldsymbol{pm}$ is the fraction of maximum fuel consumption in mode $\boldsymbol{m}$.

The default fractions in Table 5.7 can be used for the different operating modes. Proposed emission factors (kg/ton of fuel) for use are given as 3200 kg/ton of fuel for CO_2 for container ships.

Table 5.7 The fraction of maximum fuel consumption in a different mode (Trozzi and Vaccaro, 1998).

Mode		**Fraction**
Cruising		0.80
Manoeuvring		0.40
Hotelling		0.20
	Passenger	0.32
	Tanker	0.20
	Other	0.12

Total Energy Consumption of a ship while waiting to have the port operation service (TEC_S):

$$TEC_S = C_c * t_c + C_m * t_m + C_h * t_h$$

Where:

C_c is the daily energy consumption, and during cruising.

$t_c$is the time duration (day) of the crushing operation of the ship

C_m is the daily energy consumption of the ship during manoeuvring,

$t_c$is the time duration (day) of the manoeuvring operation of the ship

C_h is the daily energy consumption of the ship during hotelling.

$t_c$is the time duration (day) of the hotelling of the ship.

The integrated system's total energy consumption and all the calculation mentioned above are presented in Figure 5.19. At the same time, this calculation made different sources of energy are converted to a tonne of oil equivalent (toe). International Energy Agency (IEA) conversion factors for converting one metric tonne of oil production to one ton (a ton of oil equivalent) is used for converting all different energy types to toe. All conversion energy figures are taken from Greenhouse gas reporting conversion factors 2020 by Gov UK (2020b) in the United Kingdom public sector information website created by the Government Digital Service.

- One KWH to toe conversion is calculated as 0.0000860 toe.
- One litter Diesel to toe conversion is calculated as 0.0009800 toe.
- One litter of heavy fuel oil to toe conversion is calculated as 0.960 toe.

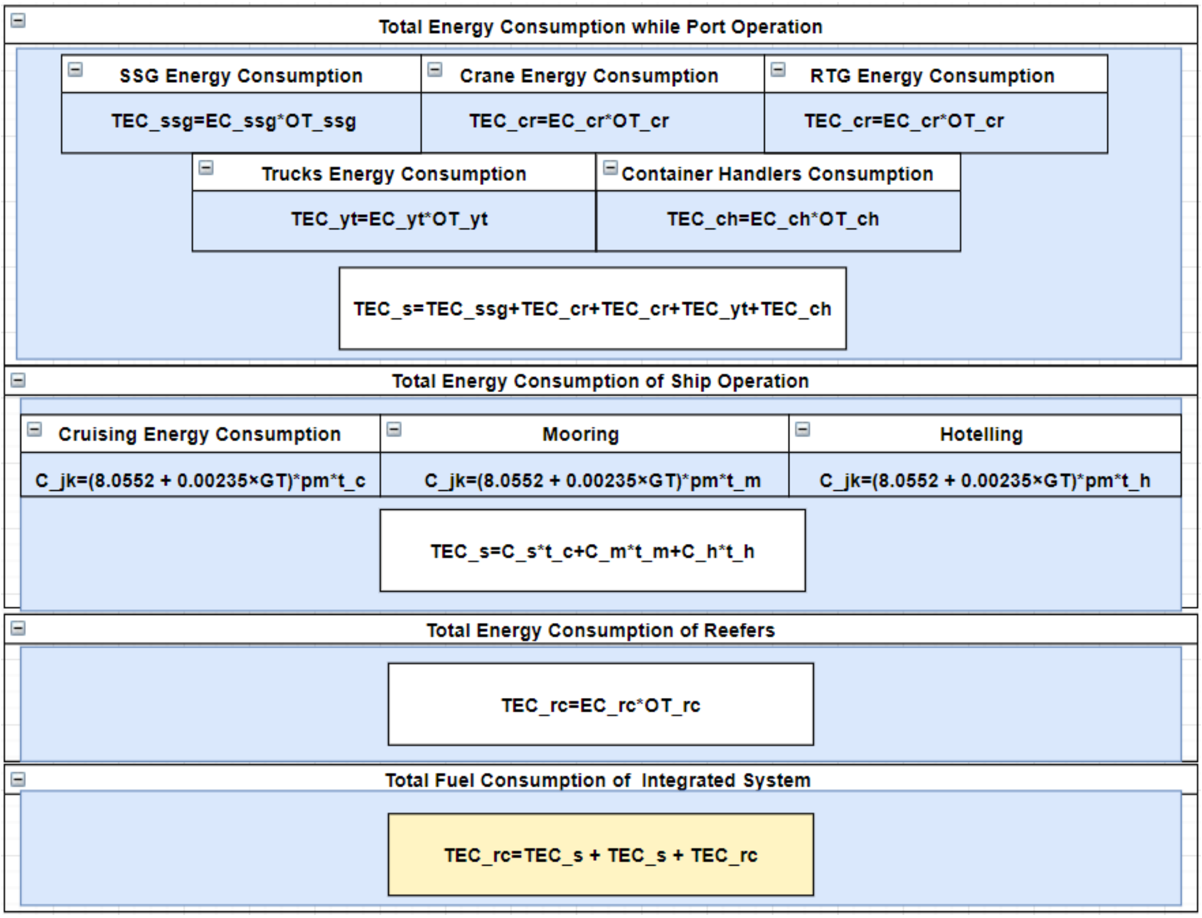


Figure 5.19 Overview of all equations of energy consumption calculation for ship and port operation.

5.2.3.2 CO_2 Emission

The conversion factor for each energy type fuel releasing CO_2 to calculate the total CO_2 emission. A "grid emission factor" is used for electricity. It refers to a CO_2 emission factor (kgCO_2/kWh) that is linked to each unit of electricity provided by an electricity system. For instance, EU carbon intensity was 0.270 kilograms of CO_2 per kilowatt-hour (kgCO_2/kWh) in 2018 and 0.235 kgCO_2/kWh in 2019. This figure was 400 gCO_2/kWh in the United States, past 500 gCO_2/kWh in Japan, about 600 gCO_2/kWh in China, and around 700 gCO_2/kWh in India and Australia (IEA, 2020). When we calculate CO_2 emission calculations from electricity consumption, these figures need to be accounted for in a case port. The emission factor for diesel (average biofuel blend) per litre to kg CO_2 was taken as 2.54603 (Department for Business, Energy & Industrial Strategy, 2020). CO_2 emission factor for Crude oil is taken between 2,940- 3,212 kilogram of CO_2 emissions per kilogram of crude oil based on the World Nuclear Association (2010) cited in Krantz (2016). CO_2 emission for fuel oil is 3,11 kilogram per kilogram (Krantz, 2016).

5.2.4 Validation and initial results:

Validation is a necessary step before simulating different cases. After the model developed with ARENA, one real ship operation is run with the model to compare the simulation result with actual data from the case study port. Validation is the determination that the model is an accurate representation of the real port system. This result will show whether the model can be used instead of the real system. Table 5.8 provides data of the `Ship S` from a real operation. This Table gives average handling times for each equipment type as minutes per move. The event log of the case Ship S is shown in Figure 5.20 for the second half of 2017. Cargo handling equipment used in this ship operation is illustrated in Table 5.9. All SSGs are used in this operation, but cranes did not work because, at that time, this ship was the only ship at the port during complete port operation. 14 SSG and 30 trucks are worked in the yard with 5 Kalmar. Cargo specification is given in Table 5.10. The ship has a total of 1473 TEU containers, and 1040 containers handled at the port. Almost a third of the cargo is imported containers, which are discharged from the ship to the port, and the rest is export containers loaded to the ship.

Table 5.8 Real average handling times for each Equipment type as minutes per moves.

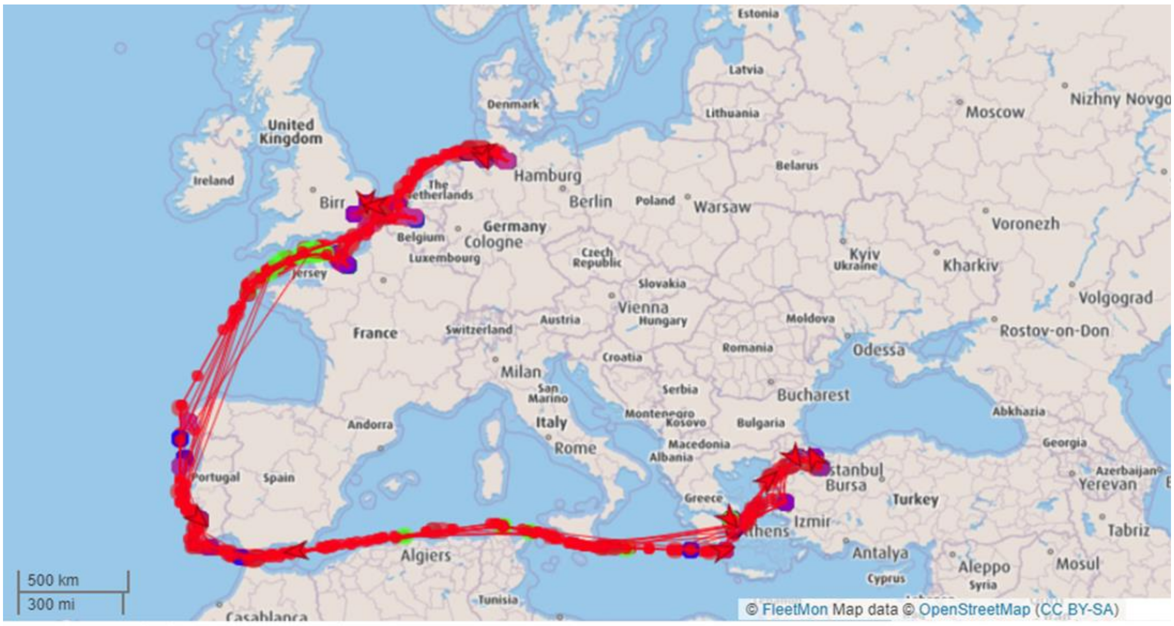
Average Handling Times for Each Equipment Type		
SSG	2.24	minutes per moves
Crain	-	minutes per moves
RTG	2.57	minutes per moves
Kalmar	1.70	minutes per moves
Truck	12.17	minutes per moves

Table 5.9 Number of Equipment used for the actual port operation of `Ship S`.

Ship Name	Total Number of SSG	Total Number of Crane	Total Number of SSG	Total Number of Kalmar	Total Number of Truck
Ship S	4	0	14	5	30

Table 5.10 Operational information of cargo from the actual `Ship S`.

<table>
<tr><th colspan="5">UNLOADING-Import</th><th colspan="2"></th></tr>
<tr><td colspan="2">Full</td><td colspan="2">Empty</td><td rowspan="2">TOTAL</td><td colspan="2"></td></tr>
<tr><td>20'</td><td>40'</td><td>20'</td><td>40'</td><td colspan="2" rowspan="2">TOTAL</td></tr>
<tr><td>59</td><td>122</td><td>181</td><td></td><td>484 TEU</td></tr>
<tr><th colspan="5">LOADING-Export</th><th>TEU</th><th>Number of Container</th></tr>
<tr><td colspan="2">Full</td><td colspan="2">Empty</td><td rowspan="2">TOTAL</td><td>1,473</td><td>1,040</td></tr>
<tr><td>20`</td><td>40`</td><td>20`</td><td>40`</td><td colspan="2"></td></tr>
<tr><td>362</td><td>312</td><td>3</td><td>0</td><td>989 TEU</td><td colspan="2"></td></tr>
</table>



© FleetMon Map data © OpenStreetMap (CC BY-SA)

Date range: 09/07/2017 19:55 - 31/12/2017 19:18

Figure 5.20 Event Log of Ship S for the case study in the year 2017.

Assign 27 in the Arena module set LOA of the ship as 274 m, load as 1473 TEU. Also, the number of full and empty containers is set at the same value as Table 5.10. Create 44 set trucks number as 30. After setting real values in the Arena model, the simulation runs the case and is completed with 9 hours of simulation time. Figure 5.21 gives the simulation as a 2D visualisation. The figure presents four different moments from the operation. The ship is arriving at the port at the first moment. The second one shows that all SSGs assigned to discharging import cargos come from different ports in Figure 5.21. This part also shows the ship LOA as 274 m in berth 1. Then the third figure indicates that trucks are loading the containers from port to ship by 4 SSGs as shown in the figure. The 4th figure shows the ship is leaving the port, and the port operation is recorded as 7.15 hours on berth 1. Then, results are saved and analysed to determine the simulation's accuracy compared to the real case data of ship S in the case port. Table 5.11 provides the key figures for each piece of equipment.

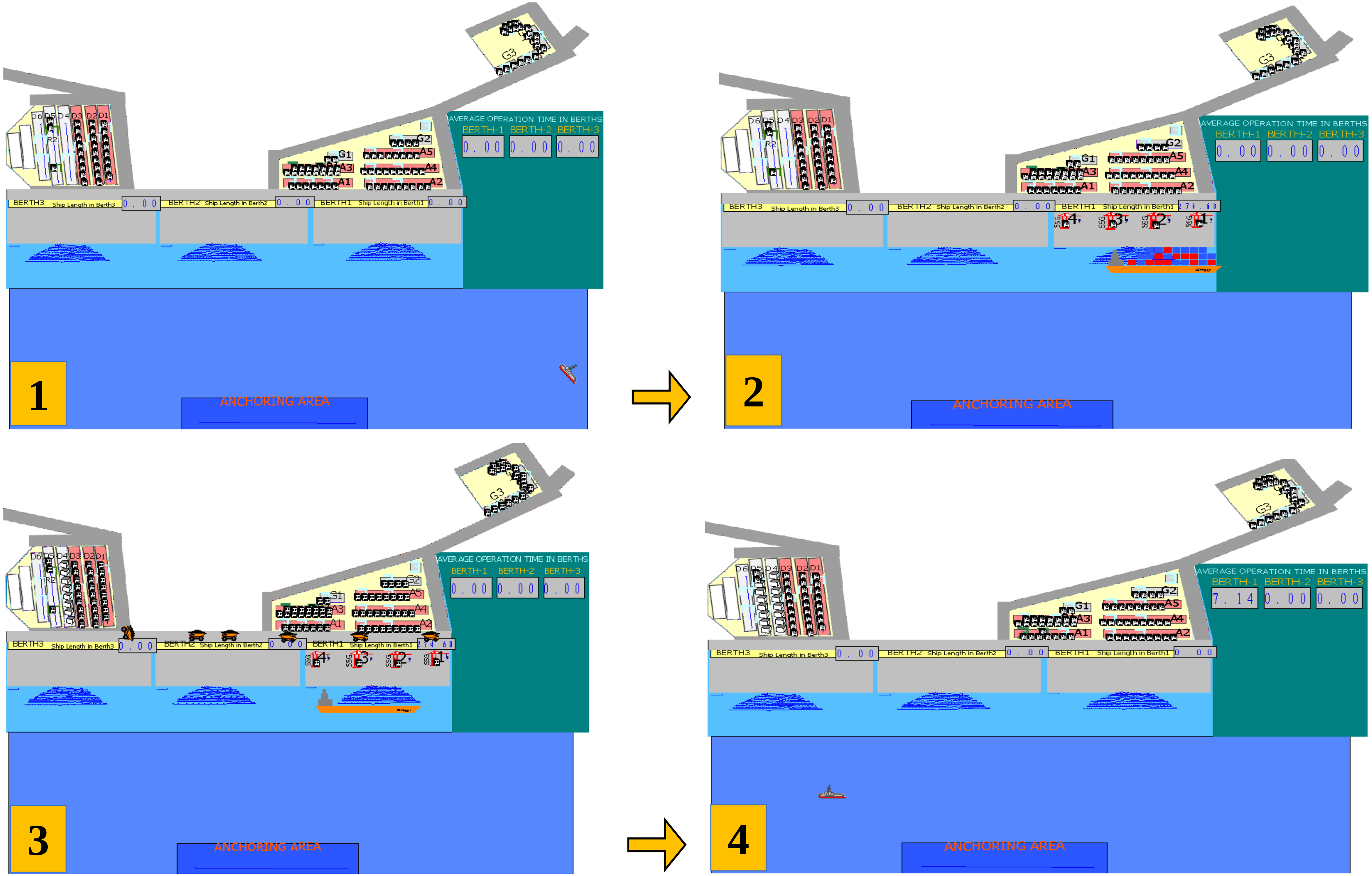
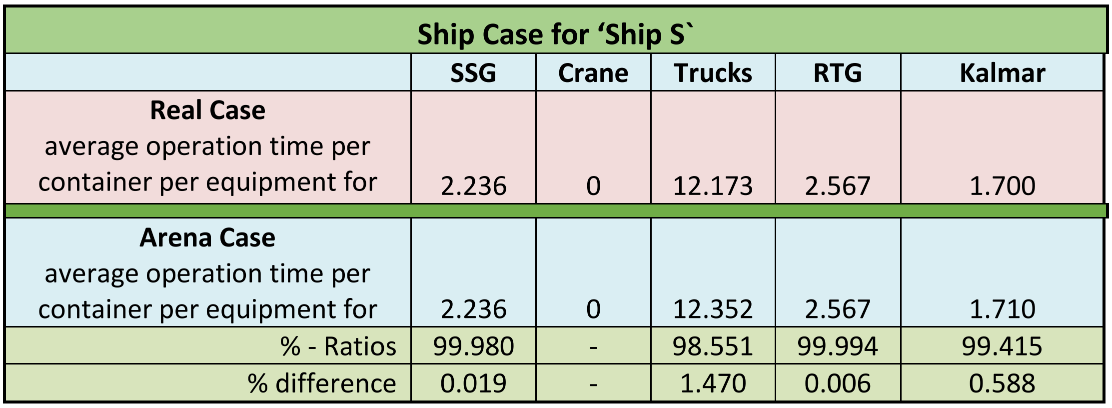


Figure 5.21 Arena Ship S Simulation with the 2D Visualisation.

Table 5.11 Comparison of ARENA results in minutes and real case data of the 'Ship S`. `



Ship Case for 'Ship S`					
	SSG	Crane	Trucks	RTG	Kalmar
Real Case average operation time per container per equipment for	2.236	0	12.173	2.567	1.700
Arena Case average operation time per container per equipment for	2.236	0	12.352	2.567	1.710
% - Ratios	99.980	-	98.551	99.994	99.415
% difference	0.019	-	1.470	0.006	0.588

The average operation time of SSG for the real case is 2.24 minutes per container, and this is almost the same result as the Arena simulation with 2.24 minutes; this provides an accuracy of 99.98%. There was no Crane worked in this operation, and the Arena did not assign any Crane for this operation. The average operation time of trucks is recorded as 12.35 minutes per container operation, and this is 12.17 minutes in the real case, and the difference is almost 1.47%. RTGs spent 2.57 minutes for each container in the real case. This result has only a 9-millisecond difference from the Arena result. Kalmar, which works with 1.7 minutes per container operation, is the fastest equipment as they work in empty container storage areas. This was recorded as 1.71 minutes in the arena simulation as well. The largest difference is around 0.5 % for Kalmar. This result shows that the simulation works well for one ship case.

The Arena module ran for three ship arrival cases to analyse the same results and the module's performance for each piece of equipment. Although three-ship operations simultaneously happen very rarely in this port, this outcome will provide the performance of the simulations for challenging cases to test the accuracy and the capability of the model. All ships are assigned as 210 meters, and the same cargo volume as the previous case was allocated to each ship. After setting real values in the Arena model, the simulation runs the case and is completed in 19 hours of simulation time. Figure 5.22 provides the 2D representation of the simulation results. The figure has six snapshots from the 19 hours of operation—three ships arriving in the port is represented by the first image.

The second one shows that all SSGs and Cranes are assigned to ships. SSG 1, SSG 2, and Crane 1 were assigned to berth 1. SSG 3, Crane 1, and Crain 2 were assigned to berth 2. SSG 4 is assigned to berth 3. This is an excellent allocation for all ships in these three berths based on the port's allocation logic.

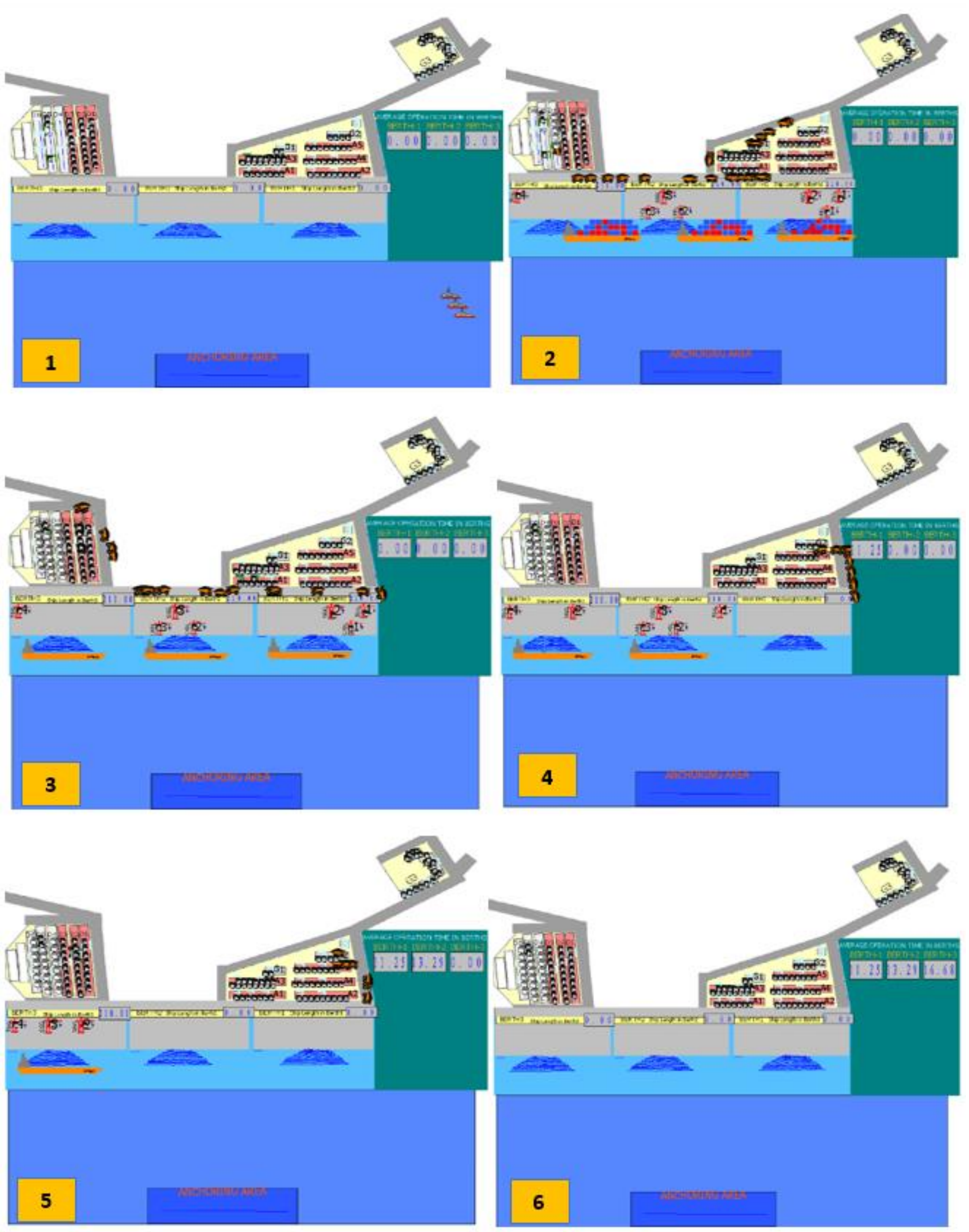


Figure 5.22 Arena Ship S Simulation 2D Visualisation.

The second image also shows all ships` LOA was set as 210 meters in with trucks in the yard. Then the third image shows the same cranes and SSGs work for loading. The 4th image indicates that the ship in berth one had finished its operation and left the berth. Then relocation cranes worked at berth 1 (SSG1, SSG, and Crane 1) due to standard operation. After that, the second ship in berth 2 completes its operation, and only one more SSG joins in fastening the 3rd ship operation in berth 3. This shows that Arena simulations only allocated cranes and SSGs based on actual port logic.

The last image in Figure 5.22 shows that all ships completed their handling operation and left the port. As recorded in the right corner of the moment, the first ship completed its operation in 11.25 hours, the second ship completed in 13.29 hours, and the last ship completed in 16.68 hours. Then, results are saved and analysed to determine the simulation's accuracy compared to the data provided from the port. Table 5.12 provides the main results for each piece of equipment from the ARENA case and port data. This time we can have a chance to see the crane results with less than 1% differences. Additionally, trucks provided accurate results with less than 0.01% difference. One of the possible reasons behind this is that all trucks worked in the system.

Table 5.12 Comparison of ARENA results in minutes and real port data for arrivals of 3 ships at the same time.

3 Ship Case					
	SSG	**Crane**	**Trucks**	**RTG**	**Kalmar**
Port Data average operation time per container per equipment for	2.2360	3.000	12.1731	2.5673	1.700
Arena Case average operation time per container per equipment for	2.2356	2.9710	12.1721	2.5675	1.7099
% - Ratios	99.981	100.986	100.008	99.994	99.415
% difference	0.01892	0.97598	0.00769	0.00595	0.58798

5.2.5 Results

The Arena module runs the model for a 4-week operation in the port. Fifty-six ships visited the port during this simulation time. After that, energy consumption has been calculated based on the energy consumption figures of port equipment. When CO_2 is calculated, the grid emission factor is taken as 0.481 kg CO_2 / kWh, all equipment powered by electricity used this conversion factor to calculate their CO_2 pollution. All other types of equipment are powered by diesel engines; therefore, we assumed that they use an average biofuel blend Diesel which releases 2.54603 CO_2 kg/per litre (Department for Business, Energy & Industrial Strategy, 2020). Tonne(s) of oil equivalent, abbreviated as a toe, is a generic energy unit. By convention, this is equal to the measured amount of energy that can be derived from one tonne of crude oil. It is a standardised unit, given a net calorific value of 41868 kilojoules/kg, and can be used to compare energy from various sources (Eurostat, 2020). One litre of Diesel fuel is equal to 0.00098 toe, and 1 kWh of electricity is equal to 0.000086 toe (Enva, 2020; Eurostat, 2020).

Table 5.13 Arena Result- energy consumption and CO_2.

	SSG	**Crane**	**Trucks**	**RTG**	**Kalmar**
Operation Time (h)	656.383	115.536	4234.590	1255.761	104.335
Electricity Consumption(kw)	154250.005	19397.860	0.000	33361.717	0.000
Fuel Consumption(litre)	0.000	501.380	26550.879	0.000	1510.864
TOE Equivalence	13.266	2.160	26.020	2.869	1.481
CO_2 pollution (kg CO_2)	74194.252	10606.899	67599.335	16046.986	3846.705
Total TEO Equivalence	45.795				
Total CO_2 pollution (kg CO_2)	172294.178				

SSG worked 656.4 hours in total, and the crane supported them with 115.5 hours at the port's quayside. Trucks worked 4234 hours to support all other handling equipment shown in Table 5.13. RTGs are worked 1255.8 hours, Kalmar has worked 104.3 hours. Trucks are consuming the highest tonne of oil equivalent (toe), 26.020 toe in total, which is 56.8% of the total energy consumption at the port, as shown in Figure 5.23. Then SSG follows it with 29% consuming 154250.005 kW electricity, which is equal to 13.266 toe. All RTGs consume around 6.3% of total consumption caused by equipment, while cranes and Kalmars consumed 4.7% and 3.2% of total consumption, respectively.

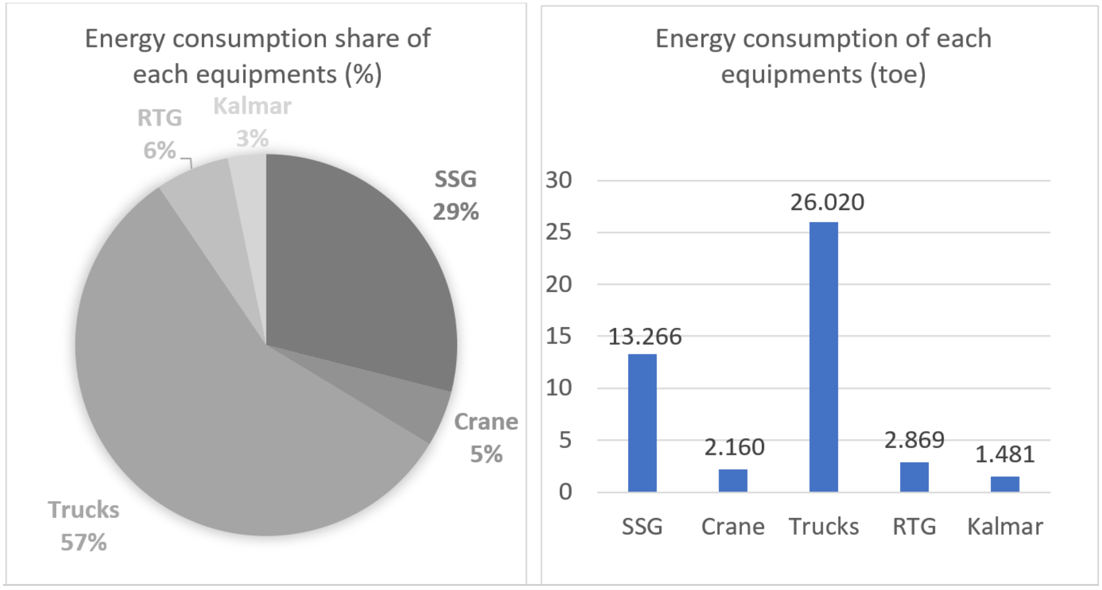


Figure 5.23 Energy consumption share in % and toe for each equipment.

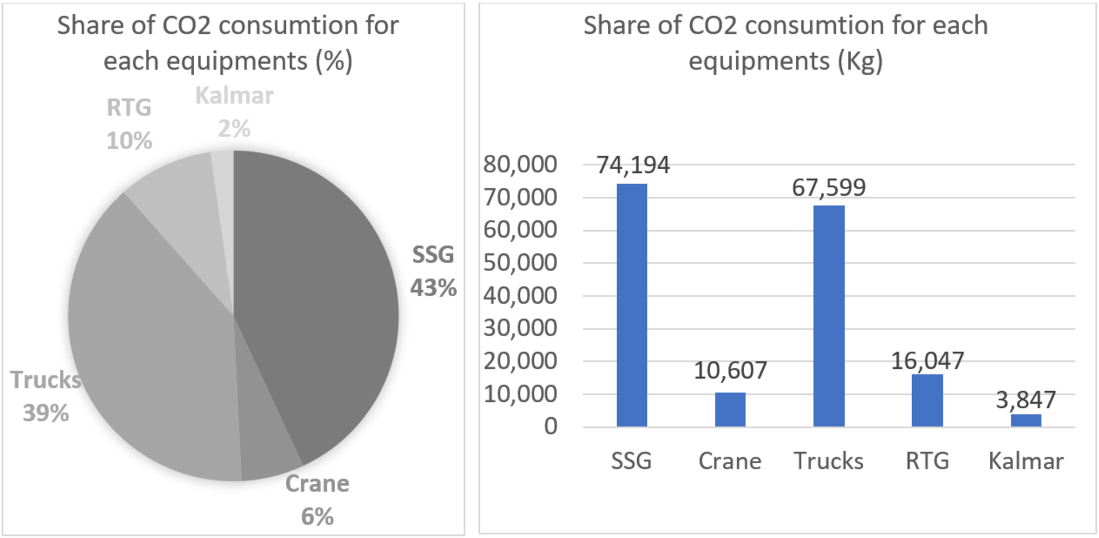


Figure 5.24 CO_2 share in percentage and kg for each equipment.

All equipment emitted around 172,300 kg of CO_2 during this 4-week time of operation at the port. SSGs emitted the highest CO_2 by 43.0% due to the high grid emission factor. The main reason behind this is that most of the electricity comes from fossil fuel-based power plants like Coal-fired or gas power plants. Trucks emit 67,600 kg of CO_2, which is 34.8% of the total CO_2 released, as demonstrated in Figure 4.32. RTGs produced almost 16,047 kg of CO_2. Cranes emitted the second lowest CO_2 with 10,607 kg (6.2%), after Kalmars with 3,847 kg (2.2%).

Energy consumption and CO_2 release per TEU is one of the common ways to show the overall performance in terms of energy consumption and CO_2 pollution. Table 5.14 shows that energy consumption per TEU is the lowest for RTGs with 0.000081 toe/TEU, and Kalmar follows it with 0.00285 toe/TEU. Trucks have the highest energy consumption value of 0.00638 toe/TEU, which is almost eight times higher than the RTGs` consumption. SSG and Cranes have high energy consumption as well, and they have 0.000366 toe/TEU and 0.000462 toe/TEU consumption, respectively. Although hourly energy consumption and CO_2 pollution are relatively high for SSGs with 0.02 toe/h and 113 kg/h, due to their high volume of handling per hour, their energy consumption and CO_2 release per TEU is not the highest, with 0.0037 toe/TEU and 2.047 CO_2 (kg)/TEU. Cranes are the biggest polluter with 2.27 kg of CO_2 per TEU. Overall energy consumption per TEU handled with all equipment is 0.00112 toe/TEU, and it causes almost 4.225 kg of CO_2 per TEU.

Table 5.14 Arena Result- Value of toe/TEU and CO_2 kg/TEU for each equipment.

	SSG	**Crane**	**Trucks**	**RTG**	**Kalmar**
toe/hour	0.020210	0.018692	0.006145	0.002285	0.014191
toe/TEU	0.000366	0.000462	0.000638	0.000081	0.000285
CO_2 kg/hour	113.035000	91.806249	15.963608	12.778691	36.868850
CO_2 kg/TEU	2.047303	2.270312	1.657659	0.450859	0.741462
Overall Energy Consumption per TEU (toe/TEU)				0.00112	
CO_2 pollution per TEU (kg/TEU)				4.22497	

5.2.5.1 Reefers

For the case port, 53 kWh/day is taken as an average consumption per reefer container per day for this calculation (Wilmsmeier, 2015). The total energy consumption of reefer containers for the 4-week time of operation in the case port is 71563.8 kW, equal to 6.2 toe and 34.4 tonnes of CO_2 release. Reefer container consumes 0,017 toe/day energy and 95,1 kg of CO_2 /day emission per TEU/day. This is 13.4% of the consumption of all the equipment (45.8 toe), and CO_2 emission is 20% of all equipment (172,3 tonne CO_2).

5.2.5.2 Ship

In this study, as explained earlier, Trozzi and Vaccaro method was applied to ships based on the ARENA simulation result of the case study to calculate energy consumption and CO_2 emissions.

5.2.5.3 Case Study

This case was chosen based on a meeting with the port. Trucks are the highest energy consumer at the port; therefore, the availability of the different numbers of trucks may affect port energy consumption. The module runs the system for the same amount of time (4 weeks) with a different number of trucks to see the best possible trucks' availability. Figure 4.33 shows each energy consumption result per TEU for a different number of trucks, which varies between 26 and 36. In the actual port case, there are 31 tracks available, but this figure shows that 28 is the best quantity to keep energy consumption at the lowest possible level. The analysis of the results shows that only adding few trucks to the operations can cause up to 6% extra energy consumption per TEU. There is also room for improvement up to 0.4 % with the changes in trucks. As presented in Figure 5.25, when the truck number decreases from 31 to 28, energy consumption per TEU reaches the optimum level is around 0.00112 toe per TEU. When trucks number decreases beyond 28, the energy consumption of all equipment starts to increase. Table 5.15 shows that this change causes around 0.18 toe saving. The table also shows that there is a possible improvement of 0.8% in CO_2 pollution by decreasing the number of truck availability from 31 to 28. This amount is equal to a 1.35-tonne reduction in CO_2 pollution for four weeks. This helps the port to reduce 17.6 tonnes of CO_2 per year. This amount of pollution is equal to a daily return journey with the Glasgow subway (10.5 km) for 167 years or more than 60 thousand round journeys (Carbon Footprint, 2021). Also, there could be an increase with any possible breakdown or extra unnecessary truck investment, which may cause an increase in energy consumption up to 6% and CO_2 pollution up to 9%, as shown in Figures 5.25 and 5.26. These figures show similar trends for energy consumption and CO_2 emissions. There is a steady increase when the truck numbers change from 28 to 34 then continue with a sharp increase. Also, the results increase in both tables when truck numbers get lower than 28. Table 5.15 illustrates all values in toe and tonne. The main reason behind this change is the port traffic, as operability changes when truck availability changes. These results only show the port side reaction to the availability of trucks. However, the seaside needs to be analysed to see the integration of the system.

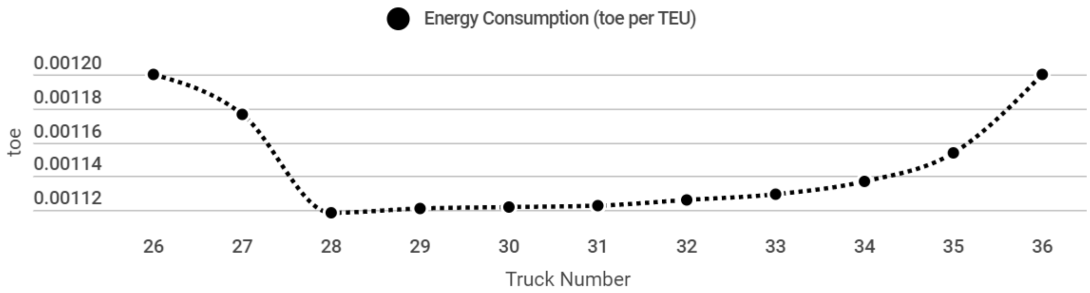


Figure 5.25 Effects of truck numbers utilised on energy consumption (toe) per TEU.

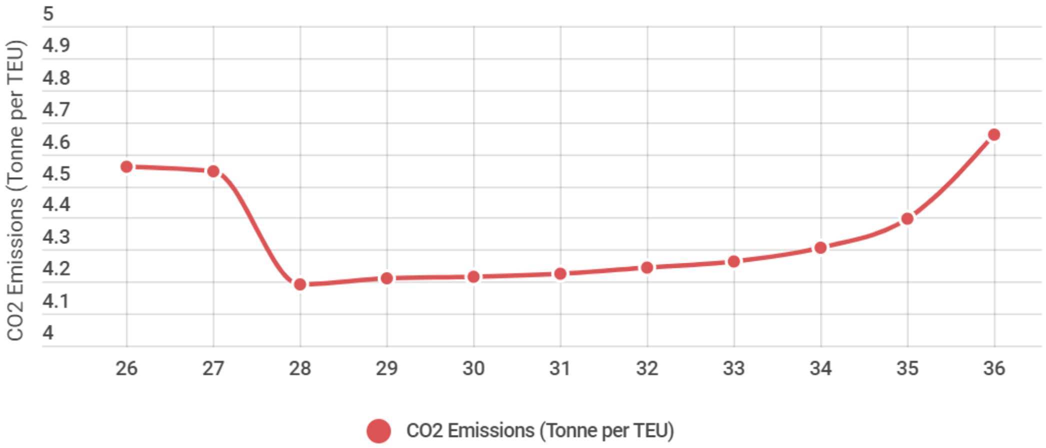
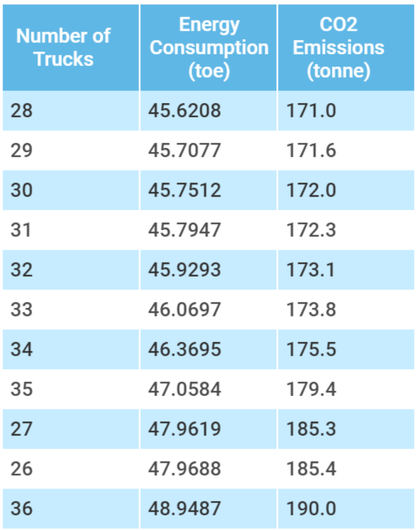


Figure 5.26 Effects of trucks quantity on CO_2 *consumption per TEU.*

Table 5.15 How the number of trucks affects total energy consumption (toe/TEU) and CO_2 *emission.*



Number of Trucks	Energy Consumption (toe)	CO2 Emissions (tonne)
28	45.6208	171.0
29	45.7077	171.6
30	45.7512	172.0
31	45.7947	172.3
32	45.9293	173.1
33	46.0697	173.8
34	46.3695	175.5
35	47.0584	179.4
27	47.9619	185.3
26	47.9688	185.4
36	48.9487	190.0

Table 5.16 Ships visited the port during ARENA simulation.

VESSEL NAME	Ship's Tonnage****	Ship LOA	Main Engine Type	Distance (nm)	Number of hours worked at port
Ship 1	39812	246.44	Low speed engine	1	1.26
Ship 2	66399	281.33	Low speed engine	1	4.72
Ship 3	28397	194.03	Low speed engine	1	3.5
Ship 4	15479	166.45	Low speed engine	1	4.02
Ship 5	9981	138.69	Medium speed engine	1	6.16
Ship 6	75000	298.07	Low speed engine	1	3.26
Ship 7	39941	239.33	Low speed engine	1	1.32
Ship 8	32060	232.18	Low speed engine	1	5.89
Ship 9	15479	168.2	Low speed engine	1	7.65
Ship 10	29181	203.25	Low speed engine	1	6.29
Ship 11	32060	222.45	Low speed engine	1	4.72
Ship 12	25715	173.59	Low speed engine	1	1.48
Ship 13	10000	136.07	Medium speed engine	1	8.55
Ship 14	32060	214.31	Low speed engine	1	5.74
Ship 15	32060	226.64	Low speed engine	1	3.62
Ship 16	39941	253	Low speed engine	1	0.8
Ship 17	71787	288.97	Low speed engine	1	4.66
Ship 18	10925	143.32	Low speed engine	1	3.59
Ship 19	9528	143.1	Medium speed engine	1	0.48
Ship 20	54771	291.26	Low speed engine	1	4.1
Ship 21	27103	176.43	Low speed engine	1	7.71
Ship 22	39812	257.25	Low speed engine	1	5.61
Ship 23	28892	202.93	Low speed engine	1	4.69
Ship 24	10925	151.72	Medium speed engine	1	4.26
Ship 25	53208	294.35	Low speed engine	1	2.26
Ship 26	51700	264.7	Low speed engine	1	4.44
Ship 27	61870	261.92	Low speed engine	1	3.83
Ship 28	64021	287.25	Low speed engine	1	9.95
Ship 29	39812	251.04	Low speed engine	1	3.24
Ship 30	11987	158.44	Low speed engine	1	7.25
Ship 31	81380	292.64	Low speed engine	1	2.42
Ship 32	39941	260.44	Low speed engine	1	1.96
Ship 33	32060	219.46	Low speed engine	1	9.18
Ship 34	25705	234.89	Low speed engine	1	2.97
Ship 35	50963	279.92	Low speed engine	1	5.33
Ship 36	75000	296.77	Low speed engine	1	1.75
Ship 37	9528	147.24	Medium speed engine	1	6.93
Ship 38	39812	253.23	Low speed engine	1	4.03
Ship 39	9068	141.03	Medium speed engine	1	16.06
Ship 40	74661	299.93	Low speed engine	1	8.05
Ship 41	39812	256.48	Low speed engine	1	6.19
Ship 42	66526	295.11	Low speed engine	1	7.58
Ship 43	29181	195.29	Low speed engine	1	12.33
Ship 44	18826	167.45	Low speed engine	1	5.98
Ship 45	32060	233.35	Low speed engine	1	10.22
Ship 46	15479	156.06	Low speed engine	1	0.97
Ship 47	8323	138.23	Medium speed engine	1	5.67
Ship 48	10925	149.24	Medium speed engine	1	7.26
Ship 49	50538	195.82	Low speed engine	1	6.72
Ship 50	51836	272.42	Low speed engine	1	10.32
Ship 51	66399	282	Low speed engine	1	0.47
Ship 52	39812	248.92	Low speed engine	1	2.47
Ship 53	28892	215.93	Low speed engine	1	8.46
Ship 54	54771	295.66	Low speed engine	1	5.31
Ship 55	39941	271.19	Low speed engine	1	5.07
Ship 56	10925	145.31	Medium speed engine	1	5.41

Ship energy consumption is calculated based on the Trozzi and Vaccaro method, which was explained earlier based on ARENA results. Fifty-six ships visited the port during the four weeks of simulation time. Ships that have visited the port is listed in Table 5.16. Their engines and details used in the method to calculate energy consumption are given in the table. Energy consumption and CO_2 release results and their trends are displayed in Figure 5.27. Table 5.17demonstrates energy consumption and CO_2 emission for ship operation in the port area in toe and tonne, respectively. These figures indicate that ships' best energy-efficient operation takes place when the truck numbers are 31 and 323 toe of energy consumed by 56 ships resulting in 1021.5-tonne CO_2 emission.

When the number of trucks increases from 21 to 32, the energy consumption and CO_2 emission increase steadily as well. The same trend is happening when the number of trucks decreases from 31 to 27 with slightly higher energy consumption and CO_2 emission. Monitoring the truck breakdown statistics can create an advantage to arrange the best resource available for the case port. In light of these simulation results, this monitoring can assist in creating a better strategy for overall port energy consumption and CO_2 emission. This result shows that port response to truck number changes is different than the overall integrated response. Therefore, the total CO_2 consumption of port operation and ship operation need to be analysed together to see the integrated energy response of the port in case of truck changes.

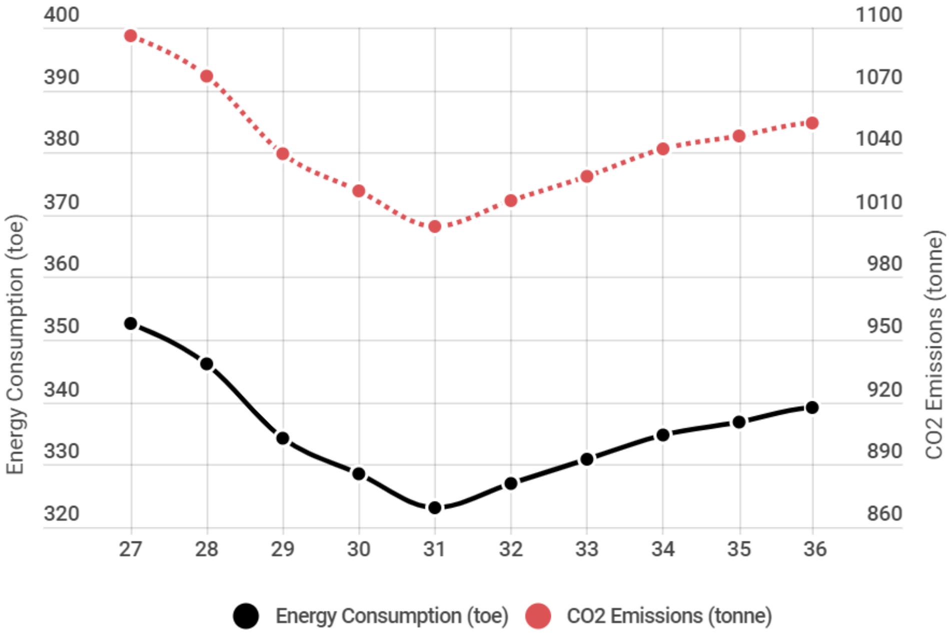
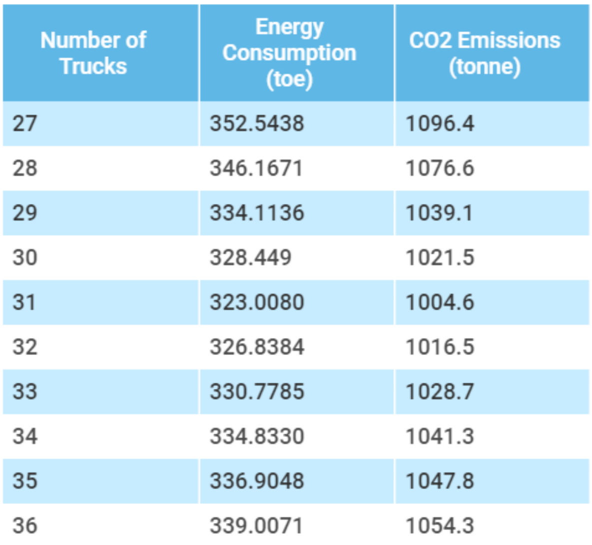


Figure 5.27 Effects of trucks quantity on total energy consumption (toe) of ships while berthing at the port, manoeuvring, and anchoring.

Table 5.17 Total energy consumption (toe/TEU) and CO_2 emission for ship operation in the port area.



Number of Trucks	Energy Consumption (toe)	CO2 Emissions (tonne)
27	352.5438	1096.4
28	346.1671	1076.6
29	334.1136	1039.1
30	328.449	1021.5
31	323.0080	1004.6
32	326.8384	1016.5
33	330.7785	1028.7
34	334.8330	1041.3
35	336.9048	1047.8
36	339.0071	1054.3

Figure 5.28 gives the total energy consumption (toe), and CO_2 figures for integrated operation include port and ship operations. These results are provided in Table 5.18. This overall result shows us that 31 truck is the most energy-efficient operation option for the actual port scenario modelled by ARENA simulation. This number was 28 for only port operation. Therefore, the port can operate 31 trucks effectively without any operational problems to reach maximum energy efficiency. Because when they consider the energy efficiency of the integrated system instead of port energy efficiency, the energy consumption of the whole system increases by 6.17%, and this also resulted in 5.99% increase in CO_2 pollution for the port area. When they choose 31 as an optimum, this results in only 0.38% increase in their total energy consumption and 0.79% increase for their CO_2 pollution for port operation. This figure confirms that the importance of the integrated operation for port and ship operations. Ships and port authorities can do more collaboration and take more initiative to make this integration possible to save energy and reduce the total CO_2 and all other possible harmful pollutants.

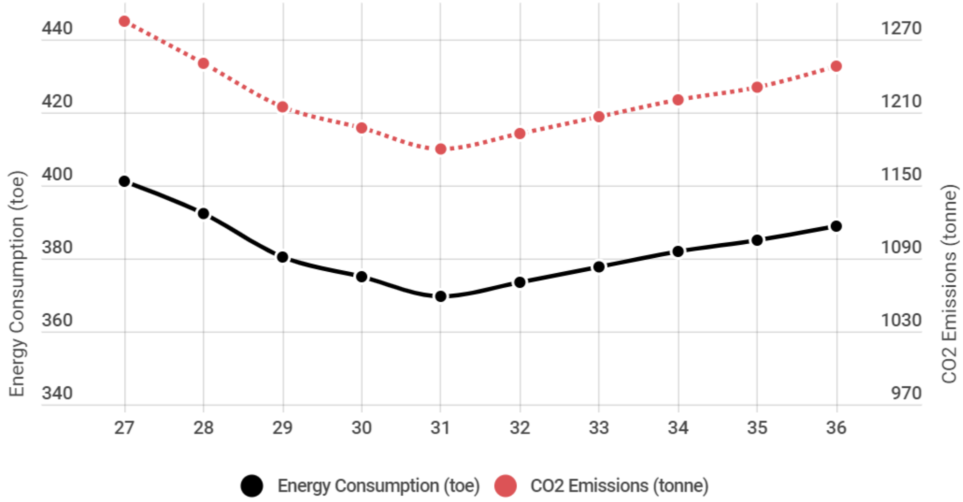


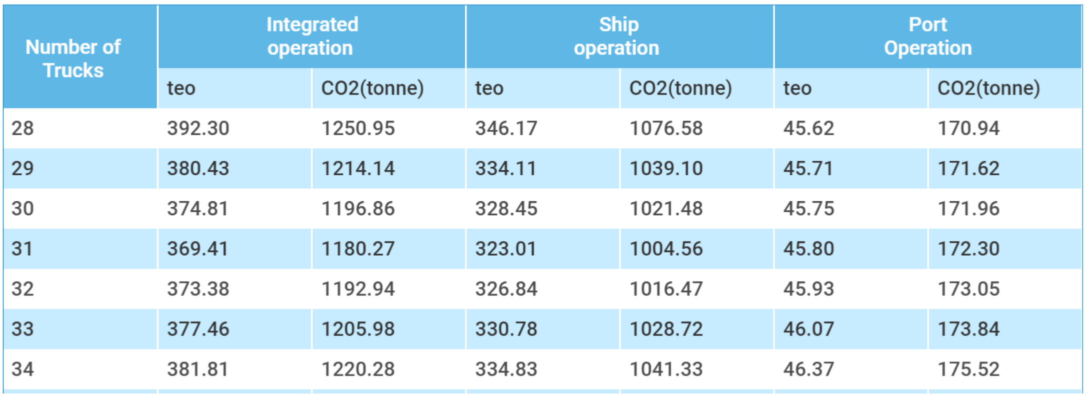
Figure 5.28 Effects of trucks quantity on total energy consumption (toe) for integrated operation include port and ship operations.

Table 5.18 All total consumption comparison (toe/TEU) and CO_2 emission for integrated operation.

Number of Trucks	Energy Consumption (toe)	CO2 Emissions (tonne)	% teo	% CO2
27	401.12	1285.11	8.58	8.88
28	392.4	1250.95	6.22	5.99
29	380.43	1214.14	2.98	2.87
30	374.81	1196.86	1.46	1.41
31	369.41	1180.27	0	0
32	373.38	1192.94	1.07	1.07
33	377.46	1205.98	2.18	2.18
34	381.81	1220.28	3.36	3.39
35	384.58	1230.59	4.1	4.26
36	388.57	1247.75	5.18	5.72

Table 5.19 compares the results for port only, ship only and integrated operations in terms of energy consumption and CO_2 emission. This figure shows a clearer impact of the ship operation on the integrated system. Arena results clearly show that ship operation is the main contributor and has a more significant effect on the integrated system. Moreover, the results also show that a minimal change in the port operation may create a notable impact on the integrated system. Therefore, this integrated approach is vital to understand shipping energy efficiency and pollution.

Table 5.19 Comparison of simulation results for an integrated system, port operation and ship operation (Energy consumption is given in teo, CO_2 emission in tonne).



Number of Trucks	Integrated operation		Ship operation		Port Operation	
	teo	CO2(tonne)	teo	CO2(tonne)	teo	CO2(tonne)
28	392.30	1250.95	346.17	1076.58	45.62	170.94
29	380.43	1214.14	334.11	1039.10	45.71	171.62
30	374.81	1196.86	328.45	1021.48	45.75	171.96
31	369.41	1180.27	323.01	1004.56	45.80	172.30
32	373.38	1192.94	326.84	1016.47	45.93	173.05
33	377.46	1205.98	330.78	1028.72	46.07	173.84
34	381.81	1220.28	334.83	1041.33	46.37	175.52

5.3 Chapter Summary

This chapter presents the results of the two applications and findings, providing a general discussion on findings for each case from BBN and ARENA. BBN focused on more comprehensive ship port integration, and ARENA analysed more micro-sized parts of this complex integrated port-ship system. These results highlight the novelties and contributions made by this research. The author is aware that the model has some assumptions and limitations that originated from a lack of data and impracticability of modelling some specific effects on energy and CO_2 calculation for energy-efficient shipping. The author believes that the ideal BBN and ARENA model should have applications for each kind of ship, cargo, voyage condition, and port terminals. Their results can be used to set different cases, which may allow much faster implementation. This method can be combined with tools like Artificial Intelligence or big data analysis. Since there are very few accessible data for some part of the BBN model, the model developed based on primary sources like a port statistic from real recorded cases and secondary sources for each case application provide a significant contribution to the field. Future work will concentrate on turning the developed model into a BBN model, and its direct integration with the ARENA simulation tool.

CHAPTER 6: DISCUSSION

6.1 Chapter Overview

This chapter provides general discussions about the research conducted in this thesis. First, achieved research aims and objectives were presented in Section 5.2 by explaining each specific objective given in Section 1.4 in Chapter 1. Following that, novelties and contributions to the literature in this PhD are provided in Section 5.3. Finally, a general discussion and primary results are presented in Section 5.4.

6.2 Discussion

The objectives listed in Chapter 1 were described as follows:

- *To review the existing literature on the energy efficiency of shipping, regulations, and measurements of energy efficiency within integrated ship port operation and understanding suitable methodologies include BBN and ARENA, to analyse this integrated system*
- *To investigate and show the usability of energy efficiency within the integrated ship and port operations*
- *Identification of useful solutions and development of a framework to increase the energy efficiency as a whole system by achieving better interoperability of ship and port services through the application of BBN modelling*

The ‘Critical Literature Review’ in Chapter 2 achieved this aim by providing an extensive literature review on the focused research topics and questions in this thesis. Reviewed topics are listed as; energy efficiency role in climate change, energy efficiency regulations, critical characteristics of integrated shipping, energy efficiency measurements in maritime transportation, and simulation-based energy efficiency applications include ARENA and BBN. The gaps in the literature focussing on the integrated energy efficiency of shipping were also identified. A framework was developed and presented in Chapter 3. This model created practical solutions to increase the energy efficiency of ports by achieving better interoperability and produced simulation results of ship and port services by applying BBN modelling and ARENA simulation.

The following objectives were achieved in Chapter 3 and Chapter 4:

- *To capture the real container port operations, including interaction with ships and practical challenges faced by conducting field trips, interviews with port operators and collecting real port operation data where possible.*
- *Application of Bayesian Beliefs Network modelling to identify the integrated system nodes to a better understanding of port and shipping fleet operation integration.*
- *Performing simulations to understand and optimise ship and port operation integration based on the know-how from the developed BBN applications. This will be performed using ARENA software with the aim of improving energy efficiency and our understanding of port and ship integration based on energy efficiency.*
- *In this research, two different developed methods with BBN and DES will be applied to ship port interface systems to analyse energy efficiency via a case study shipping route and a case study port.*

This research introduced a methodological framework to demonstrate the influence of integrated ship-port operations regarding ship energy efficiency. Chapter 3 and 4 identified the integrated system nodes for the BBN model to better understand the importance of the integration. The methodology detailed in Chapter 3 in line with BBN on the ship–port interface by utilising the interdependencies among port and ship operations in terms of ship's energy consumption and CO_2 emissions. Therefore, by establishing an inter-operability link between ship voyage and port operation aspects, a more holistic and integrated operational energy efficiency performance measure is generated. BBN steps introduced by Cao, Coutts and Lui (2013) and Smith, Madsen, and Barton (2015) adapted and advanced to apply port and ship integration. Results show that this application produces a valuable contribution to this research field.

Moreover, the ARENA simulation was presented in Chapter 3, and applied in Chapter 4 to analyse a real case study for an actual container port. The results in Chapter 5 proved that ARENA software is capable of understanding and improving the energy efficiency of port and ship as an integrated system. Chapter 5 results present that DES is a powerful tool to analyse such small changes within the port and ship integration, as mentioned in the literature review by Kelton, Sadwoski, and Sadwoski, (2007). Results also confirm that Arena software is an advanced tool that is applicable for a complex system which is highlighted by Arena (2021), Arena (2010), Cosgrove (2008) and Dragović et al. (2017). The outcomes indicate that it would be possible to increase the integrated system's energy efficiency by combining the influences of port and ship operation performances and their operational elements detailed in Chapter 5.

6.3 Novelties and Contributions to the Field

The main novelties achieved within this PhD study are given as follows:

- BBN Model: To the best of this author's understanding, this work is novel since there is no other implementation in this literature. This is most certainly due to the application's perception of the modelling is complicated and intractable. On the other hand, this PhD study takes a more practical approach, demonstrating that satisfactory calculations about energy consumption and CO_2 pollution for ships and port operations can be made.

This was achieved by establishing an interoperability framework of systems by applying BBN methodology on ship–port interface regarding the energy consumption and CO_2 emissions. Also, identification and development of parent-child hierarchy relationships of the nodes are carried out.

This methodological improvement will provide several advantages for end-users to understand their efficiency performance, energy consumption and CO_2 emissions. These advantages, which were reported in Canbulat et al. (2019) research articles published in Maritime Policy Management, are provided below:

- Capability to identify the ship and port operations' energy efficiency interdependencies.
- A better understanding of the factors that influence ship speed arrangement and route preparation in a more comprehensive manner, considering both ship and port performance parameters.
- Assessing a ship's energy efficiency while on a liner service, a time charter on a single voyage, or a consecutive voyage charter between two harbours
- Ability to pinpoint where to optimise the node output depending on multiple situations in order to produce the best results.

Systematic investigation of the ARENA literature and operational activities to develop an integrated simulation to analyse energy consumption and CO_2 pollution contributes to the following points in this field:

- To the best of this author's knowledge, this is the first study, which systematically investigates and quantifies energy consumption and CO_2 pollution within a holistic approach. There were twenty-one configurations of simulations for three-based cases, ports, ships, and their integration. Then, energy consumption and CO_2 emissions are analysed to see the best possible output. Results showed that an integrated system could be analysed successfully. This may help end-users estimate the effect of each operational change on energy consumption to develop appropriate energy consumption targets and policies for specific cases. One of the DES cases in this study shows an integrated system can improve around 6 % energy consumption and CO_2 release in the port area. Another case study with BBN showed that ship operation could impact total energy efficiency more than port operation.
- Such a model may also assist the port operators in selecting the best possible operation, which improves the ship and port energy efficiency and contributes to the environment by reducing CO_2 release.

Other major contributions to the field within this PhD study is provided below:

- Knowhow from the BBN model used to build DES models, which explained in Chapter 3. This is another contribution to improve the synthesis of two different methods to advance our understanding of port and ship operation based on energy efficiency.

6.4 General Discussion

This thesis can be separated into three main sections: literature review, building BBN and DES modelling and applying models into case studies within this PhD.

As explained in detail in Chapter 2, a comprehensive literature review has been carried out. Literature showed the research need, potential and research gaps in this field. Moreover, this available literature contributed to the development of the method and models presented in Chapter 3. There are not any publicly available tools to analyse the energy efficiency of ship and port integration. Very few private companies are working or already have like Maersk have customised tools, but there is no sufficient information available. However, there is no sign that these companies use BBN or ARENA based methods. When the author visited the case port, he realised that the case port only keeps energy consumption of the equipment and infrastructure to monitor. However, they do not have any records about ship side. Available policies and research in the literature show a growing interest during the last decade for ports and ships operation but develop strategies in isolation with regards to energy efficiency.

In chapter 3, the application of the BBN has presented four essential steps, which are highly simplified to apply for shipping operation. This gives a chance to all stakeholders in commercial shipping to use interoperability/dependability analysis to make marine transport more efficient. The development of advanced computer-based technologies and big data technologies can make this method more applicable by producing solution availability of limited data mentioned in Chapter 3, Chapter 4 and Chapter 5. The BBN results provide the probabilistic relationship between all parts of the operation as presented in Chapter 4. After a case study application, the review of various scenarios shows that different parts of the integrated system affect the entire shipping operation differently. Results show that the system's overall energy efficiency can be improved when the end-user utilises interoperability/dependability analysis results.

Moreover, a DES modelling methodology was created to explore how ports and ships can collaborate to reduce energy consumption and increase operational efficiency. Details of models are given in chapter 3, and the model application on a case study was carried out on container ships and ports in Chapter 5. The results showed the tool is effective to analyse the integrated system. However, there is a need for extensive and commercially sensitive data to run the model for more significant cases and integrations. This combination of BBN and DES models helps to formulate this PhD methodology, as it provides a comprehensive tool to analyse the research questions laid out in this study.

In Chapter 4 and 5, it was shown that Using BBN modelling to identify the integrated system's nodes help understand the interoperability of port and vessel activities. Further analyses with ARENA showed that the interdependency framework of BBN contributes to building DES modelling to improve overall energy quality in the maritime transportation sector. The final results of the case studies would help in enhancing the resource efficiency of the integrated system between port and fleet management, as well as reducing the energy usage of the integrated marine transportation system through the use of such a technique presented in this research.

The ARENA results within the second case study showed that the integrated system could impact the overall and individual energy efficiency of the port and ship operations, which are provided in Chapter 5. One of the case studies demonstrates that taking the energy efficiency of the integrated system instead of port or ship energy efficiency allows for a 6.17% improvement in energy consumption, and a 5.99% reduction of CO_2 pollution in the port area. There is no doubt; there is room to improve both energy and CO_2 performance of that integrated port-ship operations to address the environmental problems highlighted in the literature review. Moreover, this application may encourage policymakers to support their shared goals of carbon-free shipping by reducing energy consumption. When the CO_2 problem is solved in the future; we still need to reduce the total energy consumption of shipping to make it more economical and sustainable. Therefore, this study may contribute to shipping to gain further benefits.

6.5 Chapter Summary

This chapter summarises the research goals and objectives obtained, as well as a general discussion of the limitations, assumptions, and challenges encountered during the PhD review. New concepts and contributions were also clearly highlighted.

CHAPTER 7: CONCLUSIONS & FUTURE RECOMMENDATIONS

7.1 Chapter Overview

This chapter outlines the conclusions of the studies conducted during this PhD, together with future research recommendations, which can be taken as further possible research opportunities.

7.2 Conclusions

The literature review in this research showed that there are many efforts to tackle environmental challenges in the shipping sector. However, a more concerted effort is needed to solve global warming, which is getting worse with the growing energy needs from the transport sector. Therefore, this PhD study reviewed all existing relevant studies on the energy efficiency of shipping, regulations, and energy efficiency measurements within an integrated ship-port operation and proposed suitable methodologies, including BBN and ARENA, to analyse this integrated system. After the literature review investigation, a practical model is presented as a solution, which is built on BBN and ARENA to increase the energy efficiency as a whole system.

This study developed a methodology to show how integrated ship-port operations affect ship energy efficiency. This research studied the interdependencies between port and ship operations regarding ship energy consumption and CO_2 emissions and performed simulations to quantify the interdependencies. The proposed method utilised BBN and DES on the ship–port interface. As a result of creating an interoperability connection between ship voyage and port activity aspects, a more comprehensive and integrated way of measuring operational energy efficiency performance is developed.

This model created practical solutions to improve the overall energy efficiency of the integrated ports and ship operations by achieving better interoperability through the utilisation of BBN modelling and ARENA simulations. This novel approach was implemented to perform simulations to understand and optimise ship and port operation integration based on the developed BBN applications' know-how. This was achieved by using ARENA software to improve our understanding of port and ship integration and to improve the energy efficiency of the whole system.

As an outcome of the DES simulation application, the developed tool analysed more micro-sized parts of this complex integrated port-ship system. Through the simulation-based optimisation, at least 6% improvement in energy consumption was achieved for a case study application because of the integrated approach. Results indicated a higher impact on the ship operation part of the integrated system. Arena results clearly show that ship operation is the main contributor and has a more significant effect on the integrated system. Moreover, the findings also show that a minimal change in the port operation may create a notable impact on the integrated system. Therefore, this integrated approach is vital to understand shipping energy efficiency and pollution.

The analysis indicates that the model can be used as a decision support tool for the shipping industry. Simulation has the flexibility to analyse any ships and ports, which can benefit from such simulation-based analyses. User can understand how much improvement they need to make to achieve target energy efficiency through the integrated operation for each operation parts mentioned in the BBN application in Chapter 4. Users can also reach their final energy and CO_2 figures per containers or the total amount of energy consumption or CO_2 emission for a time span by using DES applications. This method also gives them a chance to analyse possible outcomes under different assumptions. For example, when a freight owner knows their ships and port options to carry their cargos, they can explore which port and ship combinations can have more likelihood to have better energy efficiency by applying the BBN tool.

On the other hand, port and shipping companies can benefit by applying the ARENA tool to improve their operations and equipment to reach the best energy-efficient port and ship operation for any single changes in their operation or equipment quantity. However, there is a fact underlined in this research that the model has some assumptions and limitations, which were originated from a lack of data and the modelling impracticability of some specific effects with regards to energy and

CO_2 calculation for energy-efficient shipping. These assumptions were made mainly due to the lack of data which can be easily solved when companies want to benefit and insert this model into their system to analyse while utilising their in-house data.

7.3 Recommendations for Future Research

Each type of ship, cargo, voyage condition, and port terminal should be supported by the ideal BBN and DES model. Their findings can be used to create various scenarios, potentially allowing for much quicker implementation and the high realisation of the maximum potential benefits. This approach can be used in combination with Artificial Intelligence (AI) or in-depth data analysis. Since some parts of the BBN model have limited data, the model produced using primary sources such as a port statistic from actual reported cases and secondary sources for each case application contributes to the field. Future work can focus on converting the built model into a BBN model and integrating it with the DES directly without manual entry.

While the models applied, all other contractual information and shipping environments are considered the same as the case condition. However, the complex logistic chain has more variables for each operational change. Therefore, it can be better to combine this method with contract terms to analyse the response of the system more comprehensively to reduce potential delays to create a better energy-efficient system. Thanks to BBN and DES, both have the flexibility to develop that system further.

It should be noted that the model was developed assuming there is no operational failure from ship and port equipment during all case studies, but conditions of mechanical equipment and their operability is dynamic and changes every second. Therefore, these changes can create an impact on these simulation results, but this can also be modelled to see the effect on the overall operations of the integrated port, including measures for potential redundancies. Although this is a reasonable assumption, it might be beneficial to consider in future applications to predict better results and do better planning.

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APPENDIX

Appendix 1: Calculation of Energy Efficiency Operational Indicator (EEOI) Based on Operational Data

1. General IMO Calculation

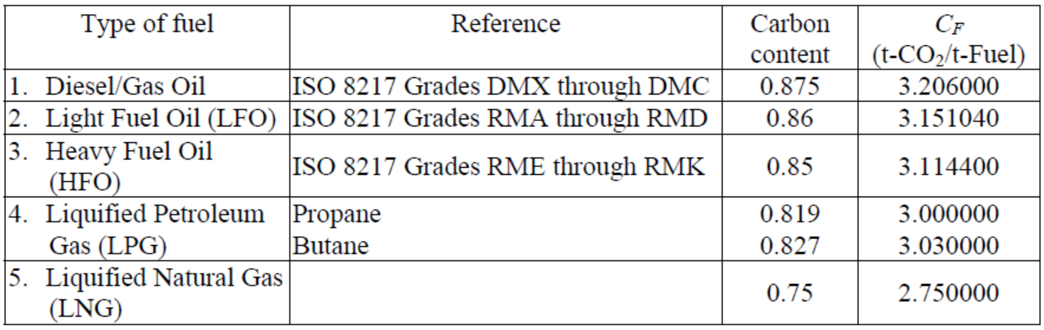
The Appendix aims to provide instructions on calculating the Energy Efficiency Operational Indicator (EEOI) using data from the ship's operations (IMO, 2009). The following information is presented in IMO (2009).

2. Data sources

The ship's logbook may be one of the primary data sources chosen (bridge logbook, engine logbook, deck logbook and other official data).

3. Fuel mass to CO_2 mass conversion factors (C_F)

C_F is a non-dimensional conversion factor between gallons of gasoline consumed and gallons of CO2 emitted based on carbon content. The following is the quality of C_F:



Type of fuel	Reference	Carbon content	C_F (t-CO_2/t-Fuel)
1. Diesel/Gas Oil	ISO 8217 Grades DMX through DMC	0.875	3.206000
2. Light Fuel Oil (LFO)	ISO 8217 Grades RMA through RMD	0.86	3.151040
3. Heavy Fuel Oil (HFO)	ISO 8217 Grades RME through RMK	0.85	3.114400
4. Liquified Petroleum Gas (LPG)	Propane Butane	0.819 0.827	3.000000 3.030000
5. Liquified Natural Gas (LNG)		0.75	2.750000

4. Indicator definition

Fuel consumption

Fuel consumption, or C_F, is characterised as all energy required by main and auxiliary engines, like boilers and incinerators, at sea and in port, or for a journey or time in question, e.g., per day.

Distance sailed.

For the voyage or time in question, "distance sailed" refers to the actual distance sailed in nautical miles (deck log-book data).

Ship and cargo types

The Regulations apply to all ships that do transport work.

1. Ships:

- dry cargo carriers
- tankers
- gas tankers
- container vessels
- ro-ro cargo vessels and ro-ro passenger vessels
- general cargo vessels
- cruise vessels

2. Cargo:

Including gas, liquid, and solid bulk cargo, general cargo, containerized cargo (including empty unit returns), break bulk, heavy lifts, frozen and chilled merchandise, timber and forest products, cargo transported on freight vehicles, cars and freight vehicles on ro-ro ferries, and passengers are all examples of cargo (for passenger and ro-ro passenger vessels).

5. Calculation of EEOI

For a flight, the simple expression for EEOI is as follows:

$$\text{EEOI} = \frac{\sum_{j} FC_j \times C_{Fj}}{m_{cargo} \times D} \tag{Equation 1}$$

When the indicator is multiplied over a time or a range of voyages, the indicator is measured as:

$$\text{Average EEOI} = \frac{\sum_{i}\sum_{j} (FC_{ij} \times C_{Fj})}{\sum_{i} (m_{cargo,i} \times D_i)} \tag{Equation 2}$$

Where:

- j is the fuel type;
- i is the voyage number;

- FC_{ij} is the mass of used fuel *j* at voyage *i*;
- CF_i is the fuel mass to CO_2 mass conversion element for fuel *j*;
- m_{cargo} is cargo carried (tonnes) or work completed (number of TEU or passengers) or gross tonnes for passenger vessels; and
- *D is the nautical mile distance referring to the freight or activities that are carried out.*

The EEOI unit is determined by the amount of cargo transported or work completed, such as tons. CO_2/ (tons• nautical miles), CO_2/ (TEU • nautical miles), CO_2/ (person • nautical miles), and so forth. It is worth noting that Equation 2 does not provide an average of EEOI over the amount of voyages i.

6. Rolling average

When using a rolling average, choose an appropriate period, such as the year nearest to the end of a voyage for that year or the number of journeys, such as nine or twelve, that are statistically relevant to the original averaging period. Equation 2 above is then used to measure the Rolling Average EEOI for this time or number of voyages.

7. Data

Data on fuel consumption, cargo transported, and distance travelled in a regular sailing pattern must be obtained for a voyage or duration, such as a day. For further details can be gained from IMO (2009).

Appendix 2: KPI Index

Table A2.1 KPI Index (KPI, 2017; KPI, 2020)

The Shipping Performance Index (SPI)	**Key Performance Indicators (KPI)**	**Performance Indicator (PI)**
SPI001: Environmental Performance	KPI001: Ballast water management violations	PI001: Actual dry-docking costs
SPI002: Health and Safety Performance	KPI002: Budget performance	PI002: Actual dry-docking duration
SPI003: HR Management Performance	KPI003: Cadets per ship	PI003: Actual unavailability
SPI004: Navigational Safety Performance	KPI004: Cargo related incidents	PI004: Agreed dry-docking costs
SPI005: Operational Performance	KPI005: CO_2 efficiency	PI005: Agreed dry-docking duration
SPI006: Security Performance	KPI006: Condition of class	PI006: Average number of officers employed
SPI007: Technical Performance	KPI007: Contained spills	PI007: Emitted mass of CO_2
SPI008: Other	KPI008: Crew disciplinary frequency	PI008: Emitted mass of NOx
	KPI009: Crew planning	PI009: Emitted mass of SOx
	KPI010: Dry-docking planning performance	PI010: Last year's AAE (Additional Authorized Expenses)
	KPI011: Environmental deficiencies	PI011: Last year's actual running costs and accruals
	KPI012: Failure of critical equipment and systems	PI012: Last year's running cost budget
	KPI013: Fire and Explosions	PI013: Number of absconded crew
	KPI014: Port state control performance	PI014: Number of allusions
	KPI015: Health and Safety deficiencies	PI015: Number of ballast water management violations
	KPI016: HR deficiencies	PI016: Number of beneficial officer terminations
	KPI017: Lost Time Injury Frequency	PI017: Number of cadets under training with the ship manager
	KPI018: Lost Time Sickness Frequency	PI018: Number of cargo related incidents
	KPI019: Navigational deficiencies	PI019: Number of crew sick for more than 24 hours
	KPI020: Navigational incidents	PI020: Number of cases where drugs or alcohol is abused
	KPI021: NOx efficiency	PI021: Number of charges of criminal offences
	KPI022: Officer retention rate	PI022: Number of collisions
	KPI023: Officers experience rate	PI023: Number of conditions of class
	KPI024: Operational deficiencies	PI024: Number of contained spills of bulk liquid
	KPI025: Passenger injury ratio	PI025: Number of crew not relieved on time
	KPI026: Port state control deficiency ratio	PI026: Number of dismissed crew
	KPI027: Port state control detention	PI027: Number of environmental related deficiencies
	KPI028: Releases of substances	PI028: Number of explosion incidents
	KPI029: Security deficiencies	PI029: Number of failures of critical equipment and systems
	KPI030: SOx efficiency	PI030: Number of fatalities due to injuries
	KPI031: Training days per officer	PI031: Number of fatalities due to sickness
	KPI032: Ship availability	PI032: Number of fire incidents
	KPI033: Vetting deficiencies	PI033: Number of groundings
		PI034: Number of health and safety related deficiencies
		PI035: Number of HR related deficiencies

		PI036: Number of logged warnings PI037: Number of lost workday cases PI038: Number of navigational related deficiencies PI039: Number of officer days onboard all ships PI040: Number of officer experience points PI041: Number of officer terminations from whatever cause PI042: Number of officer trainee man days PI043: Number of officers onboard PI044: Number of operational related deficiencies PI045: Number of passengers injured PI046: Number of permanent partial disabilities PI047: Number of permanent total disabilities (PTD) PI048: Number of PSC deficiencies PI049: Number of PSC inspections PI050: Number of PSC inspections resulting in a detention PI051: Number of PSC inspections resulting in zero deficiencies PI052: Number of recorded external inspections PI053: Number of releases of substances to the environment PI054: Number of security related deficiencies PI055: Number of severe spills of bulk liquid PI056: Number of unavoidable officer terminations PI057: Number of ships under technical management (DOC) PI058: Number of vetting deficiencies PI059: Number of vetting inspections PI060: Number of violations of rest hours PI061: Passenger exposure hours PI062: Planned unavailability PI063: Total exposure hours PI064: Transport work

Appendix 3: Details of Reviewed Publications

Table A3. 1 Details of reviewed publications – Organized based on application areas and subareas shown Figure 2.18.

No	Application areas and subareas	Authors	Year	PT	Publisher	Case Port	Country	Key Words
1	Intermodal	Roop & Koster	1988	TR	University of Texas at Austin	Port of Houston	USA	Simulation, Intermodal Container Movements, Intermodal Facility Design
2	Intermodal	Kozan	2006	J	Transp Plan Technol	Accacia Ridge, Brisbane	Australi	Intermodal container terminal, rail transportation, delays, simulation, Australia
3	Intermodal	Boschian et al	2011	J	IEEE Transac on Autom Scie and Engine	Port of Trieste	Italy	Management, modeling, simulation, transportation
4	Intermodal	Franklin et al.	2014	C	2014 Winter Simulation C	Multi Ports	USA	-
5	Intermodal	Zehendner & Feillet	2014	J	Eur J Oper Res	Grand Port Maritime de Marseille	France	Container terminal, Intermodal transportation, Resource allocation, Straddle carrier, Truck appointment system
6	Intermodal	Wall et al.	2015	J	Simulation	Port of Savannah	USA	Federation, simulation, transportation, port, Arena, VISSIM, HLA
7	Multimodal	Gbologah	2010	T	Georgia Institute of Technology	Port of Savannah	USA	-
8	Multimodal	Kotachi et al	2013	J	J of Procedia Computer Science	-	USA	Port Simulation, Complex Multimodal Transportation, Container Terminal, Arena Simulation
9	Liner Shipping	McLean & Biles	2008	C	2008 Winter Simulation Conference	Multi Ports	USA	costing, discrete event simulation, ships, ransportation
10	Automated	Vis and Harika	2004		OR Spectrum	-	Nether-lands	Container logistics Simulation AGVs and ALVs
11	Automated	Park et al.	2007	C	WSEAS Intl C on Computer Engine & Appl	-	Korea	simulation, transportation equipment, analysis of performance, automated container terminal
12	Transfer and storage equipment	Huynh et al.	2004	J	Transp Res Rec	Port of Houston	USA	-
13	Transfer and storage equipment	Huynh & Walton	2007	J	World Review of Int Transp Research	Port of Houston	USA	Discrete event simulation, Arena, marine container terminals, truck turn time, container ports, yard cranes, crane deployment
14	Transfer and storage equipment	Huynh & Walton	2008	J	J Transp Eng	Port -Houston Barbours cut CT	USA	Trucks; Optimization; Simulation; Containers; Freight transportation; Scheduling.

15	Transfer and storage equipment	Puglisi	2008	T	MSc-Georgia Institute of Technology	Port of Savannah	USA	-
16	Transfer and storage equipment	Park et al.	2009	J	J Mech Eng	Korean CT	Korea	Container terminals, container transport, operational management, simulation, information technology
17	Transfer and storage equipment	Legato et al.	2009	J	Marit Econ Logist	Gioia Tauro	Italy	Maritime container terminal logistics yard operations discrete-event simulation combinatorial optimisation ranking and selection
18	Transfer and storage equipment	Esmer et al.	2010	J	Asian J Shipp Logist	Turkish ports	Turkey	Green port, Lean port, Supply chain, Simulation, Turkish ports
19	Transfer and storage equipment	Jaoua et al.	2012	J	Simul Model Pract Theory	-	Canada	Container terminal, Surface mine, Congestion,Simulation model, Fleet management
20	Transfer and storage equipment	Sheikholes-lami et al.	2013	J	J Basic and Applied Scientific Res	Rajaee Port	Iran	Simulation model, container terminal, greedy berth allocation, quay crane assignment
21	Transfer and storage equipment	Dinu et al	2017	J	Procedia Manufacturing	-	Romania	Port efficiency, handling strategy, productivity control, simulation
22	Storage policies	Guldogan	2010	J	Simulation	Port of Izmir	Turkey	Marine applications, scheduling, transportation and traffic
23	Cargo Inspections	Salehi & Wang	2013	J	Transportation Research Record	Port of Houston	USA	-
24	Emergency evacuation	Qu et al.	2012	J	J Homeland Security & EmergManag	-	USA	Emergency evacuation; hurricanes; simulation; homeland security
25	Performance evaluation	Tahar & Hussain	2000	J	Logist Inf Manag	Kelang	UK	-
26	Performance evaluation	Ng	2001	T	MSc-Universiti Utara Malaysia	Kelang Multi Terminal Westport	Malaysia	-
27	Performance evaluation	Park et al.	2004	J	J Navigation and Port Research	Pusan-East Container-Trm	Korea	Simulation, Handling, Productivity, Container, Terminal
28	Performance evaluation	Kulak et al.	2008	J	OR Spectrum	Haydarpasa	Turkey	Simulation, performance evaluation, container termina
29	Performance evaluation	Park & Dragovic	2009	J	J Mech Eng	Korean CTs	Korea	Container terminals, container transport, operational management, simulation, information technology
30	Performance evaluation	Na and Shinozuka	2009	J	Reliab Eng Syst Saf	-	USA	Seaport, Simulation, Seismic loss, Container throughput, Revenue,Fragility curves,System analysis,Risk assessment
31	Performance evaluation	Vis & van Anholt	2010	J	OR Spectrum	Amsterdam CT	Nether-lands	Container terminals, Indented berth, Performance analysis, Design Simulation

32	Performance evaluation	Wanke	2011	J	Int J Shipp Transp Logist	Rio de Janeiro (multi-Rio CT)	Brazil	ship-berth link, SBL, simulation, queue priority, berth allocation, demurrage costs, multivariate analysis of variance, MANOVA
33	Performance evaluation	Tan	2001	T	MSc-Universiti Utara Malaysia	Westport	Malaysia	Simulation, Modeling, Performance, Container Terminal Operation, Westport
34	Performance evaluation	Esmer et al.	2013	J	Int J Logist Res Appl	Alsancak CT, Izmir	Turkey	simulation, continuous berth allocation, container terminal, container ships
35	Performance evaluation	Kotachi & Rabadi	2014	C	American Society for Engine Manag	-	USA	Port Simulation, Container Terminal, Arena Simulation, Quay Crane Simulation.
36	Performance evaluation	Lin et al.	2014	J	Simul Model Pract Theory	Humen Port	China	Container terminal, Port investment, Simulation
37	Performance evaluation	Nicoletti et al.	2014	J	Int J Simul Process Model	A medium size CT of the Mediter. area	Spain	Container terminals; modelling and simulation; decision-making; performances evaluation
38	Performance evaluation	Taner et al.	2014	J	Comput Ind Eng	Various layout of artificial CTs	Turkey	Logistics, Container terminals,Simulation, Allocation strategies
39	Performance evaluation	Ursavas	2014	J	Decis Support Syst	Izmir	Netherlands	Quayside operations, Berth allocation, Crane scheduling, Container terminal oper.
40	Performance evaluation	Ward	2014	J	MSc-Islamic University – Gaza	Port of Gaza	Palestine	-
41	Performance evaluation	Aydogdu & Aksoy	2015	J	Marit Policy Manag	Turkish port	Turkey	-
42	Performance evaluation	Labib	2015	T	MSc-Al Akhawayn University	Port of Safi	Morocco	Bulk port; Quay productivity; KPIs; Dashboards; Competitiveness
43	Performance evaluation	Kotachi et al	2016	C	2016 Winter Simulation C	Hamad’s new port of Qatar	USA	-
44	Performance evaluation	Rusca et al.	2018	J	Transport Problems	Port of Constanta	Romania	Container terminal, Simulation model, Maritime transport
45	Performance evaluation	Nasution & Arviansyah	2019	C	IOP C Seri: Materials Science and Engine	Terminal 3 Port of Tanjung Priok	Indonesia	-
46	Performance evaluation	Sislioglu et al.	2019	J	Maritime Policy & Management	Container Terminal Alpha (CT-A)	Turkey	Operation management, container terminal, terminal productivity, investment analysis, simulation
47	Logistics planning	Merkuryev et al.	1998	J	Simulation	Riga Harbour CT	Latvia	Harbour, maritime, Riga harbour, container terminal, logistics processes, discrete-event modelling, and discrete-event simulation
48	Logistics planning	Merkuryeva et al	2000	J	Stud Inform Control	Baltic CT	Montenegro	Container terminal, Simulation, CT throughput, Performance evall, Korean CT
49	Logistics planning	Lee et al.	2003	J	Maritime Policy & Management	PECT	Korea	-
50	Logistics planning	Biles et al.	2004	C	2004 Winter Simulation C	Multi Ports	USA	-
51	Logistics planning	Cortes et al.	2007	J	Simul Model Pract Theory	Port of Seville	Spain	Logistics, Freight traffic, Simulation
52	Logistics planning	Aneichyk	2009	T	MSc - Molde University College	-	Norway	-

53	Logistics planning	Guiliang & Lina	2009	WS	WS on Database Technology & App		China	Container freight station, intelligent module, simulation, optimization
54	Logistics planning	Yun et al.	2011	J	Int. J. Production Economics		Korea	Empty containers, Inventory level, inventory policy, Arena, OptQuest®
55	Logistics planning	Kulak et al.	2013	J	Flex Serv Manuf J	Istanbul	Turkey	Simulation, Performance evaluation, Seaport container terminal, Maritime trans
56	Logistics planning	Ursavas	2015	J	Ann Oper Res	Izmir	Netherl-ands	Port management, Simulation optimization, Berth allocation, Container terminal operations
57	Logistics planning	Rusca et al.	2016	C	C Series: Materials Science and Eng.	-	Romania	-
58	Logistics planning	Budipriyanto	2017	J	The Asian J of Shipping & Logis.	Tanjung Priok Port	Indonesia	Berth Allocation Problem, Uncertainty, Collaboration
59	Logistics planning	Li et al.	2017	C	Modelling and Simulation	CHINESE CONTAINER TERMINALS	China	Container Terminal, Throughput Capacity, Port Service Level, Simulation and Modeling.
60	Logistics planning	Meng et al.	2017	J	Transportation research procedia	Hong Kong port	Singa-pore	Simulation, Container Terminal, Queuing Network, Ship Size
61	Logistics planning	Rekik et al.	2018	J	Advanced Engineering Informatics	King Abdul-Aziz Seaport	Tunisia	CBR based heuristic, Knowledge representation, Container stacking, Container terminal, Dangerous goods
62	Risks and Security	Cavallaro	2007	T	MSc-Air Force Institute of Tech.	-	USA	-
63	Risks and Security	Pidgeon	2008	T	MSc-Air Force Institute of Tech.	Multi Ports	USA	-
64	Risks and Security	Rusca et al.	2015	C	IMAM	-	Romania	-
65	Risks and Security	Green	2019	T	MSc-Air Force Institute of Tech.	Multi Ports	USA	-
66	Economic Analysis	Na, Chaudhuri & Shinozuka	2007	C	C on Urban Disaster Reduction	-	USA	Seaport, earthquake, revenue loss, simulation, port operation, HAZUS
67	Economic Analysis	Moon et al.	2018	C	Adv in Production Manag Syst	Busan Port	Korea	Simulation, Container, Transshipment, Network design
68	Comparison of AM & SM	Vis et al	2005	J	Transp Sci	-	Nether-lands	Container-port terminal; freight transportation; fleet sizing; lifting vehicles; time windows
69	Integration of SM & OM	Bruzzone & Signorile	1998	J	Simulation	Port in Liguria	Italy	Harbor, maritime, genetic algorithms, decision making, artificial intelligence, shipyard, terminal, resource management, multimodel simulation
70	Integration of SM & OM	Merkuryev et al.	2004	WS	Harbour, Marit & Multim Logist M	-	Latvia	Simulation, model, marine container terml, economic efficiency, income, optim.
71	I Integration of SM & OM	Alessandri et al.	2006	C	MATHMOD	-	Italy	-
72	Integration of SM & OM	Esmer	2009	T	PhD-Dokuz Eylül University	Marport	Turkey	-

73	Integration of SM & OM	Sacone & Siri	2009	J	Math Comput Model Dyn Syst	-	Italy	Container terminal planning, discrete-event simulation, discrete-time model, optimization
74	Integration of SM & OM	Zeng & Yang	2009	J	Comput Oper Res	Port of Dalian	China	Container terminal, Genetic algorithm, Hybrid flow shop problem, Simulation optimization
75	Integration of SM & OM	Wan et al.	2010	C	IEEE 17Th Int C Indust Engine EM	-	China	Container port, handling equipments, Arena simulation, optimization
76	Integration of SM & OM	Arango et al.	2011	J	Adv Eng Inform	Port of Seville	Spain	Berth allocation, Genetic algorithms, Port operations, Container transportation
77	Integration of SM & OM	Shu & Zhang	2011	C	ICTE 2011	-	China	Vehicles, Container shipping, Industrial facilities, Travel time, Ports and harbors, Parameters, Load fact., Mathematical modl
78	Integration of SM & OM	Sinha & Ganesan	2011	C	2011 Winter Simulation Conference	-	India	Containers, discrete event simulation, logistics, marine engineering, optimisation, profitability
79	Integration of SM & OM	Zehendner et al.	2015	J	Flex Serv Manuf	Grand Port Maritime de Marseille	France	Intermodal transportation, Container terminal, Resource allocation, Straddle carriers, Mixed integer programming, Discrete event simulation
80	Integration of SM & OM	Zeng et al.	2015	J	Marit Policy Manag	Yantian International CT Shenzhen P	China	Container terminals, quay crane dual cycling, bi-level genetic algorithm, simulation optimization
81	Integration of SM & OM	Lu & Hua	2016	C	Logis, Inform & Service Scien (LISS)	Gwangyang Port	China	Simulation, Gwangyang Port, Berth Optimal Design, Cargo Capacity, Waiting ratio
82	Integration of SM & OM	Kotachi	2018	T	PhD-Old Dominion University	CT of Port of Housto	USA	-
83	Sustainability	Islam	2018	J	Int J of Logis Research and Applic	-	New Zealand	Simulation, supply chain collaboration, sustainability, carbon emission, pollution
84	Ports in general	Bruzzone et al	1998	J	WIT Transactions on The Built Env.	-	Italy	-
85	Ports in general	Fanti et al	2015	J	J Comput Sci	Trieste	Italy	Decision Support Systems, Discrete Event Simulation, Optimization, Metaheuristic algorithms, Logistics
86	Ports in general	Keceli	2016	J	Maritime Policy & Management	Turkey	Kuwait	Terminals, ports, dry bulk, containers, gate operations, simulation
87	Port or Chanal traffic	Thiers & Janssens	1998	J	Simulation	Port of Antwerp	Belgium	Port simulation, traffic simulation, harbour simulation, rivers, reusability, Antwerp, Belgium, Scheldt
88	Port or Chanal traffic	Khatiashvili et al.	2006	J	Proc Inst Civil Eng Marit Eng	Port of Dover	UK	Infrastructure planning ; ports, docks & harbours ; risk & probability analysis
89	Port or Chanal traffic	Caris et al	2011	J	J of Transport Geography	Port of Antwerp	Belgium	Inland navigation, Bundling, Hinterland access, Discrete event simulation
90	Port or Chanal traffic	Almaz & Altiok	2012	J	Simul Model Pract Theory	Delaware river and Bay, USA	USA	Port simulation, Maritime traffic, Delaware River, Deepening, Dredging, Navig. iss.
91	Port or Chanal traffic	Shahpanah et al.	2014	J	Applied Mechanics and Materials		Malaysia	Computer Simulation, Port Container Terminal, Queuing, Ship Berthing Operation, Waiting Time
92	Port or Chanal traffic	Hang et al.	2015	C	Int.C on Transp Inform & Safety	Three Gorges area	China	Three Gorges area, ship traffic flow, simulation
93	Port or Chanal traffic	Habeeb et al	2018	J	The Open Transportation J	Panjin seaport	China	Waterway capacity, Y-type intersection, Squat, Arena sm, Seaport, Port service level

94	Port or Chanal traffic	Derse & Göçmen	2018	J	Int. Scientific and Vocational Stud. J		Turkey	Terminal vehicle movements, transport of containers, simulation
95	Port or Chanal traffic	Rahimike-larijani	2018	J	Simulation Model Practice and Theo.	Houston Ship Channel	USA	Ship channel operations, Discrete event simulation, Optimal closure schedule
96	Port or Chanal traffic	Kaneria et al.	2019	J	J Waterway Port Coastal & Ocean E	Houston Ship Channel	USA	-
97	Port or Chanal traffic	Park et al.	2019	J	J Korean Soc of Marine Environ & Safety	Busan New Port	Korea	Busan New Port, Anchorage, Port Operation Method, Arena Simulation program, Necessary Anchorage Space

Table A3. 2 Main features of Arena Aplications.

No	**Writer**	**Year**	**Main features**					
			A	**B**	**C**	**D**	**E**	**F**
1	Roop & Koster	1988	0	0	1	1	0	1
2	Kozan	2006	0	0	1	0	0	1
3	Boschian et al	2011	1	0	0	0	1	0
4	Franklin et al.	2014	0	0	0	0	0	0
5	Zehendner & Feillet	2014	0	0	1	0	0	1
6	Wall et al.	2015	1	1	1	0	0	1
7	Gbologah	2010	1	1	1	1	1	0
8	Kotachi et al	2013	1	0	0	0	0	0
9	McLean & Biles	2008	0	1	0	1	0	0
10	Vis & Harika	2004	1	1	1	0	1	1
11	Park et al.	2007	1	0	1	1	0	0
12	Huynh et al.	2004	1	0	1	1	1	1
13	Huynh & Walton	2007	1	1	1	0	1	0
14	Huynh & Walton	2008	1	0	1	0	0	1
15	Puglisi	2008	1	1	0	0	1	0
16	Park et al.	2009	0	1	1	1	1	1
17	Legato et al.	2009	1	1	1	0	1	1
18	Esmer et al.	2010	1	1	0	0	0	1
19	Jaoua et al.	2012	1	1	0	0	1	1
20	Sheikholeslami et al	2013	1	1	1	0	0	0
21	Dinu et al	2017	0	1	0	0	0	1
22	Guldogan	2010	0	1	1	0	1	1
23	Salehi & Wang	2013	1	0	0	0	0	0
24	Qu et al.	2012	1	0	0	0	0	0
25	Tahar & Hussain	2000	0	0	1	0	1	1
26	Ng	2001	0	1	1	1	1	0
27	Park et al.	2004	1	0	1	1	0	0
28	Kulak et al.	2008	0	0	1	0	1	0
29	Park & Dragovic	2009	1	0	0	0	0	1
30	Na & Shinozuka	2009	1	0	1	0	0	1
31	Vis and van Anholt	2010	1	0	1	0	1	1
32	Wanke	2011	1	1	1	0	0	1
33	Tan	2001	0	1	1	0	0	0
34	Esmer et al.	2013	0	1	0	1	0	1
35	Kotachi & Rabadi	2014	1	1	0	0	1	0
36	Lin et al.	2014	1	1	1	0	1	1
37	Nicoletti et al.	2014	1	1	0	1	0	1
38	Taner et al.	2014	1	1	1	0	1	1
39	Ursavas	2014	1	0	0	1	1	1
40	Ward	2014	1	0	1	0	1	1
41	Aydogdu & Aksoy	2015	1	0	0	1	0	1
42	Labib	2015	0	1	1	0	1	0
43	Kotachi et al	2016	1	0	0	0	0	0
44	Rusca et al.	2018	0	1	1	0	0	0
45	Nasution & Arviansyah	2019	0	0	0	0	0	0
46	Sislioglu et al.	2019	1	0	0	0	1	0
47	Merkuryev et al.	1998	1	0	0	0	0	1
48	Merkuryeva et al	2000	1	1	1	1	1	1
49	Lee et al.	2003	1	0	1	0	1	1
50	Biles et al.	2004	1	1	1	0	0	0
51	Cortes et al.	2007	0	1	1	1	1	1
52	Aneichyk	2009	1	1	0	1	0	0

53	Guiliang & Lina	2009	1	0	0	0	0	0
54	Yun et al.	2011	1	0	0	0	1	0
55	Kulak et al.	2013	1	0	1	0	1	1
56	Ursavas	2015	1	1	1	0	0	1
57	Rusca et al.	2016	1	1	1	0	0	0
58	Budipriyanto	2017	1	1	0	0	0	0
59	Li et al.	2017	1	1	0	0	0	0
60	Meng et al.	2017	1	1	1	0	1	0
61	Rekik et al.	2018	1	1	1	1	1	0
62	Cavallaro	2007	0	1	0	1	0	0
63	Pidgeon	2008	0	1	0	1	0	0
64	Rusca et al.	2015	0	1	1	1	0	0
65	Green	2019	0	1	0	1	0	0
66	Na, Chaudhuri & Shinozuka	2007	1	0	0	1	0	0
67	Moon et al.	2018	0	0	0	0	0	1
68	Vis et al	2005	0	0	1	0	0	1
69	Bruzzone & Signorile	1998	1	0	1	1	1	1
70	Merkuryev et al.	2004	0	0	0	0	0	1
71	Alessandri et al.	2006	0	1	1	1	0	1
72	Esmer	2009	1	1	1	1	1	0
73	Sacone & Siri	2009	1	1	1	0	1	1
74	Zeng & Yang	2009	1	0	0	0	0	1
75	Wan et al.	2010	1	1	0	0	0	0
76	Arango et al.	2011	0	1	1	1	1	1
77	Shu & Zhang	2011	1	1	0	0	0	0
78	Sinha & Ganesan	2011	1	0	0	0	1	1
79	Zehendner et al.	2015	0	0	1	0	0	1
80	Zeng et al.	2015	1	1	1	0	0	1
81	Lu & Hua	2016	1	0	0	0	0	0
82	Kotachi	2018	0	1	1	1	1	1
83	Islam	2018	1	0	0	0	0	0
84	Bruzzone et al	1998	0	0	0	0	1	0
85	Fanti et al	2015	1	1	0	1	1	1
86	Keceli	2016	1	0	0	0	0	0
87	Thiers & Janssens	1998	1	0	1	0	0	1
88	Khatiashvili et al.	2006	1	0	1	0	0	1
89	Caris et al	2011	0	0	1	0	0	0
90	Almaz & Altiok	2012	1	0	1	0	1	1
91	Shahpanah et al.	2014	0	0	0	0	0	0
92	Hang et al.	2015	1	0	0	1	0	0
93	Habeeb et al	2018	1	1	1	0	0	0
94	Derse & Göçmen	2018	0	1	0	0	1	1
95	Rahimikelarijani	2018	1	1	1	0	0	0
96	Kaneria et al.	2019	1	1	1	0	0	0
97	Park et al.	2019	0	0	0	0	0	0

Appendix 4: Key Data for DES Application

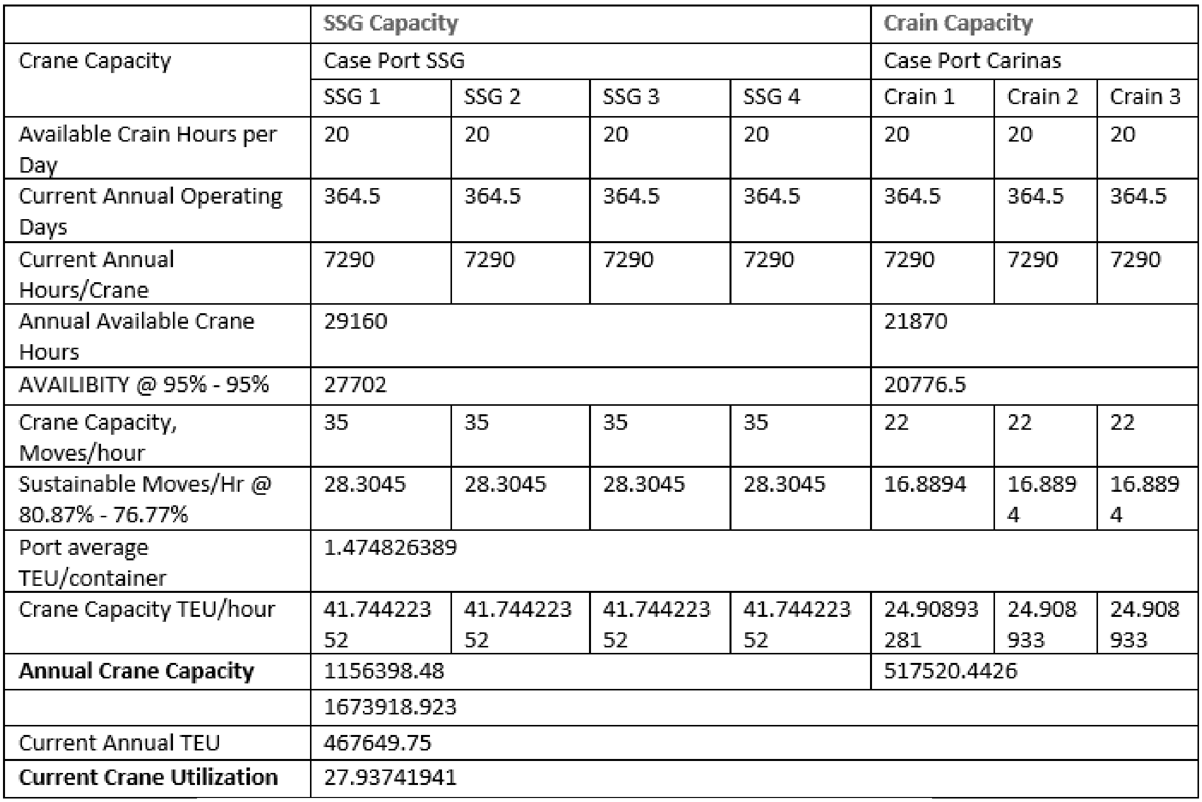
Table A4. 1 Cargo and ship volume of the case container port for DES Arena Application

Year	**Month**	**Number of Ship**	**Total Container (TEU)**	**Export (TEU)**	**Import (TEU)**
2017	Jan-17	42	38407	19505	18902
	Feb-17	46	35985	19606	16379
	Mar-17	51	30916	13204	17712
	Apr-17	58	38032	18809	19223
	May-17	62	42963	23127	19836
	Jun-17	61	43458	21008	22450
	Jul-17	65	36843	19340	17503
	Aug-17	58	36,379	14470	21909
	Sep-17	56	38517	19666	18851
	Oct-17	55	43871	22108	21763
	Nov-17	61	48279	25748	22531
	Dec-17	51	36239	15215	21024
2018	Jan-18	67	41425	20128	21297
	Feb-18	53	36403	17740	18663
	Mar-18	57	38565	18082	20483
	Apr-18	54	35820	18093	17727

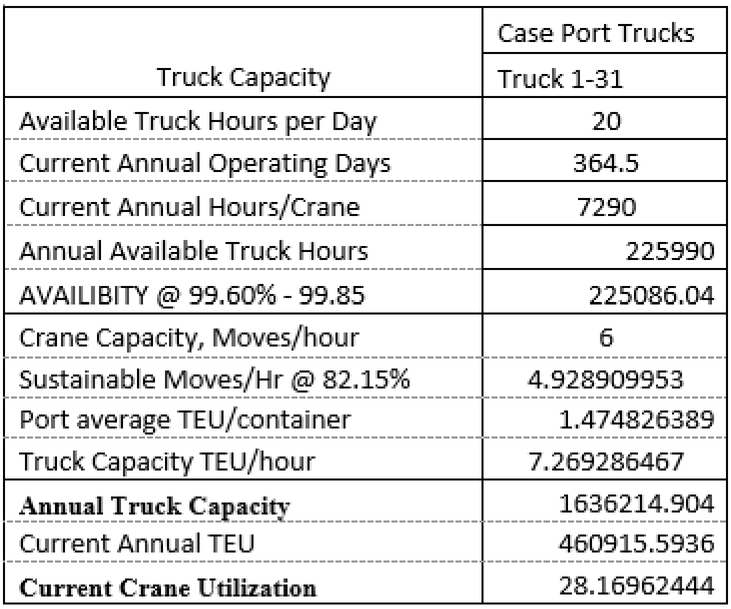
Table A4. 2 Real data collected for each ship and their operations.

Name of the Data		
Vessel Name Voyage No Berthing Time Agent Name LOA Pier No of the Port Pilot Start Time Berthed Time Commenced Time Completed Time Sailed Time Pilot Finish Time Time in Port	Waiting Time Service Time Operation Waiting Time Time in Port Total Waiting Time Total Service Time Total Idle Time Post Number Operation Break Waiting Total Handle Container (TEU) Full Discharge Container Empty Discharge Container Full Load Container	Empty Load Container Transit Load-Strip Container Shifting for Discharge Total Handle Container Move Full Load Container Empty Load Container Transit Load-Strip Shifting for Load Transit Load Total Load Discharge Load Total Total Shifting

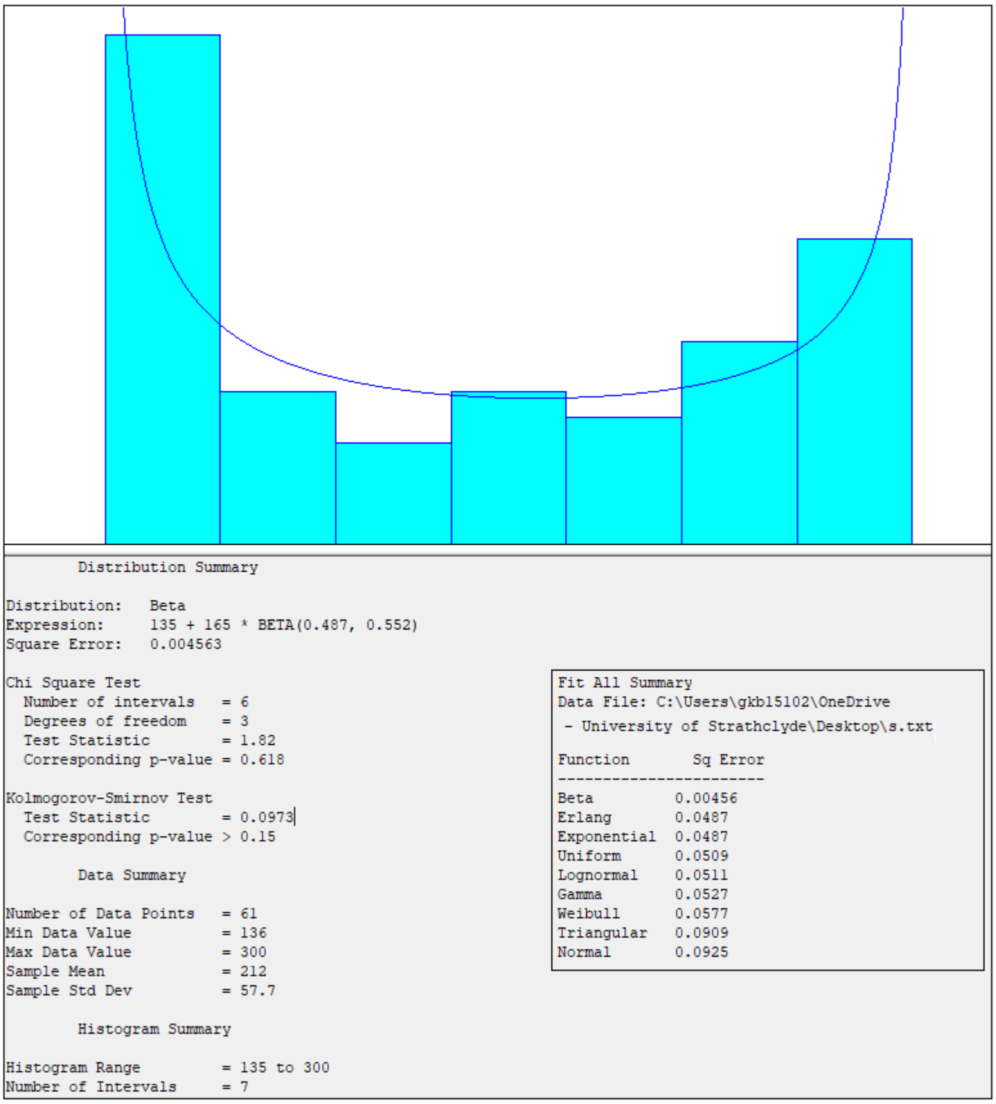
Table A4. 3 Capacity utilisation of SSG, Careens and Trucks the port based on real data (Author's calculations).



	SSG Capacity				Crain Capacity		
Crane Capacity	Case Port SSG				Case Port Carinas		
	SSG 1	SSG 2	SSG 3	SSG 4	Crain 1	Crain 2	Crain 3
Available Crain Hours per Day	20	20	20	20	20	20	20
Current Annual Operating Days	364.5	364.5	364.5	364.5	364.5	364.5	364.5
Current Annual Hours/Crane	7290	7290	7290	7290	7290	7290	7290
Annual Available Crane Hours	29160				21870		
AVAILIBITY @ 95% - 95%	27702				20776.5		
Crane Capacity, Moves/hour	35	35	35	35	22	22	22
Sustainable Moves/Hr @ 80.87% - 76.77%	28.3045	28.3045	28.3045	28.3045	16.8894	16.8894	16.8894
Port average TEU/container	1.474826389						
Crane Capacity TEU/hour	41.74422352	41.74422352	41.74422352	41.74422352	24.90893281	24.908933	24.908933
Annual Crane Capacity	1156398.48				517520.4426		
	1673918.923						
Current Annual TEU	467649.75						
Current Crane Utilization	27.93741941						



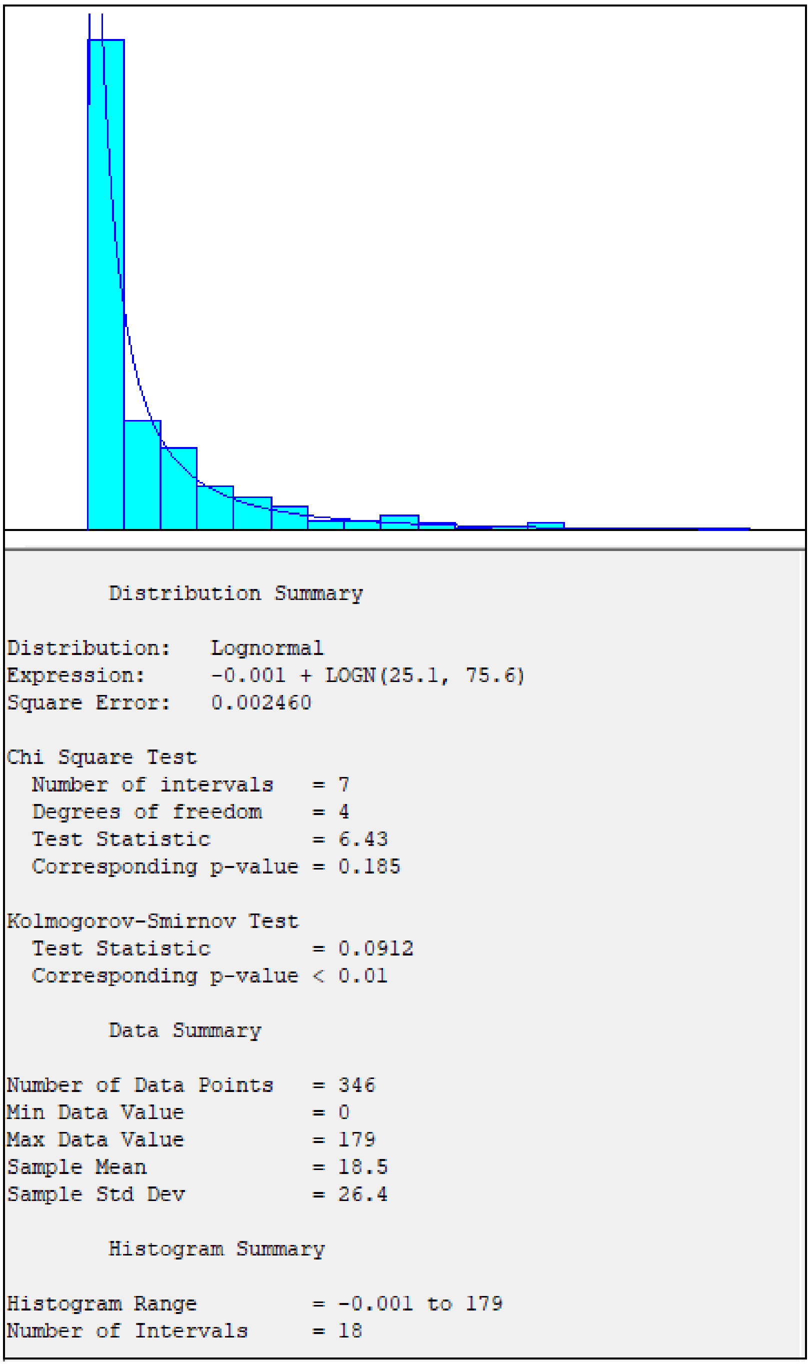
Truck Capacity	Case Port Trucks
	Truck 1-31
Available Truck Hours per Day	20
Current Annual Operating Days	364.5
Current Annual Hours/Crane	7290
Annual Available Truck Hours	225990
AVAILIBITY @ 99.60% - 99.85	225086.04
Crane Capacity, Moves/hour	6
Sustainable Moves/Hr @ 82.15%	4.928909953
Port average TEU/container	1.474826389
Truck Capacity TEU/hour	7.269286467
Annual Truck Capacity	1636214.904
Current Annual TEU	460915.5936
Current Crane Utilization	28.16962444



```
        Distribution Summary

Distribution:   Beta
Expression:     135 + 165 * BETA(0.487, 0.552)
Square Error:   0.004563

Chi Square Test
  Number of intervals   = 6
  Degrees of freedom    = 3
  Test Statistic        = 1.82
  Corresponding p-value = 0.618

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0973
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 61
Min Data Value          = 136
Max Data Value          = 300
Sample Mean             = 212
Sample Std Dev          = 57.7

        Histogram Summary

Histogram Range         = 135 to 300
Number of Intervals     = 7
```

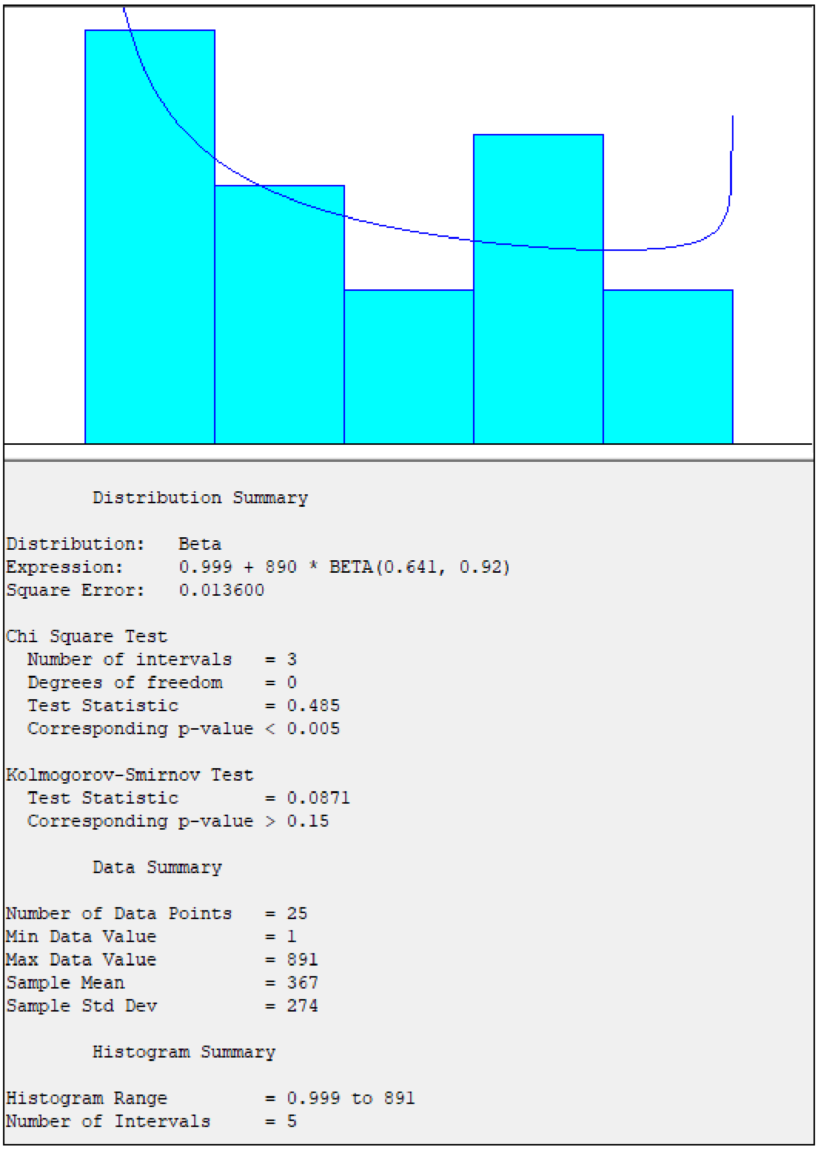
```
Fit All Summary
Data File: C:\Users\gkb15102\OneDrive
 - University of Strathclyde\Desktop\s.txt

Function       Sq Error
-----------------------
Beta          0.00456
Erlang        0.0487
Exponential   0.0487
Uniform       0.0509
Lognormal     0.0511
Gamma         0.0527
Weibull       0.0577
Triangular    0.0909
Normal        0.0925
```

Figure A4. 1 Distribution of Ship LOA for Arena Application



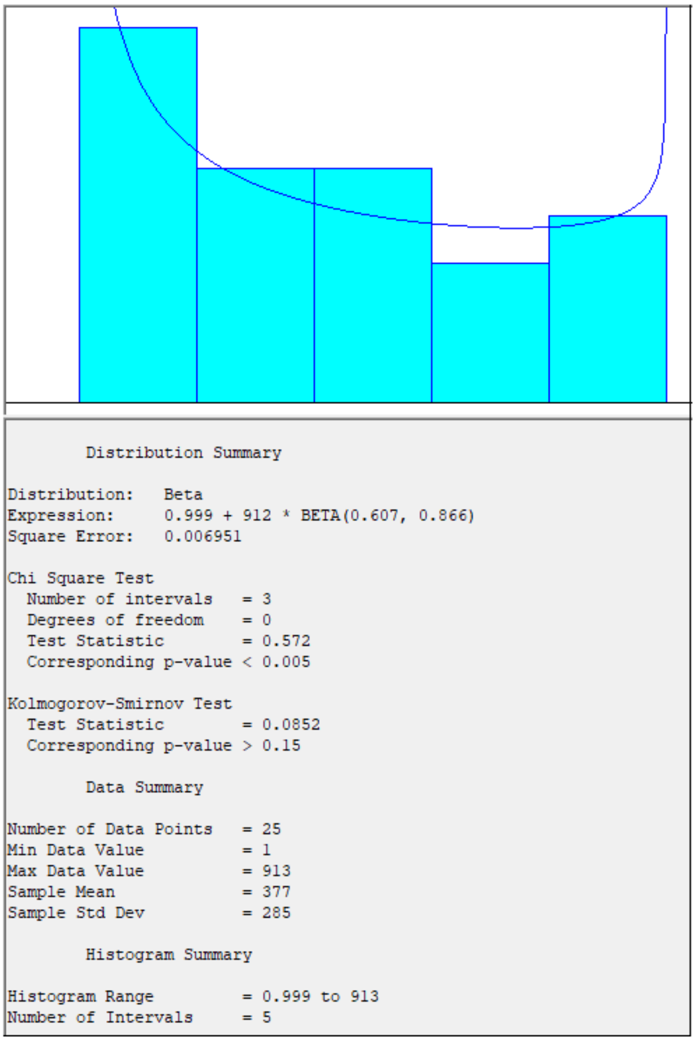
```
        Distribution Summary

Distribution:   Lognormal
Expression:     -0.001 + LOGN(25.1, 75.6)
Square Error:   0.002460

Chi Square Test
  Number of intervals   = 7
  Degrees of freedom    = 4
  Test Statistic        = 6.43
  Corresponding p-value = 0.185

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0912
  Corresponding p-value < 0.01

        Data Summary

Number of Data Points   = 346
Min Data Value          = 0
Max Data Value          = 179
Sample Mean             = 18.5
Sample Std Dev          = 26.4

        Histogram Summary

Histogram Range         = -0.001 to 179
Number of Intervals     = 18
```

Figure A4. 2 Distribution of Empty Container for Ship Loading (TEU) for Arena Application



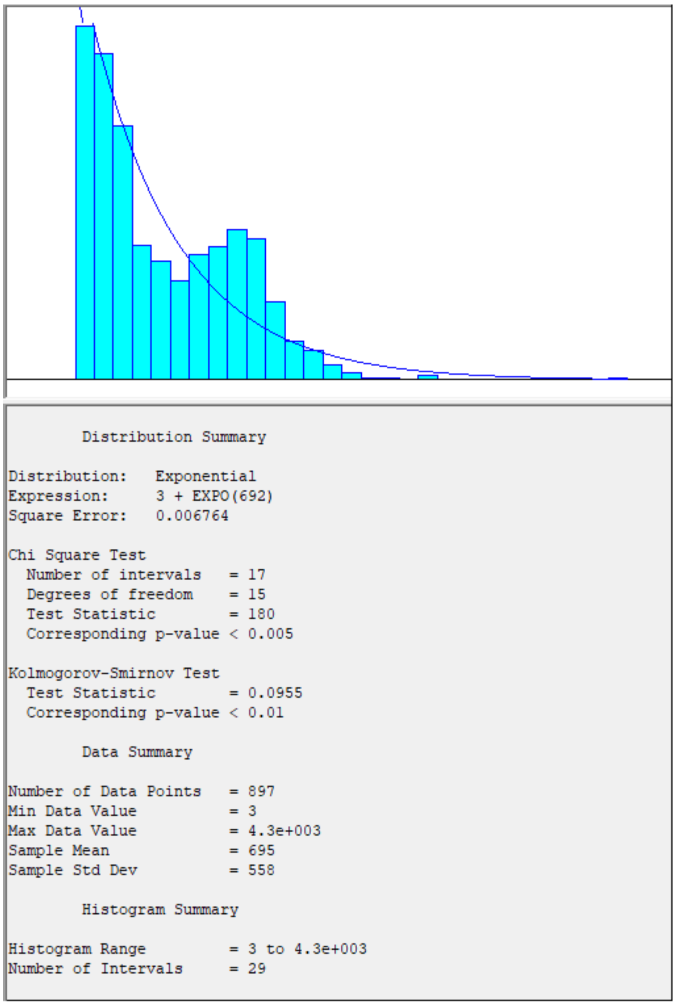
```
        Distribution Summary

Distribution:   Beta
Expression:     0.999 + 890 * BETA(0.641, 0.92)
Square Error:   0.013600

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 0.485
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0871
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 25
Min Data Value          = 1
Max Data Value          = 891
Sample Mean             = 367
Sample Std Dev          = 274

        Histogram Summary

Histogram Range         = 0.999 to 891
Number of Intervals     = 5
```

Figure A4. 3 Distribution of Full Container for Ship Loading (TEU) for Arena Application



```
        Distribution Summary

Distribution:   Beta
Expression:     0.999 + 912 * BETA(0.607, 0.866)
Square Error:   0.006951

Chi Square Test
  Number of intervals   = 3
  Degrees of freedom    = 0
  Test Statistic        = 0.572
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0852
  Corresponding p-value > 0.15

        Data Summary

Number of Data Points   = 25
Min Data Value          = 1
Max Data Value          = 913
Sample Mean             = 377
Sample Std Dev          = 285

        Histogram Summary

Histogram Range         = 0.999 to 913
Number of Intervals     = 5
```

Figure A4. 4 Distribution of Total Container for Ship Loading (TEU) for Arena Application



```
        Distribution Summary

Distribution:   Exponential
Expression:     3 + EXPO(692)
Square Error:   0.006764

Chi Square Test
  Number of intervals   = 17
  Degrees of freedom    = 15
  Test Statistic        = 180
  Corresponding p-value < 0.005

Kolmogorov-Smirnov Test
  Test Statistic        = 0.0955
  Corresponding p-value < 0.01

        Data Summary

Number of Data Points   = 897
Min Data Value          = 3
Max Data Value          = 4.3e+003
Sample Mean             = 695
Sample Std Dev          = 558

        Histogram Summary

Histogram Range         = 3 to 4.3e+003
Number of Intervals     = 29
```

Figure A4. 5 Distribution of Total Container for Ship Unloading (TEU) for Arena Application

Appendix 5: Assignment of SSG and Cranes to Ships

Table A5. 1 Assignment of SSG and Cranes to Ships.

	Number	Module Type	Module Name	Definition	Properties and Function
Loading / Unloading Process on Ships at quay	1		Create 21	*Defines SSGs in the system and provides their access to the system*	Entity Type:sSSG1, time Between Arrivals: Type:Random (Expo), Value:1, Units:Hours, Entities per arrival:1, Max Arrivals:1, First Creation:0
	2		Create 22		Entity Type:sSSG2, time Between Arrivals: Type:Random (Expo), Value:1, Units:Hours, Entities per arrival:1, Max Arrivals:1, First Creation:0
	3		Create 23		Entity Type:sSSG3, time Between Arrivals: Type:Random (Expo), Value:1, Units:Hours, Entities per arrival:1, Max Arrivals:1, First Creation:0
	4		Create 24		Entity Type:sSSG4, time Between Arrivals: Type:Random (Expo), Value:1, Units:Hours, Entities per arrival:1, Max Arrivals:1, First Creation:0
	5		Create Crane 1	Defines Cranes in the system and provides their access to the system	Entity Type:Crane 1, time Between Arrivals: Type:Random (Expo), Value:1, Units:Hours, Entities per arrival:1, Max Arrivals:1, First Creation:0
	6		Create Crane 2		Entity Type:Crane 3, time Between Arrivals: Type:Random (Expo), Value:1, Units:Hours, Entities per arrival:1, Max Arrivals:1, First Creation:0
	7		Create Crane 3		Entity Type:Crane 4, time Between Arrivals: Type:Random (Expo), Value:1, Units:Hours, Entities per arrival:1, Max Arrivals:1, First Creation:0
	8		Create 29	In order for the trucks to operate in the system, they must initially notice at least one container with the filled of quay	Entity Type:Entity 1, Time Between Arrivals; Type:Random(Expo), Value:1, Units:Secons, Entities per Arrival:1, Max Arrivals:1, First Creation:0.0
	9		Create 30		Entity Type:Entity 1, Time Between Arrivals; Type:Random(Expo), Value:1, Units:Secons, Entities per Arrival:1, Max Arrivals:1, First Creation:0.1
	10		Create 31		Entity Type:Entity 1, Time Between Arrivals; Type:Random(Expo), Value:1, Units:Secons, Entities per Arrival:1, Max Arrivals:1, First Creation:0.2
	11		Hold 82	The Hold module keeps the SSG and the Cranes in the quay until the ships come and unload.	Type: Wait for Signal, Wait for Value:19, Queue Type:Queue, QueueName:Hold 82.Queue
	12		Hold 83		Type: Wait for Signal, Wait for Value:19, Queue Type:Queue, QueueName:Hold 83.Queue
	13		Hold 84		Type: Wait for Signal, Wait for Value:19, Queue Type:Queue, QueueName:Hold 84.Queue
	14		Hold 85		Type: Wait for Signal, Wait for Value:19, Queue Type:Queue, QueueName:Hold 85.Queue
	15		Hold 96		Type: Wait for Signal, Wait for Value:19, Queue Type:Queue, QueueName:Hold 96.Queue
	16		Hold 97		Type: Wait for Signal, Wait for Value:19, Queue Type:Queue, QueueName:Hold 97.Queue
	17		Hold 98		Type: Wait for Signal, Wait for Value:19, Queue Type:Queue, QueueName:Hold 98.Queue
	18		Delay 11	When the vessel is at the quay the SSG and Cranes are held for 2 seconds until the incoming signal is transmitted.	Allocation:Other, Delay Time:2, Units:Seconds
	19		Delay 21		Allocation:Other, Delay Time:2, Units:Seconds
	20		Delay 22		Allocation:Other, Delay Time:2, Units:Seconds
	21		Delay 23		Allocation:Other, Delay Time:2, Units:Seconds
	22		Delay 45		Allocation:Other, Delay Time:2, Units:Seconds
	23		Delay 46		Allocation:Other, Delay Time:2, Units:Seconds
	24		Delay 47		Allocation:Other, Delay Time:2, Units:Seconds
	25		Decide 65	They form the decision mechanism that assigns SSGs to work on which quay	Type:2-way by Condition, If:Expression, Value:rihtim1 > 0
	26		Decide 66		Type:2-way by Condition, If:Expression, Value:((rihtim2 > 0) && (rýhtým2gemiboyu >= 90) && (rýhtým3gemiboyu >= 90)) || ((rihtim3 == 0) && (rýhtým2gemiboyu >= 140)) || ((rihtim2 > 0) && (rýhtým3gemiboyu >= 140))
	27		Decide 67		Type:2-way by Condition, If:Expression, Value:(rihtim3 > 0) && (rýhtým3gemiboyu >=190)
	28		Decide 68		Type:2-way by Condition, If:Expression, Value:(rihtim1 > 0) && (rýhtým1gemiboyu >= 90)
	29		Decide 69		Type:2-way by Condition, If:Expression, Value:(rihtim2 > 0) && (rýhtým3gemiboyu < 140)
	30		Decide 70		Type:2-way by Condition, If:Expression, Value:(rihtim3 > 0) && (rýhtým3gemiboyu >= 140)
	31		Decide 71		Type:2-way by Condition, If:Expression, Value:((rihtim2 > 0) && (rýhtým1gemiboyu < 140) &&(rýhtým3gemiboyu < 90)) || ((rihtim2 > 0) && (rýhtým2gemiboyu >= 90))
	32		Decide 72		Type:2-way by Condition, If:Expression, Value:(rihtim3 > 0) && (rýhtým3gemiboyu >= 90)
	33		Decide 73		Type:2-way by Condition, If:Expression, Value:(rihtim1 > 0) && (rýhtým1gemiboyu >= 140)
	34		Decide 74		Type:2-way by Condition, If:Expression, Value:rihtim3 > 0
	35		Decide 75		Type:2-way by Condition, If:Expression, Value:(rihtim2 > 0) && (rýhtým1gemiboyu > 90)
	36		Decide 76		Type:2-way by Condition, If:Expression, Value:(rýhtým1gemiboyu >= 190)
	37		Decide 282	They set up the decision mechanism which assigns the cranes to work at which quay.	Type:2-way by Condition, If:Expression, Value:((rihtim1 > 0) && (totalgemiboyutu >= 225) &&((rihtim2 > 0) || (rihtim3 > 0))) || ((rihtim1> 0) && (totalgemiboyutu >= 250) && (rihtim2 == 0) &&(rihtim3> 0) && ((rýhtým3gemiboyu >=90) || (rihtim1 > 0))) || ((rihtim1> 0) && (totalgemiboyutu >= 225) && (rihtim2 == 0) &&(rihtim3> 0)) || ((rihtim1> 0)&&(rihtim2> 0) && (rýhtým1gemiboyu >= 170) && (rýhtým2gemiboyu >= 90))
	38		Decide 274		Type:2-way by Condition, If:Expression, Value:(((rihtim2 > 0) && (rýhtým2gemiboyu >= 220)) || ((rihtim2> 0) && (totalgemiboyutu >= 225) &&(rihtim1>0) && (rihtim3> 0)) || ((rihtim2> 0) && (rýhtým2gemiboyu >= 90) && (rýhtým2gemiboyu <= 190) &&(rihtim1> 0) && (rihtim3> 0) && (totalgemiboyutu > 225)))
	39		Decide 275		Type:2-way by Condition, If:Expression, Value:(((rihtim3 > 0) && (totalgemiboyutu > 250)) || ((rihtim3> 0) && (rýhtým3gemiboyu >= 170) &&(rihtim2>0) && (rýhtým2gemiboyu>= 140) && (rihtim1== 0)) || ((rihtim3> 0) && (totalgemiboyutu > 225) && (rihtim1> 0)))

	40		Decide 276		Type:2-way by Condition, If:Expression, Value:((rihtim2 > 0) && (rýhtým2gemiboyu <90) && (rihtim1> 0) && (rýhtým1gemiboyu >= 190) && ((rihtim3> 0) && (rýhtým3gemiboyu< 90))|| (rihtim3== 0)) || ((rihtim2 > 0) && (rýhtým2gemiboyu <=90) && (rihtim1> 0) && (rihtim3> 0) && (rýhtým3gemiboyu >= 90)) || ((rihtim2 > 0) && (rýhtým2gemiboyu >=90) && (rýhtým2gemiboyu <140) && (rihtim3> 0) && (rihtim1> 0) && (rýhtým1gemiboyu >= 90)) || ((rihtim2 > 0) && (rýhtým2gemiboyu >=90) && (rýhtým2gemiboyu <140)) && (rihtim3> 0) &&(rýhtým3gemiboyu >= 140) && (rihtim1> 0) && (rýhtým1gemiboyu <90) || ((rihtim2 > 0) && (rýhtým2gemiboyu >=140) && (rýhtým2gemiboyu <190) && (rihtim1> 0) && (rihtim3> 0))|| ((rihtim2 > 0) && (rýhtým2gemiboyu >=140) && (rýhtým2gemiboyu <190) && (rihtim1==0) && (rihtim3> 0) && (rýhtým3gemiboyu >=90)) || ((rihtim2 > 0) && (totalgemiboyutu > 225) && (rýhtým2gemiboyu <190) && ((rihtim3==0) && (rihtim1> 0) && (totalgemiboyutu > 225))) || ((rihtim2 > 0) && (rýhtým2gemiboyu >=190))
	41		Decide 277		Type:2-way by Condition, If:Expression, Value:(((rihtim1 > 0) && (totalgemiboyutu > 225) && (rihtim2> 0))||((rihtim1> 0) && (totalgemiboyutu > 225) && (rihtim2>0) && (rýhtým2gemiboyu >=90) && (rýhtým2gemiboyu <140)) ||((rihtim1 > 0) && (rýhtým1gemiboyu >= 190) && (rihtim2> 0) && (totalgemiboyutu > 225)))
	42		Decide 278		Type:2-way by Condition, If:Expression, Value:(((rihtim3 > 0) && (totalgemiboyutu > 225)) || ((rihtim3 > 0) && (rihtim2 > 0) && (rihtim1== 0) && (rýhtým3gemiboyu >= 190) && (rýhtým2gemiboyu <140)) || ((rihtim3 > 0) && (rihtim2 ==0) && (rihtim1>0) && (totalgemiboyutu >= 225)))
	43		Decide 279		Type:2-way by Condition, If:Expression, Value:((rihtim3 > 0) && (totalgemiboyutu > 225) && (rihtim2 > 0) && (rýhtým2gemiboyu >= 90) && (rihtim1 > 0)) || ((rihtim3 > 0) && (totalgemiboyutu > 225) && (rihtim2 > 0) && (rýhtým2gemiboyu>= 140) && (rihtim1 ==0)) || ((rihtim1 > 0) && (rihtim2 > 0) && (totalgemiboyutu > 225))
	44		Decide 280		Type:2-way by Condition, If:Expression, Value:((rihtim3 > 0) && (totalgemiboyutu > 225)) || ((rihtim2> 0) && (totalgemiboyutu > 225) &&(rihtim1>0) && (rihtim3> 0)) || ((rihtim2> 0) && (rýhtým2gemiboyu>= 90) && (rýhtým2gemiboyu<= 190) &&(rihtim1> 0) && (rihtim3> 0)&& (rýhtým3gemiboyu >= 90) && (rýhtým1gemiboyu >= 90)) || ((rihtim2> 0) && (rýhtým2gemiboyu >=140) &&(rihtim1>0) && (rýhtým1gemiboyu >=190) && (rihtim3== 0)) || ((rihtim2> 0)&&(rýhtým2gemiboyu >190) &&(rihtim1>0))
	45		Decide 281		Type:2-way by Condition, If:Expression, Value:((rihtim1 > 0) && (totalgemiboyutu > 225) && (rihtim2 == 0) && (rihtim3 ==0)) || ((rihtim1 > 0) && (totalgemiboyutu > 225) && (rihtim2> 0))
	46		Assign 32	It instantly calculates how many SSGs are working on which quay. Increases when assigned to the quay; decrease when leave the quay.	Assignements; Type:Variable, Varible Name:NumberofSSGinBerth1, New Value:NumberofSSGinBerth1+1; End of list
	47		Assign 34		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth2, New Value:NumberofSSGinBerth2+1; End of list
	48		Assign 36		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth3, New Value:NumberofSSGinBerth3+1; End of list
	49		Assign 39		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth1, New Value:NumberofSSGinBerth1+1; End of list
	50		Assign 40		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth2, New Value:NumberofSSGinBerth2+1; End of list
	51		Assign 41		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth3, New Value:NumberofSSGinBerth3+1; End of list
	52		Assign 45		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth2, New Value:NumberofSSGinBerth2+1; End of list
	53		Assign 46		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth3, New Value:NumberofSSGinBerth3+1; End of list
	54		Assign 47		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth1, New Value:NumberofSSGinBerth1+1; End of list
	55		Assign 51		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth3, New Value:NumberofSSGinBerth3+1; End of list
	56		Assign 52		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth2, New Value:NumberofSSGinBerth2+1; End of list
	57		Assign 53		Assignements; Type:Variable, Varible Name:NumberofSSGinBerth1, New Value:NumberofSSGinBerth1+1; End of list
	58		Decide 212	They help to decide whether the SSG assigned to the quay will load or unload and direct them accordingly.	Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth1Status == 0) && (NQ(fullc1.Queue) >= 5)`, if:Expression, Value:Berth1Status == 1`, End of list
	59		Decide 213		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth2Status == 0) && (NQ(fullc2.Queue) >= 5)`, if:Expression, Value:Berth2Status == 1`, End of list
	60		Decide 214		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth3Status == 0) && (NQ(fullc3.Queue) >= 5)`, if:Expression, Value:Berth3Status == 1`, End of list
	61		Decide 215		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth1Status == 0) && (NQ(fullc1.Queue) >= 5)`, if:Expression, Value:Berth1Status == 1`, End of list
	62		Decide 216		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth2Status == 0) && (NQ(fullc2.Queue) >= 5)`, if:Expression, Value:Berth2Status == 1`, End of list
	63		Decide 217		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth3Status == 0) && (NQ(fullc3.Queue) >= 5)`, if:Expression, Value:Berth3Status == 1`, End of list
	64		Decide 218		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth2Status == 0) && (NQ(fullc2.Queue) >= 5)`, if:Expression, Value:Berth2Status == 1`, End of list
	65		Decide 219		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth3Status == 0) && (NQ(fullc3.Queue) >= 5)`, if:Expression, Value:Berth3Status == 1`, End of list
	66		Decide 220		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth1Status == 0) && (NQ(fullc1.Queue) >= 5)`, if:Expression, Value:Berth1Status == 1`, End of list
	67		Decide 221		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth3Status == 0) && (NQ(fullc3.Queue) >= 5)`, if:Expression, Value:Berth3Status == 1`, End of list
	68		Decide 222		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth2Status == 0) && (NQ(fullc2.Queue) >= 5)`, if:Expression, Value:Berth2Status == 1`, End of list
	69		Decide 223		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth1Status == 0) && (NQ(fullc1.Queue) >= 5)`, if:Expression, Value:Berth1Status == 1`, End of list
	70		Decide 283	They help to decide whether the Crane assigned to the quay will load or unload and direct them accordingly.	Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth1Status == 0) && (NQ(fullc1.Queue) >= 5)`, if:Expression, Value:Berth1Status == 1`, End of list
	71		Decide 285		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth2Status == 0) && (NQ(fullc2.Queue) >= 5)`, if:Expression, Value:Berth2Status == 1`, End of list
	72		Decide 288		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth3Status == 0) && (NQ(fullc3.Queue) >= 5)`, if:Expression, Value:Berth3Status == 1`, End of list
	73		Decide 290		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth2Status == 0) && (NQ(fullc2.Queue) >= 5)`, if:Expression, Value:Berth2Status == 1`, End of list
	74		Decide 292		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth1Status == 0) && (NQ(fullc1.Queue) >= 5)`, if:Expression, Value:Berth1Status == 1`, End of list
	75		Decide 294		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth3Status == 0) && (NQ(fullc3.Queue) >= 5)`, if:Expression, Value:Berth3Status == 1`, End of list
	76		Decide 296		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth2Status == 0) && (NQ(fullc2.Queue) >= 5)`, if:Expression, Value:Berth2Status == 1`, End of list
	77		Decide 298		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth3Status == 0) && (NQ(fullc3.Queue) >= 5)`, if:Expression, Value:Berth3Status == 1`, End of list
	78		Decide 300		Type:N-way by Conditor, Conditions; `if:Expression, Value:(Berth1Status == 0) && (NQ(fullc1.Queue) >= 5)`, if:Expression, Value:Berth1Status == 1`, End of list
	79		S1B1U	"These modules are the process modules, ie they are used to specify the processing times and the operator when SSG or Cranes are discharged or loaded. These modules are coded as follows;	Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG1rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	80		S1B1L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG1rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	81		S1B2U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG1rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2

	82		S1B2L	S / C ""? "" B ""? "" "" / L "": Q: Indicates that the operator is SSG and the number in front of it shows which SSG is that. C: Indicates that the operator is Crane and the number in front of it shows which Crane is that. B: B indicates is quay and the number in front of it shows which quay is that. U / L: If the operator is loading "" L "", if "" is discharging, "" U "" is indicated by the letter. For example; S3B3U module; 3. It shows that SSG is discharging at the 3rd quay. "	Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG1rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	83		S1B3U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG1rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	84		S1B3L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG1rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	85		S2B1U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG2rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	86		S2B1L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG2rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	87		S2B2U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG2rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	88		S2B2L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG2rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	89		S2B3U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG2rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	90		S2B3L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG2rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	91		S3B2U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG3rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	92		S3B2L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG3rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	93		S3B3U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG3rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	94		S3B3L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG3rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	95		S3B1U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG3rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	96		S3B1L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG3rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	97		S4B3U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG4rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	98		S4B3L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG4rB3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	99		S4B2U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG4rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	100		S4B2L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG4rB2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	101		S4B1U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG4rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	102		S4B1L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:SSG4rB1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):1.8, Std Dev: .2
	103		C1B1U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN1B1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	104		C1B1L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN1B1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	105		C1B2U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN1B2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	106		C1B2L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN1B2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	107		C1B3U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN1B3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	108		C1B3L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN1B3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	109		C2B2U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN2B2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	110		C2B2L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN2B2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	111		C2B1U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN2B1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5

	112		C2B1L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN2B1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	113		C2B3U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN2B3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	114		C2B3L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN2B3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	115		C3B2U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN3B2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	116		C3B2L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN3B2, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	117		C3B3U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN3B3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	118		C3B3L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN3B3, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	119		C3B1U		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN3B1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	120		C3B1L		Type:Standard; `Logic; Action:Seize Delay Release; Piority:Medium(2);` Resources:`Type:Resource, Resource Name:CRN3B1, Units to seize/Release:1`, end of list``; Delay Type:Normal, Units:Minutes, Allocation:Value Added, Value(Mean):2.96, Std Dev: .5
	121		Station 167	In the loading process, this is the station where the containers brought by trucks from the field will arrive.	Station Type:Station, Station Name: Station 167
	122		Station 168		Station Type:Station, Station Name: Station 168
	123		Station 169		Station Type:Station, Station Name: Station 169
	124		Dropoff 76	These Dropoff modules allow trucks to drop containers	Quatitiy:1, Statring Rank:1, Member Attribute:Take All Representative Values
	125		Dropoff 79		Quatitiy:1, Statring Rank:1, Member Attribute:Take All Representative Values
	126		Dropoff 80		Quatitiy:1, Statring Rank:1, Member Attribute:Take All Representative Values
	127		Assign 159	It is used to assign the images of the loaded containers to the animation.	Assignments:`type:Entitiy Picture, Entity Picture:Picture.Container`, end of list
	128		Assign 160		Assignments:`type:Entitiy Picture, Entity Picture:Picture.Container`, end of list
	129		Assign 161		Assignments:`type:Entitiy Picture, Entity Picture:Picture.Container`, end of list
	130		Route 169	Allows trucks to go back to the site again after leaving the container on board of ship	Route Time:0, Units:Hours, Destination Type:Station, Station Name:TruckDecideLogic
	131		Route 172		Route Time:0, Units:Hours, Destination Type:Station, Station Name:TruckDecideLogic
	132		Route 173		Route Time:0, Units:Hours, Destination Type:Station, Station Name:TruckDecideLogic
	133		EmptyShip1	It is the Hold module where the loads brought by the trucks are kept before the ship is loaded.	Type:Infinite Hold, Queue Type:Queue, Queue Name:EmptyShip1.Queue
	134		EmptyShip2		Type:Infinite Hold, Queue Type:Queue, Queue Name:EmptyShip2.Queue
	135		EmptyShip3		Type:Infinite Hold, Queue Type:Queue, Queue Name:EmptyShip3.Queue
	136		Hold 115	In the loading process, the trucks hold the SSG and Cranes in this Hold module until the truck bring a container, releasing the SSG and Cranes when a truck arrives.	Type:Scan for Condition, Condition:`NQ(EmptyShip2.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 115.Queue
	137		Hold 116		Type:Scan for Condition, Condition:`NQ(EmptyShip2.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 116.Queue
	138		Hold 117		Type:Scan for Condition, Condition:`NQ(EmptyShip2.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 117.Queue
	139		Hold 118		Type:Scan for Condition, Condition:`NQ(EmptyShip2.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 118.Queue
	140		Hold 119		Type:Scan for Condition, Condition:`NQ(EmptyShip2.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 119.Queue
	141		Hold 120		Type:Scan for Condition, Condition:`NQ(EmptyShip2.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 120.Queue
	142		Hold 121		Type:Scan for Condition, Condition:`NQ(EmptyShip2.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 121.Queue
	143		Hold 122		Type:Scan for Condition, Condition:`(NQ(EmptyShip1.Queue) > 0) || (Berth1Status == 0)`, Queue Type:Queue, Queue Name:Hold 122.Queue
	144		Hold 123		Type:Scan for Condition, Condition:`NQ(EmptyShip1.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 123.Queue
	145		Hold 124		Type:Scan for Condition, Condition:`NQ(EmptyShip1.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 124.Queue
	146		Hold 125		Type:Scan for Condition, Condition:`NQ(EmptyShip1.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 125.Queue
	147		Hold 126		Type:Scan for Condition, Condition:`NQ(EmptyShip1.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 126.Queue
	148		Hold 127		Type:Scan for Condition, Condition:`NQ(EmptyShip1.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 127.Queue
	149		Hold 128		Type:Scan for Condition, Condition:`NQ(EmptyShip1.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 128.Queue
	150		Hold 129		Type:Scan for Condition, Condition:`NQ(EmptyShip3.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 129.Queue
	151		Hold 130		Type:Scan for Condition, Condition:`NQ(EmptyShip3.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 130.Queue
	152		Hold 131		Type:Scan for Condition, Condition:`NQ(EmptyShip3.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 131.Queue
	153		Hold 132		Type:Scan for Condition, Condition:`NQ(EmptyShip3.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 132.Queue
	154		Hold 133		Type:Scan for Condition, Condition:`NQ(EmptyShip3.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 133.Queue
	155		Hold 134		Type:Scan for Condition, Condition:`NQ(EmptyShip3.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 134.Queue
	156		Hold 135		Type:Scan for Condition, Condition:`NQ(EmptyShip3.Queue) > 0`, Queue Type:Queue, Queue Name:Hold 135.Queue
	157		Pickup 48	These are the modules that show that SSGs handle containers from the ship for discharge.	Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc1.Queue
	158		Pickup 49		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc3.Queue
	159		Pickup 50		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc2.Queue

	160		Pickup 51		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc1.Queue
	161		Pickup 52		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc2.Queue
	162		Pickup 53		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc3.Queue
	163		Pickup 54		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc2.Queue
	164		Pickup 55		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc3.Queue
	165		Pickup 56		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc1.Queue
	166		Pickup 57		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc3.Queue
	167		Pickup 58		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc2.Queue
	168		Pickup 59		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc1.Queue
	169		Pickup 100	These are the modules that show that the Cranes are handling the containers from the ship for discharge.	Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc1.Queue
	170		Pickup 101		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc2.Queue
	171		Pickup 102		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc3.Queue
	172		Pickup 103		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc2.Queue
	173		Pickup 104		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc1.Queue
	174		Pickup 105		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc3.Queue
	175		Pickup 106		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc2.Queue
	176		Pickup 107		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc3.Queue
	177		Pickup 108		Quatitiy:1, Queue Type:Queue, Statring Rank:1, Queue Name:fullc1.Queue
	178		Dropoff 51	This module is used for the SSGs to hand out the containers they handle.	Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	179		Dropoff 52		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	180		Dropoff 53		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	181		Dropoff 54		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	182		Dropoff 55		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	183		Dropoff 56		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	184		Dropoff 57		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	185		Dropoff 58		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	186		Dropoff 59		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	187		Dropoff 60		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	188		Dropoff 61		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	189		Dropoff 62		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	190		Dropoff 107	This module is used for the Cranes to hand out the containers they handle.	Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	191		Dropoff 108		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	192		Dropoff 109		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	193		Dropoff 110		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	194		Dropoff 111		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	195		Dropoff 112		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	196		Dropoff 113		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	197		Dropoff 114		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	198		Dropoff 115		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	199		Decide 319	During loading, if there is no truck from the field, it is used to direct SSGs to another job without loading.	Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip1.Queue) > 0, End of list
	200		Decide 320		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip2.Queue) > 0, End of list
	201		Decide 321		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip3.Queue) > 0, End of list
	202		Decide 322		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip1.Queue) > 2, End of list
	203		Decide 323		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip2.Queue) > 0, End of list
	204		Decide 324		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip3.Queue) > 2, End of list
	205		Decide 325		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip2.Queue) > 0, End of list
	206		Decide 326		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip3.Queue) > 0, End of list
	207		Decide 327		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip1.Queue) > 0, End of list
	208		Decide 328		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip3.Queue) > 0, End of list
	209		Decide 329		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip2.Queue) > 0, End of list
	210		Decide 330		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip1.Queue) > 0, End of list
	211		Decide 309	During the installation, if there was no truck from the field, it was used to direct the Cranes to another job without loading.	Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip1.Queue) > 0, End of list
	212		Decide 310		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip2.Queue) > 0, End of list
	213		Decide 311		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip3.Queue) > 0, End of list
	214		Decide 312		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip2.Queue) > 0, End of list
	215		Decide 313		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip1.Queue) > 0, End of list

	216		Decide 314		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip3.Queue) > 0, End of list
	217		Decide 316		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip2.Queue) > 0, End of list
	218		Decide 317		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip3.Queue) > 0, End of list
	219		Decide 318		Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(EmptyShip1.Queue) > 0, End of list
	220		Pickup 73	These are the modules that show the SSGs handling the containers from the truck for loading.	Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip1.Queue
	221		Pickup 75		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip2.Queue
	222		Pickup 76		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip3.Queue
	223		Pickup 79		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip1.Queue
	224		Pickup 80		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip2.Queue
	225		Pickup 81		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip3.Queue
	226		Pickup 82		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip2.Queue
	227		Pickup 83		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip3.Queue
	228		Pickup 84		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip1.Queue
	229		Pickup 85		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip3.Queue
	230		Pickup 86		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip2.Queue
	231		Pickup 87		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip1.Queue
	232		Pickup 109	These are the modules that show the cranes handling the containers from the truck for loading.	Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip1.Queue
	233		Pickup 110		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip2.Queue
	234		Pickup 111		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip3.Queue
	235		Pickup 112		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip2.Queue
	236		Pickup 113		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip1.Queue
	237		Pickup 114		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip3.Queue
	238		Pickup 115		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip2.Queue
	239		Pickup 116		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip3.Queue
	240		Pickup 117		Quantity:1, Queue Type:Queue, Starting Raank:1, Queue Name:EmptyShip1.Queue
	241		Dropoff 81	This module is used for the SSGs to release the containers they handle.	Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	242		Dropoff 82		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	243		Dropoff 83		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	244		Dropoff 84		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	245		Dropoff 85		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	246		Dropoff 86		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	247		Dropoff 87		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	248		Dropoff 88		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	249		Dropoff 89		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	250		Dropoff 90		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	251		Dropoff 91		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	252		Dropoff 92		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	253		Dropoff 116	This module is used for the Cranes to release the containers they handle.	Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	254		Dropoff 117		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	255		Dropoff 118		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	256		Dropoff 119		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	257		Dropoff 120		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	258		Dropoff 121		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	259		Dropoff 122		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	260		Dropoff 123		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	261		Dropoff 124		Quantity:1, Starting Rank:1, Member Attributes:Take All Representative Values
	262		Assign 117	It is used to assign the images of the containers emptied and filled in the animation.	Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	263		Assign 118		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	264		Assign 119		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	265		Assign 120		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	266		Assign 121		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	267		Assign 122		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	268		Assign 123		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	269		Assign 124		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	270		Assign 125		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	271		Assign 126		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list

	272		Assign 127		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	273		Assign 128		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	274		Assign 129		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	275		Assign 130		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	276		Assign 131		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	277		Assign 132		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	278		Assign 133		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	279		Assign 134		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	280		Assign 135		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	281		Assign 136		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	282		Assign 137		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	283		Assign 138		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	284		Assign 139		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	285		Assign 140		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	286		Assign 141		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	287		Assign 142		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	288		Assign 143		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	289		Assign 144		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	290		Assign 145		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	291		Assign 146		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	292		Assign 147		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	293		Assign 148		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	294		Assign 149		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	295		Assign 150		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	296		Assign 151		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	297		Assign 152		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	298		Assign 153		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	299		Assign 154		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	300		Assign 155		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	301		Assign 156		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	302		Assign 157		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	303		Assign 158		Assignements; Type:Entity Picture,Entity Picture:Picture.Container; End of list
	304		Signal 16	When the ship is discharged to the site, it is the signals from the unloaded containers to the trucks.	Signal Valua:16
	305		Signal 17		Signal Valua:16
	306		Signal 18		Signal Valua:16
	307		gemi1	These are the places where the ship is unloaded and the trucks are loaded.	Type: Infinite Hold, Queue Type: Queue, Queue Name:gemi1.Queue
	308		gemi2		Type: Infinite Hold, Queue Type: Queue, Queue Name:gemi2.Queue
	309		gemi3		Type: Infinite Hold, Queue Type: Queue, Queue Name:gemi3.Queue
	310		Separate 11	As the load brought by truck and loaded with SSG are 40", we divide them into 20" containers.	Type: Duplicate Original, Percen Cost to duplicates(0-100): 50, #of Duplicates: %1
	311		Separate 12		Type: Duplicate Original, Percen Cost to duplicates(0-100): 50, #of Duplicates: %1
	312		Separate 13		Type: Duplicate Original, Percen Cost to duplicates(0-100): 50, #of Duplicates: %1
	313		Batch 13	For the ship being loaded, the incoming containers are batch here and loaded to the ship.	Type:Permanent, Batch Size:1, Save Criterion:Last, Rule:Any Entity
	314		Batch 14		Type:Permanent, Batch Size:1, Save Criterion:Last, Rule:Any Entity
	315		Batch 15		Type:Permanent, Batch Size:1, Save Criterion:Last, Rule:Any Entity
	316		Batch 16		Type:Permanent, Batch Size:gemidolulugu1, Save Criterion:Last, Rule:Any Entity
	317		Batch 17		Type:Permanent, Batch Size:gemidolulugu2, Save Criterion:Last, Rule:Any Entity
	318		Batch 18		Type:Permanent, Batch Size:gemidolulugu3, Save Criterion:Last, Rule:Any Entity
	319		Signal 7	Sends a signal for the ships that have finished loading to leave the quay.	Signal Valua:7
	320		Signal 8		Signal Valua:8
	321		Signal 9		Signal Valua:9
	322		Hold 78	This is where the ship will take the container in the combined and finished loading process.	type:Infinite Hold, Queue Type:Queue, Queue Name:Hold 78.Queue
	323		Hold 79		type:Infinite Hold, Queue Type:Queue, Queue Name:Hold 79.Queue
	324		Hold 80		type:Infinite Hold, Queue Type:Queue, Queue Name:Hold 80.Queue
	325		Hold 101	During the loading and unloading of SSG and Cranes, if there is no container found to be loaded or unloaded, they hold here.	Type:Scan for Condition, Condition:((((Berth1Status == 0)&& (NQ(fullc1.Queue) > 5)) || ((Berth2Status == 0) && (NQ(fullc2.Queue) > 5) && (rýhtým2gemiboyu >= 140)) || ((Berth3Status == 0) && (NQ(fullc3.Queue) > 5)) && (rýhtým3gemiboyu >= 190)) || (((Berth1Status == 1) && (NQ(EmptyShip1.Queue) > 0)) || ((Berth2Status == 1) && (NQ(EmptyShip2.Queue) > 0) && (rýhtým2gemiboyu >= 140)) || ((Berth3Status == 1) && (NQ(EmptyShip3.Queue) > 0) && (rýhtým3gemiboyu >= 190)))), Queue Type:Queue, Queue Name:Hold 101.Queue

	326		Hold 102		Type:Scan for Condition, Condition:((((Berth1Status == 0)&& (NQ(fullc1.Queue) > 0)) || ((Berth2Status == 0)&& (NQ(fullc2.Queue) > 0)) || ((Berth3Status == 0)&& (NQ(fullc3.Queue) > 0))) || (((Berth1Status == 1) && (NQ(EmptyShip1.Queue) > 0)) || ((Berth2Status == 1) && (NQ(EmptyShip2.Queue) > 0)) || ((Berth3Status == 1) && (NQ(EmptyShip3.Queue) > 0)))), Queue Type:Queue, Queue Name:Hold 102.Queue
	327		Hold 103		Type:Scan for Condition, Condition:((((Berth1Status == 0)&& (NQ(fullc1.Queue) > 0)) || ((Berth2Status == 0)&& (NQ(fullc2.Queue) > 0)) || ((Berth3Status == 0)&& (NQ(fullc3.Queue) > 0))) || (((Berth1Status == 1) && (NQ(EmptyShip1.Queue) > 0)) || ((Berth2Status == 1) && (NQ(EmptyShip2.Queue) > 0)) || ((Berth3Status == 1) && (NQ(EmptyShip3.Queue) > 0)))), Queue Type:Queue, Queue Name:Hold 103.Queue
	328		Hold 104		Type:Scan for Condition, Condition:((((Berth1Status == 0)&& (NQ(fullc1.Queue) > 0)) || ((Berth2Status == 0)&& (NQ(fullc2.Queue) > 0)) || ((Berth3Status == 0)&& (NQ(fullc3.Queue) > 0))) || (((Berth1Status == 1) && (NQ(EmptyShip1.Queue) > 0)) || ((Berth2Status == 1) && (NQ(EmptyShip2.Queue) > 0)) || ((Berth3Status == 1) && (NQ(EmptyShip3.Queue) > 0)))), Queue Type:Queue, Queue Name:Hold 104.Queue
	329		Hold 105		Type:Scan for Condition, Condition:((((Berth1Status == 0)&& (NQ(fullc1.Queue) > 0)) || ((Berth2Status == 0)&& (NQ(fullc2.Queue) > 0)) || ((Berth3Status == 0)&& (NQ(fullc3.Queue) > 0))) || (((Berth1Status == 1) && (NQ(EmptyShip1.Queue) > 0)) || ((Berth2Status == 1) && (NQ(EmptyShip2.Queue) > 0)) || ((Berth3Status == 1) && (NQ(EmptyShip3.Queue) > 0))) && (((rihtim1 + rihtim2 + rihtim3) >= 2) || (totalgemiboyutu > 200))), Queue Type:Queue, Queue Name:Hold 105.Queue
	330		Hold 106		Type:Scan for Condition, Condition:((((Berth1Status == 0)&& (NQ(fullc1.Queue) > 0)) || ((Berth2Status == 0)&& (NQ(fullc2.Queue) > 0)) || ((Berth3Status == 0)&& (NQ(fullc3.Queue) > 0))) || (((Berth1Status == 1) && (NQ(EmptyShip1.Queue) > 0)) || ((Berth2Status == 1) && (NQ(EmptyShip2.Queue) > 0)) || ((Berth3Status == 1) && (NQ(EmptyShip3.Queue) > 0))) && (((rihtim1 + rihtim2 + rihtim3) >= 2) || (totalgemiboyutu > 200))), Queue Type:Queue, Queue Name:Hold 106.Queue
	331		Hold 107		Type:Scan for Condition, Condition:((((Berth1Status == 0)&& (NQ(fullc1.Queue) > 0)) || ((Berth2Status == 0)&& (NQ(fullc2.Queue) > 0)) || ((Berth3Status == 0)&& (NQ(fullc3.Queue) > 0))) || (((Berth1Status == 1) && (NQ(EmptyShip1.Queue) > 0)) || ((Berth2Status == 1) && (NQ(EmptyShip2.Queue) > 0)) || ((Berth3Status == 1) && (NQ(EmptyShip3.Queue) > 0))) && (((rihtim1 + rihtim2 + rihtim3) >= 2) || (totalgemiboyutu > 200))), Queue Type:Queue, Queue Name:Hold 107.Queue
	332		Hold 108		Type:Scan for Condition, Condition:((rýhtým1gemiboyu >= 190) || ((rihtim2 > 0) && (rýhtým1gemiboyu > 90)) || (rihtim3 > 0)), Queue Type:Queue, Queue Name:Hold 108.Queue
	333		Hold 109		Type:Scan for Condition, Condition:((((rihtim2 > 0) && (rýhtým1gemiboyu < 140) &&(rýhtým3gemiboyu < 90)) || ((rihtim2 > 0) && (rýhtým2gemiboyu >= 90))) || ((rihtim3 > 0) && (rýhtým3gemiboyu >= 90)) || ((rihtim1 > 0) && (rýhtým1gemiboyu >= 140))), Queue Type:Queue, Queue Name:Hold 109.Queue
	334		Hold 110		Type:Scan for Condition, Condition:(((rihtim1 > 0) && (rýhtým1gemiboyu >= 90)) || ((rihtim2 > 0) && (rýhtým3gemiboyu < 140)) || ((rihtim3 > 0) && (rýhtým3gemiboyu >= 140))), Queue Type:Queue, Queue Name:Hold 110.Queue
	335		Hold 112		Type:Scan for Condition, Condition:(((rihtim3 > 0) && (rihtim1 > 0) && (totalgemiboyutu > 225)) || ((rihtim1 > 0) && (rihtim2 > 0) && (totalgemiboyutu > 225))), Queue Type:Queue, Queue Name:Hold 112.Queue
	336		Hold 113		Type:Scan for Condition, Condition:(((rihtim3 > 0) && (rihtim1 > 0) && (totalgemiboyutu > 225)) || ((rihtim1 > 0) && (rihtim2 > 0) && (totalgemiboyutu > 225))), Queue Type:Queue, Queue Name:Hold 113.Queue
	337		Hold 114		Type:Scan for Condition, Condition:(((rihtim3 > 0) && (rihtim1 > 0) && (totalgemiboyutu > 225)) || ((rihtim1 > 0) && (rihtim2 > 0) && (totalgemiboyutu > 225))), Queue Type:Queue, Queue Name:Hold 114.Queue
	338		Record 4	Records the working times of SSGs and Cranes.	Statistic Definitions: `Type:Time Interval, Attribute Name:SSG1B1tnow, Tally Name:SSG1inBerth1_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	339		Record 5		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG1B2tnow, Tally Name:SSG1inBerth2_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	340		Record 6		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG1B3tnow, Tally Name:SSG1inBerth3_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	341		Record 7		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG2B1tnow, Tally Name:SSG2inBerth1_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	342		Record 8		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG2B2tnow, Tally Name:SSG2inBerth2_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	343		Record 9		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG2B3tnow, Tally Name:SSG2inBerth3_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	344		Record 10		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG3B2tnow, Tally Name:SSG3inBerth2_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	345		Record 11		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG3B3tnow, Tally Name:SSG3inBerth3_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	346		Record 12		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG3B1tnow, Tally Name:SSG3inBerth1_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	347		Record 13		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG4B3tnow, Tally Name:SSG4inBerth3_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	348		Record 14		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG4B2tnow, Tally Name:SSG4inBerth2_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	349		Record 15		Statistic Definitions: `Type:Time Interval, Attribute Name:SSG4B1tnow, Tally Name:SSG4inBerth1_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	350		Record 16		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane1B1tnow, Tally Name:Crane1inBerth1_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	351		Record 17		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane1B2tnow, Tally Name:Crane1inBerth2_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	352		Record 18		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane1B3tnow, Tally Name:Crane1inBerth3_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	353		Record 19		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane2B2tnow, Tally Name:Crane2inBerth2_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	354		Record 20		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane2B1tnow, Tally Name:Crane2inBerth1_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	355		Record 21		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane2B3tnow, Tally Name:Crane2inBerth3_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	356		Record 22		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane3B2tnow, Tally Name:Crane3inBerth2_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	357		Record 23		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane3B3tnow, Tally Name:Crane3inBerth3_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	358		Record 24		Statistic Definitions: `Type:Time Interval, Attribute Name:Crane3B1tnow, Tally Name:Crane3inBerth1_TimeInterval`, End of list:` type: Value:1 Counter Name: Counter 1`
	359		Assign 166	It is used for the sum of the recorded periods of SSG and Cranes.	Assignements; Type:Variable, Variable Name:TotalTimeIntervalSSG1Berth1, New Value:TotalTimeIntervalSSG1Berth1 + TVALUE(SSG1inBerth1_TimeInterval); End of list
	360		Assign 167		Assignements; Type:Variable, Variable Name:TotalTimeIntervalSSG1Berth2, New Value:TotalTimeIntervalSSG1Berth2 + TVALUE(SSG1inBerth2_TimeInterval); End of list
	361		Assign 168		Assignements; Type:Variable, Variable Name:TotalTimeIntervalSSG1Berth3 , New Value:TotalTimeIntervalSSG1Berth3 + TVALUE(SSG1inBerth3_TimeInterval); End of list
	362		Assign 169		Assignements; Type:Variable, Variable Name:TotalTimeIntervalSSG2Berth1 , New Value:TotalTimeIntervalSSG2Berth1 + TVALUE(SSG2inBerth1_TimeInterval); End of list
	363		Assign 170		Assignements; Type:Variable, Variable Name: TotalTimeIntervalSSG2Berth2, New Value:TotalTimeIntervalSSG2Berth2 + TVALUE(SSG2inBerth2_TimeInterval); End of list
	364		Assign 171		Assignements; Type:Variable, Variable Name:TotalTimeIntervalSSG2Berth3, New Value:; End of list
	365		Assign 172		Assignements; Type:Variable, Variable Name: TotalTimeIntervalSSG3Berth2, New Value:TotalTimeIntervalSSG2Berth3 + TVALUE(SSG2inBerth3_TimeInterval); End of list
	366		Assign 173		Assignements; Type:Variable, Variable Name:TotalTimeIntervalSSG3Berth2 , New Value:TotalTimeIntervalSSG3Berth2 + TVALUE(SSG3inBerth2_TimeInterval); End of list

	367		Assign 174		Assignements; Type:Variable, Variable Name:TotalTimeIntervalSSG3Berth3 , New Value:TotalTimeIntervalSSG3Berth3 + TVALUE(SSG3inBerth3_TimeInterval); End of list
	368		Assign 175		Assignements; Type:Variable, Variable Name: TotalTimeIntervalSSG3Berth1, New Value:TotalTimeIntervalSSG3Berth1 + TVALUE(SSG3inBerth1_TimeInterval); End of list
	369		Assign 177		Assignements; Type:Variable, Variable Name: TotalTimeIntervalSSG4Berth3, New Value:TotalTimeIntervalSSG4Berth3 + TVALUE(SSG4inBerth3_TimeInterval); End of list
	370		Assign 178		Assignements; Type:Variable, Variable Name: TotalTimeIntervalSSG4Berth1, New Value:TotalTimeIntervalSSG4Berth1 + TVALUE(SSG4inBerth1_TimeInterval); End of list
	371		Assign 179		Assignements; Type:Atribute, Atribute Name: Crane1B3tnow, New Value:TNOW; End of list
	372		Assign 180		Assignements; Type:Atribute, Atribute Name: Crane1B2tnow, New Value:TNOW; End of list
	373		Assign 181		Assignements; Type:Atribute, Atribute Name: Crane1B1tnow, New Value:TNOW; End of list
	374		Assign 182		Assignements; `Type:Variable, Variable Name: Crane1inBerth1, New Value:Crane1inBerth1 + 1;`,`Type:Variable, Variable Name: TotalTimeIntervalCrane1Berth1, New Value:TotalTimeIntervalCrane1Berth1 + TVALUE(Crane1inBerth1_TimeInterval);`, End of list
	375		Assign 183		Assignements; `Type:Variable, Variable Name: Crane1inBerth2, New Value:Crane1inBerth2 +1;`,`Type:Variable, Variable Name: TotalTimeIntervalCrane1Berth2, New Value:TotalTimeIntervalCrane1Berth2 + TVALUE(Crane1inBerth2_TimeInterval);`, End of list
	376		Assign 184		Assignements; `Type:Variable, Variable Name: Crane1inBerth3, New Value:Crane1inBerth3 + 1;`,`Type:Variable, Variable Name: TotalTimeIntervalCrane1Berth3, New Value:TotalTimeIntervalCrane1Berth3 + TVALUE(Crane1inBerth3_TimeInterval);`, End of list
	377		Assign 185		Assignements; Type:Atribute, Atribute Name: Crane2B2tnow, New Value:TNOW; End of list
	378		Assign 186		Assignements; Type:Atribute, Atribute Name: Crane2B1tnow, New Value:TNOW; End of list
	379		Assign 187		Assignements; Type:Atribute, Atribute Name: Crane2B3tnow, New Value:TNOW; End of list
	380		Assign 188		Assignements; `Type:Variable, Variable Name: TotalTimeIntervalCrane2Berth2, New Value:TotalTimeIntervalCrane2Berth2 + TVALUE(Crane2inBerth2_TimeInterval);`,`Type:Variable, Variable Name: Crane2inBerth2, New Value:Crane2inBerth2 + 1;`, End of list
	381		Assign 189		Assignements; `Type:Variable, Variable Name:TotalTimeIntervalCrane2Berth1 , New Value:TotalTimeIntervalCrane2Berth1 + TVALUE(Crane2inBerth1_TimeInterval);`,`Type:Variable, Variable Name: Crane2inBerth1, New Value:Crane2inBerth1 + 1;`, End of list
	382		Assign 190		Assignements; `Type:Variable, Variable Name:TotalTimeIntervalCrane2Berth3 , New Value:TotalTimeIntervalCrane2Berth3 + TVALUE(Crane2inBerth3_TimeInterval);`,`Type:Variable, Variable Name: Crane2inBerth3, New Value:Crane2inBerth3 + 1;`, End of list
	383		Assign 191		Assignements; Type:Atribute, Atribute Name: Crane3B1tnow, New Value:TNOW; End of list
	384		Assign 192		Assignements; Type:Atribute, Atribute Name: Crane3B3tnow, New Value:TNOW; End of list
	385		Assign 193		Assignements; Type:Atribute, Atribute Name: Crane3B2tnow, New Value:TNOW; End of list
	386		Assign 194		Assignements; `Type:Variable, Variable Name:TotalTimeIntervalCrane3Berth2 , New Value:TotalTimeIntervalCrane3Berth2 + TVALUE(Crane3inBerth2_TimeInterval);`, `Type:Variable, Variable Name: Crane3inBerth2, New Value:Crane3inBerth2 + 1;`,End of list
	387		Assign 195		Assignements; `Type:Variable, Variable Name: , New Value:;`,`Type:Variable, Variable Name: , New Value:;`, End of list
	388		Assign 196		Assignements; `Type:Variable, Variable Name: TotalTimeIntervalCrane3Berth3, New Value:TotalTimeIntervalCrane3Berth3 + TVALUE(Crane3inBerth3_TimeInterval);`,`Type:Variable, Variable Name:Crane3inBerth3 , New Value:Crane3inBerth3 + 1;`, End of list
	389		hold 167		Type:Scan for Condition, Condition:(Berth1Status == 1) || (NQ(fullc1.Queue) > 5), Queue Type:Queue, Queue Name:Hold 167.Queue
	390		hold 168		Type:Scan for Condition, Condition:(Berth2Status == 1) || (NQ(fullc2.Queue) > 5), Queue Type:Queue, Queue Name:Hold 168.Queue
	391		hold 169		Type:Scan for Condition, Condition:(Berth3Status == 1) || (NQ(fullc3.Queue) > 5), Queue Type:Queue, Queue Name:Hold 169.Queue
	392		hold 170		Type:Scan for Condition, Condition:(Berth1Status == 1) || (NQ(fullc1.Queue) > 5), Queue Type:Queue, Queue Name:Hold 170.Queue
	393		hold 171		Type:Scan for Condition, Condition:(Berth2Status == 1) || (NQ(fullc2.Queue) > 5), Queue Type:Queue, Queue Name:Hold 171.Queue
	394		hold 172		Type:Scan for Condition, Condition:(Berth3Status == 1) || (NQ(fullc3.Queue) > 5), Queue Type:Queue, Queue Name:Hold 172.Queue
	395		hold 173		Type:Scan for Condition, Condition:(Berth2Status == 1) || (NQ(fullc2.Queue) > 5), Queue Type:Queue, Queue Name:Hold 173.Queue
	396		hold 174		Type:Scan for Condition, Condition:(Berth3Status == 1) || (NQ(fullc3.Queue) > 5), Queue Type:Queue, Queue Name:Hold 172.Queue
	397		hold 175		Type:Scan for Condition, Condition:(Berth1Status == 1) || (NQ(fullc1.Queue) > 5), Queue Type:Queue, Queue Name:Hold 175.Queue
	398		hold 176		Type:Scan for Condition, Condition:(Berth3Status == 1) || (NQ(fullc3.Queue) > 5), Queue Type:Queue, Queue Name:Hold 176.Queue
	399		hold 177		Type:Scan for Condition, Condition:(Berth2Status == 1) || (NQ(fullc2.Queue) > 5), Queue Type:Queue, Queue Name:Hold 177.Queue
	400		hold 178		Type:Scan for Condition, Condition:(Berth1Status == 1) || (NQ(fullc1.Queue) > 5), Queue Type:Queue, Queue Name:Hold 178.Queue
	401		hold 179		Type:Scan for Condition, Condition:(Berth1Status == 1) || (NQ(fullc1.Queue) > 5), Queue Type:Queue, Queue Name:Hold 179.Queue
	402		hold 180		Type:Scan for Condition, Condition:(Berth2Status == 1) || (NQ(fullc2.Queue) > 5), Queue Type:Queue, Queue Name:Hold 180.Queue
	403		hold 181		Type:Scan for Condition, Condition:(Berth3Status == 1) || (NQ(fullc3.Queue) > 5), Queue Type:Queue, Queue Name:Hold 181.Queue
	404		hold 182		Type:Scan for Condition, Condition:(Berth2Status == 1) || (NQ(fullc2.Queue) > 5), Queue Type:Queue, Queue Name:Hold 182.Queue
	405		hold 183		Type:Scan for Condition, Condition:(Berth1Status == 1) || (NQ(fullc1.Queue) > 5), Queue Type:Queue, Queue Name:Hold 183.Queue
	406		hold 184		Type:Scan for Condition, Condition:(Berth3Status == 1) || (NQ(fullc3.Queue) > 5), Queue Type:Queue, Queue Name:Hold 184.Queue
	407		hold 185		Type:Scan for Condition, Condition:(Berth2Status == 1) || (NQ(fullc2.Queue) > 5), Queue Type:Queue, Queue Name:Hold 185.Queue
	408		hold 186		Type:Scan for Condition, Condition:(Berth3Status == 1) || (NQ(fullc3.Queue) > 5), Queue Type:Queue, Queue Name:Hold 186.Queue
	409		hold 187		Type:Scan for Condition, Condition:(Berth1Status == 1) || (NQ(fullc1.Queue) > 5), Queue Type:Queue, Queue Name:Hold 187.Queue
	410		Assign 227		Assignements;Type:Atribute, Atribute Name: SSG1B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth1, New Value:SSG1inBerth1 + 1; End of list
	411		Assign 228		Assignements;Type:Atribute, Atribute Name: SSG1B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth1, New Value:SSG1inBerth1 + 1; End of list
	412		Assign 229		Assignements;Type:Atribute, Atribute Name: SSG1B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth2, New Value:SSG1inBerth2 + 1; End of list
	413		Assign 230		Assignements;Type:Atribute, Atribute Name: SSG1B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth2, New Value:SSG1inBerth2 + 1; End of list
	414		Assign 231		Assignements;Type:Atribute, Atribute Name: SSG1B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth1, New Value:SSG1inBerth1 - 1; End of list
	415		Assign 232		Assignements;Type:Atribute, Atribute Name: SSG1B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth2, New Value:SSG1inBerth2 - 1; End of list

	416		Assign 233		Assignements;Type:Atribute, Atribute Name: SSG1B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth3, New Value:SSG1inBerth3 + 1; End of list
	417		Assign 234		Assignements;Type:Atribute, Atribute Name: SSG1B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth3, New Value:SSG1inBerth3 + 1; End of list
	418		Assign 235		Assignements;Type:Atribute, Atribute Name: SSG1B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG1inBerth3, New Value:SSG1inBerth3 - 1; End of list
	419		Assign 236		Assignements;Type:Atribute, Atribute Name: SSG2B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth1, New Value:SSG2inBerth1 + 1; End of list
	420		Assign 237		Assignements;Type:Atribute, Atribute Name: SSG2B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth1, New Value:SSG2inBerth1 + 1; End of list
	421		Assign 238		Assignements;Type:Atribute, Atribute Name: SSG2B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth1, New Value:SSG2inBerth1 - 1; End of list
	422		Assign 239		Assignements;Type:Atribute, Atribute Name: SSG2B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth2, New Value:SSG2inBerth2 + 1; End of list
	423		Assign 240		Assignements;Type:Atribute, Atribute Name: SSG2B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth2, New Value:SSG2inBerth2 + 1; End of list
	424		Assign 241		Assignements;Type:Atribute, Atribute Name: SSG2B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth2, New Value:SSG2inBerth2 - 1; End of list
	425		Assign 242		Assignements;Type:Atribute, Atribute Name: SSG2B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth3, New Value:SSG2inBerth3 + 1; End of list
	426		Assign 243		Assignements;Type:Atribute, Atribute Name: SSG2B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth3, New Value:SSG2inBerth3 + 1; End of list
	427		Assign 244		Assignements;Type:Atribute, Atribute Name: SSG2B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG2inBerth3, New Value:SSG2inBerth3 - 1; End of list
	428		Assign 245		Assignements;Type:Atribute, Atribute Name: SSG3B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth2, New Value:SSG3inBerth2 + 1; End of list
	429		Assign 246		Assignements;Type:Atribute, Atribute Name: SSG3B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth2, New Value:SSG3inBerth2 + 1; End of list
	430		Assign 247		Assignements;Type:Atribute, Atribute Name: SSG3B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth2, New Value:SSG3inBerth2 - 1; End of list
	431		Assign 248		Assignements;Type:Atribute, Atribute Name: SSG3B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth3, New Value:SSG3inBerth3 + 1; End of list
	432		Assign 249		Assignements;Type:Atribute, Atribute Name: SSG3B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth3, New Value:SSG3inBerth3 + 1; End of list
	433		Assign 250		Assignements;Type:Atribute, Atribute Name: SSG3B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth3, New Value:SSG3inBerth3 - 1; End of list
	434		Assign 251		Assignements;Type:Atribute, Atribute Name: SSG3B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth1, New Value:SSG3inBerth1 + 1; End of list
	435		Assign 252		Assignements;Type:Atribute, Atribute Name: SSG3B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth1, New Value:SSG3inBerth1 + 1; End of list
	436		Assign 253		Assignements;Type:Atribute, Atribute Name: SSG3B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG3inBerth1, New Value:SSG3inBerth1 - 1; End of list
	437		Assign 254		Assignements;Type:Atribute, Atribute Name: SSG4B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth3, New Value:SSG4inBerth3 + 1; End of list
	438		Assign 255		Assignements;Type:Atribute, Atribute Name: SSG4B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth3, New Value:SSG4inBerth3 + 1; End of list
	439		Assign 256		Assignements;Type:Atribute, Atribute Name: SSG4B3tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth3, New Value:SSG4inBerth3 - 1; End of list
	440		Assign 257		Assignements;Type:Atribute, Atribute Name: SSG4B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth2, New Value:SSG4inBerth2 + 1; End of list
	441		Assign 258		Assignements;Type:Atribute, Atribute Name: SSG4B2tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth2, New Value:SSG4inBerth2 + 1; End of list
	442		Assign 259		Assignements;Type:Atribute, Atribute Name: SSG4B2tnow, New Value, TNOW; End of list
	443		Assign 260		Assignements;Type:Atribute, Atribute Name: SSG4B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth1, New Value:SSG4inBerth1 + 1; End of list
	444		Assign 261		Assignements;Type:Atribute, Atribute Name: SSG4B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth1, New Value:SSG4inBerth1 + 1; End of list
	445		Assign 262		Assignements;Type:Atribute, Atribute Name: SSG4B1tnow, New Value, TNOW; Type:Variable, Variable Name: SSG4inBerth1, New Value:SSG4inBerth1 - 1; End of list
	446		Assign 264		Assignements; Type:Atribute, Atribute Name: Crane1B1tnow, New Value:TNOW; End of list
	447		Assign 265		Assignements; Type:Atribute, Atribute Name: Crane1B2tnow, New Value:TNOW; End of list
	448		Assign 266		Assignements; Type:Atribute, Atribute Name: Crane1B3tnow, New Value:TNOW; End of list
	449		Assign 267		Assignements; Type:Atribute, Atribute Name: Crane2B2tnow, New Value:TNOW; End of list
	450		Assign 268		Assignements; Type:Atribute, Atribute Name: Crane2B1tnow, New Value:TNOW; End of list
	451		Assign 269		Assignements; Type:Atribute, Atribute Name: Crane2B3tnow, New Value:TNOW; End of list
	452		Assign 270		Assignements; Type:Atribute, Atribute Name: Crane3B2tnow, New Value:TNOW; End of list
	453		Assign 271		Assignements; Type:Atribute, Atribute Name: Crane3B3tnow, New Value:TNOW; End of list
	454		Assign 272		Assignements; Type:Atribute, Atribute Name: Crane3B1tnow, New Value:TNOW; End of list

Appendix 6: Assignment` Logic of Cranes and SSG to Ships in Berths

SSG Logic

SSG1

```
IF berth1 > 0 GO TO Berth 1
IF NOT
    IF ((berth2 > 0) && (berth2shipLOA >= 90) && (berth3shipLOA >= 90)) || ((berth3 == 0) && (berth2shipLOA >= 140)) || ((berth2 > 0) && (berth3shipLOA >= 140)) GO TO Berth 2
    IF NOT
        IF (berth3 > 0) && (berth3shipLOA >=190) GO TO Berth 3
        IF NOT Strat Again
```

SSG2

```
IF (berth1 > 0) && (berth1shipLOA >= 90) GO TO Berth 1
IF NOT
    IF (berth2 > 0) && (berth3shipLOA < 140) GO TO Bert 2
    IF NOT
        IF (berth3 > 0) && (berth3shipLOA >= 140 GO TO Berth 3
        IF NOT Strat Again
```

SSG3

```
IF ((berth2 > 0) && (berth1shipLOA < 140) && (berth3shipLOA < 90)) || ((berth2 > 0) && (berth2shipLOA >= 90)) GO TO Berth 2
IF NOT
    IF (berth3> 0) && (berth3shipLOA >= 90) GO TO Berth 3
    IF NOT
        IF (berth1 > 0) && (berth1shipLOA >= 140) GO TO Berth 1
        IF NOT Strat Again
```

SSG4

```
IF berth3 > 0 GO TO Berth 3
IF NOT
    IF (berth2 > 0) && (berth1shipLOA > 90) GO TO Berth 2
    IF NOT
        IF (berth1shipLOA >= 190) GO TO Berth 1
        IF NOT Strat Again
```

CRANES Logic

Crane 1

```
IF (berth1 > 0) && (totalshipLOA >= 225) && ((berth2> 0) || (berth3 > 0))) || ((berth1> 0) && (totalshipLOA >= 250) && (berth2 == 0) &&( berth3> 0) && ((berth3shipLOA >=90) || (berth1 > 0) )) || ((berth1> 0) && (totalshipLOA >= 225) && (berth2 == 0) &&(berth3> 0)) || ((berth1> 0)&&( berth2> 0) && (berth1shipLOA >= 170) && (berth2shipLOA >= 90) GO TO Berth 1
IF NOT
    IF (((berth2 >0) && (berth2shipLOA >= 220)) || ((berth2> 0) && (totalshipLOA >= 225) &&(berth1>0) && (berth3> 0)) || ((berth2> 0) && (berth2shipLOA >=
```

```
    90) && (berth2shipLOA <= 190) && (berth1> 0) && (berth3> 0) && (totalshipLOA > 225))) GO TO Berth 2
    IF NOT
        IF (((berth3 > 0) && ( totalshipLOA > 250)) || ((berth3> 0) && (berth3shipLOA >= 170) &&( berth2>0) && (berth2shipLOA>= 140) && ( berth1== 0)) || ((berth3> 0) && (totalshipLOA > 225) && (berth1> 0))) GO TO Berth 3
        IF NOT Strat Again
```

Crane 2

```
IF ((berth2 > 0) && (berth2shipLOA <90) && (berth1shipLOA >= 190) && ((berth3> 0) && (berth3shipLOA< 90)) || (berth3== 0)) || ((berth2 > 0) && (berth2shipLOA <=90) && (berth1> 0) && (berth3shipLOA >= 90)) || ((berth2 > 0) && (berth2shipLOA >= 90) && (berth2shipLOA <140) && (berth3> 0) && (berth1shipLOA >= 90)) || ((berth2shipLOA >=90) && (berth2shipLOA <140)) && berth3shipLOA >= 140) && (berth1> 0) && (berth1shipLOA <90) || ((berth2shipLOA >=140) && (berth2shipLOA <190) && (berth1> 0) && (berth3> 0 ))|| (( berth2shipLOA >=140) && ( berth2shipLOA <190 ) && ( berth1==0) && (berth3shipLOA >= 90)) ||  ((berth2 > 0) && (totalshipLOA > 225) && (berth2shipLOA <190) && ((berth3==0) && (berth1> 0) && (totalshipLOA > 225))) || (berth2shipLOA >=190) GO TO Berth 2
IF NOT
    IF (((berth1 > 0) && (totalshipLOA > 225) && (berth2> 0)) || ((berth1> 0) && (totalshipLOA > 225) && (berth2>0) && (berth2shipLOA >=90) && (berth2shipLOA <140)) ||((berth1 > 0) && ( berth1shipLOA >= 190) && (berth2> 0) && (totalshipLOA > 225))) GO TO Berth 1
    IF NOT
        IF (((berth3 > 0) && (totalshipLOA > 225)) ||  ((berth3 > 0) && (berth2 > 0) && (berth1== 0) && (berth3shipLOA >= 190) && (berth2shipLOA <140)) ||  ((berth3 > 0) && (berth2 ==0) && (berth1>0) && (totalshipLOA >= 225))) GO TO Berth 3
        IF NOT Strat Again
```

Crane 3

```
IF ((berth3 > 0) && (totalshipLOA > 225) && (berth2 > 0) && (berth2shipLOA >= 90) && (berth1 > 0)) || ((berth3 > 0) && (totalshipLOA > 225) && (berth2 > 0) && (berth2shipLOA>= 140) && (berth1 ==0)) || ((berth1 > 0) && (berth2 > 0) && (totalshipLOA > 225)) GO TO Berth 2
IF NOT
    IF ((berth3 > 0) && (totalshipLOA > 225)) || ((berth2> 0) && (totalshipLOA > 225) &&(berth1>0) && (berth3> 0)) || ((berth2> 0) && (berth2shipLOA>= 90) && (berth2shipLOA<= 190) &&( berth1> 0) && (berth3> 0)&& (berth3shipLOA >= 90) && (berth1shipLOA >= 90)) || ((berth2>0) && (berth2shipLOA >=140) &&(berth1>0) && (berth1shipLOA >=190) && (berth3== 0)) || ((berth2> 0 )&&(berth2shipLOA >190) &&(berth1>0)) GO TO Berth 3
    IF NOT
        IF ((berth1 > 0) && (totalshipLOA > 225) && (berth2 == 0) && (berth3 ==0)) || ((berth1 > 0) && (totalshipLOA > 225) && (berth2> 0)) GO TO Berth 1
        IF NOT Strat Again
```

Appendix 7: Container Storages Areas and Truck Logic of ARENA Module

Table A7. 1 Description Table of Container Storages Areas and Truck Logic of ARENA Module.

Number	Module Name	Definition	Properties and Function
1	Create 44	Truck entries to the system are made from this module.	Entity Type:Trucks, `Time Between Arrivals; Type:Rondom(Expo), Value:1, Units: Hours, Entities per Arrival: 31, Max Arrivals:1, First Creation:0.0`
2	Hold 159	The trucks are held in the Hold Module unit until the ship berthing quay and start unloading.	Type:Scan for Condition, Condition:`(NQ(gemi1.Queue) > 0) || (NQ(gemi2.Queue) > 0) || (NQ(gemi3.Queue) > 0) ||(Berth1Status == 1) || (Berth2Status == 1) || (Berth3Status == 1)`, Queue Type:Queue, Queue Name:Hold 159.Queue
3	Decide 460	Decides whether or not trucks are going to unload.	Type:2-way by Condition, If:Expression, Value:((NQ(gemi1.Queue) + NQ(gemi2.Queue) + NQ(gemi3.Queue)) == 0) && (Berth1Status == 1) || (Berth2Status == 1) || (Berth3Status == 1), End of List
4	Route 361	It sends the trucks to the loading process.	Route Time:0, Unites:Hours, Destination Type:Station, Station Name:TruckDecideLogic
5	Decide 336	During the evacuation, he decides which quay the trucks will go to.	Type:N-way by Conditor, Conditions; `if:Expression, Value:(NQ(gemi1.Queue) + NQ(gemi2.Queue) + NQ(gemi3.Queue)) == 0`, `if:Expression, Value:(NQ(gemi1.Queue) >= NQ(gemi2.Queue)) && (NQ(gemi1.Queue) >= NQ(gemi3.Queue))`, `if:Expression, Value:NQ(gemi2.Queue) >= NQ(gemi3.Queue)`,End of list
6	Assign 220	The starting time of the trucks (while they are unloading) and the data of the containers they carry are recorded here.	Assignements; Type:Attribute,AttributeName:TruckTime, New Value:TNOW, Type:Variable, Variable Name:ContainersFromBerth1, New Value:ContainersFromBerth1 + 1
7	Assign 221		Assignements; Type:Attribute,AttributeName:TruckTime, New Value:TNOW, Type:Variable, Variable Name:ContainersFromBerth2, New Value:ContainersFromBerth2 + 1
8	Assign 222		Assignements; Type:Attribute,AttributeName:TruckTime, New Value:TNOW, Type:Variable, Variable Name:ContainersFromBerth3, New Value:ContainersFromBerth3 + 1
9	Station 145	They indicate the direction of the trucks in the system during discharge.	Station Type:Station, Station Name: Station 145
10	Station 146		Station Type:Station, Station Name: Station 146
11	Station 147		Station Type:Station, Station Name: Station 147
12	Station 148		Station Type:Station, Station Name: Station 148
13	Station 149		Station Type:Station, Station Name: Station 149
14	Station 150		Station Type:Station, Station Name: Station 150
15	Route 269		Route Time:0, Unites:Hours, Destination Type:Station, Station Name:Station 148
16	Route 270		Route Time:0, Unites:Hours, Destination Type:Station, Station Name:Station 149
17	Route 271		Route Time:0, Unites:Hours, Destination Type:Station, Station Name:Station 150
18	Pickup 119	Assigns containers to trucks assigned to berths.	Quantitiy:1, Queue Type:Queue, Starting Rank:1, Queue Name:ship1.Queue
19	Pickup 120		Quantitiy:1, Queue Type:Queue, Starting Rank:1, Queue Name:ship2.Queue
20	Pickup 121		Quantitiy:1, Queue Type:Queue, Starting Rank:1, Queue Name:ship3.Queue
21	Decide 461	Determines whether containers loaded into trucks are full or empty.	Type:2-way by Chance, Percent True (0-100):72.3%
22	Decide 462		Type:2-way by Chance, Percent True (0-100):72.3%
23	Decide 463		Type:2-way by Chance, Percent True (0-100):72.3%
24	EmptyDecide	Decides which area of the port field will be suitable to be unloaded empty containers in trucks.	Type:N-way by Conditor, Conditions; `if:Expression, Value:( NQ(G1.Queue) <= NQ(G2.Queue) ) && ( NQ(G1.Queue) <= NQ(G3.Queue) ) && ( NQ(G1.Queue) <= NQ(G4.Queue) )`, `if:Expression, Value:( NQ(G2.Queue) <= NQ(G3.Queue) ) && ( NQ(G2.Queue) <= NQ(G4.Queue) )`, `if:Expression, Value:(NQ(G3.Queue) <= NQ(G4.Queue)), End of List
25	Decide 338	Determines where the full containers in trucks transported in the port field.	Type:N-way by Conditor, Conditions; `if:Expression, Value:( NQ(D4.Queue) <= NQ(D5.Queue) ) && ( NQ(D4.Queue) <= NQ(D6.Queue) )`, `if:Expression, Value:( NQ(D5.Queue) <= NQ(D6.Queue) )`, End of List

26	Decide 430	Distinguishes REEFERs in full containers.	Type:2-way by Chance, Percent True (0-100):99%
27	Decide 431	Decides which area the reefer will go to in the port field.	Type:2-way by Conditor, Conditions; `if:Expression, Value:NQ(Reefer1.Queue) <= NQ(Reefer2.Queue)`
28	Station 60	Specifies the stations of the trucks loaded from the ship to go to the site.	Station Type:Station, Station Name:Station 60
29	Station 61		Station Type:Station, Station Name:Station 61
30	Station 62		Station Type:Station, Station Name:Station 62
31	Station 65		Station Type:Station, Station Name:Station 65
32	Station 66		Station Type:Station, Station Name:Station 66
33	Station 67		Station Type:Station, Station Name:Station 67
34	Station 68		Station Type:Station, Station Name:Station 68
35	Station 156		Station Type:Station, Station Name:Station 156
36	Station 157		Station Type:Station, Station Name:Station 157
37	Route 262	Route modules that direct trucks to the site	Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 52
38	Route 263		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 53
39	Route 264		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 63
40	Route 265		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 64
41	Route 266		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 42
42	Route 267		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 41
43	Route 268		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 39
44	Route 272		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station 54
45	Route 273		Route Time:UNIF(10,14.5), Units:Minutes, Destination Type:Station, Station Name:Station46
46	TruckDecideLogic	Sends the trucks to the port field for loading.	Station Type: Station, Station Name:TruckDecideLogic
47	Record 28	Records the transport times for unloading trucks	Statistic Definitions:Type: Time Interval, Attribute Name:TruckTime, Tally Name:Unloading_Truck_Time, End of List
48	Assign 223	The total times of transport times of trucks (while they are unloading) are recorded here	Assigments:Type:Varible, Varible Name:TotalUnloadingTruckTime, New Value:TotalUnloadingTruckTime + TVALUE(Unloading_Truck_Time), End of List
49	Record 29	Saves the carrying times for the unit product of loading trucks	Statistic Definitions:Type: Time Interval, Attribute Name:TruckTime, Tally Name:Unloading_Truck_Time, End of List
50	Assign 108	Counts total truck movement for loading process	Assigments:Type:Varible, Varible Name:tt4, New Value:tt4+1, Type:Varible, Varible Name:TotalLoadingTruckTime, New Value:TotalLoadingTruckTime + TVALUE(Loading_Truck_Time), End of List
51	Hold 160	The trucks sent for loading are held here if there are no ships in the quay.	Type:Scan for Condition, Condition:`(((Berth1Status + Berth2Status + Berth3Status)==1) ‖ ((Berth1Status + Berth2Status + Berth3Status)==6) ‖ ((Berth1Status + Berth2Status + Berth3Status)==11)) ‖ ((Berth1Status + Berth2Status + Berth3Status) == 2) ‖ ((Berth1Status + Berth2Status + Berth3Status) == 7) ‖ ((Berth1Status + Berth2Status + Berth3Status) == 3) ‖ ((Berth1Status + Berth2Status + Berth3Status) == 0) ‖ (NQ(gemi1.Queue) >= 35) ‖ (NQ(gemi2.Queue) >= 35) ‖ (NQ(gemi3.Queue) >= 35)`, Queue Type:Queue, Queue Name:Hold 160.Queue
52	Decide 339	It is the decision place that makes the assignment of the trucks according to the loading or unloading of the ships at the quay.	Type:N-way by Conditor , Conditions;((Berth1Status + Berth2Status + Berth3Status)==1) ‖ ((Berth1Status + Berth2Status + Berth3Status)==6) ‖ ((Berth1Status + Berth2Status + Berth3Status)==11) `if:Expression, Value:`,`if:Expression, Value:(Berth1Status + Berth2Status + Berth3Status) == 2 `, `if:Expression, Value:(Berth1Status + Berth2Status + Berth3Status) == 7` , `if:Expression, Value:(Berth1Status + Berth2Status + Berth3Status) == 3` , End of List
53	whichshipempty1	These Decide modules assign trucks according to the state of the berths. If there is no ship in the quay, the berth value is 5, If the ship is docked and emptied at the	Type:N-way by Conditor , If:Expression, Value:`(Berth1Status == 1)`, If:Expression, Value:`(Berth2Status == 1)`, End of List
54	Decide 340		Type:N-way by Conditor , If:Expression, Value:`Berth3Status == 0`, If:Expression, Value:`Berth2Status == 0`, End of List
55	Decide 341		Type:N-way by Conditor, If:Expression, Value:`NumberofSSGinBerth1 == 1`, If:Expression, Value:`NumberofSSGinBerth1 == 2`,If:Expression, Value:`NumberofSSGinBerth1 == 3`, End of List

<table>
<tr><td>56</td><td>Decide 342</td><td rowspan="37">berth, the berth value is 0,
If there are ships on the quay and loading is done, the quay value is assigned to 1. According to this, the sum of the berth values can be The sum of the berth values indicates different conditions at the berth. For example, in the case of a berth of 6, the docks may have the following conditions;
105,150,510,501,051,015
For example: 105 status; 1. shows the loading on the quay, 2. unloading on the quay and the 3rd quay on the quay. Decide modules in each of them makes the truck assignment according to all possibilities.
It does not designate only according to the condition of the docks; it also assigns trucks according to the number of SSGs on the docks.
E.g; The number of SSGs on the quay, if two, will direct half of the incoming trucks to this berth.</td><td>Type:N-way by Conditor, If:Expression, Value:`NumberofSSGinBerth2 == 1`,If:Expression, Value:`NumberofSSGinBerth2 == 2`,If:Expression, Value:`NumberofSSGinBerth2 == 3`, End of List</td></tr>
<tr><td>57</td><td>Decide 343</td><td>Type:2-way by Chance, Percent True(0-100): 25%</td></tr>
<tr><td>58</td><td>Decide 344</td><td>Type:2-way by Chance, Percent True(0-100): 50%</td></tr>
<tr><td>59</td><td>Decide 345</td><td>Type:2-way by Chance, Percent True(0-100):75%</td></tr>
<tr><td>60</td><td>Decide 346</td><td>Type:2-way by Chance, Percent True(0-100): 25%</td></tr>
<tr><td>61</td><td>Decide 347</td><td>Type:2-way by Chance, Percent True(0-100): 50%</td></tr>
<tr><td>62</td><td>Decide 348</td><td>Type:2-way by Chance, Percent True(0-100):75%</td></tr>
<tr><td>63</td><td>Decide 349</td><td>Type:N-way by Conditor, If:Expression, Value:`NumberofSSGinBerth3 == 1`,If:Expression, Value:`NumberofSSGinBerth3 == 2`,If:Expression, Value:`NumberofSSGinBerth3 == 3`, End of List</td></tr>
<tr><td>64</td><td>Decide 350</td><td>Type:2-way by Chance, Percent True(0-100): 25%</td></tr>
<tr><td>65</td><td>Decide 351</td><td>Type:2-way by Chance, Percent True(0-100): 50%</td></tr>
<tr><td>66</td><td>Decide 352</td><td>Type:2-way by Chance, Percent True(0-100):75%</td></tr>
<tr><td>67</td><td>Decide 353</td><td>Type:2-way by Condition, If:Expression, Value:`NumberofSSGinBerth3 == 1`, End of List</td></tr>
<tr><td>68</td><td>Decide 354</td><td>Type:2-way by Condition, If:Expression, Value:`NumberofSSGinBerth1 == 2`, End of List</td></tr>
<tr><td>69</td><td>Decide 355</td><td>Type:N-way by Chance, Percentage True(0-100):`50`,Percentage True(0-100):`25`, End of List</td></tr>
<tr><td>70</td><td>Decide 356</td><td>Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`50`, End of List</td></tr>
<tr><td>71</td><td>Decide 357</td><td>Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`25`, End of List</td></tr>
<tr><td>72</td><td>Decide 358</td><td>Type:2-way by Condition, If:Expression, Value:`NumberofSSGinBerth2 == 1`, End of List</td></tr>
<tr><td>73</td><td>Decide 359</td><td>Type:2-way by Condition, If:Expression, Value:`NumberofSSGinBerth1 == 2`, End of List</td></tr>
<tr><td>74</td><td>Decide 360</td><td>Type:N-way by Chance, Percentage True(0-100):`50`,Percentage True(0-100):`25`, End of List</td></tr>
<tr><td>75</td><td>Decide 361</td><td>Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`50`, End of List</td></tr>
<tr><td>76</td><td>Decide 362</td><td>Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`25`, End of List</td></tr>
<tr><td>77</td><td>Decide 363</td><td>Type:2-way by Condition, If:Expression, Value:`NumberofSSGinBerth1 == 1`, End of List</td></tr>
<tr><td>78</td><td>Decide 364</td><td>Type:2-way by Condition, If:Expression, Value:`NumberofSSGinBerth2 == 1`, End of List</td></tr>
<tr><td>79</td><td>Decide 365</td><td>Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`50`, End of List</td></tr>
<tr><td>80</td><td>Decide 366</td><td>Type:N-way by Chance, Percentage True(0-100):`50`,Percentage True(0-100):`25`, End of List</td></tr>
<tr><td>81</td><td>Decide 367</td><td>Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`25`, End of List</td></tr>
<tr><td>82</td><td>Decide 368</td><td>Type:N-way by Conditor If:Expression, Value:`(Berth1Status == 1) &&  ( Berth2Status == 1 )`,If:Expression, Value:`(Berth1Status == 1) &&  ( Berth3Status == 1 )`, End of List</td></tr>
<tr><td>83</td><td>Decide 369</td><td>Type:N-way by Conditor , If:Expression, Value:`((NumberofSSGinBerth1 == 1)  && (NumberofSSGinBerth2 == 1)) ||  ( (NumberofSSGinBerth1 == 2)  && (NumberofSSGinBerth2 == 2) )`,If:Expression, Value:`(NumberofSSGinBerth1 == 1)  && (NumberofSSGinBerth2 == 2)`,If:Expression, Value:`(NumberofSSGinBerth1 == 1)  && (NumberofSSGinBerth2 == 3)`, End of List</td></tr>
<tr><td>84</td><td>Decide 370</td><td>Type:2-way by Chance, Percent True(0-100): 50%</td></tr>
<tr><td>85</td><td>Decide 371</td><td>Type:2-way by Chance, Percent True(0-100): 33%</td></tr>
<tr><td>86</td><td>Decide 372</td><td>Type:2-way by Chance, Percent True(0-100): 25%</td></tr>
<tr><td>87</td><td>Decide 373</td><td>Type:2-way by Chance, Percent True(0-100): 75%</td></tr>
<tr><td>88</td><td>Decide 374</td><td>Type:N-way by Conditor, If:Expression, Value:`((NumberofSSGinBerth1 == 1)  && (NumberofSSGinBerth3 == 1)) ||  ( (NumberofSSGinBerth1 == 2)  && (NumberofSSGinBerth3 == 2) )`,If:Expression, Value:`(NumberofSSGinBerth1 == 1)  && (NumberofSSGinBerth3 == 2)`, If:Expression, Value:`(NumberofSSGinBerth1 == 1)  && (NumberofSSGinBerth3 == 3)`,End of List</td></tr>
<tr><td>89</td><td>Decide 375</td><td>Type:2-way by Chance, Percent True(0-100): 50%</td></tr>
<tr><td>90</td><td>Decide 376</td><td>Type:2-way by Chance, Percent True(0-100): 33%</td></tr>
<tr><td>91</td><td>Decide 377</td><td>Type:2-way by Chance, Percent True(0-100): 25%</td></tr>
<tr><td>92</td><td>Decide 378</td><td>Type:2-way by Chance, Percent True(0-100): 75%</td></tr>
</table>

93	Decide 379		Type:N-way by Conditor, If:Expression, Value:`((NumberofSSGinBerth2 == 1)  && (NumberofSSGinBerth3 == 1)) || ( (NumberofSSGinBerth2 == 2)  && (NumberofSSGinBerth3 == 2) )`,If:Expression, Value:`(NumberofSSGinBerth2 == 1)  && (NumberofSSGinBerth3 == 2)`,If:Expression, Value:`(NumberofSSGinBerth2 == 1)  && (NumberofSSGinBerth3 == 3)`, End of List
94	Decide 380		Type:2-way by Chance, Percent True(0-100): 50%
95	Decide 381		Type:2-way by Chance, Percent True(0-100): 33%
96	Decide 382		Type:2-way by Chance, Percent True(0-100): 25%
97	Decide 383		Type:2-way by Chance, Percent True(0-100): 75%
98	Decide 384		Type:N-way by Conditor, If:Expression, Value:`(Berth1Status + Berth2Status + Berth3Status)==1`,If:Expression, Value:`(Berth1Status + Berth2Status + Berth3Status) == 6`, End of List
99	Decide 385		Type:N-way by Conditor, If:Expression, Value:`( NumberofSSGinBerth1 == 1 )  &&  ( NumberofSSGinBerth2 == 1 )  &&  ( NumberofSSGinBerth3 == 2 )`,If:Expression, Value:`( NumberofSSGinBerth1 == 1 )  &&  ( NumberofSSGinBerth2 == 2 )  && ( NumberofSSGinBerth3 == 1 )`, End of List
100	Decide 386		Type:N-way by Chance, Percentage True(0-100):`50`,Percentage True(0-100):`25`, End of List
101	Decide 387		Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`50`, End of List
102	Decide 388		Type:N-way by Chance, Percentage True(0-100):`25`,Percentage True(0-100):`25`, End of List
103	Decide 389		Type:N-way by Conditor, If:Expression, Value:`Berth1Status == 5`,If:Expression, Value:`Berth2Status == 5`, End of List
104	Decide 390		Type:N-way by Conditor, If:Expression, Value:`(NumberofSSGinBerth2 == 1) && (NumberofSSGinBerth3 == 1)`,If:Expression, Value:`(NumberofSSGinBerth2 == 2) && (NumberofSSGinBerth3 == 1)`, If:Expression, Value:`(NumberofSSGinBerth2 == 1) && (NumberofSSGinBerth3 == 2)`,If:Expression, Value:`(NumberofSSGinBerth2 == 2) && (NumberofSSGinBerth3 == 2)`,If:Expression, Value:`(NumberofSSGinBerth2 == 3) && (NumberofSSGinBerth3 == 1)`, End of List
105	Decide 391		Type:2-way by Chance, Percent True(0-100): 50%
106	Decide 392		Type:2-way by Chance, Percent True(0-100): 66%
107	Decide 393		Type:2-way by Chance, Percent True(0-100): 33%
108	Decide 394		Type:2-way by Chance, Percent True(0-100): 75%
109	Decide 395		Type:2-way by Chance, Percent True(0-100): 25%
110	Decide 396		Type:2-way by Condition, If:Expression, Value:`Berth3Status == 1`
111	Decide 397		Type:N-way by Conditor, If:Expression, Value:`(NumberofSSGinBerth2 == 1) && (NumberofSSGinBerth3 == 1)`,If:Expression, Value:`(NumberofSSGinBerth2 == 2) && (NumberofSSGinBerth3 == 1)`, If:Expression, Value:`(NumberofSSGinBerth2 == 1) && (NumberofSSGinBerth3 == 2)`,If:Expression, Value:`(NumberofSSGinBerth2 == 2) && (NumberofSSGinBerth3 == 2)`, If:Expression, Value:`(NumberofSSGinBerth2 == 3) && (NumberofSSGinBerth3 == 1)`, End of List
112	Decide 398		Type:2-way by Chance, Percent True(0-100): 50%
113	Decide 399		Type:2-way by Chance, Percent True(0-100): 66%
114	Decide 400		Type:2-way by Chance, Percent True(0-100): 33%
115	Decide 401		Type:2-way by Chance, Percent True(0-100): 75%
116	Decide 402		Type:2-way by Chance, Percent True(0-100): 25%
117	Decide 403		Type:2-way by Conditor, Conditions; `if:Expression, Value:Berth1Status == 1`
118	Decide 404		Type:N-way by Conditor, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth3 == 1)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth3 == 1)`, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth3 == 2)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth3 == 2)`, If:Expression, Value:`(NumberofSSGinBerth1 == 3) && (NumberofSSGinBerth3 == 1)`, End of List
119	Decide 405		Type:2-way by Chance, Percent True(0-100): 50%
120	Decide 406		Type:2-way by Chance, Percent True(0-100): 66%
121	Decide 407		Type:2-way by Chance, Percent True(0-100): 33%

122	Decide 408		Type:2-way by Chance, Percent True(0-100): 75%
123	Decide 409		Type:2-way by Chance, Percent True(0-100): 25%
124	Decide 410		Type:N-way by Conditor, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth3 == 1)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth3 == 1)`, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth3 == 2)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth3 == 2)`, If:Expression, Value:`(NumberofSSGinBerth1 == 3) && (NumberofSSGinBerth3 == 1)`, End of List
125	Decide 411		Type:2-way by Chance, Percent True(0-100): 50%
126	Decide 412		Type:2-way by Chance, Percent True(0-100): 66%
127	Decide 413		Type:2-way by Chance, Percent True(0-100): 33%
128	Decide 414		Type:2-way by Chance, Percent True(0-100): 75%
129	Decide 415		Type:2-way by Chance, Percent True(0-100): 25%
130	Decide 416		Type:2-way by Condition, If:Expression, Value:`Berth1Status == 1`,
131	Decide 417		Type:N-way by Conditor, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth2 == 1)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth2 == 1)`, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth2 == 2)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth2 == 2)`, If:Expression, Value:`(NumberofSSGinBerth1 == 3) && (NumberofSSGinBerth2 == 1)`, End of List
132	Decide 418		Type:2-way by Chance, Percent True(0-100): 50%
133	Decide 419		Type:2-way by Chance, Percent True(0-100): 66%
134	Decide 420		Type:2-way by Chance, Percent True(0-100): 33%
135	Decide 421		Type:2-way by Chance, Percent True(0-100): 75%
136	Decide 422		Type:2-way by Chance, Percent True(0-100): 25%
137	Decide 423		Type:N-way by Conditor, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth2 == 1)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth2 == 1)`, If:Expression, Value:`(NumberofSSGinBerth1 == 1) && (NumberofSSGinBerth2 == 2)`,If:Expression, Value:`(NumberofSSGinBerth1 == 2) && (NumberofSSGinBerth2 == 2)`, If:Expression, Value:`(NumberofSSGinBerth1 == 3) && (NumberofSSGinBerth2 == 1)`, End of List
138	Decide 424		Type:2-way by Chance, Percent True(0-100): 50%
139	Decide 425		Type:2-way by Chance, Percent True(0-100): 66%
140	Decide 426		Type:2-way by Chance, Percent True(0-100): 33%
141	Decide 427		Type:2-way by Chance, Percent True(0-100): 75%
142	Decide 428		Type:2-way by Chance, Percent True(0-100): 25%
143	Decide 429		Type:N-way by Conditor, If:Expression, Value:`Berth1Status == 1`,If:Expression, Value:`Berth2Status == 1`, End of List
144	Worksforberth1	The trucks coming to the berths are combined at these points.	Allocation:Other, Delay Time:0.0 Units:Hours
145	Worksforberth2		Allocation:Other, Delay Time:0.0 Units:Hours
146	Worksforberth3		Allocation:Other, Delay Time:0.0 Units:Hours
147	Assign 102	The quay assigned in trucks is defined	Assignments: Type:Attribute, Attribute Name:shiploading, New Value:1, End of list
148	Assign 103		Assignments: Type:Attribute, Attribute Name: shiploading, New Value:2, End of list
149	Assign 104		Assignments: Type:Attribute, Attribute Name: shiploading, New Value:3, End of list
150	Decide 432	Determines whether the truck going to the pier will take an empty container or a full container.	Type:N-way by Conditor, If:Expression, Value:` shipload1<= Gemi1eYuklenecekDoluSayýsý`,If:Expression, Value:`Gemi1eYüklenecekToplamKont > gemidolulugu1`, End of List
151	Decide 447		Type:N-way by Conditor, If:Expression, Value:` shipload2<= Gemi2yeYuklenecekDoluSayýsý`,If:Expression, Value:`Gemi2yeYüklenecekToplamKont > gemidolulugu2`, End of List
152	Decide 448		Type:N-way by Conditor, If:Expression, Value:` shipload3<= Gemi3eYuklenecekDoluSayýsý`,If:Expression, Value:`Gemi3eYüklenecekToplamKont > shipload3`, End of List

153	Assign 109	Full containers delivered to ships are counted here	Assignments: `Type: Variable, Variable Name: shipload1, New Value: shipload1+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`
154	Assign 110		Assignments: `Type: Variable, Variable Name:gemidolulugu1, New Value: shipload1+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`
155	Assign 111		Assignments: `Type: Variable, Variable Name: shipload2, New Value: shipload2+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`
156	Assign 112		Assignments: `Type: Variable, Variable Name: shipload2, New Value: shipload2+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`
157	Assign 113		Assignments: `Type: Variable, Variable Name:shipload3, New Value: shipload3+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`
158	Assign 114		Assignments: `Type: Variable, Variable Name:shipload3, New Value: shipload3+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`
159	Decide 450	Decides the full containers to be loaded from the Reefer.	Type:2-way by Cahnce, Percent True (0-100):1%
160	Decide 454		Type:2-way by Cahnce, Percent True (0-100):1%
161	Decide 456		Type:2-way by Cahnce, Percent True (0-100):1%
162	Decide 453	Decides where will trucks go in the Reefer field in the port.	Type:2-way by Cahnce, Percent True (0-100):50%
163	Decide 455		Type:2-way by Cahnce, Percent True (0-100):50%
164	Decide 457		Type:2-way by Cahnce, Percent True (0-100):50%
165	FullContainerLoad2	Decides where trucks will receive full containers in the port field.	Type:N-way by Conditor, If:Expression, Value:`(NQ(A1.Queue) > NQ(A2.Queue)) && (NQ(A1.Queue) > NQ(A3.Queue))&& (NQ(A1.Queue) > NQ(A4.Queue))&& (NQ(A1.Queue) > NQ(A5.Queue))&& (NQ(A1.Queue) > NQ(D1.Queue))&& (NQ(A1.Queue) > NQ(D2.Queue))&& (NQ(A1.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A2.Queue) > NQ(A3.Queue))&& (NQ(A2.Queue) > NQ(A4.Queue))&& (NQ(A2.Queue) > NQ(A5.Queue))&& (NQ(A2.Queue) > NQ(D1.Queue))&& (NQ(A2.Queue) > NQ(D2.Queue))&& (NQ(A2.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A3.Queue) > NQ(A4.Queue))&& (NQ(A3.Queue) > NQ(A5.Queue))&& (NQ(A3.Queue) > NQ(D1.Queue))&& (NQ(A3.Queue) > NQ(D2.Queue))&& (NQ(A3.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A4.Queue) > NQ(A5.Queue))&& (NQ(A4.Queue) > NQ(D1.Queue))&& (NQ(A4.Queue) > NQ(D2.Queue))&& (NQ(A4.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A5.Queue) > NQ(D1.Queue))&& (NQ(A5.Queue) > NQ(D2.Queue))&& (NQ(A5.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(D3.Queue) > NQ(D2.Queue)) && (NQ(D3.Queue) > NQ(D1.Queue))`, If:Expression, Value:`(NQ(D2.Queue) > NQ(D1.Queue))` End of List
166	FullContainerLoad2		Type:N-way by Conditor, If:Expression, Value:`(NQ(A1.Queue) > NQ(A2.Queue)) && (NQ(A1.Queue) > NQ(A3.Queue))&& (NQ(A1.Queue) > NQ(A4.Queue))&& (NQ(A1.Queue) > NQ(A5.Queue))&& (NQ(A1.Queue) > NQ(D1.Queue))&& (NQ(A1.Queue) > NQ(D2.Queue))&& (NQ(A1.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A2.Queue) > NQ(A3.Queue))&& (NQ(A2.Queue) > NQ(A4.Queue))&& (NQ(A2.Queue) > NQ(A5.Queue))&& (NQ(A2.Queue) > NQ(D1.Queue))&& (NQ(A2.Queue) > NQ(D2.Queue))&& (NQ(A2.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A3.Queue) > NQ(A4.Queue))&& (NQ(A3.Queue) > NQ(A5.Queue))&& (NQ(A3.Queue) > NQ(D1.Queue))&& (NQ(A3.Queue) > NQ(D2.Queue))&& (NQ(A3.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A4.Queue) > NQ(A5.Queue))&& (NQ(A4.Queue) > NQ(D1.Queue))&& (NQ(A4.Queue) > NQ(D2.Queue))&& (NQ(A4.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A5.Queue) > NQ(D1.Queue))&& (NQ(A5.Queue) > NQ(D2.Queue))&& (NQ(A5.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(D3.Queue) > NQ(D2.Queue)) && (NQ(D3.Queue) > NQ(D1.Queue))`, If:Expression, Value:`(NQ(D2.Queue) > NQ(D1.Queue))` End of List

167	FullContainerLoad3		Type:N-way by Conditor, If:Expression, Value:`(NQ(A1.Queue) > NQ(A2.Queue)) && (NQ(A1.Queue) > NQ(A3.Queue))&& (NQ(A1.Queue) > NQ(A4.Queue))&& (NQ(A1.Queue) > NQ(A5.Queue))&& (NQ(A1.Queue) > NQ(D1.Queue))&& (NQ(A1.Queue) > NQ(D2.Queue))&& (NQ(A1.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A2.Queue) > NQ(A3.Queue))&& (NQ(A2.Queue) > NQ(A4.Queue))&& (NQ(A2.Queue) > NQ(A5.Queue))&& (NQ(A2.Queue) > NQ(D1.Queue))&& (NQ(A2.Queue) > NQ(D2.Queue))&& (NQ(A2.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A3.Queue) > NQ(A4.Queue))&& (NQ(A3.Queue) > NQ(A5.Queue))&& (NQ(A3.Queue) > NQ(D1.Queue))&& (NQ(A3.Queue) > NQ(D2.Queue))&& (NQ(A3.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A4.Queue) > NQ(A5.Queue))&& (NQ(A4.Queue) > NQ(D1.Queue))&& (NQ(A4.Queue) > NQ(D2.Queue))&& (NQ(A4.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(A5.Queue) > NQ(D1.Queue))&& (NQ(A5.Queue) > NQ(D2.Queue))&& (NQ(A5.Queue) > NQ(D3.Queue))`, If:Expression, Value:`(NQ(D3.Queue) > NQ(D2.Queue)) && (NQ(D3.Queue) > NQ(D1.Queue))`, If:Expression, Value:`(NQ(D2.Queue) > NQ(D1.Queue))` End of List
168	Assign 110	Empty containers taken to ships are counted here	Assignments: `Type: Variable, Variable Name:Loadofship1 ,New Value: Loadofship1+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`, End the list
169	Assign 112		Assignments: `Type: Variable, Variable Name: Loadofship2,New Value:g Loadofship2+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`, End the list
170	Assign 114		Assignments: `Type: Variable, Variable Name: Loadofship3,New Value: Loadofship3+2`, `Type: Variable, Variable Name:TruckTime, New Value:TNOW`, End the list
171	EmptyContainer Load1	Decides where trucks will receive empty containers in the port field.	Type:N-way by Conditor, If:Expression, Value:`(NQ(G2.Queue) > NQ(G1.Queue)) && ( NQ(G2.Queue) > NQ(G3.Queue)) && (NQ(G2.Queue) > NQ(G4.Queue))`, `if:Expression, Value :(NQ(G1.Queue) > NQ(G3.Queue)) && ( NQ(G1.Queue) > NQ(G4.Queue))`, `if:Expression, Value:( NQ(G3.Queue) > NQ(G4.Queue))` End the list
172	EmptyContainer Load2		Type:N-way by Conditor, If:Expression, Value:`(NQ(G2.Queue) > NQ(G1.Queue)) && ( NQ(G2.Queue) > NQ(G3.Queue)) && (NQ(G2.Queue) > NQ(G4.Queue))`, `if:Expression, Value :(NQ(G1.Queue) > NQ(G3.Queue)) && ( NQ(G1.Queue) > NQ(G4.Queue))`, `if:Expression, Value:( NQ(G3.Queue) > NQ(G4.Queue))` End the list
173	EmptyContainer Load3		Type:N-way by Conditor, If:Expression, Value:`(NQ(G2.Queue) > NQ(G1.Queue)) && ( NQ(G2.Queue) > NQ(G3.Queue)) && (NQ(G2.Queue) > NQ(G4.Queue))`, `if:Expression, Value :(NQ(G1.Queue) > NQ(G3.Queue)) && ( NQ(G1.Queue) > NQ(G4.Queue))`, `if:Expression, Value:( NQ(G3.Queue) > NQ(G4.Queue))` End the list
174	Decide 470	If there is a truck running for loading in the system even though the ship is completed, it will redirect them to the main decision point. After the decision point, the Hold module is held to direct.	Type:2-way by Condition, If:Expression, Value:`gshipload2 > TotalConteinerwillbeLoadedinShip2`
175	Decide 471		Type:2-way by Condition, If:Expression, Value:`shipload1 > TotalConteinerwillbeLoadedinShip1`
176	Decide 472		Type:2-way by Condition, If:Expression, Value:`shipload3 > TotalConteinerwillbeLoadedinShip3`
177	Hold 161		Type:Scan for Condition, Condition:`gemidolulugu1 == NQ(Batch 13.Queue)`, Queue Type: Queue, Queue Name: Hold 161.Queue
178	Hold 162		Type:Scan for Condition, Condition:`gemidolulugu2 == NQ(Batch 14.Queue)`, Queue Type: Queue, Queue Name: Hold 162.Queue
179	Hold 163		Type:Scan for Condition, Condition:`gemidolulugu3 == NQ(Batch 15.Queue)`, Queue Type: Queue, Queue Name: Hold 163.Queue
180	Hold 164		Type:Scan for Condition, Condition:`NQ(Batch 13.Queue)== shipload1`, Queue Type: Queue, Queue Name: Hold 164.Queue
181	Hold 165		Type:Scan for Condition, Condition:`NQ(Batch 14.Queue)== shipload2`, Queue Type: Queue, Queue Name: Hold 165.Queue
182	Hold 166		Type:Scan for Condition, Condition:`NQ(Batch 15.Queue)== shipload3`, Queue Type: Queue, Queue Name: Hold 166.Queue
183	Station 244	They are the stations where the trucks will go to the field.	Station Type:Station, Station Name:Station 244
184	Station 247		Station Type:Station, Station Name:Station 247
185	Station 248		Station Type:Station, Station Name:Station 248
186	Station 249		Station Type:Station, Station Name:Station 249
187	Station 250		Station Type:Station, Station Name:Station 250
188	Station 251		Station Type:Station, Station Name:Station 251
189	Route 274	Route modules that lead and drive the assigned truck in the field.	Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 55
190	Route 275		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 56
191	Route 276		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 57

192	Route 277		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 58
193	Route 278		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 59
194	Route 279		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 43
195	Route 280		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 44
196	Route 281		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 45
197	Route 307		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 179
198	Route 308		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 178
199	Route 309		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 180
200	Route 310		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 181
201	Route 349		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 245
202	Route 356		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 246
203	Route 238		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 69
204	Route 325		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 55
205	Route 326		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 56
206	Route 327		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 57
207	Route 328		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 58
208	Route 329		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 59
209	Route 330		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 43
210	Route 331		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 44
211	Route 332		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 45
212	Route 357		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 245
213	Route 358		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 246
214	Route 333		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 179
215	Route 334		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 178
216	Route 335		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 180
217	Route 336		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 181
218	Route 323		Route Time: 0, Units: Minutes, Destination Type: Station, Station Name:TruckDecideLogic
219	Route 337		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 55
220	Route 338		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 56
221	Route 339		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 57
222	Route 340		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 58
223	Route 341		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 59
224	Route 342		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 43
225	Route 343		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 44
226	Route 344		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 45
227	Route 359		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 245
228	Route 360		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 246
229	Route 345		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 179
230	Route 346		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 178
231	Route 347		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 180
232	Route 348		Route Time: UNIF(10,14.5), Units: Minutes, Destination Type: Station, Station Name:Station 181
233	Route 324		Route Time: 0, Units: Minutes, Destination Type: Station, Station Name:TruckDecideLogic
234	Station 39	These are the stations that are defined in the field in order for the trucks to arrive at the field.	Station Type:Station, Station Name:Station 39
235	Station 41		Station Type:Station, Station Name:Station 41
236	Station 42		Station Type:Station, Station Name:Station 42
237	Station 55		Station Type:Station, Station Name:Station 55

238	Station 56		Station Type:Station, Station Name:Station 56
239	Station 57		Station Type:Station, Station Name:Station 57
240	Station 58		Station Type:Station, Station Name:Station 58
241	Station 59		Station Type:Station, Station Name:Station 59
242	Station 43		Station Type:Station, Station Name:Station 43
243	Station 44		Station Type:Station, Station Name:Station 44
244	Station 45		Station Type:Station, Station Name:Station 45
245	Station 245		Station Type:Station, Station Name:Station 245
246	Station 246		Station Type:Station, Station Name:Station 246
247	Station 178		Station Type:Station, Station Name:Station 178
248	Station 179		Station Type:Station, Station Name:Station 179
249	Station 180		Station Type:Station, Station Name:Station 180
250	Station 181		Station Type:Station, Station Name:Station 181
251	Station 52		Station Type:Station, Station Name:Station 52
252	Station 53		Station Type:Station, Station Name:Station 53
253	Station 63		Station Type:Station, Station Name:Station 363
254	Station 64		Station Type:Station, Station Name:Station 64
255	Station 46		Station Type:Station, Station Name:Station 46
256	Station 54		Station Type:Station, Station Name:Station 54
257	Dropoff 131	The trucks use the Dropoff module to stock full containers into this area by transporting from loading vessels.	Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
258	Dropoff 132		Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
259	Dropoff 133		Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
260	Assign 105	Counts trucks that discharge	Assignments:Variable, Variable Name:tt, New Value: tt+1, End the list
261	Assign 106		Assignments:Variable, Variable Name:tt2, New Value: tt2+1, End the list
262	Assign 107		Assignments:Variable, Variable Name:tt3, New Value: tt3+1, End the list
263	D6process	Shows the operation of the RTGs that discharge the container from the truck to the field.	Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG11, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG13, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
264	D5process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG10, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG12, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
265	D4process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG9, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
266	D6	It is the stock area where IMPORTED full containers are kept.	Type:Scan for Condition, Condition:NQ(D6.Queue) == 744, Queue Type:Queue, Queue Name:D6.Queue
267	D5		Type:Scan for Condition, Condition:NQ(D5.Queue) == 744, Queue Type:Queue, Queue Name:D6.Queue
268	D4		Type:Scan for Condition, Condition:NQ(D4.Queue) == 930, Queue Type:Queue, Queue Name:D6.Queue
269	Create 45	The container is produced as much as the average number of containers in the field at the beginning.	Entity Type:Entity 1, `Time Between Arrivals; Type:Rondom(Expo), Value:20, Units: Minutes, Entities per Arrival: 1, Max Arrivals:Infinite, First Creation:0.0`
270	Create 48		Entity Type:Entity 1, `Time Between Arrivals; Type:Rondom(Expo), Value:20, Units: Minutes, Entities per Arrival: 1, Max Arrivals:Infinite, First Creation:0.0`
271	Decide 464	Modules decide a stack area for each defined containers which created as a full container at the being.	Type:N-way by Chance, `Percentages:Percent True (0-100): 12.25%`, `Percentages:Percent True (0-100): 12.25%`, `Percentages:Percent True (0-100): 12.25%`, `Percentages:Percent True (0-100): 12.25%`, `Percentages:Percent True (0-100): 12.25%`, `Percentages:Percent True (0-100): 12.25%`, `Percentages:Percent True (0-100): 12.25%`, End of List

272	Decide 449		Type:N-way by Conditor, Conditions: `If:Expression, Value:`NQ(A1.Queue) < 875``,`If:Expression, Value:`NQ(A2.Queue) < 980``,`If:Expression, Value:`NQ(A3.Queue) < 875``,`If:Expression, Value:`NQ(A4.Queue) < 910``,`If:Expression, Value:`NQ(A5.Queue) < 875``,`If:Expression, Value:`NQ(D3.Queue) < 961``,`If:Expression, Value:`NQ(D2.Queue) < 868``,`If:Expression, Value:`NQ(D1.Queue) < 806``,`If:Expression, Value:```, End the list
273	A1process	Defines the RTG process used to unloading incoming containers to the field.	Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG17, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG18, Unit to Seize/Release:1`,`Type:Resource, Resource Name:RTG22, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
274	A2process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG14, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG21, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
275	A3process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG15, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG16, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
276	A4process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG19, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG23, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
277	A5process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG20, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG24, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
278	D3process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG8, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
279	d2process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG7, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:4
280	D1process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG6, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:5
281	A1	Stock areas of EXPORTS containers in the port.	Type:Infinite Hold, Queu Type:Queue, Queue Name:A1.Queue
282	A2		Type:Infinite Hold, Queu Type:Queue, Queue Name:A2.Queue
283	A3		Type:Infinite Hold, Queu Type:Queue, Queue Name:A3.Queue
284	A4		Type:Infinite Hold, Queu Type:Queue, Queue Name:A4.Queue
285	A5		Type:Infinite Hold, Queu Type:Queue, Queue Name:A5.Queue
286	D3		Type:Infinite Hold, Queu Type:Queue, Queue Name:D3.Queue
287	D2		Type:Infinite Hold, Queu Type:Queue, Queue Name:D2.Queue
288	D1		Type:Infinite Hold, Queu Type:Queue, Queue Name:D1.Queue
289	Pickup 122	Export containers are loaded from the field with the Trucks` Pickup module	Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:A1.Queue
290	Pickup 123		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:A2.Queue
291	Pickup 124		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:A3.Queue
292	Pickup 125		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:A4.Queue
293	Pickup 126		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:A5.Queue
294	Pickup 127		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:D3.Queue
295	Pickup 128		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:D2.Queue
296	Pickup 129		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:D1.Queue
297	Pickup 134		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:Reefer1.Queue
298	Pickup 135		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:Reefer2.Queue
299	Decide 435	The module decides which truck will go to which quay.	Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
300	Decide 436		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list

301	Decide 437		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
302	Decide 438		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
303	Decide 439		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
304	Decide 440		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
305	Decide 441		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
306	Decide 442		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
307	Decide 451		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
308	Decide 452		Type:N-way by Conditor, Conditions: `If:Attribute, Named:GemiDoldurma, ==, Value:1``, `If:Attribute, Named:GemiDoldurma, ==, Value:2``, End the list
309	Route 282	Determines the direction of the truck loaded in the field and leads to the quay.	Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
310	Route 284		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
311	Route 285		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
312	Route 286		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
313	Route 287		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
314	Route 288		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
315	Route 289		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
316	Route 290		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
317	Route 291		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
318	Route 292		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
319	Route 293		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
320	Route 294		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
321	Route 295		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
322	Route 296		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
323	Route 297		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
324	Route 298		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
325	Route 299		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
326	Route 300		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
327	Route 301		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
328	Route 302		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
329	Route 303		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
330	Route 304		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
331	Route 305		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
332	Route 306		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
333	Route 350		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
334	Route 351		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
335	Route 352		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169
336	Route 353		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 167
337	Route 354		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 168
338	Route 355		Route Time:0, Units:Hours, Destination Type:Station, Station Name:Station 169

339	Create 46	Creates the starting stock for the Reefer area.	Entity Type:Entity 1, `Time Between Arrivals; Type:Rondom(Expo), Value:1, Units: Seconds Entities per Arrival: 1, Max Arrivals:172, First Creation:0.0`
340	Decide 458	Modules decide about created reefer containers concerning which reefer area to go to.	Type:2-way by Chance, Percent True:(0-100):50%
341	R1process	Defines the process of loading and unloading RTGs in the reefer area	Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG15, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG16, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
342	R2process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), `Resources: `Type:Resource, Resource Name:RTG10, Unit to Seize/Release:1`, `Type:Resource, Resource Name:RTG12, Unit to Seize/Release:1`,` Ed the list``, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:3
343	Reefer1	Stock area of reefer containers in the field.	Type:Infinite Hold, Queue Type: Queue, Queue Name:Reefer1.Queue
344	Reefer2		Type:Infinite Hold, Queue Type: Queue, Queue Name:Reefer2.Queue
345	Create 47	Creates the starting stock for the empty container area.	Entity Type:Entity 1, `Time Between Arrivals; Type:Rondom(Expo), Value:0.4, Units: Hours Entities per Arrival: 1, Max Arrivals:infinite, First Creation:0.0`
346	Create 49		Entity Type:Entity 1, `Time Between Arrivals; Type:Rondom(Expo), Value:1, Units: Seconds Entities per Arrival: 1, Max Arrivals:4000, First Creation:0.0`
347	Pickup 130	The trucks that come to get empty containers, with this module, keep the container in themselves.	Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:G1.Queue
348	Pickup 131		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:G2.Queue
349	Pickup 132		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:G3.Queue
350	Pickup 133		Quantity:1, Queue Type:Queue, Starting Rank:1, Queue Name:G4.Queue
351	Decide 443	Modules decide that which quay needed to be delivered by the truck loaded in the field	Type:N-way by Conditor, Conditions: `If:Attribute, Named: ShipLoading,, ==, Value:1``, `If:Attribute, Named:ShipLoading, ==, Value:2``, End the list
352	Decide 444		Type:N-way by Conditor, Conditions: `If:Attribute, Named: ShipLoading, ==, Value:1``, `If:Attribute, Named: ShipLoading,, ==, Value:2``, End the list
353	Decide 445		Type:N-way by Conditor, Conditions: `If:Attribute, Named: ShipLoading, ==, Value:1``, `If:Attribute, Named: ShipLoading, ==, Value:2``, End the list
354	Decide 446		Type:N-way by Conditor, Conditions: `If:Attribute, Named: ShipLoading, ==, Value:1``, `If:Attribute, Named: ShipLoading, ==, Value:2``, End the list
355	Route 311	Determines the direction of the truck loaded in the field and leads to the quays	Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 167
356	Route 312		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 168
357	Route 313		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 169
358	Route 314		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 167
359	Route 315		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 168
360	Route 316		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 169
361	Route 317		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 167
362	Route 318		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 168
363	Route 319		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 169
364	Route 320		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 167
365	Route 321		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 168
366	Route 322		Route Time:0., Units: Hours, Destination Type: Station, Station Name:Station 169
367	Decide 465	Modules decide the empty containers defined in the system with Create will go to which stock area.	Type:2-way by Chance, Percent True:(0-100):25%, Percent True:(0-100):25%, Percent True:(0-100):25%, End of list
368	Decide 459		Type:2-way by Chance, Percent True:(0-100):25%, Percent True:(0-100):25%, Percent True:(0-100):25%, End of list
369	Station 52	There are stations defined in the field. They allow empty container trucks to enter fields to unload containers.	Station Type:Station, Station Name:Station 52
370	Station 53		Station Type:Station, Station Name:Station 53
371	Station 63		Station Type:Station, Station Name:Station 63

372	Station 64		Station Type:Station, Station Name:Station 64
373	Dropoff 127	In unloading, this module is used to bring the empty container to the field and release them.	Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
374	Dropoff 128		Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
375	Dropoff 129		Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
376	Dropoff 130		Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
377	G1process	Modules defined KALMAR which unloaded trucks that comes from outside of the port with the cargo.	Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), \`Resources: \`Type:Resource, Resource Name:kalmar1, Unit to Seize/Release:1\`, \`Type:Resource, Resource Name:kalmar2, Unit to Seize/Release:1\`,\` Ed the list\`\`, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:1.71
378	G2process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), \`Resources: \`Type:Resource, Resource Name:kalmar3, Unit to Seize/Release:1\`, Ed the list\`\`, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:1.71
379	G3process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), \`Resources: \`Type:Resource, Resource Name:kalmar4, Unit to Seize/Release:1\`, \`Type:Resource, Resource Name:kalmar5, Unit to Seize/Release:1\`,\` Ed the list\`\`, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:1.71
380	G4process		Type:Standard, Logic:Anction:Seize Delay Release, Priority:Medium(2), \`Resources: \`Type:Resource, Resource Name:kalmar6, Unit to Seize/Release:1\`, \`Type:Resource, Resource Name:kalmar7, Unit to Seize/Release:1\`,\` Ed the list\`\`, Delay Type: Constant, Units:Munutes, Allocation:Value Added, Value:1.71
381	Dropoff 134	The trucks use the Dropoff module for unloading full containers from vessels to stock them in this are.	Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
382	Dropoff 135		Quantity:1, Starting Rank:1, Member Attributes: Take All Representative Values
383	Assign 197	The number of containers brought to or discharge from field is recorded here.	Assignments:Variable, Variable Name:StorageD6, New Value: StorageD6 + 1, Type: Entity Picture, Entitiy Picture:Picture Box, End the list
384	Assign 198		Assignments:Variable, Variable Name:StorageD5, New Value: StorageD5 + 1, Type: Entity Picture, Entitiy Picture:Picture Box, End the list
385	Assign 199		Assignments: Variable, Variable Name:StorageD4, New Value: StorageD4 + 1, Type: Entity Picture, Entitiy Picture:Picture Box, End the list
386	Assign 200		Assignments:Variable, Variable Name:StorageA1, New Value: StorageA1 + 1, End the list
387	Assign 201		Assignments:Variable, Variable Name:StorageA2, New Value: StorageA2 + 1, End the list
388	Assign 202		Assignments:Variable, Variable Name:StorageA3, New Value: StorageA3 + 1, End the list
389	Assign 203		Assignments:Variable, Variable Name:StorageA4, New Value: StorageA4 + 1, End the list
390	Assign 204		Assignments:Variable, Variable Name:StorageA5, New Value: StorageA5 + 1, End the list
391	Assign 205		Assignments:Variable, Variable Name:StorageD3, New Value: StorageD3 + 1, End the list
392	Assign 206		Assignments:Variable, Variable Name:StorageD2, New Value: StorageD2 + 1, End the list
393	Assign 207		Assignments:Variable, Variable Name:StorageD1, New Value: StorageD1 + 1, End the list
394	Assign 208		Assignments:Variable, Variable Name:StorageR1, New Value: StorageR1 + 1, Variable Name:ExportedReefers, New Value:ExportedReefers + 1, End the list
395	Assign 209		Assignments:Variable, Variable Name:StorageR2, New Value: StorageR2 + 1, Variable Name:ExportedReefers, New Value:ExportedReefers + 1, End the list
396	Assign 210		Assignments:Variable, Variable Name:StorageR1, New Value: StorageR1 + 1, Variable Name:ImportReefers, New Value:ImportReefers + 1, End the list
397	Assign 211		Assignments:Variable, Variable Name:StorageR2, New Value: StorageR2 + 1, Variable Name:ImportReefers, New Value:ImportReefers + 1, End the list
398	Assign 212		Assignments:Variable, Variable Name:StorageG1, New Value: StorageG1 + 1, Variable Name:ExportedEmptyContainers, New Value:ExportedEmptyContainers + 1, End the list
399	Assign 213		Assignments:Variable, Variable Name:StorageG2, New Value: StorageG2 + 1, Variable Name:ExportedEmptyContainers, New Value:ExportedEmptyContainers + 1, End the list

400	Assign 214		Assignments:Variable, Variable Name:StorageG3, New Value: StorageG3 + 1, Variable Name:ExportedEmptyContainers, New Value:ExportedEmptyContainers + 1, End the list
401	Assign 215		Assignments:Variable, Variable Name:StorageG4, New Value: StorageG4 + 1, Variable Name:ExportedEmptyContainers, New Value:ExportedEmptyContainers + 1, End the list
402	Assign 216		Assignments:Variable, Variable Name:StorageG1, New Value: StorageG1 + 1, Variable Name:ImportedEmptyContainers, New Value:ImportedEmptyContainers + 1, End the list
403	Assign 217		Assignments:Variable, Variable Name:StorageG2, New Value: StorageG2 + 1, Variable Name:ImportedEmptyContainers, New Value:ImportedEmptyContainers + 1, End the list
404	Assign 218		Assignments:Variable, Variable Name:StorageG3, New Value: StorageG3 + 1, Variable Name:ImportedEmptyContainers, New Value:ImportedEmptyContainers + 1, End the list
405	Assign 219		Assignments:Variable, Variable Name:StorageG4, New Value: StorageG4 + 1, Variable Name:ImportedEmptyContainers, New Value:ImportedEmptyContainers + 1, End the list