Anouk Pelser

The impact of the implementation of category loading at container terminals

A simulation study into the implementation of a less compelling loading concept in which containers are loaded to deep-sea vessels at maritime container terminals

TU Delft

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A simulation study into the implementation of a less compelling loading concept in which containers are loaded to deep-sea vessels at maritime container terminals

By

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Preface

This document is part of my Master of Science graduation. The idea of doing my thesis on the subject of category loading came from Europe Container Terminals (ECT) at the Maasvlakte Rotterdam, in the person of Charlotte Goos. The goal of this thesis is to gain more insight in the loading concept of category loading. The concept is considered to have a high potential by the people of ECT and therefore a first step into the subject is done in this research. The way of approaching this subject and the subject itself combines several aspects of my bachelor Technology, Policy and Management and the Master of Transport, Infrastructures and Logistics. I am therefore thankful for this opportunity, I had a really nice time working on my thesis at the container terminal. Especially the way of working at the terminal made it a good time. The possibility of walking through the planning department, discussing their way of work and being in a working Quay Crane really helped for the understanding of the process, and it was just cool to be there.

Many thanks go out to Charlotte and the people of the department of Logistics Development to have me there for 8 months and answering all my questions at all times. Then, thank you Rudy and Bart for your daily support. You thorough reading of my report and your critical view on my work was very helpful. Bart in special for learning me a lot on how to build a report and Rudy for your critical view on the details of my research. Lastly, I want to thank Prof. Lodewijks for his guidance of the graduation process.

Beside my committee several other people played an important role during my study. Berry, my boyfriend, thank you for listening all the time and for your patience when I was nervous for a meeting or an exam during the last years of my study, I couldn't have done this in this way without you! Then of course my parents, my sister and brother in law, I could call you or join you for dinner anytime. Your unconditionally support means a lot to me.
Beside my family, my housemates, study friends (Michiel for the company and discussions at ECT, Baptiste for the discussions and company at the TU Delft and especially Judith for reading my report during my graduation research), rowing friends, colleagues from my student jobs; I had a great study time!

For now, I'm looking forward to the next step in life, which will be my job at Mieloo & Alexander.

Anouk Pelser
Delft, October 2017

Summary

This thesis presents and discusses a loading concept to improve the efficiency of loading containers to deep-sea vessels at maritime container terminals. The efficiency includes the overall service time to handle a deep-sea vessel at the quay of a container terminal. Nowadays, the terminals are threatened by overcapacity due to a decreasing growth of container throughput and the vessels becoming larger. Shipping companies benefit from shorter times spend in the harbour and therefore put pressure on the process of handling the vessels. The container terminals have to invest heavily to meet the demands of services requests of the shipping lines.

Researching literature about improving the loading process, it turned out that the bottleneck of the service time at container terminals can be found in the loading of the vessels. The loading of containers to the deep-sea vessels is more complex than discharging the containers from the deep-sea vessel. This due to the applied loading sequence that has to be retained during the loading, which is necessary for a couple of reasons: the weight distribution of the containers over the vessel and the locations of special containers, for example container that contain dangerous goods or have to be connected to the power for climate control, have to be placed carefully.
An optimal solution for the loading process is not found yet. As a consequence of the complexity and the number of different variables that have to be optimized in this one process. Different situations as loading an airplane or truck and the handlings in warehouses offer partly solutions that could be used to the loading process of a deep-sea vessel. These solutions are helpful in a way of identifying important influences, like the reachability of goods in warehouses and the different moments of arrivals of goods which can cause problems during the loading sequence of the various transport means. Research in the literature focussing on the loading process at maritime container terminals shows that especially the output of the stacking yard crane, that facilitates the yard, delays the loading process.
A promising concept of loading that is mentioned in literature classifies containers in categories. An improvement of 5% in performance of the utilization of the quay crane during loading, compared to a situation without categories is mentioned. The loading concept that is researched is a less compelling way of loading compared to the current situation and according to further research improvements of the loading process are shown. However, the research that is done uses assumptions on the loaded containers and only one way of classifying the containers is tested. Furthermore, no attention is payed to the changes in the process of loading the containers on board of a deep-sea vessel. Lastly, the research is done 15 years ago, the performance of the equipment and the size of the vessels is changed over time.

To investigate the influence of loading container using categories, the following research question is formed:

What is the operational influence of the category loading concept on the service time for deep-sea vessels at a container terminal?

To answer the research question, the current situation is explained first. For the current situation a configuration of a stacking yard equipped with one Automated Stacking Crane (ASC), Automated Guided Vehicles (AGVs) for the horizontal transport and manned Quay Cranes (QCs) is used for the terminal. This configuration is used, because of the trend of automated equipment nowadays and because data from the container terminal Europe Container Terminals Delta terminal at the Maasvlake at Rotterdam will be used in this thesis. The configuration of equipment used at ECT is same as described.

A Terminal Operating System (TOS) controls the equipment and on the moment that an AGV becomes available for a next job the TOS chooses the next container according a pre-set loading sequence. This moment is a suitable moment to create a less stiff loading sequence to improve the overall service time. In the current situation, every container has its own unique category, creating as much categories as there are containers. On the moment of relaxing the loading sequence the number of categories will decrease, since more containers are classified in one category based on the characteristics of the container. The characteristics of the container that are taken into account are the port of destination, the size of the container (20ft, 40ft or 45ft), the weight of the container (up to 35 tonnes), whether a container is full or empty and whether a container is special or not. A container will be classified as special in the case that it contains dangerous goods, requires power for climate control or has deviating measurements. The concept contains that the best reachable container on that moment will be chosen to be loaded. Best reachable container is defined as the container that has the least containers on top, and therefore as less as possible moves, called shuffles, have to be made and the corresponding ASC has the least orders for containers waiting.

It is tested whether the concept of category loading could improve the output of the stack and if, by keeping the dynamics of the Automated Guided Vehicles and the Quay Crane the same, the overall service time for deep-sea vessels at the quay of a container terminal could be decreased compared to the current situation. In order to do this, a simulation model of the current situation is provided and the following KPIs, which are identified in the literature, are used to measure the differences between the current loading process and the decrease in number of categories:

- Output of the stack [containers/hour]
- Total number of Shuffles [#shuffles]
- Waiting time AGVs at the stack [minutes]
- Utilization Quay Crane [%]
- Overall service time [Hours]

The simulation is done for the data available of three different deep-sea vessels. To test the decrease in categories during loading, all containers are classified in one and the same category at first. In this situation the Terminal Operating System will make a choice between all containers that are available for the crane that requested a container, based on the number of shuffles that have to be made and the workload of the corresponding Automated Stacking Crane, together the penalty points of the container. The less penalty point, the more reachable the container. The results show a clear improvement of the performance of the loading process. The total loading time decreases with 3.6% to 6.5%. Furthermore, the number of shuffles decreases by 35% to 64% for the analysed deep-sea vessels. Additionally, the output of the stack shows a higher number of containers per hour and the waiting time of the AGVs at the stack is decreased. Meaning, all KPIs show a significant improvement.

Since it is not realistic to classify all containers in the same category, due the requirement of weight distribution of the deep-sea vessels, special containers that contain dangerous goods or deviating measurement and the desire for convenient locations of the containers that have to be unloaded at the next stop, the containers are split in more categories. The following scenarios were defined:

- Only empty containers in categories
- Empty containers in categories and full containers split in two weight categories
- Empty containers in categories and full containers split in thee weight categories
- Empty containers in categories and full containers split in six weight categories

The results of the scenarios are such that it can be said that the operational impact of implementing the category loading concept provides a shorter overall loading time. Especially, the number of shuffles is reduced by applying the concept. It turned out that the bigger choice for containers on the moment a next job has to be assigned to an AGV and ASC, based on the required shuffles and workload of the ASC, during the process leads to a more efficient output of the stacking yard. Noticeable is the small increase in the individual stack output, defined as the average number of containers per hour. Considering the reduced overall service time, shuffles and waiting time for the AGVs it turned out that the distribution of the workload of all stacks can be spread more equally.

In the case of implementing the concept of category loading, as well as in the control of the terminal as in the processes around the loading of the deep-sea vessels changes have to be adapted. A change in the Terminal Operating System have to be done and therefore the software has to be adjusted.
In the processes several parties are involved. From outside the terminal the shipping lines and the vessel operators are important stakeholders. Contractual agreements on the planning of the vessel and the corresponding loading sequence are maintained. A change in loading concept would affect this. Furthermore, the planners of the terminal have to change their way of working, since no exact planning has to be made anymore. Agreement with all involved parties is highly recommended before expensive changes in the software and control of the system will be done.

Beside agreement of the involved parties, shortcomings of the simulation and aspects that are outside the scope of this research have to be taken into account. In the case of implementing category loading at a container terminal, it is important to be aware of the shortcomings as simplification and aggregations of the used simulation model. The aggregation of the dynamics of the AGVs and the influences of other jobs for the Automated Stacking Cranes and the corresponding stacking yards during the loading process are not taken into account in this research and can be of influence.
Moreover, the classification of the categories for the containers can be investigated further on. For example, flexible categories related to the set of containers that have to be loaded.

Table of contents

List of abbreviations

AGV	Automated Guided Vehicle
ASC	Automated Stacking Crane
CP	Central Planner(ships)
ECT	Europe Container Terminals
POD	Port Of Destination
PPC	Previous Port of Call
QC	Quay Crane
TEU	Twenty feet Equivalent Unit
TP	Transfer Point

(ECT, 2014)

List of figures

List of tables

1 Introduction

Up until 2007, intercontinental transportation of containers has seen a drastic increase, predominantly in the Asian and European markets. Although a further growth of intercontinental maritime container transportation had been expected for the years after 2007, but the expected increase did not occur. The expectation of further growth resulted in a larger handling capacity, increased productivity of equipment, changes in the lay-out of terminals, and changes in IT support, logistics control software and automation developments (Kim & Gunther, 2007). However, nowadays a turnaround has manifested; an overcapacity is threatening the container industry at the port of Rotterdam (Tavasszy, 2014). This overcapacity is caused by the decreased growth of the container throughput (Port of Rotterdam, 2015; Tavasszy, 2014). Because of competition, container terminals try to sustain client relations by offering more and faster services, supported by automation and improvement of current equipment. Shipping companies benefit from shorter time spend in the harbour. Therefore, they have to invest heavily to meet the demands for faster service and higher quality (Wang & Cullinane, 2006). The higher productivity is needed to handle deep-sea vessels; where in 2001 vessels with a capacity of 10.000 TEU (Twenty Equivalent Unit, a standardized container measurement) were expected, at this moment deep-sea vessels of almost 20.000 TEU are handled at several terminals (Cullinane & Khanna, 2000; UNCTAD, 2015).
The primary vessel operations at a container terminal are the discharging and loading of containers. The growth of capacity (TEU) of deep-sea vessels puts increasing pressure on the container terminals to perform faster operations, otherwise the economies of scale caused by the larger vessels will be nullified at the terminals (Meersmans & Dekker, 2001). In order to speed up, the processes at a container terminal need to be improved; this development can be done in several ways. One way of improvement is the optimization of the number of port equipment, the equipment being the Automated Guided Vehicles (AGVs), Quay Cranes (QCs) and Automated Stacking Cranes (ASCs) (Stahlbock & Voß, 2008). Moreover, an optimization of the scheduling of the equipment is recommended (Chen et al., 2007). Another way to improve the handling time at the terminals, is a change in the type of equipment. For example, through the decoupling of the stack and the transportation to the Quay Crane by Automated Lifting Vehicles (ALVs) instead of AGVs. Here, a buffer rack at the Transfer Point (TP) is needed and the AGV is equipped with a lifting system and should no longer need to wait on a stacking crane. This solution, amongst others, is implemented at the Port of Brisbane (Stahlbock & Voß, 2008) and at APMII at Rotterdam (APM Terminals, 2016). Lastly, changes in the control of the process can be performed. For example, the way of putting the containers in the stacking yard or forming the loading sequence.
Nowadays, the development of material handling and information technologies is done by automation (Ioannou et al., 2000; Meersmans, 2002). This is a significant cause of bottlenecks in the scheduling of automated equipment. Disjointed scheduling may lead to sub-standard performance or even to deadlock situations at the terminal (Lau & Zhao, 2008). The main bottleneck identified in the process of loading deep-sea vessels is the loss of performance suffered at the transfer between the Automated Stacking Crane, which is the crane that picks the containers from the stacking yard, and the Automated Guided Vehicle (AGV), that transports the containers to the quay where it is loaded to a vessel. The container output of the stack by the ASC is the shortcoming in the process (Meersmans & Dekker, 2001). This bottleneck affects in its turn the performance of the Quay Crane (QC); when the crane has to wait for a container from the AGV, it cannot drive a maximal performance. When no maximal performance is reached, the service time, which is the time needed to handle a vessel at the quay, increases.

In the operations of the container stack, the horizontal transport to the quay and the handling from ship to shore and vice versa, a differentiation is made between loading and unloading of a vessel, as the loading of deep-sea vessels is a more complex process than the unloading of the vessel. During loading the stowage of the deep-sea vessel, the lay-out that shows where the containers are planned or placed, has to be respected, which is not the case during discharging (Meersmans & Dekker, 2001). Respecting the stowage is of importance because of the distribution of the mass of the deep-sea vessel, if this is unbalanced the vessel cannot sail. Furthermore, the next destination of the containers and the presence of dangerous goods are part of the stowage (Imai et al., 2006).

Altogether, there is a bottleneck in the output of the stack in the loading process of vessels. The waiting time caused by the bottleneck increases the service time, because the Quay Crane is not continuously loading the vessel. This bottleneck occurs during the loading of the vessel, because of the complexity of the process. To decrease the service time at the terminal, the productivity of the terminal equipment has to be increased during the loading process. Solutions to reduce the bottleneck at the output of the stack and thereby increase the performance of the QC can be found in the literature. One of this solutions is given by Duinkerken et al. (2001). Duinkerken et al. (2001) investigated whether loading the containers using categories instead of an exact loading sequence, could improve the utilization of the QC. It turned out that this loading concept improves the utilization of the cranes with 5%. This can save over an hour per call when, for example, a call is handled in 24 hours. At this moment the category loading concept is, as far as is known, never been introduced anywhere in the world.

1.1 Knowledge gap

Since the start of the containerization multiple improvements have been achieved and the development of the loading process of containers to deep-sea vessels is still continuing. The loading concept of category loading, introduced by Duinkerken et al., (2001), shows a 5% improvement in Quay Crane utilization compared to an exact loading sequence. The simulation study that is performed does uses a lot of assumptions according the containers that have to be loaded and is based on the situation of the year 2001. Nowadays the performances of, for example, equipment and vessel sizes are different. Moreover, the categories are not defined and containers that contain dangerous cargo or need a power connection are not taken into account. At last, only the concept is researched, but there is no insight given in the effects on the way of working with the concept and the involved parties. This research will therefore attempt to fill this gap by investigating this promising concept.

1.2 Research objectives and research questions

This thesis will analyse the effects caused by relaxing the loading sequence during the loading process of deep-sea vessels at a container terminal. The concept that will be studied is the concept of category loading. The goal of this thesis is to estimate the operational impact of the category loading concept, and to provide insight for container terminals about the loading concept. The outcome of this research will be academically valuable in a way that the theory about category loading will be specified and tested further on and practically valuable for container terminals in order to provide an advice on whether the concept of category loading offers any potential to the operational process of loading containers to deep-sea vessels.
In order to investigate the concept of category loading, the following research question is formulated:

What is the operational influence of the category loading concept on the service time for deep-sea vessels at a container terminal?

To support the research question, the following sub questions are formulated:

SQ1: What does the current process of loading deep-sea vessels entail?

SQ2a: What is considered the state of the art of the loading of deep-sea vessels?
SQ2b: What is Category Loading?

SQ3: What is the current performance of the loading process of the ECT Delta terminal?

SQ4a: Which scenarios can be formulated for implementing the Category Loading concept at a container terminal?
SQ4b: What is the impact of different scenarios of implementing Category Loading at a container terminal?
SQ4c: Which people that are involved in the loading process will be affected by a change of loading concept and how?

1.3 Methodology

In this research, the theory of category loading presented by Duinkerken et al. (2001) will be specified further on and tested using historical data. Therefore, the theory oriented case study methodology of Dul & Hak (2008) can be used as basis for the methodology of this thesis. According to Dul & Hak (2008), a literature study will be conducted to introduce and work out the theory, which will be tested subsequently. In detail the following methodology is used: in this first phase the problem is identified and the research objective and questions are formed, followed by the analysis phase. In this phase the current way of loading, the equipment that is used, the decisions that are made and the way the equipment is controlled will be analysed. Furthermore, a conceptual model will be provided, which will give the required insights and a scope of the research of this thesis. Then, a literature review is conducted. Research carried out the loading process so far and how the bottleneck is addressed in the literature will be described and used to present the concept of category loading. Moreover, the Key Performance Indicators (KPIs) will be derived from the literature. Next, the current situation will be simulated. For validation and verification, data of Europe Container Terminals will be used. The current situation and the category loading situation will be compared using the simulation model for the experimental design. Different scenarios will be tested. Based on the results of the tests, a conclusion will be formulated and recommendations will be presented.

An overview of the approach and chapters of this thesis is presented in **Figure 1**.

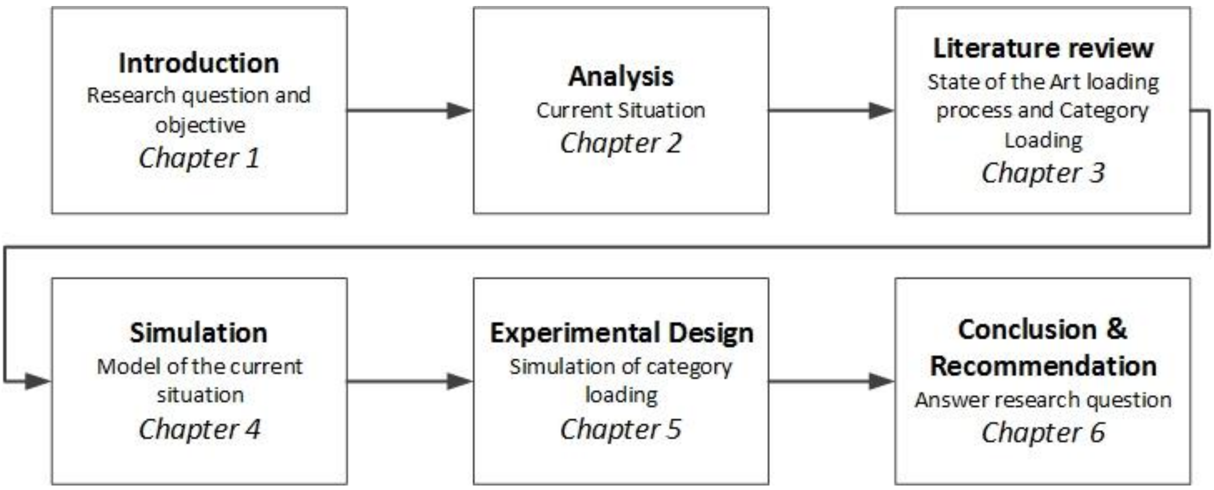


Figure 1 - Methodology

2 Current container terminal loading situation

In this thesis the potential of category loading will be researched. To do this, the current situation of the loading process in the container terminals has to be clear. The loading process will be described for three different levels to show the boundaries of this thesis and to understand the process, being the strategic level, the tactical level and the operational level.

2.1 Strategic level – Terminal lay-out and rough stowage

At the strategic level the decision is made which kind of equipment is be used, based on the design of a terminal. Decisions are made are for a time period in yearly increments.
In this thesis, only the loading process is considered, as the unloading process is a lot less complex than the loading process. This complexity is caused by the stowage of the deep-sea vessel (Meersmans & Dekker, 2001). The loading of deep-sea vessels is part of the so called 'waterside process' of the terminal. In this section, the planning of the waterside process and the possibilities for the lay-out of terminals is explained at the strategic level.

2.1.1 Lay-out of a container terminal

To perform terminal operations equipment is needed. A distinction is made between equipment for the handling of deep-sea vessels and equipment for the handling of hinterland connections: the waterside (the deep-sea vessels) and landside (the hinterland connections). Hinterland connections include the handling of containers to and from trains, inland vessels and trucks (Kemme, 2013).
The waterside process consists of three parts: the stacking yard, the horizontal transport from the stack to the quay and the handling from the quay to the deep-sea vessel. Different types of equipment can be used for each part. **Figure 2** illustrates the waterside and de landside, the stacking yard equipped with an Automated Stacking Crane (ASC), the horizontal transport as Automated Guided Vehicles (AGVs) and the shore to ship handling by a Quay Crane (QC).

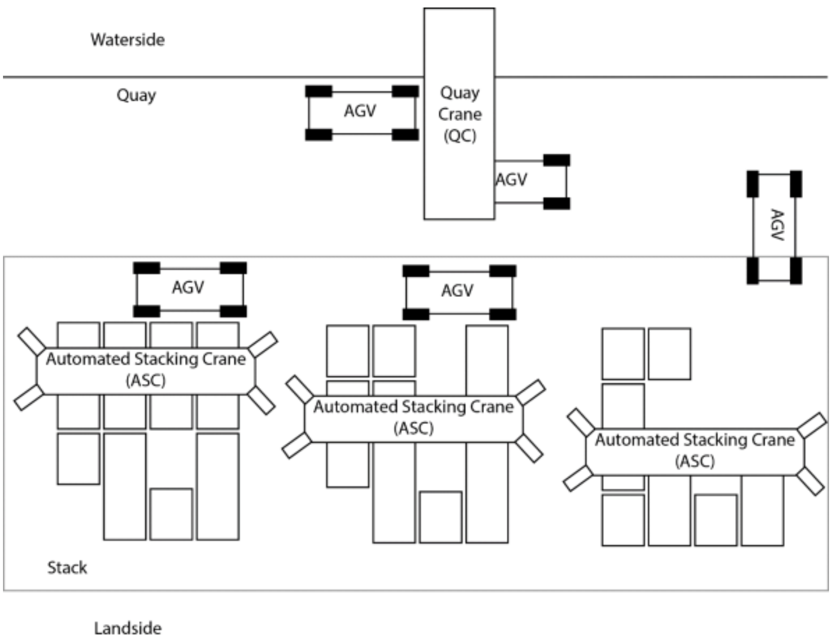


Figure 2 - Overview waterside process (equipment: ASC, AGV and QC)

For loading the container from shore to ship so called Quay Cranes (QCs) are used. The cranes are developed according the development of size of the deep-sea vessels and are equipped with an advanced spreader that can pick up containers easily (Ham van & Rijsenbrij, 2012). Due to innovations such as the twist lock, and the spreader, which is used to pick-up containers from the horizontal

transport equipment, the terminal becomes more efficient. Another example of innovations in container handling is twin lifting; handling two 20’ feet containers at once.
Two kinds of Quay Cranes can be distinguished; single-trolley cranes and dual trolley cranes. A single-trolley crane transfers the container from the shore to the vessel and the container is placed directly on board from the horizontal transport equipment or from the quay. The single-trolley crane is operated manually. In case of a dual trolley-crane the first trolley picks up the container from the quay and it is placed on a platform. The second trolley picks up the containers from this platform to place it on board. The trolley that moves the container from the shore to the platform is automated, the other trolley is man driven. Nowadays a semi-automated steering system is used and remote control and automation being developed. The performance of the Quay Crane, expressed in moves per hour, depends on the kind of crane. A distinction is made between design/technical performance and the operational performance. The first one performs in a range of 50-60 moves per hour, while in the operation performance of 20-30 moves per hour is achieved (Steenken, Voß, & Stahlbock, 2004). **Figure 3** presents a schematic visualisation of a Quay Crane (single-trolley). The choice for the type of crane influences the scheduling between the equipment that takes care of the horizontal transport.

Different types of equipment can be used for horizontal transport. To transfer the containers from the stacking yard to the Quay Crane Straddle Carriers, Multi-Trailer Systems, Truck Trailer Units and Automated Guided Vehicles (AGVs) are equipment that is often used (Kemme, 2013; Steenken et al., 2004; Vis & de Koster, 2003). **Figure 4** presents the different types of equipment. Multi Trailer Systems require a lot of space per container and are used on terminals that has a lot of room for stacking. Straddle Carriers and AGVs require less space in the stacking yard, and with the tendency to use automated equipment, the AGV has become an often used type of equipment. AGVs are not only used at container terminals; flexible manufacturing systems and warehouse operation (Liu, et al., 2002) or indoor warehouses and production facilities (Egbelu & Tanchoco, 1984) also use these unmanned vehicles. Kemme (2013) classifies the Automated Guided Vehicles in two types: passive vehicles and active vehicles. The passive vehicles have to be loaded by other equipment, where the active ones have a lifting system and are capable to place a container on a rack. The vehicles can carry either a 40- or 45-feet container or two 20- feet containers. Lastly the AGVs are following sensors that are integrated in the pavement of the container terminal.

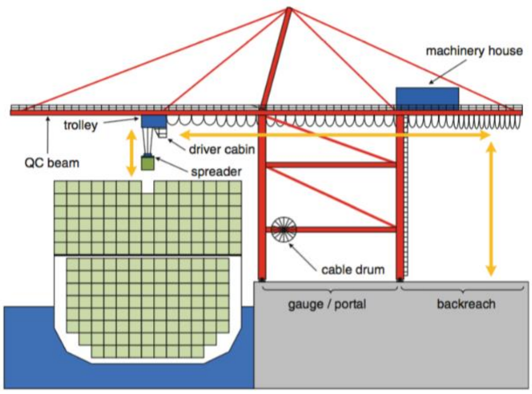


Figure 3 - Quay Crane schematic (Kemme, 2013)

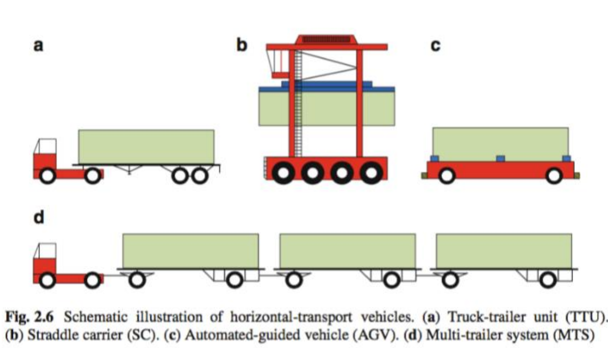


Figure 4 - Horizontal Transport (Kemme, 2013)

The last part of the terminal is the stacking yard, where all containers are stored. To move the containers, equipment is needed. Steenken et al. (2004) defined three types of cranes for the stacking yard: Rail Mounted Gantry Cranes (RMG), Rubber Tired Gantry Cranes (RTG) and Overhead Bridge Cranes (OBC). The advantage of RTG is the flexibility in the operation, while RMG and OBC are more stable. A new development for the RMG is the double crane; two cranes of different heights are working in one stacking yard. Because of the different heights no buffer zone in the middle of a yard is required while operating the two cranes. In many cases, the automated RMG is preferred as the type of equipment for the stacking yard, as had been applied in Rotterdam, Thamesport and Hamburg. Straddle Carriers, Reach Stackers and forklifts can be used for the staking of containers as well. When the containers are directly placed on trailers by the Quay Crane, no extra stacking equipment is necessary (Saanen, 2004; Steenken et al., 2004; Vis & de Koster, 2003).

This thesis uses the configuration of an automated Rail-Mounted Gantry Crane, used to pick up the containers from the stacking yard. In its automated form this crane is called Automated Stacking Crane (ASC). The Automated Guided Vehicle (AGV) receives the containers from the ASC at a Transfer Point (TP) at the end of the stacking yard and takes care of the horizontal transport to the QC. The QC picks up the containers from the AGV and loads the container on a deep-sea vessel (Böse, 2011; Chen et al., 2007; Dekker et al., 2006; Lau & Zhao, 2008), see **Figure 5.** This choice is made for two reasons. Firstly, there is a tendency to use automated equipment. In this combination the equipment of the stack and the horizontal transport are fully automated, the Quay Crane is semi-automated. The second reason is the data that will be used in this research; at the Europe Container Terminals Delta terminal at the Maasvlakte Rotterdam this configuration is used.

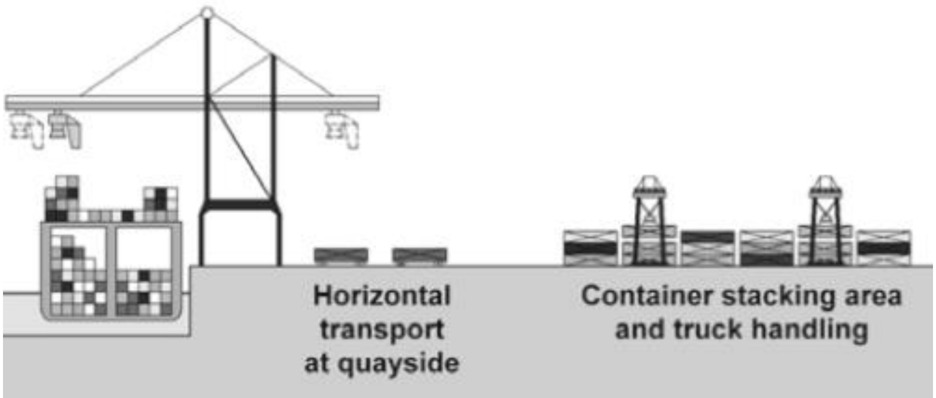


Figure 5 - QC, AGV and ASC configuration (Böse, 2011)

2.1.2 Rough stowage

The rough stowage is part of the waterside process. Deep-sea vessels that transport containers travel in 'round-robin' routes; they will call in several ports during the journey of the deep-sea vessel and in these ports containers will be loaded. A rough plan about which containers have to be placed where on board, the stowage, is planned on the strategic level in the loading process. To facilitate the loading of the deep-sea vessels on their route, an as cost-effective way as possible is desired and this is the cause of the stowage problem (Wilson et al., 2001). The rough stowage is the first step of two in creating a final stowage for a deep-sea vessel (Steenken et al., 2004). This rough stowage is made by the Central Planner (CP) of the shipping lines and part of the planning on strategic level (Dekker et al., 2006). This CP is employed by the shipping line and receives all bookings that are made. These bookings can be done by the shipping line itself or via a booking office, depending on the policy of the shipping line, or via other shipping lines according to the alliances in the container business (Steenken et al., 2004). These alliances have a slot allocation agreement and can book an agreed number of TEU at certain vessels of each other; the so called Container Booking Forecast (CBF), which is taken into account by the CP. The bookings are sent to the CP who can make a block or rough stowage for the deep-sea vessel for a specific route. The information used by the CP is delivered in categories (Cullinane & Khanna, 2000). These categories are different per supplier of information, see **Figure 6**.

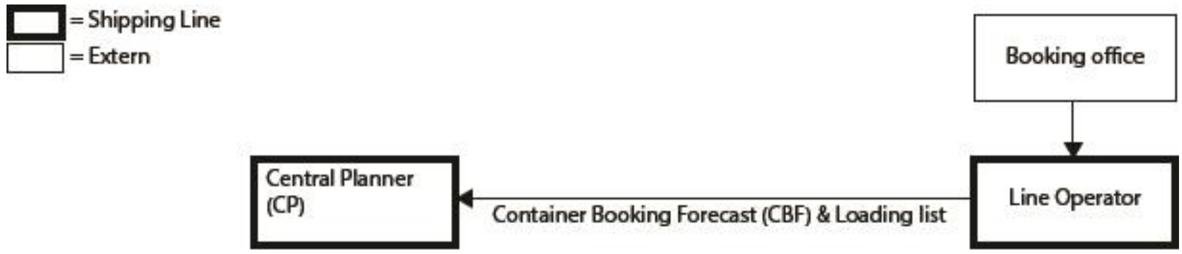


Figure 6 - Loading information for the Central Planner

To make a stowage, some constraints according to the stability of the vessel have to be taken into account. Most important is the distance between the centre of gravity (G) and the metacentre (M), where a larger distance between the G and the M implies a more stable situation. Beside the GM, the angle of heeling during the loading, called 'list', and the longitudinal slope of the vessel, called 'trim', are of importance (Delgado et al., 2010; Imai et al., 2006), see **Figure 7.** Next to the stability other requirements have to be met; a vessel is divided in several spaces, below and above deck. The spaces below deck are covered with a hatch-lid. On this hatch-lid more containers can be assigned and placed. A schematic example of a hatch-lid is given in **Figure 8**. Removing such a hatch-lid adds two extra movements from the shore, as it has to be taken of the vessel by the Quay Crane and at the end it has to be placed back. To avoid the extra movements, containers with the same port of destination are placed under the same hatch-lid (Wilson et al., 2001). In the spaces, containers are placed in stacks. Containers with the same destination are planned according to the blocks in the rough stowage. Based on the route of the deep-sea vessel and a few container characteristics it is decided which containers will be placed in which block.

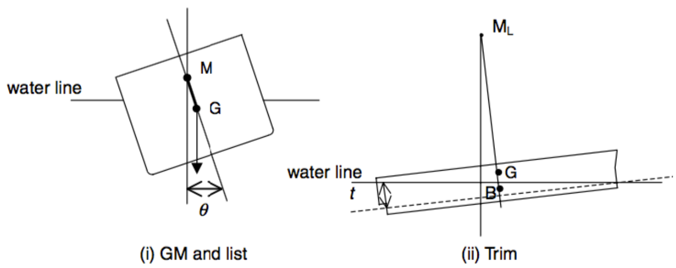


Figure 7 - Stability (Imai et al., 2006)

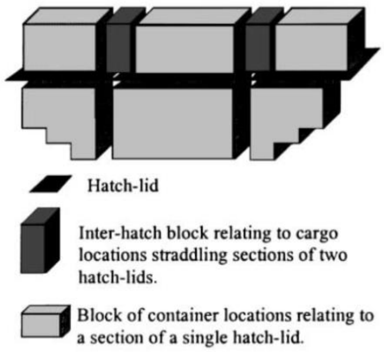


Figure 8 - Example Hatch-lid deep-sea vessel (Wilson, et al., 2001)

2.2 Tactical level – Choice of equipment and final stowage

On tactical level, decisions about the stacking yards, the number of AGVs and Quay Cranes that will be used at a certain call are made. A timeframe of days or weeks is taken into account. Moreover, the loading sequence as result of a specified stowage will be formed according the waterside process on this level of planning.

2.2.1 Choice of the number of equipment for loading a deep-sea vessel

The containers are placed in a few stack yards in advance at the container terminal. All the stacks are equipped with an ASC, and chosen because they are close to the mooring location of the deep-sea vessel that has to be loaded. The Terminal Operating System (TOS) controls the equipment that facilitates the loading of the deep-sea vessels. On a tactical level planning takes place and it becomes clear from which stacking yards the containers are needed. Furthermore, the number of AGVs and Quay Cranes are determined (Vis & de Koster, 2003). The number of equipment and which equipment is needed depends on, for example, the call size (the number of containers that have to be loaded) and the way of working at the container terminal. An optimal number of equipment is used, because too little equipment will result in below optimal performance and too much equipment can cause congestion or even deadlocks within the terminal.

2.2.2 From rough stowage to final stowage and a loading sequence

The specific stowage is the second step, on tactical level (Steenken et al., 2004) and formed by the container terminal in cooperation with the shipping line that provides the rough stowage. To create a stowage, the vessel is classified in slots. A specific slot can be identified by its bay, row and tier number (Ambrosino et al., 2004; Delgado et al., 2010). This classification is explained in **Figure 9**.

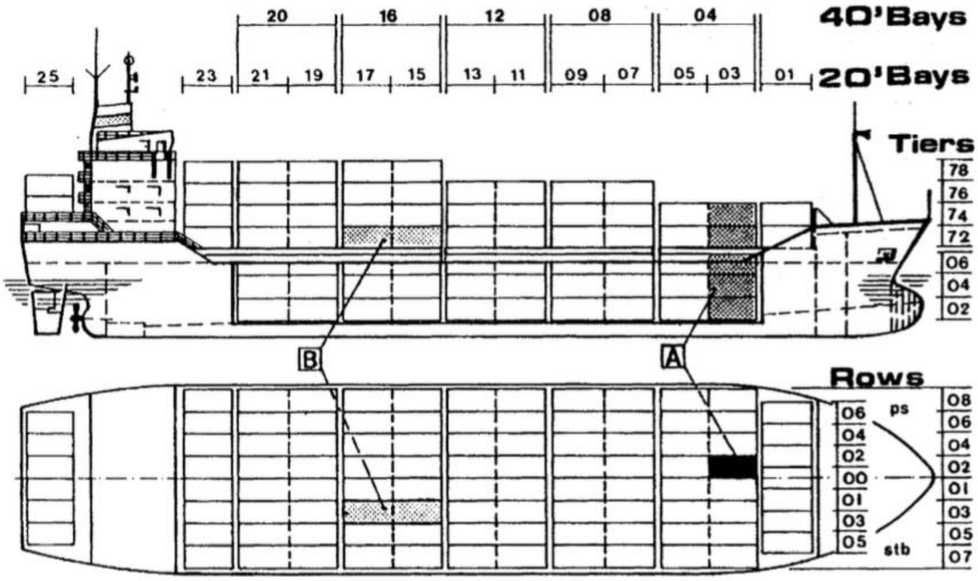


Figure 9 - Bays, rows and tiers (Ambrosino et al., 2004)

The blocks that are defined on strategic level can be more specified on this level. Containers are placed in piles in the blocks on board of a deep-sea vessel. A pile cannot be heavier than a certain maximum and when a container is placed on another container it has to be lighter than the container on which it is placed (Delgado et al., 2010). Beside the differences in weight containers can also differ in size. Containers that are 'out of gauge' are different from the standard containers of 1 Twenty-feet Equivalent Unit (TEU) (20' x 8' x 8' feet) or 2 TEU (40' x 8' x 8' feet) and have to be placed on top of the stacks or on a specific location at the deep-sea vessel (Ham van & Rijsenbrij, 2012). Furthermore, for containers that contain dangerous cargo or have to be connected to power for climate regulation (reefers) specific places are assigned. These specific locations are included in the information that the container terminal receives in advance (Ambrosino et al., 2004). The last classification that can be made is the difference between full and empty containers. Empty containers (or empties) are classified separate because when a shipping line requests empties, most of the time no specific containers are needed. As long as the containers are empty and from the requesting shipping line, the request is satisfied.

The loading sequence, the sequence of the containers that have to be loaded, is formed by using the final stowage. Currently, the loading sequence of containers for the deep-sea vessels is formed according to an exact plan; every container has a specific location on board of the deep-sea vessel (Delgado et al., 2010). In this order the containers are requested from the stacking yard, transported to the quay and loaded by the QCs on board of the deep-sea vessel. Because more cranes are working on one deep-sea vessel a small set of orders is pending for the ASCs of the assigned stacks, the assigning of these jobs is explained in more detail at the operational level, see also **Figure 10.**

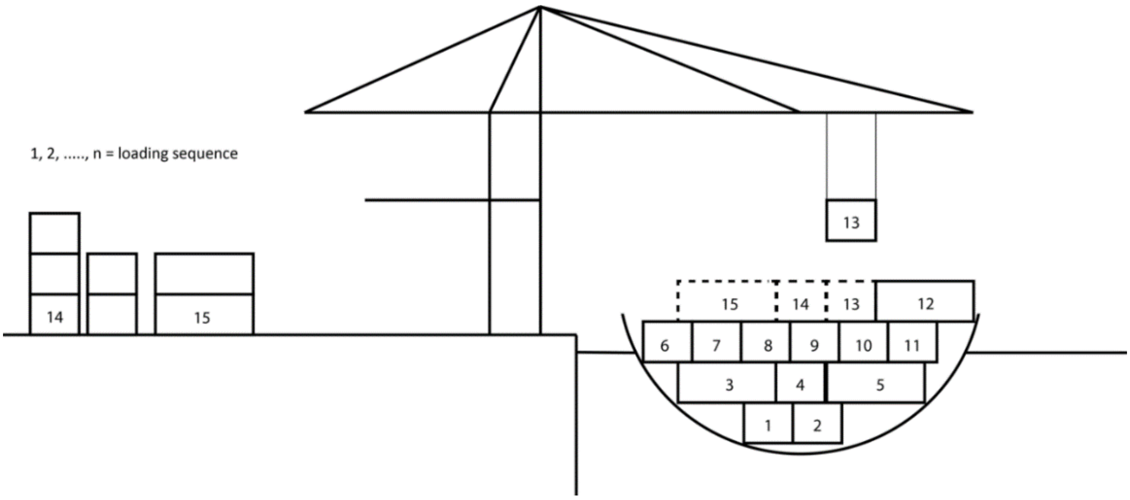


Figure 10 - Current loading situation

The process at the container terminal starts from the moment the rough stowage, or pre-stow, is received from the central planner and loaded in the database. Moreover, a loading list is provided by the shipping line and is loaded into the systems of the terminal. Apart from the information of the shipping line, the terminal also receives information about which containers are loaded and a specified location of these containers on the moment of departure at the previous port of call. Using all this information, the terminal decides on a so-called 'cut-off moment' on the detailed stowage (Ambrosino, et al., 2004). The cut-off moment is an agreement between the terminal and the shipping line. On the moment of the cut-off, only containers available at that moment will be planned. Containers that are not available on that moment will be cancelled. These containers have, for example, not arrived yet or have a custom clearance blockage.
The moment that the object planner finishes the final stowage this has to be confirmed by the vessel operator and the central planner will also be informed. The ship operators will check on stability based on the weight of the container and the vessel's own ballast (fuel and water for the balance) (Dekker et al., 2006; Hartog, 2016; Boer & Saanen, 2014). An overview of the communication in the processes is given in **Figure 11.**

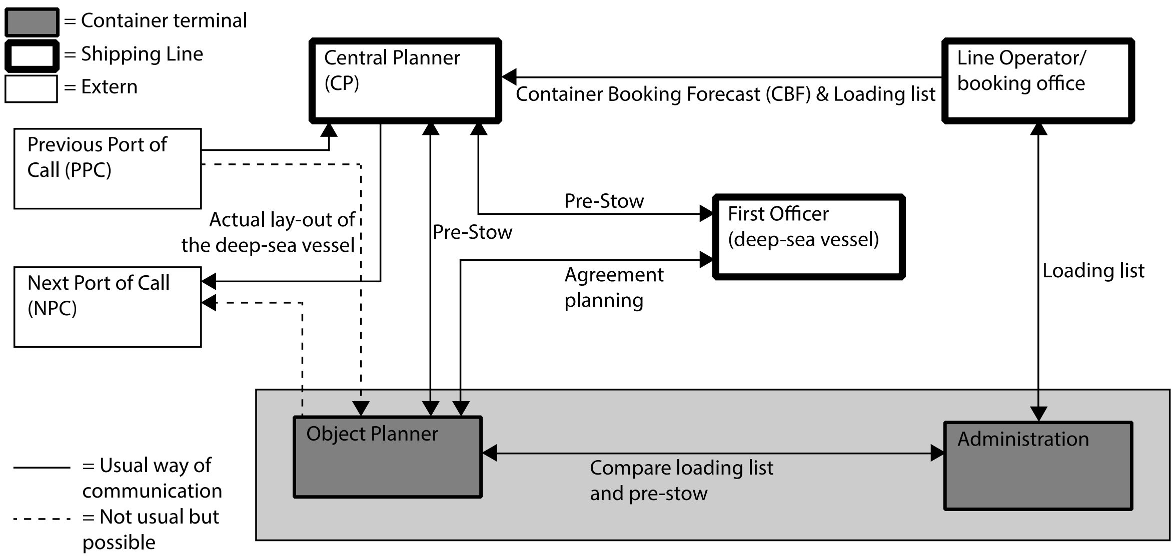


Figure 11 - Communication waterside process

2.3 Operational level – Control of equipment

At the operational level the planning from minutes or hours is taken into account. The focus lies on the control of the waterside process; the specific allocation of equipment during the loading process (Vis & de Koster, 2003). The collaboration between the loading sequence and the waterside process to load the deep-sea vessel is done at the operational level.

In the configuration of ASC, AGV and QC, that is used in this research, the ASC and the AGV are automated equipment and the QC is controlled by a crane operator who is employed by the container terminal in most cases. An overall control software assigns jobs to the equipment, which is driven by the loading sequence that is formed according to the stowage. A job consists of the required actions to pick up a specific container. The overall control software is the Terminal Operating System (TOS). TOS is the heart of the terminal operation and is a software application that supports the planning, scheduling and equipment control. TOS is responsible for all accurate operations at the terminal. From the origin TOS was an administrative system that contains all the information about the containers. Gradually it changed into a real time control system. A few TOS systems are off the shelf and are operational at several terminals. The other part of the market is spanned by in-house developed systems (Agerschou, 2004; Boer & Saanen, 2012; Stahlbock & Voß, 2008).

Furthermore, TOS performs measurements on the system. For example, when an AGV has delivered its container to the QC and becomes available for a next job, a signal is sent to the system. Based on the loading sequence, a next order for a container is assigned to the equipment.

The order is sent to the equipment as a job. This job describes the actions for the equipment. The available AGVs, the workload of the ASC and the loading sequence indicate a state of the system; by performing an action the locations of a few containers will be changed for example. The system is changing over the time.

2.4 Conceptualization of the loading system at container terminals

To analyse the system a conceptual model is made. A conceptual model is useful to present the level of aggregation and the system boundaries clearly. The model is presented in **Figure 12**. A System & Control cycle is used (Negenborn, 2013). Only a part of the real system at a container terminal is taken into account, strictly speaking the loading operation of the waterside process, including the equipment and control.

In the cycle a set of containers that have to be loaded to a deep-sea vessel enters the model. This set is coming from the planners of the terminal. At the moment the first order for the loading process is requested the process control of the Terminal Operating System starts looking for the requested container according to the planning of the vessel. When a container is found, the system assigns actions to the available AGVs and the corresponding ASCs, that will start working on the order. The AGV drives to the stacking yard, the ASC picks the containers from the stacking yard and transports it to the transfer point where the AGV is arrived. After transferring the container to the AGV, it brings the container to the Quay Crane and the container will be handled on board. During this process the Terminal Operating System is constantly measuring the equipment: the QCs loads will send a request for a next order, the AGV will request a new order when it is released from its previous container and the ASC had a queue for the orders of the requested containers.

The process will continue until the last container is loaded, the list of containers will be empty and no new orders will be sent. All containers are on board and the deep-sea vessel is handled.

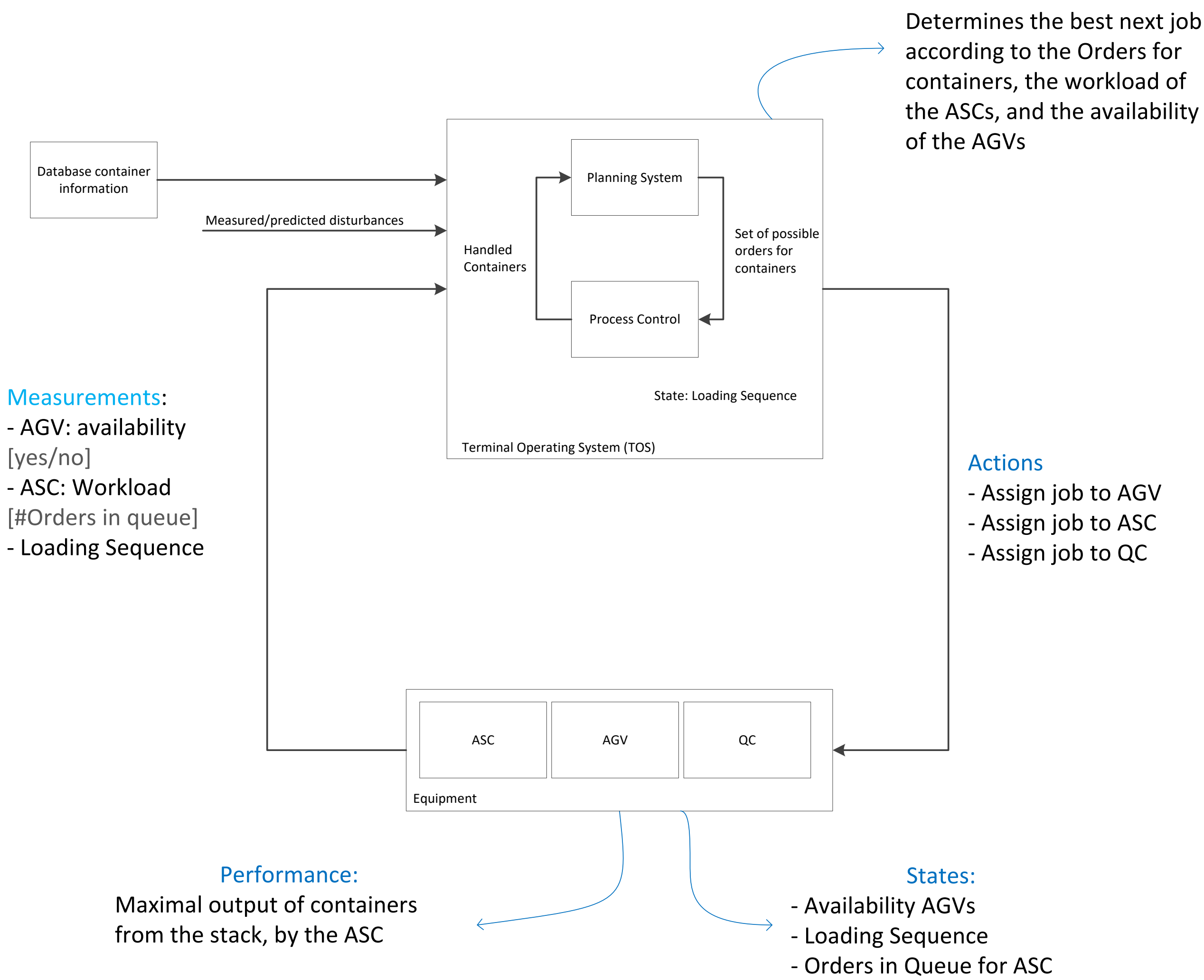


Figure 12 - System & Control Cycle Loading deep-sea vessels

2.5 Conclusions of the current way of loading

The bottleneck that is taken into account in this research is identified at the output of the stacking crane. AGVs are waiting at the Transfer Points for the containers. This causes a delay in the process and the supply of containers at the Quay Crane is disrupted. A graphical representation of this is provided in **Figure 13**. The blocks represent the processes by the equipment and the arrows from above represent the trigger for the equipment. The containers move through the process as an entity that is handled, starting from the stack. The ‘available AGVs’ are the waiting AGVs at the transfer point from the ASC to the AGV and represent the bottleneck.

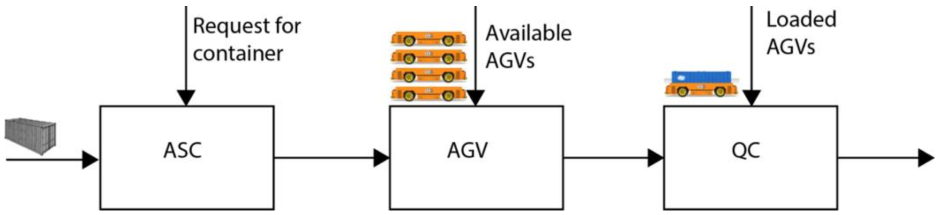


Figure 13 - Loading a deep-sea vessel

At this moment the orders that are sent to the AGVs and the ASCs follow the strict loading sequence that is made according the stowage of the deep-sea vessel. This means that when a certain container is requested the connected ASC will get the order, independent of the number of orders that already is assigned to that ASC. Moreover, the containers do not arrive in the same sequence as they will be loaded in the stacking yard beforehand. This will cause shuffles during the loading of the deep-sea vessel and therewith a delay in the output of the containers from the stack to the AGV. Another reasons for shuffles can be cancelled containers by custom blockages or (too) late arrivals that cause changes in the loading list on the last moment. Therefore, no perfect preferred stacking yard is possible. There are several ways to improve the performance of the output of the stack by the ASC and thereby the performance of the loading process at container terminals. The influences of the equipment, the stowage of the deep-sea vessel, the control on the current loading process and how this is improved over time, which will be investigated in the following chapter.

3 Loading problem in literature

Now the current situation and the bottleneck in the process are clear, it is time to take a closer look to how the bottleneck is approached in literature and what are important objectives and characteristics of the process according to this literature. To structure this chapter, the loading process is addressed in comparable situations followed by a more detailed part about maritime container terminals. Based on this, a review on the category loading concept will be given. Lastly, the Key Performance Indicators will be identified.

3.1 Loading process of cargo

A loading process is a wide concept and a lot of research into the loading of cargo has been done. Here, the loading process will be addressed in general first. A short look into comparable situations to the maritime container terminal and the provided solutions for the output problem will be given. A few comparable situations to the loading process of the container terminal can be found. The problem of a sequence that is formed according the characteristics of the cargo that have to be loaded does not only occur for the deep-sea vessel link in the transport chain, but also in the former steps in the transport chain of the cargo that will be transported by the deep-sea vessel. In the former steps of the transport chain of the cargo that will be transported by deep-sea vessels requirements according the order of loading has to be met. Moreover, the loading of other transport modes as aircrafts, trains and trucks also require a certain loading sequence as well. In the next paragraph, the loading of the trucks, trains and the aircrafts will be discussed followed by a discussion of the way of loading of the containers itself. Lastly, retrieving the goods from a warehouse, to load the container for example, will be discussed.

Amiouny et al. (1992) and Martin-Vega (1985) looked into the problem of loading aircrafts and trucks. Like for the loading for deep-sea vessels, the gravity point is of importance for these modes as well. Dependent on the characteristics as the weight and the measurements of the cargo, a sequence can be formed according the requirements of the weight distribution of the truck or aircraft. In the case of an aircraft it is, similar to deep-sea vessels, of importance to meet balance requirements to fly more safely, faster and use less fuel (Mongeau, 2003). However, the amount of cargo that fits a truck or an airplane is not as high as a deep-sea vessel can transport. Moreover, an important difference between the truck or airplane and loading of the deep-sea vessels can be noticed in the complexity of retrieving the cargo from the storage to the transport mode. Nowadays, special Unit Load Devices are developed that can be prepared and immediately be placed in the aircraft on the moment of arriving and trucks are loaded with one, two or three prepared containers. A last difference can be found in the three dimensional storage space of the deep-sea vessel and to the fact that the containers have to be retrieved from a stacking yard (Imai et al., 2006). Another mode that set requirements to loading process is the loading of containers to railcars. An efficient planning for the trains require as less as possible time and energy consumed by the equipment and a maximal utilization of the wagon carrying capacity. Containers of various sizes and properties are taken into account. According to this planning, empty wagons have to be sequenced in a contiguous block at the rear of train in a way that these wagons can be detached (Corry & Kozan, 2008). Despite the fact that the loading process faces also a lot of complexity caused by the characteristics of the cargo and the different parts in the process that can be optimized, such as utilization of the capacity, the number of container that have to be loaded on the train is much smaller. Consider a problem of 50 containers for trains and up to 4000 containers for deep-sea vessels.

Furthermore, in some cases the preparation of a container that will be transported is also restricted to a short time. The loading of the cargo in a container can be seen as the loading of trucks. This happens when cargo have to be merged that arrives from different locations by different means of transport. A lot of research into the optimal loading of containers or trucks has been is done. Mathur (1998) presented an algorithm for a one-dimensional loading problem that packs homogenous blocks of a given length and weight in a container, in such a way that the point of gravity fits the pre-assigned location for the container as good as possible. The proposed algorithm is based on the situation presented as a Knapsack problem, were items of different weights and utilities have to fit a maximum weight of the sack with an as high as possible utilization. A natural generalization of this one- and late also two-dimension problem is the three-dimensional packing problem. The complexity of arraign cargo into the container or truck is caused by the different aspects that can be optimized. Examples if these aspects are the best use of resources and the utilization of the containers. For the sequence of the loading of containers to groups are defined: Static sequencing and dynamic sequencing. Static sequencing refers to a fixed ranking of boxes before the start of the packing and the dynamic sequencing refers to the rule that decides for the next space or box during the loading of the container. According to the authors, no best approach can be pointed out (Zhao et al., 2014). The static sequencing can be compared with the fixed loading sequence of the containers to a deep-sea vessel. Another comparison that is made in literature is between the container stacking yard and a warehouse. Ascheuer et al. (1999) schedule the automated stacking crane that serves the stacking yard at a container terminal as a stacker crane in an automated warehouse. The sequence is modelled as an Asymmetric Traveling Salesman problem and for solving this problem heuristics and exact Branch and Cut algorithms were used to retrieve the cargo from the warehouse. The travel time of the cargo is improved by 40%. This travel time can be explained as the time that is needed to move the cargo from the location where it is stored, to the requested location. Moreover, a lot of attention is payed to the different way of picking the goods from the storage, but reorganisation or shuffles are mostly not taken into account (Koster et al., 2007). The problem of stacked containers at maritime container terminals is that when a container at the bottom of the stack is required one or more shuffles have to be accomplished to get to the required container. So-called random access systems in distribution warehouses circumvent this problem and make it possible to directly reach the required cargo. These kind of systems are not applied to container storages because the weight of one pallet (up to 1 tonnes) is considerably less than the weight of a fully loaded container (up to 30 tonnes). The weight makes such a system for containers very expensive (Meersmans, 2002). Others claim that the storage of containers cannot be compared to warehouses, the intention of the terminals is the transhipment of containers, where the stack is only a buffer of the transhipment function (Kemme, 2013; Meersmans & Dekker, 2001). However, on a higher level of aggregation, warehouses form a bottleneck in the transportation chain. Cargo arrives on different times in the warehouse and have to be loaded to the next transport mean together (Koster et al., 2007). This situation can be compared to the stacking yard and the different ways of processing the orders in the warehouses to the order for containers in the stack. The objective of a high service level in the warehouses corresponds to the objective of an as short as possible service time for deep-sea vessels at the container terminals.

Summarizing, similarities of the loading processes that are described compared to the loading process of containers to deep-sea vessels are several characteristics of the cargo that is loaded and a few objectives that are set. The weight and the measurements are characteristics that will be taken into account in this thesis. The objective will be the as short as possible loading time, which is the same for the loading of the other modes and the service level of the warehouses. Furthermore, the loading process of the deep-sea vessels and the loading of other transport modes, containers and warehouses show some important differences in the amount of cargo that have to be loaded and therefore in complexity of the problem. This complexity caused by the number of containers that have to be loaded is affected by different part of the process. From here on, the focus will be on how the different parts of the loading process influence the service level at maritime container terminals, taken into account the important characteristics.

3.2 Loading process at maritime containers terminals

Parts of the loading process at maritime terminals and ways to improve these parts will be described in this section. Of particular interest for this thesis are the objectives of the methods that are used to describe and optimize these parts in the literature. This section describes which characteristics of the loading process play an important role in the efficiency of loading process. After describing the influences of the scheduling of the equipment to each other and the loading sequence and stowage on the process, the bottleneck, the output of the stack, as described in literate literature for the bottleneck will be discussed.

3.2.1 Scheduling of the equipment of the waterside process

In this thesis is chosen to consider a configuration of a stacking yard equipped with one Automated Stacking Crane (ASC), Automated Guided Vehicles (AGVs) for the horizontal transport and manned Quay Cranes (QCs). The way of scheduling the equipment next to each other is of importance. Despite the fact that the way scheduling will not be changed in the different situations in this thesis, it is important to be aware of possible influences on the investigation. Different ways of scheduling will be explained and at the end of this section will be explained which way will be used in this thesis.

Meersmans (2002) stated that, when the configuration of AGVs and stacking cranes are used, an important loss of performance is that the uncoordinated scheduling of the equipment. Loss can be seen by the empty waiting AGVs for the stacking cranes. These AGVs are waiting at the end of the staking yard, the place where the AGV receives a container from the ASC. This place is called the Transfer Point (TP). The number of TPs per stack depends on the lay-out of the stack and the equipment that facilitates the stack. These points can, beside the function of transferring a container between the different types of equipment, be used to park AGVs that are idle (Duinkerken & Ottjes, 2000). The way of scheduling described by Meersmans (2002) assumes a case in which all AGV pass a common point after they are released of their container by the Quay Crane. On the moment the AGV passes this point, a new action according to the loading sequence, is given. It is shown that this way of working influences the remaining part of the scheduling of the equipment. On this point a Beam Search Algorithm is used to select the next order and therefore action of the AGV, this algorithm is based on earlier research of Meersmans. After receiving the order, the AGV drives to its next destination. In the scope of this thesis this next destination would be the TP of a requested container as long as containers will be available. Other options can be a refuelling station, the TP of a stack to park or to pick up containers for other deep-sea vessels. Another way of scheduling is that the AGVs do not pass a common point during the loading process. Thereby the AGV can for example, make use of shortcuts. In this latter case a mixed integer programming formulation is used (Meersmans, 2002; Meersmans & Dekker, 2001). The loading process that is considered in this thesis will be driven on the availability of the AGVs. When AGVs are used in a research several attributes such as driving speed, driving distance, congestion caused the number of AGVs and possible deadlocks can be of importance (Steenken et al., 2004).
Lee et al. (2007) also stated the importance of the scheduling problem of the transtainer (the crane that facilitates the stacking yard). The influence of the number of stacking cranes on one stacking yard in relation to the number of Quay Cranes that is used is not always considered and a solution to the problem of serving one quay crane with more than one stacking crane is not given yet, according to Lee et al. (2007). However, Kim et al. (2005) and Ng, (2005) do take this into account, but here the loading sequence is not considered. By investigation the scheduling of the equipment mathematical data is used a lot, but no real data according the equipment can be found (Steenken et al., 2004).

In this thesis the concept for AGVs that receive their next order on a certain point after releasing their container will be used. The reason is the configuration of equipment that will be used later on in this thesis. Furthermore, the dynamics of the AGVs driving from the Quay Crane to the stack and vice versa will be taken into account as assembled time that needed to drive to the Quay Crane. Lastly, the different distances from the stacking yards to the QCs between the stack that contain containers for the deep-sea vessel will be considered.

The choice for the next order that is assigned to the AGVs after delivering the previous container to the QC is made based on the stowage of the deep-sea vessel. In the next section will be elaborated on the several possibilities for making this choice.

3.2.2 Forming of the loading sequence of a deep-sea vessel

The loading sequence influences the loading process, because containers are retrieved from the stacking yard in line with this sequence. The stowage of the deep-sea vessel forms the base for this sequence. To decide on and optimize the detailed stowage many different methods have developed. These methods facilitate different optimization objectives. A short overview will be given and how the planning of the stowage contributes to the efficiency of the loading process is discussed. Stahlbock & Voß (2008) consider some of these methods in an overview, this overview is used to gain the necessary insights into the bottleneck and is presented below. At the end of the section will be explained what will be used in this thesis.

As stated by Atkins, (1991) the available space on board of a deep-sea vessel has to be used as efficient as possible. Moreover, the berthing time of the vessels has to be minimised. Wilson et al. (2001) divided the forming of the stowage in two phases; a strategical and a tactical step. These steps correspond to the process of forming the stowage nowadays at the terminal. The strategical step is comparable to the forming of the rough stowage and the tactical step to the detailed stowage. Their solutions for both steps lead to suboptimal results. The most important variables that were tried to be optimised are as less a possible mixing of containers with different destination during placing the containers in the holds of the vessel, weight constrains and as less a possible re-handles, which are defined as handles of containers that have to be removed to reach other containers.

Next, the so-called Master Bay Plan Problem (MBPP) is researched. Ambrosino, et al. (2006) investigated the MBPP with the aim to minimize the overall loading time of container on the deep-sea vessel. The presented three phase algorithm is based on Ambrosino et al. (2004). The proposed approach takes the constraints of container size, type, weight, destination and distribution of the weight of the vessel into account. Botter & Brinati (1992) and Imai et al. (2002) also proposed a solution for the MBPP by using Integer Linear Programming, but according to Ambrosino, et al. (2006) these solutions are not suitable for real life large scale applications. However, the approach only takes the start port of the journey of the deep-sea vessel into account and in the next ports only unloading operation are allowed. Sciomachen & Tanfani (2007) aim to evaluate how stowage plans can influence the performance of the quay with a heuristic method for solving the MBPP by make the connection to the three-dimensional bin packing problem. Despite the fact that this method shows promising results, the same is done by Ambrosino, et al. (2006); no containers are loaded during the trip of the vessel in this approach. In the system that is analysed in this thesis the loading of possible containers is taken into account, in the strategical planning face the Central Planner of the shipping line takes considered these movements.

Another focus of improving the loading time of the deep-sea vessels at container terminal by planning the stowage is to minimize the number of restows. A restow or loading related re-handle is an unload and, later on a load, move of the Quay Crane of a container that forms an obstacle on board during the loading or unloading process. This phenomena is, amongst others, optimised by Haghani & Kaisar (2001) and Martin et al. (1988). This last objective, re-handles during the unloaded process of the deep-se vessel is out of the scope of this research, but might prove to be of importance and is therefore mentioned here. Aim is to minimize re-handles in the stacking yard are tried to minimized or put in other words, the need for shuffles during the loading process. A shuffle is defined as whether or not a container in the stacking yard has to be repositioned to pick a container below the shuffled container. The cause of this shuffles can be explained as follows: containers that have to be loaded arrive at different times at the terminal via the hinterland transport or by another deep-sea vessel. Therefore, it is very likely that containers are not placed according the loading sequence in the stack and shuffles have to take place. Shuffling can be avoided during the load operation when

reorganisation can be carried out in advance. However, shuffling in advance is only possible when the handling equipment is idle and buffer space in the stack area is available Research to the relation of the stability of the vessel and shuffles is done by Imai et al., 2006. For the number of shuffles probability is used. In this thesis the data of the containers terminal ECT Delta terminal Rotterdam will be used, therefore no probability has to be used on the number of shuffles.
The most recent work found is from Araújo et al. (2016), which continues the work of Azevedo et al. (2014) and the research tries to solve the 3D Container Ship Loading Plan Problem (CLLP). Based on a literature review Azevedo et al. (2014) proposed three metaheuristics with representation by rules, to prevent for infeasible solutions. However, only one objectives of the two that are taken into account, instability of the vessel and the number of moves, could be optimized at the time. The latter work proposed a Pareto Clustering Search that enables the decision maker to choose a solution that best meets their interest on that moment. For example stability in times of rough water and weather or movements an penalties in other ports during calm water (Araújo et al., 2016).

According to the loading sequence that is based on the stowage, an attempt was made to optimize several variables in the loading process. It turned out that optimizing more variables at the same time cannot be achieved yet due to the complexity of the loading process. Moreover, it can be concluded that the port of destination and the weight distribution are considered a lot to optimize the number re-handles on the vessels and the number of shuffles in the stacking yard. The size of the containers and the possibility on exceptions are not taken into account. These last two variables, together with the weight distributions and the port of destination will be used to improve the number of shuffles that have to be made. The number of re-handles that are made by the QCs during the loading of a deep-sea vessel is out of the scope of thesis and will not be taken into account further on.
The improvement of the number of shuffles is one way to increase the output of the stack, more on this improvement will be discussed in the next section.

3.2.3 Improve the stack output using the way of stacking

Apart from retrieving the containers in a faster way from the stack, it is also possible to place the containers in a more efficient way in the stacking yard. In this section the way of putting the containers in the stack and how this can be used to improve the output will be described.

The productivity of the Automated Stacking Crane can be improved by decreasing the number of shuffles during the loading process. Moreover, an increase of the output of the stack can be improved by use other ways of putting the containers in the stack. In other words; to use a different stacking strategy. For the stacking strategy a two phase approach is used; first a suitable stack is identified, followed by the step to find a suitable spot in that stack for a container. To do so, a weighted scoring mechanism, using penalty points, is used (Boer & Saanen, 2014). The stacks at the terminal are split in different areas. Reefer containers (containers that can regulate temperature inside the container) have pre-assigned places as they need to be connected to the power. Import and export containers are defined and placed at certain locations. Lastly, containers that have exceptional sizes or dangerous goods have special assigned places (Steenken et al., 2004).
In this research the export containers, including the exceptional sized and dangerous cargo containers, are taken into account; these are the containers that have to be loaded. Despite the fact that the stacking yard is assumed in this thesis, an interesting strategy that is mentioned is category stacking. Here, the containers are classified in categories, which correspond to the loading plan of a deep-sea vessel. The containers in the same category can be exchanged freely and are placed in the same stacking pile as much as possible. As not all information, including the port of destination of the container, is available at the moment of stacking, the containers cannot be stacked in a perfect way with the use of this algorithm. However, the concept shows promising results according to the authors. The classifications of the categories are also of interest for this thesis. The weight, destination and type of container is taken into account and 90 categories for deep-sea vessels are defined, this is

a fairly low number of categories compared to the deep-sea vessels and categories used in this thesis. The containers that had the same vessel, destination, weight are stacked together in piles, scattered over an area. The categories are matched to the stowage criteria and shows a remarkable lower number of shuffles (Dekker et al., 2006; Steenken et al., 2004).

The focus of the review above shows that planning of the stowage of deep-sea vessels is a very complex process and a lot of research about improving the service time of deep-sea vessels by improving the stowage has been carried out. Despite the fact that the workload of the stacking crane is considered in this literature many times, no investigation to relaxing the loading sequence during the loading process, the proposed concept of Duinkerken et al. (2001) excepted, can be found. Interesting is the decrease of the workload of the ASC, one of the objectives used a lot in the problem solving described above. The distribution of the categories over different stacks had a lowering effect on the ASC operations. In this thesis the stacking strategy is out of the scope, but the concept of distributing the workload by picking containers of a category is used. In the next section more about this concept will be explained.

3.3 Category Loading

In literature the concept of category loading is mentioned by Duinkerken et al., (2001), which stresses the urgency to increase the performance of the port facilities. This urgency is caused by larger ships (Notteboom & Winkelmans, 2001). The container terminals can be divided in two kind of terminals according to Wiegmans et al. (2008); the multi-user and the single-user terminals. The multi-user terminals handle containers of any container carrier. The terminals are operated by large global operators and concentrate on the terminal operations, realising profits and developing their global container terminal network. One of these multi-user terminals is Hutchison Port Holdings (HPH), which owns terminals all over the world and one of those terminals is the ECT Delta terminal at Rotterdam. These independent operating terminals experience a lot of competition from the single-user terminals. The single-user terminals are dedicated terminals that are operated by container carriers themselves. An example of such a carrier is Maersk Line, which operate, amongst others, APM Terminals at Rotterdam.
Apart from the dedicated container carriers, alliances also play an important role in the growing size of vessels; carriers have set up lines together to use the large vessels as efficient as possible. These alliances are a trigger of the growth in vessel size up to 20.000 TEU. Moreover, the container carriers co-operate with the terminal operators and create a dedicated single-user facility within the multi-user terminals (Midoro, et al., 2005; Wiegmans et al., 2008). Since supply and demand are hard to match and trigger the carriers to become more efficient by using larger vessels, use concepts as slow steaming and cooperation (Nieuwsblad Transport, 2016), the terminals experience a lot of pressure. When a terminals offer sufficient capacity and the capacity is available, speed is one important selection criteria for container carriers (TU Delft, 2007).
To improve the speed at the container terminals the category loading concept is investigated by Duinkerken et al., (2001). Category loading is explained as the relaxing of the load planning by introducing load categories. Containers that have the same characteristics are classified in the same category. At the moment the next order for a container is coming in, a choice can be made between a small number of containers rather than one specific container. Resulting, the freedom for the load sequence an improvement of the stack response is expected. The stack response is defined according the following KPIs:

- Quay Crane utilization: complementary the time that the QC is waiting for an AGV
- Shifting: percentage of containers that have to be shuffled to reach the output of one container
- Average move: average time that is needed to perform 1 move of the ASC
- ASC utilization: percentage of time that the ASC is active

The loading in categories avoid shifting, or shuffling as it is called in this thesis. When the containers are more or less the same the need for an extra movement of the ASC disappears. In the paper of Duinkerken et al. (2001), four kind of stack strategies are taken into account. The stack strategies are used to compare strict loading and category based loading. The category based loading shows an improvement of 5% in Quay Crane utilization compared to the strict loading sequence with the same stacking strategy. Notable is also the decrease of the percentage of shuffles of 5%. Duinkerken et al. (2001) also compared strict loading and category based loading to different stacking strategies, maximum stack height, number of AGVs and dedicated stacking lines. The combination of the stack strategies and the way of loading show improvements of these topics.
The simulation that is done for this paper can be applied on the automated container terminals in Rotterdam. The automated terminal of Europe Combined Terminals[1] is used in the research; the logistic chain of the container terminals consists of the Quay Cranes, the intra-terminal or horizontal transport by AGVs and the container stack equipped with an Automated Stacking Crane (ASC).

In this thesis not all aspects of Duinkerken et al., (2001) will be considered in a similar way. First of all, unloading will not be included in this research because the unloading is not as complex as loading is. Back in time of the research jumbo vessels of 8000 TEU were handled during that time, whereas nowadays deep-sea vessel up to 20.000 TEU call at the container terminals in Rotterdam. Furthermore, the containers that will be used are containers that are loaded in the real system, no different stack strategies will be considered.
To define categories for containers, the characteristics of the container are taken into account. Next, an overview of the characteristics that can be used to form categories will be given.

3.4 Defining categories using container characteristics

The container is a standardized box. Despite the standardization several characteristics can be distinguished. These characteristics form the basis of the categories for the loading concept of a reduced number of categories. The following characteristics are of importance for the forming of categories:

- Full or empty container
- Weight of the container
- Measurements of the container
- Special container or not
- Destination port of the container

The characteristics of the container are described in the following paragraphs.
First of all, containers can be classified as *full or empty*. Then, the *weight* of the full containers is important for the stowage, placing the centre of gravity of the vessel in the right place. If this is not the case, the vessel will encounter problems during sailing due the waves and other balance issues. If the centre of gravity is too high, the forces on the containers and their twist locks can be too high and the connection between containers may be lost. In the worst situation containers can fall, the vessel can capsize or can break.
Apart from the weight, containers differ in size, for example a 20ft container needs half of the room of a 40ft container. Based on the 20ft container the standardized name for a container is formed: a Twenty Feet Equivalent Unit (TEU), meaning that a 40ft container is equivalent to 2 TEU and a 45ft container to 2.25 TEU. This characteristic includes the *measurements* of the container.
Furthermore, it has to be decided whether a container is *special or not*. Special container can, for example, be so-called tankers (see **Figure 14**), containers with an over height or flat racks (see **Figure 15**). These containers will always keep their own unique category, because the location of the containers on the vessel can be specifically assigned for these type of containers. Other containers

[1] Nowadays Europe Combined Terminals goes under the name Europe Container Terminals (ECT)

that can be classified as special are containers that contain dangerous cargo, the so-called IMO containers. They are based on the classification scheme for dangerous goods of the International Maritime Organisation (IMO). Despite the fact that these containers can have normal physical characteristics, several rules for their location on board are applied to them. The last kind of containers that can be classified as special are containers that need electricity, the so-called reefers. These containers are cooling or heating its cargo. On board and in the stack places are equipped with electricity connections.

Figure 14 - Tanker Container


Figure 15 - Flat Rack Container

Lastly, the *destination* is of importance, as not all containers on one vessel have the same destination; the containers that have to be unloaded at the next destination of the vessel have to be reachable. This is of importance, because re-stows (discharging and loading again of containers to reach another container) are time consuming and therefore expensive (Dekker et al., 2006; Ham van & Rijsenbrij, 2012; Steenken et al., 2004).

In this thesis all the characteristics will be used to classify categories. Some characteristics are easy to classify: the port of destination of a container, the measurements and the whether a container is full or empty. To determine whether a container is special or not depends on how its defined. Here, a container is classified as special in the case it is not standard. Therefore, containers that contain dangerous goods, have an open top, have to be connected to the power because of climate regulations (reefers) or are classified as tanker will be treated as special. Lastly, the classification of the weight of the containers have to be done. Because this can be done in various ways, the classification will be variated in the scenarios of this thesis.

3.5 Key Performance Indicators (KPIs) for loading deep-sea vessels

To be able to measure the current process Key Performance Indicators are identified. KPIs are adequate measurement criteria that have to be developed to establish relations between actions and the output of the system (Böse, 2011). The KPIs are based on the variables that are of importance according the cited literature.

To analyse the bottleneck in the process, the output of the stack is taken into account. The output of the stack is defined as the number of containers that are loaded on the AGVs per hour by the Automated Stacking Crane. This KPI will be higher when the loading time becomes shorter, but not directly. The dynamics of the AGVs can influence this KPI. Moreover, the distribution of the containers among the various stacking yards can be of influence. Therefore, the effect of reducing categories of containers during the loading on the output of the stack will be analysed here in the first place.

$$Output\ stack\ \ [\#containers/hour]$$

The performance of the ASC is mentioned often in literature and includes the moves for the output of containers, the shuffles that have to be made and a landside move every now and again. Because the stowage and the loading sequence are specified in advance, the suspicion is raised that the exact number of shuffles can be calculated. However, the calculation can be done for the predetermined loading sequence and the nature of the problem makes it quite difficult to do this. Therefore, probability is used for the number of shuffles and is combined in a distribution that includes all moves (Imai et al., 2006). However, the data that will be used in this thesis includes a snapshot of the whole stacking yard on the moment the loading of the deep-sea vessel starts. Because of this snapshot, the initial number of shuffles can be determined. During the loading process, all shuffles that will be made will be recorded and summed. The total number of shuffles that is made by all ASC during the loading process will be presented.

$$Shuffles\ [\#shuffles]$$

To estimate the effects of the output of the stack, the waiting time of the AGV at the Transfer Point (TP) is taken into account as KPI. The waiting time will be measured from the moment of arrival of the AGV at the Transfer Point until the AGV leaves to the Quay Crane. This waiting time will present the time that is needed to wait for the ASC that is working on other orders (landside or waterside) and is delayed by shuffles that have to be made. Ideally, the AGV do not have to wait, because no other orders or shuffles have to be done and the driving time of the AGV to the stacking yard is used to pick up the container and bring it to the Transfer Point.

$$Waiting\ time\ AGV\ [minutes]$$

One of the most important KPIs according to the shipping lines is the utilization of the Quay Crane. The best performance of the waterside process is achieved when a maximal utilization of the crane is reached. The utilization is measured from the first pickup by the QC until the last put down of the Quay Crane of the loading of one deep-sea vessel. There are more cranes working on one deep-sea vessel. The performances of the different QCs are considered as average and calculated as percentage of utilization during the indicated period. Complementary the percentage of the crane waiting for AGVs delivering containers can be calculated (Duinkerken et al., 2001; Duinkerken & Ottjes, 2000; Stahlbock & Voß, 2008).

$$Utilization\ QC\ [\%]$$

Lastly the overall service time of the deep-sea vessel will be presented. This indicator can be used to estimate the difference between the current situation and the category loading situations in hours. This KPI will be measured from the moment the model starts running until the last container loaded. The model starts running on the moment that is first order is assigned to the AGVs. In this KPI the operational loading time is taken into account, the time that is needed, for example, to moor the deep-sea vessel or to positioning the Quay Cranes is not considered.

$$Overall\ Service\ Time\ [Hours]$$

In **Figure 16** is an overview of the KPIs according the terminal is presented.

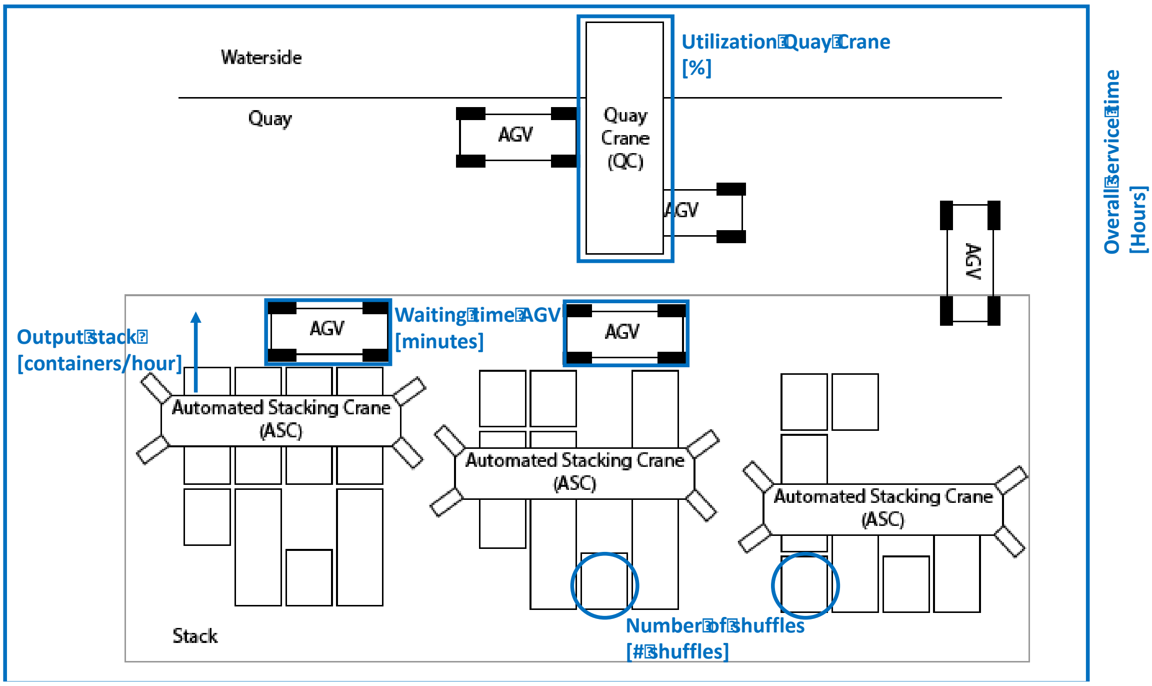


Figure 16 - Overview KPIs

3.6 The next steps for category loading

First a short summary of the literature study will be given to get clear what will be used and what will be different or developed further on in this thesis. This will be followed by how the next steps will be approached.

The bottleneck at the output of the stack, identified by the waiting AGVs, is part of the loading process of containers on board of deep-sea vessels at maritime container terminals. To improve this loading process by optimizing different parts of the process a lot of research is done on these parts of the process. First the process is compared to other situations: loading trucks, trains and aircrafts and the cargo in container itself. It turned out that the loading of these transport modes and containers face less complexity because the volume that have to be loaded is smaller and the sequence does not cause such delays as during the loading of deep-sea vessels. Then the comparison to retrieving cargo from warehouses is made, but solutions as the use of random access systems are not applicable for container stacks. However, the characteristics of the measurements of the cargo, the distribution of weight of the transport mean and the objectives of an as high as possible service level, explained as an as short as possible loading time will be used in this thesis.
Narrowing the scope of the loading process to only maritime container terminals, it turned out that due to the different parts of the loading process it is not yet possible to optimize all these parts at the same time to reach an as high as possible service level. However, the same objective will be aimed in this thesis and several important characteristics are identified. These characteristics include the port of destination, the measurements and the weight of containers. The same as in the literature, these characteristics will be used to improve the number of shuffles in the stacking yard. Other characteristics of a containers that will be considered will be whether a container is special or not and whether it is full or empty. Furthermore, re-handles of the Quay Crane are studied. Because the scope of this thesis is set to the output of the stacking yard, these re-handles will not be taken into account. To improve the output of the stack, the focus can be on how the containers are placed in the stack, but also on how the next container from the stack is chosen. Here, the focus will be on the latter one, especially by using a concept called category loading. This concept classifies all containers in several categories, where on this moment every container has its own unique category, the number of

categories will decrease because containers that have the same characteristics will be classified in the same category. On the moment the choice for the next container has to be made by the Terminal Operating System, more containers due the category that is requested will be available. Because of the research of Duinkerken et al. (2001), it is expected that the larger choice for containers during the loading process by decreasing the number of categories will lead to a more efficient loading of the deep-sea vessel. A more efficient loading can be measured by the overall service time and explained by the QC utilization, the waiting time of AGVs at the stack, the number of shuffles made by the ASC and the output of the stack. Results of 5% improvement by using category loading are mentioned. In the case that the loading of a deep-sea vessel takes 24 hours, a reduction of more than an hour (1 hour and 12 minutes) can be achieved. In **Figure 17** the current situation and the category loading situation are presented next to each other. The left pictures show the stowage and the corresponding loading sequence indicated by the numbers on the containers. It can be seen that for the next container shuffles have to be made. The right picture shows a category loading situation. The stowage and corresponding loading sequence according categories are presented by the numbers on the containers. A choice between containers for the next one in the sequence can be made.

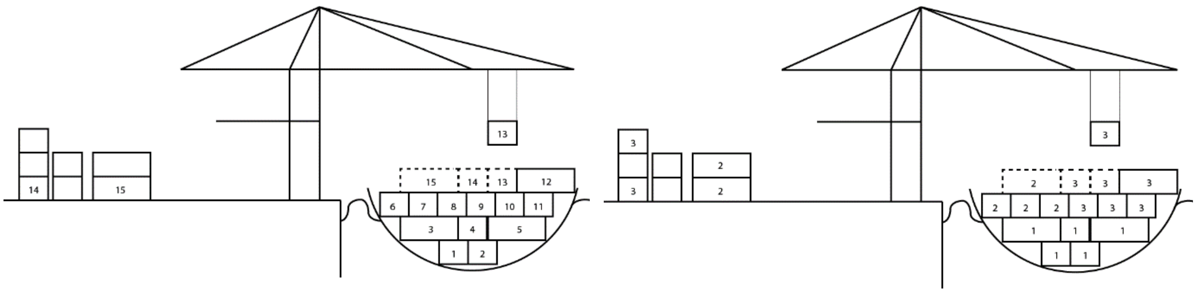


Figure 17 - Current situation and category loading situation

To test the expectations regarding category loading, an approach is required. Due to the complexity of the equipment and the growing size of the operations it has become hard to determine the performance of terminals analytically. Furthermore, the control techniques in relation to the dynamic behaviour of the equipment does not make it easier to analyse and measure performance. Therefore a simulation tool is an established approach to deal with terminals (Angeloudis & Bell, 2011). Furthermore, a simulation contributes to this research because simulation is an easy way to communicate and understand results (Rohrer, 2000), which will be helpful by the objective of providing an advice about the loading concept to container terminals. Different kind of simulations are available. To determine which kind will fit, characteristics of the system will be set and a decision about an applicable software will be made in the next chapter.

In this thesis historical data of the ECT Delta terminal Rotterdam will be used to investigate the concept of decreasing the number of categories during the loading containers on board of deep-sea vessels. Therefore, the current stack strategy that is used to put containers in the stack will be used and not changed. All containers will have a fixed initial position in the stack. What will be changed by decreasing the number of categories is the choice for the next container in the loading sequence, this choice will be based on the reachability of the container. The reachability is defined as the number of shuffles that have to be made to pick up the requested container and the number of orders that is already assigned to the ASC that has to pick up the container.

4 Simulation model of the loading process of a container terminal

This research concerns the loading process of containers on board of a deep-sea vessel. This process will be modelled to investigate the effect of decreasing the number of categories that are classified by the characteristics of the containers that have to be loaded. To choose the way of modelling and a suitable software package for the model, a classification of the model is specified. This classification can be used as the requirements for the software package (Kelton et al., 2011).

4.1 Classification of the way of modelling and simulation software

The term simulation is used in a wide range objectives, activities and methods. In this section a classification is made. This classification will be used to choose the way of modelling and the simulation software package.

4.1.1 Classification of the loading process of containers

In this section a distinction between static and dynamic, continuous-change and discrete change and deterministic and stochastic models will be discussed and applied to the system of loading containers to a deep-sea vessel.

Static versus Dynamic models: In a static simulation, the time does not play a role during the operation of the system. Examples of this type of simulation can be a gambling game. During dynamic simulation, time is an important factor. Examples of dynamic simulation ca be a queuing-type systems or inventory systems. During the loading process of the containers time plays an important role. The equipment and containers involved in the loading process will be presented as movements of the equipment, arrivals of the containers and equipment at different processes such as the Quay Crane and departures of the containers when they are loaded at the vessel are a typical supply chain model that includes logistics (Kelton, et al., 2014). The loading process of the containers to the deep-sea vessels can therefore be classified as dynamic.

Continuous-Change versus Discrete-Change models: Since the loading process is classified as a dynamic model, a distinction between continuous-change models and discrete-change models can be made. In the dynamic models usually state variables are defined. These variables describe the state of the model at a particular point in time, for example the length of the waiting queue for orders at the stack or the status of the QC (idle or busy). In case of a continuous-change kind of model, these states can continuously change over time. An example is the level of water in a tank. When states only change at instantaneous points in time, the dynamic model can be classified as discrete-change. Here, the queues, the idle and busy times, the number of shuffles of a container and more states of the system only change at discrete point in time and can therefore be classified as discrete-change (Kelton et al., 2011).
Four discrete modelling paradigms are evolved over time: event-oriented, process-oriented, object-oriented and Agent-Based Modelling. In an event-oriented model certain point in time are set for the change of states. By process-oriented modelling a sequence of actions that take place over time will be provided. Object-oriented modelling is done from a point of view of the facility and Agent-Based Modelling is a special case of object-oriented modelling, where separated components as part of a whole are studied (Kelton, et al., 2014). The process and the boundaries for this thesis are shown in the System & Control cycle of Negenborn (2013), see **Figure 12**. In this way of presenting the process, the information that concerns the containers and the equipment is most important. The Terminal Operating System (TOS) measures data from the equipment and uses this to assign the next actions to the equipment. Therefore, the data has to be considered first and the processes secondary in such a system. The processes are not determined in advance, because it depends on the information provided by the measurements of the container properties (e.g. location, destination, etc.) and the equipment (e.g. availability, distance to location, etc.). For example; an AGV will only drive to a stack

if a container is requested from that stack. According to (Constantine, 1989), such an object-oriented methodology fits the system of loading containers. An object-oriented approach contains object classes, that contain their attributes and operations and can be used to describe the input of the model within the defined boundaries of this thesis. A class can be active or passive. An active class can perform operations, is able to make decisions, can be part of the operations of other active objects and can determine the behaviour of the system. In the terminal system the equipment that is needed to load containers can be defined as active. Passive objects undergo operations of other (active) objects and can influence operations of active object. Here, containers are passive. Decisions are made on the attributes of the containers, for example the category or the position of a container by the AGV, ASC and QC. An overview of the passive and active classes is given in **Table 1** and **Table 2**. Only the attributes that are needed in this research are taken into account here.

Table 1 - Passive Object Class

Container
Category Start Time Stack Crane Position

Table 2 - Active Object Classes

Object classes	**Automated Stack Crane (ASC)**	**Automated Guided Vehicle (AGV)**	**Quay Crane (QC)**
attributes	Number Cycle Time	Average speed	Cycle Time
operations	Handle containers from the stack to horizontal transport	Transport containers	Handle containers from horizontal transport to deep-sea vessel

Deterministic versus Stochastic models: Lastly, the difference between deterministic and stochastic models will be made. When only fixed values are used, a model is classified as deterministic. As at least some of the input values are specified as random draws from probability distributions a model will be classified as stochastic. Stochastic models are used when uncertainties about the input data or activities involving people will be the case. The randomness and variation that occur in real life can be presented in statistical distributions. Deterministic model has no variation and are used for model-based decision support such as scheduling and emulation applications (Kelton, et al., 2014). For this thesis, all data is available and the consisting system, that will be simulated first, will be compared to different scenarios where the input data will be changed. Therefore, a deterministic model will be created here.

All together a dynamic, discrete-change deterministic model have to be built. In the next section a suitable simulation software will be chosen to do this.

4.1.2 Suitable simulation software for the simulation of the loading process

To simulate the loading process, a simulation software is needed. This software must be able to model a dynamic discrete-change deterministic model. Several simulation package can be used for such a model. Arena, ExtendSim, Promodel, Flexsim, Delphi, Simio and Simul8 are examples of these kinds of packages. Since all these packages are suitable for the model a choice is made based on the availability of the programs, the user friendliness and the experiences of the author of this thesis. The simulation package Simio is the result of these considerations. The user friendliness of the program ensures that no programming skills are needed. Simio consists of intelligent objects that can be modified and has an object-based paradigm. Furthermore, the objects are visualized as simple graphical processes which makes it possible to follow the entities in the processes and to create easily an animation of the model. Animation will be helpful to explain the simulation very well to the stakeholders, here the containers terminals, without a very well understanding of the simulation software (Verbraeck et al., 2006).

4.2 Inputs and outputs of the simulation model

The simulation model that will be used to answer the research question of this thesis uses the data of the Delta terminal of Europe Container Terminals (ECT). The configuration and the data of this terminal are used to build the model logic. Because the information of the places of the containers in the stacking yard at the start time of the loading process are needed, only vessels that called in July of 2016 or later could be used, from this moment snapshots of the stack are registered. Furthermore, deep-sea vessels that are chosen are part of a weekly service of shipping line Evergreen. This service sails every week to Asia and transport both full and empty containers. Because the calls of this service are mainly loading calls and facing therefore a lot of complexity, possible improvements would be of interest for the container terminal. In this thesis only the loading process is taken into account and therefore these calls are useable to validate the model and to provide a useful advice on the loading concept to the terminal. A general representation of the input and output variables is given in **Figure 18**. The variables are explained in the following paragraphs.

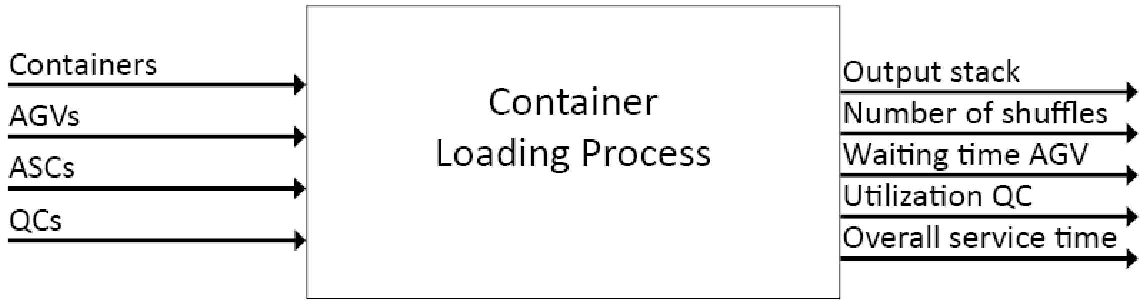


Figure 18 - Overview input and output simulation model

4.2.1 Inputs of the simulation model

For the input of the simulation model, data of the ECT Delta terminal is used. Three deep-sea vessels that are frequently handled at the terminal are considered. The vessels are of the same size and capacity and facilitate the weekly service of the shipping line Evergreen. As already mentioned the vessels are chosen because the availability of data and the interest for potential improvements for this service. An overview of these vessels, together with the analysed date of call are given in **Table 3.** As can be seen the call of the 23th of July is missing. The deep-sea vessel was replaced in the planning at the quay on the last moment, the containers that had to be loaded were spread throughout the terminal. Because the potential for the weekly service will be tested, this call will not useable. For further research, such exceptional situation could be of interest but for now this call is not taken into account. The vessels which have called are named Thalassa Doxa, Thalassa Niki and Thalassa Mana. Of one of the vessels for which the loading process will be analysed a picture is presented below in **Figure 19.** This is the Thalassa Doxa.

Table 3 - Deep-sea vessels

Deep sea vessel	Line operator	Date of call
Thalassa Doxa	Evergreen	09-07-2016
Thalassa Niki	Evergreen	16-07-2016
Thalassa Mana	Evergreen	30-07-2016

Figure 19 - Thalassa Doxa (source: MarineTraffic.com)

The objects and their criteria that are used in the analyse are explained in the following paragraphs.

Container: The containers that will be used in the simulation model have to own several properties. First of all, the containers have to be containers that need to be loaded on a deep-sea vessel, because in this thesis only the loading process is taken into account. Next, the containers own a place in a stack. This place is identified by stack number, row number, section number and the height, see **Figure 20.**

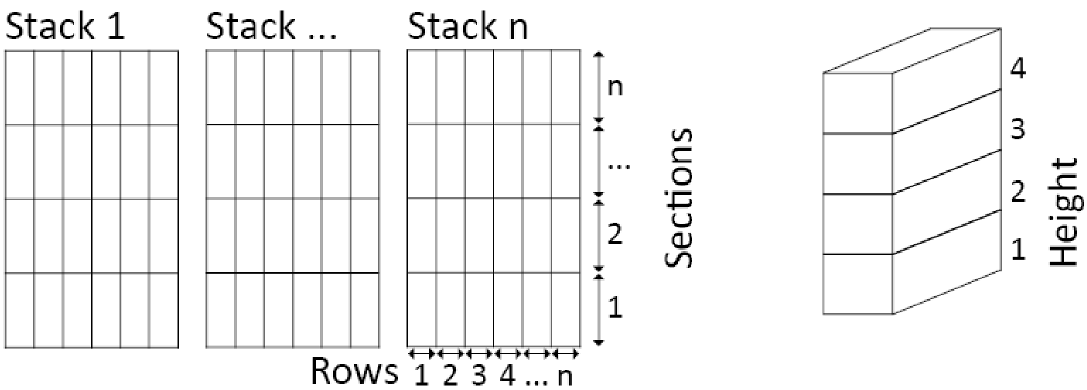


Figure 20 - Classification stack

Moreover, a category is added to the containers, represented by a number. The loading sequence uses this number in the model. While modelling the current situation every container has to own a unique category. The number of categories is therefore equal to the number containers that have to be loaded in the initial situation. Later on, in the experimental design, more containers will own the same category. These categories will be formed by using the characteristics of the containers. The characteristics of the containers will therefore not be directly part of the input of the simulation. Lastly the initial number of shuffles is added to the properties of the containers. This is done by using the height of the container and check on other containers in the same stack, row and section.
Historical data of the three deep-sea vessel calls are used. However, not all information of all containers is correctly stored during the process. Because of this lack of data these containers are left out. Moreover, part of the loaded containers is re-stow containers. These are counted as loaded containers, but have never been in the stacking yard. Re-stows containers are discharged and placed

in a lane behind the Quay Crane, later these containers are loaded again. Because re-stow containers do not add complexity to the retrieving of the stacking yard, they are left out. The number of containers that is loaded during these kind of calls can be up to 3800 containers. The percentage of containers that will be left out because a lack of information or concerns a re-stow is 15%. The number of containers useable in the dataset per deep-sea vessel is presented in **Table 4** below.

Table 4 - Number containers loaded

Deep sea vessel	Number containers loaded
Thalassa Doxa	3224 containers
Thalassa Niki	3207 containers
Thalassa Mana	3106 containers

Automated Guided Vehicles: during a typical loading process the amount of AGVs is approximately 7 AGVs per quay crane. In the case of six cranes the number of AGVs is 42, this number of vehicles will be used in the model. Moreover, a driving velocity is required as input. The AGVs need some time to accelerate and to decelerate, taking this into account the average driving speed is set to 2.8 meter/second (Stevenson, 2015).
The capacity of an AGV is 2 TEU. This means one 40 or 45 feet container or two 20 feet containers. During the loading at the Delta terminal twin lifting is applied. This means that two 20 feet containers can be handled at once by the QC. In that case, the AGV has to pick up 2 containers, sometimes at two different stacks. In this simulation model, twin lifting is not taken into account. This means that the QC have to make more moves than in the real situation and the waiting time of the AGV at the transfer point at the stacking yard can be different according to the data of the real situation. The more moves that have to be made will be around the 650, according to the three deep-sea vessels that are taken into account. For now, it will be kept in mind, but here the potential of the loading concept will be tested without twin lifting.

Automated Stacking Crane: the required input for the ASC is the cycle time. The cycle time is defined as the duration of picking up the container, hoisting the container, the horizontal driving time, lower and placing the container on the AGV and the time required to go to the next location. Because of the driving distance of the ASC and the different hoisting heights, caused by the stacking height of the container, the cycle times can differ.
It takes at least 1 minute and 21 seconds to reach a container and put it on an AGV, according to the three selected dataset of the deep-sea vessel loading. On average 2 minutes and 16 seconds are required. A graphical presentation of all the values that are used can be found in **Appendix A** - Input parameters.

Quay Crane: the cycle time is defined almost equally to the cycle time of the ASC; the duration of the cycle time is defined as picking up the container, hoisting the container, the horizontal driving time, lowering and placing the container on board and the time required to go back to the starting position. As the AGVs arrives at the QC it has to wait until the container can be picked up by the QC, from this point the AGV is released from its container and moves on to its next job. The time that is needed to pick up the container from the AGV, is specified on its own. The time that the AGV is claimed by the QC is on average 18 seconds. The cycle time of the QC is on average 2 minutes and 12 seconds. A graphical overview of all the values that are used can be found in **Appendix A** - Input parameters.

4.2.2 Outputs Simulation model

At the end of the simulation run the program will provide an output. Some of the outputs are standard and some are built-in. The output of the model will be the Key Performance Indicators:

Output of the stack: the output of the stack shows the number of containers per hour that are transferred from the stacking yard to the AGV. Not all moves of the ASC are taken into account in the model, the landside handles and the number of shuffles that are made will not be counted in this variable.

Total number of shuffles: during the run the initial number of shuffles decreases when a container above is removed. On the moment the container has to be handled the number of shuffles on that moment is registered. At the end of the simulation run the total number of shuffles that is registered will be presented per stack.

Waiting time AGVs: the time AGVs are waiting at the output of the stack to receive a container. This depends on the moment of arriving of the AGV, which is always 1 minute and 21 seconds; the minimum time that is needed to handle a container by the ASC, after the orders is assigned. This is done for the following reason. In the real system not 42 dedicated AGVs are assigned to one deep-sea vessel, but 42 AGV are working for the vessel. The most favourable AGV of all AGVs operating on that moment will be chosen. This makes it possible that an AGV is already at the required stack or close by and the AGV will always at the transfer point on the moment the container is handled at the transfer point. In an ideal world, the ASC has no other jobs and has a container very close to the transfer point and without shuffles. It delivers the container to the AGV directly after it is arrived. In the model the waiting time of the AGV will be the time the AGV has to wait for other orders of the ASC and possible shuffles.

Utilization of the Quay Crane: percentage of time the QC is handling containers and the time that it is waiting for containers. This output is measured over the time from the first order that is assigned to an AGV for the crane until the time the last container for that crane is handled. This is done because the number of containers that is handled per crane can differ a lot.

Overall service time: the time the deep-sea vessel spends at the quay of the terminal. The measurement starts from the moment the first job is assigned to the equipment until the last container leaves the system, which means that this container is loaded.

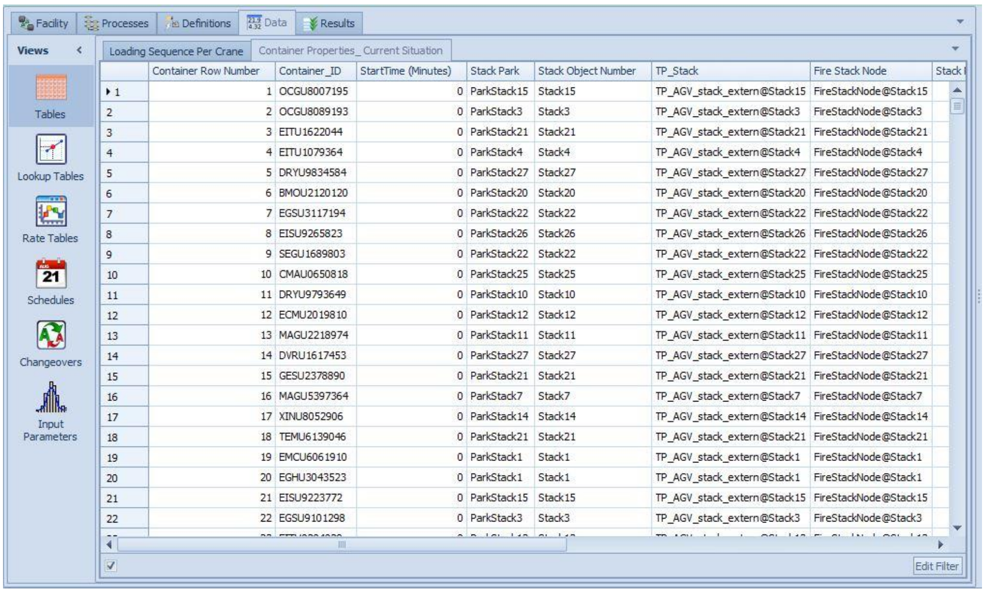
The output of the model as described above is the result of the simulation model. The simulation model is build, based on the configuration of the ECT Delta terminal at Rotterdam. It turned out that the loading system as a whole was too big for this thesis. Therefore, some aggregations had to be done. The consequences of these aggregation need to be kept in mind when drawing conclusions based on the results. A short description about the development of the simulation model will be given in the next section.

4.3 Development of the simulation model

In the simulation model the different object classes are modelled as entities. Despite that the simulation software has some built in modules, these entities are easier to control and therefore used.

The simulation run of the model starts at the moment that the model is manually started and the first order for a container will be assigned to an AGV. Therefore, orders have to be available, AGVs have to be accessible and the containers have to be positioned in the stacking yards.
Containers are modelled as entities and are passive. The entities are coupled to a table that is added to the simulation program. This table contains all the containers that have to be loaded during a call of a deep-sea vessel. The characteristics of the containers are in the table and on the moment of creating the container as an entity in the model, these characteristics are assigned to the container entity as entity states. In the current situation, every container has its own category. Because a table is used to define the containers that enter the model, different sets of containers can be added easily.

Real data of containers can be used, but also fictional sets can be added. An example of a table is given in **Figure 21**.



	Container Row Number	Container_ID	StartTime (Minutes)	Stack Park	Stack Object Number	TP_Stack	Fire Stack Node
1	1	OCGU8007195	0	ParkStack15	Stack15	TP_AGV_stack_extern@Stack15	FireStackNode@Stack15
2	2	OCGU8089193	0	ParkStack3	Stack3	TP_AGV_stack_extern@Stack3	FireStackNode@Stack3
3	3	EITU1622044	0	ParkStack21	Stack21	TP_AGV_stack_extern@Stack21	FireStackNode@Stack21
4	4	EITU1079364	0	ParkStack4	Stack4	TP_AGV_stack_extern@Stack4	FireStackNode@Stack4
5	5	DRYU9834584	0	ParkStack27	Stack27	TP_AGV_stack_extern@Stack27	FireStackNode@Stack27
6	6	BMOU2120120	0	ParkStack20	Stack20	TP_AGV_stack_extern@Stack20	FireStackNode@Stack20
7	7	EGSU3117194	0	ParkStack22	Stack22	TP_AGV_stack_extern@Stack22	FireStackNode@Stack22
8	8	EISU9265823	0	ParkStack26	Stack26	TP_AGV_stack_extern@Stack26	FireStackNode@Stack26
9	9	SEGU1689803	0	ParkStack22	Stack22	TP_AGV_stack_extern@Stack22	FireStackNode@Stack22
10	10	CMAU0650818	0	ParkStack25	Stack25	TP_AGV_stack_extern@Stack25	FireStackNode@Stack25
11	11	DRYU9793649	0	ParkStack10	Stack10	TP_AGV_stack_extern@Stack10	FireStackNode@Stack10
12	12	ECMU2019810	0	ParkStack12	Stack12	TP_AGV_stack_extern@Stack12	FireStackNode@Stack12
13	13	MAGU2218974	0	ParkStack11	Stack11	TP_AGV_stack_extern@Stack11	FireStackNode@Stack11
14	14	DVRU1617453	0	ParkStack27	Stack27	TP_AGV_stack_extern@Stack27	FireStackNode@Stack27
15	15	GESU2378890	0	ParkStack21	Stack21	TP_AGV_stack_extern@Stack21	FireStackNode@Stack21
16	16	MAGU5397364	0	ParkStack7	Stack7	TP_AGV_stack_extern@Stack7	FireStackNode@Stack7
17	17	XINU8052906	0	ParkStack14	Stack14	TP_AGV_stack_extern@Stack14	FireStackNode@Stack14
18	18	TEMU6139046	0	ParkStack21	Stack21	TP_AGV_stack_extern@Stack21	FireStackNode@Stack21
19	19	EMCU6061910	0	ParkStack1	Stack1	TP_AGV_stack_extern@Stack1	FireStackNode@Stack1
20	20	EGHU3043523	0	ParkStack1	Stack1	TP_AGV_stack_extern@Stack1	FireStackNode@Stack1
21	21	EISU9223772	0	ParkStack15	Stack15	TP_AGV_stack_extern@Stack15	FireStackNode@Stack15
22	22	EGSU9101298	0	ParkStack3	Stack3	TP_AGV_stack_extern@Stack3	FireStackNode@Stack3

Figure 21 - Table containers simulation software

The containers that have to be loaded are organized in stacking yards that are close to the location of the deep-sea vessel at the quay. Approximately 28 stacks are used per call, these are all equipped with Automated Stacking Cranes. Because the simulation starts on the moment of the first request for a container given, all containers have to be available in their stacking yards. The start time assigned to the containers is therefore zero and all containers are created and placed in the yards immediately. A part of the stacking yards is presented in **Figure 22** by the red square.

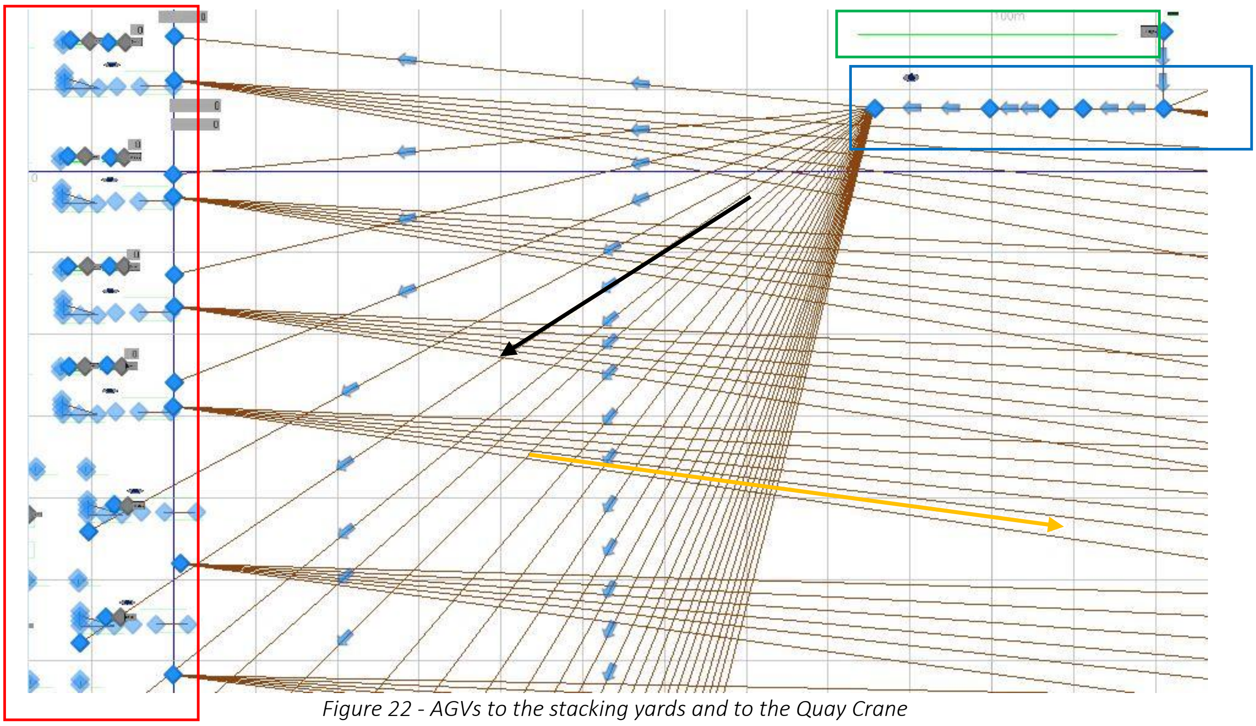


Figure 22 - AGVs to the stacking yards and to the Quay Crane

In the real system the orders for containers are made by the Terminal Operating System (TOS). The TOS creates a planning for half an hour, this means that orders are available at any time during the simulation run until all containers are loaded. In the model these orders are placed in a queue. This queue is presented in **Figure 22** by the green square. On the moment the order is made, it is placed at the back of the queue. The orders are modelled as entities and the properties category and crane number are assigned on the moment the orders are created. These properties are assigned according the loading sequence that is specified per crane.

The AGVs that takes care of the horizontal transport are assigned to the deep-sea vessel that is simulated and only serve this boat during the run. The AGVs are not dedicated to a crane, but serve all cranes. The first time after creation in the simulation model or after delivering a container to the Quay Crane, the AGVs pass a certain point. In the real system this point is the end of the quay lane, in the simulation model this 'point' is indicated by the blue square. Passing these points takes zero time, but are split because several states have to be updated. These states take care of assigning the right locations to the AGV for their next job and activate the ASC, see **Figure 23**. In this way the processes will not intermingle.

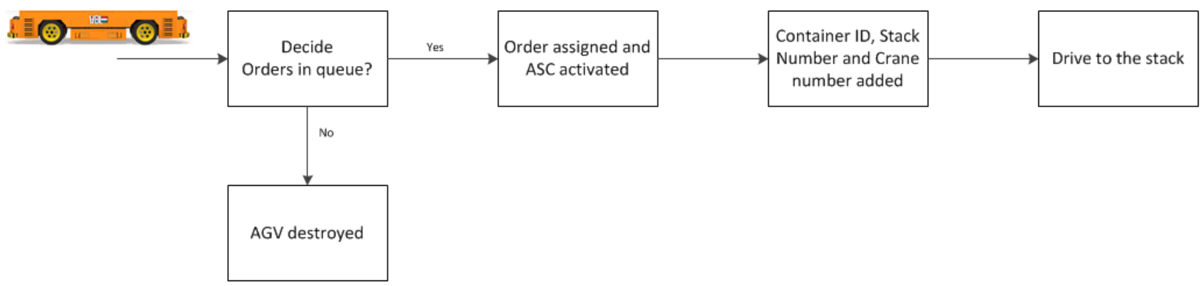


Figure 23 - Assign jobs to AGVs

After receiving a new job and all information the AGV drives to the right stacking yard in the direction of the black arrow in **Figure 22.**

Every stack owns one Automated Stacking Crane and these cranes are also modelled as entities. At the start of the run all ASCs are created and waiting for jobs. On the moment an order arrives, the ASC will become active. The stack is not taken into account as object, but modelled as a waiting area without any characteristics. This makes it possible to search for specific containers and the position of the container is assigned as property to the container entity. Other characteristics of the stack are outside the scope of this research and therefore not taken into account. After the ASC has delivered a container to the AGV, the AGV drives to the Quay Crane in the direction of the yellow arrow in **Figure 22**.

Lastly, the Quay Crane is modelled. When AGVs arrive, the AGV and container claims the QC and will be handled. Six cranes are modelled in the simulation model in a sub model, depending on the situation the number of cranes can be adjusted. The QCs are presented in **Figure 24** in the green square.

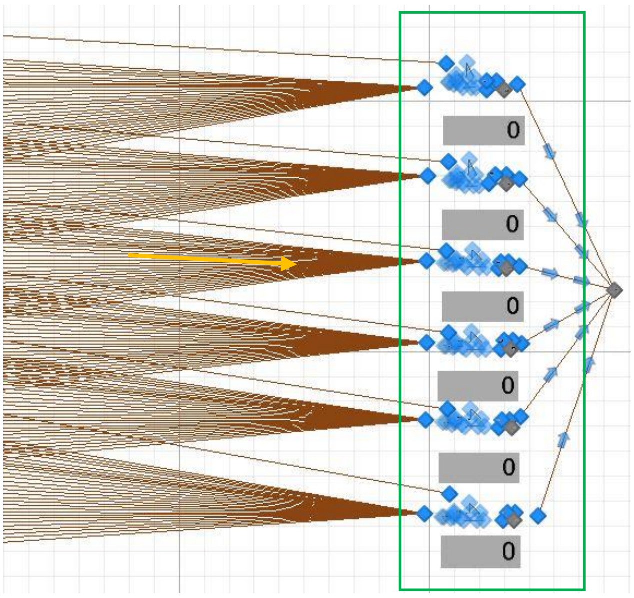


Figure 24 - Arrival QCs

After delivering the container to the QC, the AGV drives back to the point where the vehicle will receive tis next job.

The sequence of the orders is set by category number. On the moment a container from a category is requested, all containers that fit that category will be selected. From this selection the container that contains the lowest number of shuffles and is positioned in the stack that has the lowest workload on that moment is chosen. The number of shuffles and the workload together represent the number of penalty point of the container. In the current situation, each container owns its own category, therefore only one container is selected and chosen.

When the last order is assigned to an AGV and ASC the order queue of the model will be empty. The AGV that arrives at the end of the quay lane will be sent to a sink in the model and will be destroyed. On the moment the last container is handled by the QC the run will end. At the end of the run the results will be presented in the software program.

An important aggregation of the loading system is the driving time from the stacking yard to the QC by the AGV. The dynamics of the AGVs, which include interactions between the vehicles, congestion and the dispatching of the AGVs that in the real system not only work for one loading process are important simplifications of the system and have to be taken into account in the conclusions about the concept of category loading. A more detailed description of the simulation model and the processes behind the nodes can be found in **Appendix B** - Simulation model.

4.4 Verification & Validation

To use the model to find an answer on the research question it has to be validated and verified.

4.4.1 Verification

Verification is important to ensure that the process performs as intended and the model does not contain bugs or incorrect programmatic codes (Kleijnen, 1995).
Verification is continuously done during the construction of the model. The model is built step by step. First a simple model of the system is built consisting of one stack, one AGV, a few containers and one quay crane. The stacking yard including the corresponding AGV and the QC are built in sub models. Hereafter, the sub models are copied and the model is expanded further on. During the expansion entities of the model are followed and it is checked whether the behaviour is as expected. Especially, the interaction between the different parts of the model is intensively checked. A lot of different

model states need to be updated during the process and added to an AGV. But the software does not allow that AGV entities to update states of other entities, in this model the container entities. To solve this problem, extra general model states are added. The entity can update a general model state and subsequently, the general state can be used to update the state of a different kind of entity. This way of working caused long processes in zero time. To avoid that the general states update more entities than intentioned, extra resources are added. When, for example, an AGV enters a part of the model that has a long process it has to claim a resource first. Because the resource has a capacity of one, the next AGV entity has to wait until the resource is released. In this way the states and entities cannot mingle.
When the model did not fit the expectations a previous version was taken again and other ways to simulate the desired behaviour are applied and tested. By using this iterative way of working and constantly check on all components of the model after adding new or more parts, the model is verified.

4.4.2 Validation

To validate a model, it has to be an 'accurate representation of the system under study' (Kelton et al., 2014). To create a validated model of the loading process of deep-sea vessels the configuration of the system and the data of the ECT Delta Terminal is used. In real life the system is more complex than in the simulation model. Only the variables that are in the scope of the model are taken into account and a few processes are modelled together. An overview of this processes can be found in **Appendix B** - Simulation model. Nevertheless, representative values have to be achieved to make a useful comparison to the current situation later on.
To do this, the data of a weekly deep-sea vessel loop from ECT is used. The data and the performance of the equipment can be used for the simulation model.
Here, historical data of three deep-sea vessels that are loaded according the weekly loop are used. The containers and the characteristics of the containers, the cycle times of the cranes and the driving speed of the AGVs are derived from the real data. The output of the simulation model of the current situation is compared to the performance of the system in real life. Not all variables will be equal because of the aggregations that are done. The differences will be explained and taken into account later on when an advice to the container terminals is formed in this thesis.

Output stack: the output of the stack is defined as the number of containers that is transferred from the stack to the horizontal transport by the ASC. In the ideal situation, an as high as possible output is desired. The shorter the loading time, the higher the output has to be. The average number of containers of the loading of the three deep-sea vessels is presented below in **Table 5**

Table 5 - Output stack

Deep-sea Vessel	**Average output stack ASC** *Simulation*	**Average output stack ASC** *Real system*
Thalassa Doxa	3.54 container/hour	4.03 containers/hour
Thalassa Niki	3.37 containers/hour	4.09 container/hour
Thalassa Mana	2.92 container/hour	3.87 containers/hour

The real system shows a half to one container more per hour than the simulation results. These differences can be explained by the data of the real system. First of all, the number of containers that is removed from dataset because of the lack of information (about 15% for every vessel) can be abstracted. Second, the total number of containers that is retrieved to the waterside from the stacking yards by the ASC is not only for one vessel in real life, which is not the case in the simulation model. This means that from the 28 stacking yards, depending on which vessel, 300 – 500 containers are retrieved for other vessels. Because the range of the stacks that are used during the loading is wider than the length of the deep-sea vessel, several stacks are also assigned to other deep-sea vessels. The number of containers that is retrieved for other vessels depend on the time of arrival and the number of containers that will be loaded and discharged to and from the other vessel. The containers for other vessels and their retrieving is for here out of the scope. In case that the theory of the decreasing number of categories offer potential to the loading process it will become of interest to investigate the impact of these containers.

Shuffles: the number of shuffles that have to be made is of influence to the time that is needed to transfer containers from the stack to the AGV. In the ideal world the container that is requested stands on top of a pile of containers and can be picked up directly. The less shuffles, the shorter time is needed and the more containers can be handled per hour. To compare this number, the total number of shuffles during the period of loading the deep-sea vessel are used. Because also shuffles are made for the landside moves and the waterside moves are not only dedicated to one ship, the number of shuffles per containers is determined. Moreover, it is assumed that the inbound moves of the ASC not cause any shuffles. In **Table 6** the total number of shuffles per deep-sea vessel in the simulation, the number of shuffles per container in the real system and the number of shuffles that should be occurred taken into account the number of container that is loaded in the simulation are presented. For the determination of the shuffles per container, see **Appendix C** - Validation

Table 6 - Validation shuffles

Deep-Sea Vessel	**Number of shuffles** *Simulation*	**Number of shuffles per container** *Real system*	**Number containers loaded** *Simulation*	**Number of shuffles** *Real system*
Thalassa Doxa	1338	0.53	3224 containers	1712
Thalassa Niki	1252	0.53	3207 containers	1700
Thalassa Mana	1245	0.42	3106 containers	1305

The number of shuffles that occurs is higher than in the simulation model. It stands out that for the first two vessels a difference around the 25% can be noticed, where for the last vessel a difference of 3% is determined. The reason can be found in the fact that in the simulation model only counts the shuffles for the waterside moves for a specific deep-sea vessel. In the real system the ASC starts organizing the stack when no orders are available. These moves are also counted as shuffles and in the simulation reorganizing does not take place. These external influences are of importance for the real situation, but for testing the decreasing categories these values will be used.

Waiting time AGV: the waiting time of an AGV is the time that an AGV has to wait at the Transfer Point of the stacking yard. The AGV always arrives at the transfer point in the case that the ASC never has to wait. In the case that the ASC has to make shuffles or other water or land side moves, the AGV will wait at the Transfer Point of the stack. In the desired situation no shuffles have to be made and the output of containers to the AGV is distributed over the stacks in order that the AGV does not have to wait. The average waiting time of the AGVs at the Transfer Points of the stacking yards in the simulation and in the real system is presented in **Table 7** below.

Table 7 - Validation waiting time AGVs at TP stack

Deep-sea Vessel	**Average waiting time AGV** *Simulation*	**Average Waiting time AGV** *Real system*
Thalassa Doxa	03:23 minutes	04:33 minutes
Thalassa Niki	03:22 minutes	04:19 minutes
Thalassa Mana	03:14 minutes	04:53 minutes

Large differences between the waiting time in the simulation model and the real system are noticed. Taking a closer look to the data there are some extreme values in the real system, waiting time over an hour can be found. In the simulation model no waiting times longer than 20 minutes can be found.

By taking out the extreme values, the values become clearly closer, but still differ half a minute. The dynamics of the equipment outside the boundaries of the simulation of the control of the system clearly influences the waiting times in real life. An overview of the reduced averages of the waiting time of the AGV at the stack and the plots of the waiting times can be found in **Appendix C** - Validation

Utilization Quay Crane: the utilization of the Quay Crane can be used to indicate the time that the QC is waiting on an AGV that delivers its container. In the ideal world, an AGV is parked on the transfer point on the moment the crane finished its previous move and can work without waiting. The utilization would be 100% in this desired situation.

Table 8 - Validation utilization QC

Deep-sea Vessel	**Utilization Quay Crane** ***Simulation***
Thalassa Doxa	78%
Thalassa Niki	80%
Thalassa Mana	82%

The ECT Delta terminal stated that the cranes have a performance of 70%. Where 10% is assigned to meal breaks of the crane employees, 10% to waiting time for AGVs by the QC and the last 10% is caused to so called waste. Waste can be for example technical issues. In the simulation model, the meal breaks are not modelled. Therefore, the performance 80% is comparable and can therefore validated.

Overall service time Deep-sea vessel: the overall service time of the deep-sea vessel is the time measured from the order for the first container until the last container is loaded and represents the result of the loading process in hours.

Table 9 - Validation service time deep-sea vessels

Deep-sea Vessel	**Service time Simulation**	**Service time Real system**
Thalassa Doxa	33:31 hours	36:00 hours
Thalassa Niki	34:37 hours	37:41 hours
Thalassa Mana	38:24 hours	36:36 hours

A difference between the service time can be noticed in **Table 9**. As well longer loading times as a shorter loading time can be seen. These differences can be explained by different aspects. First of all, the number of shuffles differs from the real system. For the Thalassa Doxa and Niki clearly more shuffles in the real system are registered, where for the Thalassa Mana an almost equal number of shuffles can be seen. Furthermore, it stands out that the number of containers that have to loaded for the Thalassa Doxa is less than the other two vessels. This cannot directly be seen in the loading time. Moreover, the stack output and the utilization of the Quay Crane do not offer an explanation of the differences in the loading time. However, the aggregation of the horizontal transport can be a cause of the difference. In the simulation model the dynamics of the AGVs are taken into account in way that the AGVs have to wait, depending on the container, longer or shorter at a Transfer Point from the stacking yard and the drive time between stack differ because of the distance. What is aggregated in the drive time is the interaction and possible congestion at the quay when the AGVs drive from the stack to the Quay Cranes.

For the objective of this thesis, a part of the loading process of deep-sea vessels is simulated. However, it turned out that the size and complexity of loading process in combination with the set of boundaries

show differences, between the simulation and the available data, in the performance of the loading process. It is of importance to be aware of the differences between the simulation results and the real system, but to come to a conclusion for this thesis it is not essential to achieve the exact same results. This is valid since all input values will remain the same during the simulation of different scenarios. The simulation model can be used to compare the simulated current situation and possible new situations. The concept will be tested taking into account the differences, which will lead to a first indication of the potential of the concept.
Several scenarios for the loaded containers are defined and will be tested in the next chapter.

5 Results of reduced number of categories

The setup of the model for the implementation of category loading is based on the possible concept of category loading. This means that one of the properties assigned to the containers is a category. A few scenarios with different classifications of categories will be described and tested.

5.1 Scenarios – the effect of different number of categories

Different scenarios can be investigated for the implementation of category loading. To investigate whether the category loading concept is useful, data of the container terminal ECT is used. The data of ECT is used to model the current situation and it will be tested whether classifying the same set of containers into categories will show different results from the current loading process. Therefore, all containers will be placed in different sets of categories. The following scenarios will be specified by removing categories according the characteristics of the containers. The first scenario is the current situation and contains the most categories possible, every container owns its own category. In the following scenarios, categories will be removes until only one category for all container is left. The following scenarios are run with the model:

- All containers in unique category (current situation);
- Empties divided in categories and full split in six weight classes;
- Empties divided in categories and full split in three weight classes;
- Empties divided in categories and full split in two weight classes;
- Empties divided in separate categories and full with unique numbers;
- All containers in one category.

The current situation, where all containers have their own unique category, is presented in the previous chapter. In the following sections the other scenarios will be explained further on and the results will be discussed.

In this thesis is chosen to test a few scenarios based on the classification full or empty, destination and weight of the containers. In the classification of weight, a lot of different classifications can be made. Because this research will look into the possibilities of the concept, weight classifications will be divided is groups of 15t, 10t and 5t. It will become clear whether reducing the number of categories will be of influence on the loading process.
The results of the scenarios will be produced by adjusting the categories of the containers in the simulation software. The loading sequence of the cranes is specified by categories and will also be adjusted. In contrast to the current situation, the choice for containers according the category will be bigger than one container. To explain the classifying of the categories clearly, the structure of the report will start with the scenario where all containers are classified in one and the same category. Thereafter, more categories will be added from the starting point of current situation (as much as possible categories). At the end of this chapter the results will be presented together per KPI.

5.1.1 One category

First, all containers are placed in the same category. The number of categories will be equal to the number of containers that have to loaded and the number of containers per category is one, see **Table 10**.

Table 10 - Number of categories one category

	Number of Container Categories		
	Doxa	Niki	Mana
Total number of categories	**1**	**1**	**1**

The loading sequence in this case only depends on the number of shuffles and the current workload of the stack. Because the category does not matter, every container can be picked every time the AGVs will request a next order. The number of shuffles and the current workload both assign both penalty points to the containers, the container with the least penalty points will be chosen and transported to the vessel through the whole process.
An overview of the results is presented in **Table 11**.

Table 11 - Results one category

Deep-sea vessel	Output Stack (average)	Number of shuffles (total)	Waiting time AGV at stack (average)	Utilization QC	Overall service time
Thalassa Doxa	3,71 containers/hour	470	2:04 minutes	84%	31:20 hours
Thalassa Niki	3,57 containers/hour	536	2:06 minutes	85%	32:45 hours
Thalassa Mana	3,00 containers/hour	681	2:19 minutes	86%	37:07 hours

What immediately stands out is the reduction in the total number of shuffles, the waiting time of the AGVs at the stack and the overall service time compared to the current situation. Thereby is the output of the stack and the utilization of the quay crane increased. It can be concluded that selecting the containers based on the workload of the stack and the number of shuffles, instead of using a specific sequence, causes an increase in stack output and a reduction in the overall service time. A closer look shows that the improvements differ per deep-sea vessel. Where at the Thalassa Doxa a reduction of 65% in the number of shuffles is achieved is the reduction for the Thalassa Mana 37%. For the waiting time of the AGV the same improvements of the ratio of the shuffles are achieved. The output of the stacking yard is therefore improved with 6% for the Thalassa Doxa and Niki, for the Thalassa Mana an increase of 2% is showed. For the utilization of Quay Crane, the differences between the vessels is smaller, but the same trend can be seen. For Doxa the utilization is increase with 6%, for Niki 5% and for Mana 4%. The same as the utilization applies to the overall service time.
Together, an improvement of performance of all deep-sea vessels can be seen, but the improvement is not the same for all vessels. Therefore, in the following scenarios it will be investigated what the difference in performance is by reducing the categories from the most possible to less categories.

5.1.2 Only empties as category

In this scenario the full and empty containers are divided compared to the current situation. The full and special containers will keep their same unique category as in the current situation. The empty containers are divided in categories according to the destinations of the containers. Moreover, the empty containers are split again to the measurements of the containers, as the size is of importance when a container is placed on board. A distinction between 20 feet containers, 40 feet containers and 45 feet container is made. No special empty containers are distinguished. The categories of the empty containers consist now of empty containers, classified by size and destination. Pie charts of the classification of full or empty containers and the destinations of the containers for the deep-sea vessel Thalassa Doxa are showed below in **Figure 25**. The pie charts of the Thalassa Niki and the Thalassa Mana can be found in

Appendix D - Categories, but are more or less equal to these results.

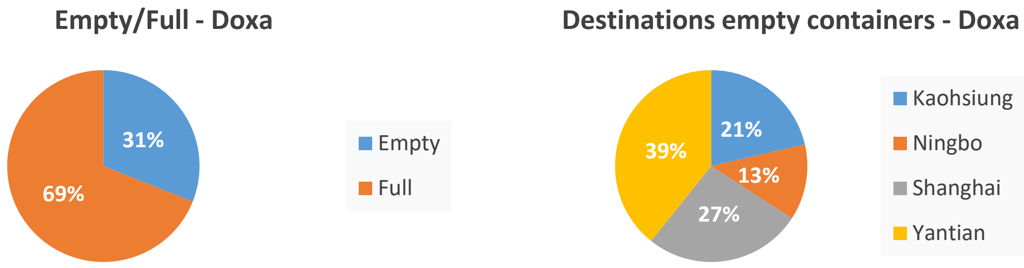


Figure 25 - Categories empties Thalassa Doxa

The number of categories is presented in **Table 12**, an overview of all defined categories can be found in

Appendix D - Categories. For the categories of the empty containers an average of 125, 158 and 111 containers per category, depending on the vessel, can be found. However, the difference per category are enormous. Some categories exist of two containers where the biggest category contains 670 containers. In the latter case the choice on the moment an order has to be assigned is huge, where for the categories that exist of a few containers nothing change that much.

Table 12 - Number of categories for empty containers

	Number of Container Categories		
	Doxa	Niki	Mana
Full and special containers (all own categories)	2223	1947	1994
Categories empty containers	8	8	10
Total number of categories	**2231**	**1955**	**2315**

The result of classifying the empty containers in categories is presented in **Table 13** below. It can be seen that the classification caused a reduction in the overall service time compared to the current situation for all three vessels. Compared to the scenario of all containers in one category clearly more time is needed to load the vessels and a lower stack output is observed.
This shows that reducing the number of categories and increase the choice for containers during the loading process will affect the loading process in the right direction. But again, differences in how much the improvement are can be noticed.

Table 13 - Results categories for empties

Deep-sea vessel	**Output Stack (average)**	**Number of shuffles (total)**	**Waiting time AGV at stack (average)**	**Utilization QC**	**Overall service time**
Thalassa Doxa	3,49 containers/hour	1244	3:05 minutes	79%	33:07 hours
Thalassa Niki	3,37 containers/hour	1153	3:02 minutes	81%	34:14 hours
Thalassa Mana	2,92 containers/hour	1188	3:01 minutes	83%	38:14 hours

5.1.3 Empties in categories and full containers in two weight categories

After classifying the empty containers, categories for the full containers are introduced. The specifications for the classification of full containers includes more variables than in the case of empty containers. In the case of the three deep-sea vessels the number of destinations increases, compared to the empty containers. An overview of the destinations of the Thalassa Doxa is given in **Figure 26** below, the pie charts of the Thalassa Niki and the Thalassa mana can be found in

Appendix D - Categories.

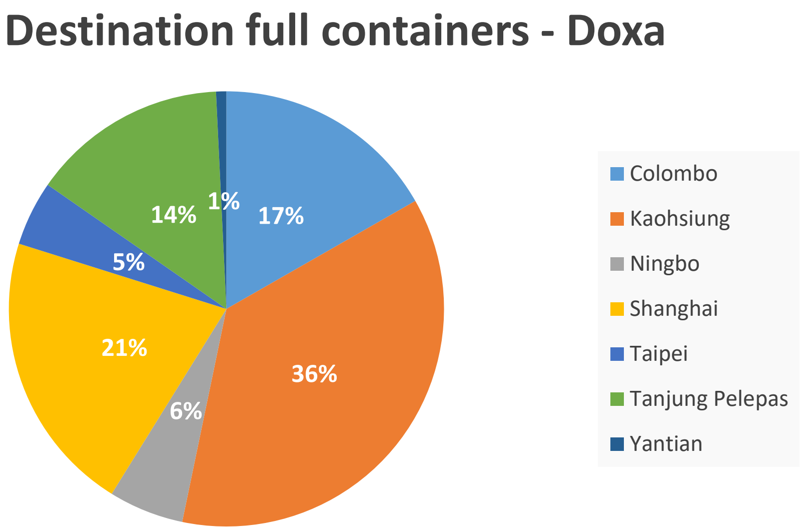


Figure 26 - Destinations Thalassa Doxa

Apart from the destination, the size of the containers has to be taken into account. The same as the empty containers, a distinction between 20 feet, 40 feet and 45 feet can be made. Moreover, full containers can be special or not and the weights of the containers differ from each other. Special containers, that have deviating characteristics, have to follow strict rules according their location on board and therefore they will always keep their unique category number in this thesis. In this scenario the weight of the containers is split in 2 categories, containers lighter than 20 tonnes and containers of 20 tonnes or more. The heaviest container will be around the 35 tonnes and the lightest full container around the 5 tonnes. An empty containers have a weight of 4 to 5 tonnes. The categories will therefore be of 15 tonnes in weight. The total number of categories on the three deep-sea vessel that have been selected for this thesis can be found in **Table 14**. It is of importance that the number of defined categories is not equal to the used number of categories. For example, in the defined category 'destination Colombo, size 45 feet, weight above 20 tonnes', no containers have to be transported and this category is not count and not classified as used category in **Table 14.** An overview of the distribution of the weight of the containers and the specification of the categories can be found in

Appendix D - Categories.

Table 14 - Number of categories for empty containers and two weight categories full containers

	Number of container Categories		
	Doxa	Niki	Mana
Special containers	276	255	283
Categories empty containers	8	8	10
Categories full containers	25	29	27
Total number of categories	**309**	**292**	**320**

Split the full container in categories shows a large decrease in the number of containers compared to the previous scenario, that only classifies the empty containers. The same as by the categories of the empty containers the number of containers per category varies widely. A single category owns 1 container where others are almost up to 200 containers per category. The number of containers per category decreases compared to the previous scenario. Despite the fact that small categories (consisting of one or two containers) are formed it can be seen that a wide range of containers for different categories is available and that the same category for a different vessel has other amounts of containers. For example, the number containers that have the destination Kaohsiung, have the size of 20 feet and have a weight above 20 tonnes for the Thalassa Doxa, Niki and Mana are respectively 160, 228 and 135.
Adding the categories for the full containers shows a reduction in service time, waiting time for the AGV and the number of shuffles compared to the scenario where only the empty containers are classified in categories. Moreover, an increase in utilization of the QC and the output of the stack is found. A decrease in the number of categories by classifying the full containers results in a reduced overall service time.

Table 15 - Result categories for empty containers and two weight categories full containers

Deep-sea vessel	**Output Stack (average)**	**Number of shuffles (total)**	**Waiting time AGV at stack (average)**	**Utilization QC**	**Overall service time**
Thalassa Doxa	3,60 containers/hour	953	2:31 minutes	81%	32:18 hours
Thalassa Niki	3,47 containers/hour	919	2:29 minutes	83%	33:25 hours
Thalassa Mana	3,00 containers/hour	1031	2:35 minutes	84%	37:25 hours

5.1.4 Empties in categories and full containers in three weight categories

The previous sections have shown that classifying containers into categories result in a better performance of the loading process. Now more categories for the full containers are defined. In this scenario the full containers are split in categories of 10 tonnes, leading to one extra defined category and 11 or 12 more used categories for the three selected deep-sea vessels. In the first category, containers with a weight ranging from 5 to 15 tonnes, including the few full containers that have a weight lower than 5 tonnes, are categorized. It is assumed that the weight is recorded wrong and the weight of the container itself is left out. The second category ranges from 15 to 25 tonnes and the third category ranches from 25 tonnes an up. An overview of the number of categories, is given in **Table 16**. An overview of the categories and the number of containers per category can be found in

Appendix D - Categories. The total number of categories differ slightly from the number of categories from the previous scenario (the 11 or 12 categories more).

Table 16 - Categories for empty containers and three weight categories for full containers

Categories	**Number of Container Categories**		
	Doxa	Niki	Mana
Special containers	276	255	283
Empty containers	8	8	10
Full containers	36	41	39
Total number of categories	**320**	**304**	**332**

The result of adding some extra categories to the full containers can be found in **Table 17**. These extra categories show a very small change in performance compared to situation of only two weight categories. Especially in the stack output and the utilization of the Quay Crane, no difference can be noticed. The difference in the number of shuffles, the waiting time of the AGV and the overall service time show a small deterioration. However, still an improvement compared to the exact loading sequence (the current situation) can be seen, caused by the choice for more containers based on categories during the loading process.
The small differences compared to the previous category can be seen together with the small increase in number of categories. This decrease of categories affects the loading process, despite the fact that is not much.

Table 17 - Result categories for empty containers and three weight categories for full containers

Deep-sea vessel	**Output Stack (average)**	**Number of shuffles (total)**	**Waiting time AGV at stack (average)**	**Utilization QC**	**Overall service time**
Thalassa Doxa	3,60 containers/hour	960	2:32 minutes	81%	32:21 hours
Thalassa Niki	3,47 containers/hour	981	2:34 minutes	83%	33:29 hours
Thalassa Mana	3,00 containers/hour	1044	2:36 minutes	84%	37:24 hours

5.1.5 Empties in categories and full containers in six weight categories

Lastly, the containers are split in categories of 5 tonnes per category. This results in six weight categories for the full containers. The weight is classified from 5t to 10t (including the few containers that have a weight lower than 5t), from 10t to 15, from 15t to 20t, from 20t to 25t, from 30t and higher. An increase around the 30 extra used categories compared to the scenario of 3 weight categories can be seen in **Table 18**. An overview of the categories and the number of containers per category can be found in

Appendix D - Categories.

Table 18 - Categories for empty containers and six weight categories for full containers

Categories	**Number of Container Categories**		
	Doxa	Niki	Mana
Special containers	276	255	283
Empty Containers	8	8	10
Full containers	67	70	65
Total number of categories	**351**	**333**	**358**

Despite the fact that the number of categories is increased more than the previous step, the results only differ slightly compared to the situation of three weight categories. In all cases the total number of shuffles has increased and the waiting time for the AGV shows a small increase. For all the vessels the utilization has not changed. However, the output of the stacking yard shows for the Thalassa Doxa a small increase, where for the Thalassa Niki a decrease can be seen. The Thalassa Mana shows the same output compared to the previous situation and therefore also to the scenario of the 10 tonnes weight categories. Moreover, the overall service time slightly increases for the Thalassa Niki and Mana, but apart from the fact that the waiting time and the number of shuffles show a small increase the overall service time is a little shorter, see **Table 19**. The different results between the vessels is of interest. In the net section all the results will be placed together to get overview.

Table 19 - Results categories empties and six weight categories full containers

Deep-sea vessel	**Output Stack (average)**	**Number of shuffles (total)**	**Waiting time AGV at stack (average)**	**Utilization QC**	**Overall service time**
Thalassa Doxa	3,60 containers/hour	1036	2:35 minutes	81%	32:20 hours
Thalassa Niki	3,47 containers/hour	1010	2:35 minutes	83%	33:40 hours
Thalassa Mana	3,00 containers/hour	1076	2:39 minutes	84%	37:29 hours

5.2 Overview results of the scenarios

For a good comparison the results of the scenarios are plotted in graphics per Key Performance Indicator. The values of the KPIs are presented on the y-axis and the number of categories per deep-sea vessel on the x-axis.

Output stack: First the output of the stack, an average of the number of containers per hour, is presented. A small increase can be seen when the number of categories decreases.
The attention is drawn to the scenario of by splitting the full containers in six weight classes of 5 tonnes (Doxa – 352 categories, Niki – 333 categories and Mana – 358 categories in the graphics). In the results of the Thalassa Doxa an increase is notable, while the scenarios with less categories show a smaller output. The opposite is the case for the Thalassa Niki, the slightly increasing trend is interrupted by a lower value in this scenario.
For the Thalassa Mana is stands out that the stack output differs according the scenarios less than the other deep-sea vessels. Especially the last four scenarios the output stays the same.
Because all variables, except the choice for the container, are kept the same as for the current situation and the scenarios during the simulation the choice for the containers cause the differences. The number of containers per category influences the size of the choice during the loading process. Furthermore, the way of dividing the container does not take into account the number of categories or the number of containers per categories, but only the characteristics of every individual container. As stated not all defined categories are used, this depends on the loading of the deep-sea vessels. This means that the distribution of the orders over the stacking yards and over the time change. The little

trend to a higher output shows that the workload of the ASCs, which includes the number of orders and the number of shuffles, is spread better and facilitates a shorter loading time in the end.

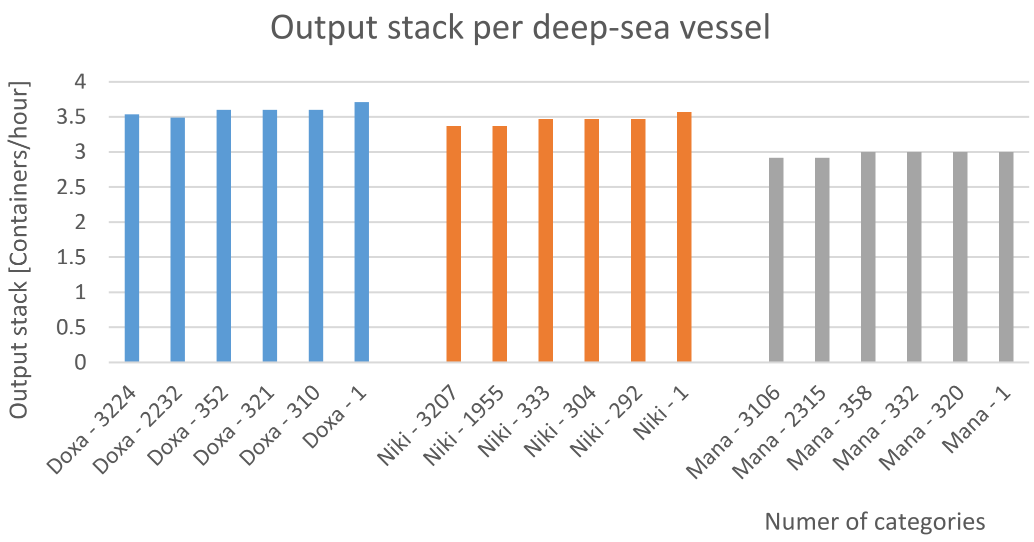


Figure 27 - Graphics output stack

Shuffles: In the overview of the shuffles a clear trend can be seen. The less categories, the less shuffles are made. Because the simulation model chooses the lowest number of shuffles in combination with the lowest number of waiting orders in the stack the containers with no or a few shuffles are chosen first. By removing containers from a stack, the containers below the removed containers are reduced in shuffles. At the moment a container is chosen, possible shuffles are already taken away. Compared to the KPI of stack output, the trend decreases together with the decrease of the number of categories. The decline in number of shuffles compared to the categories is not the same for the different deep-sea vessels. Moreover, when all containers are grouped in the same category, there still have to be made shuffles. The reason for this is that containers still have to be loaded by a specific crane in the simulation model. This shows that even with this broad choice for containers, every limitation cause shuffles. It would be of interest to combine this with flexibility in crane allocation.

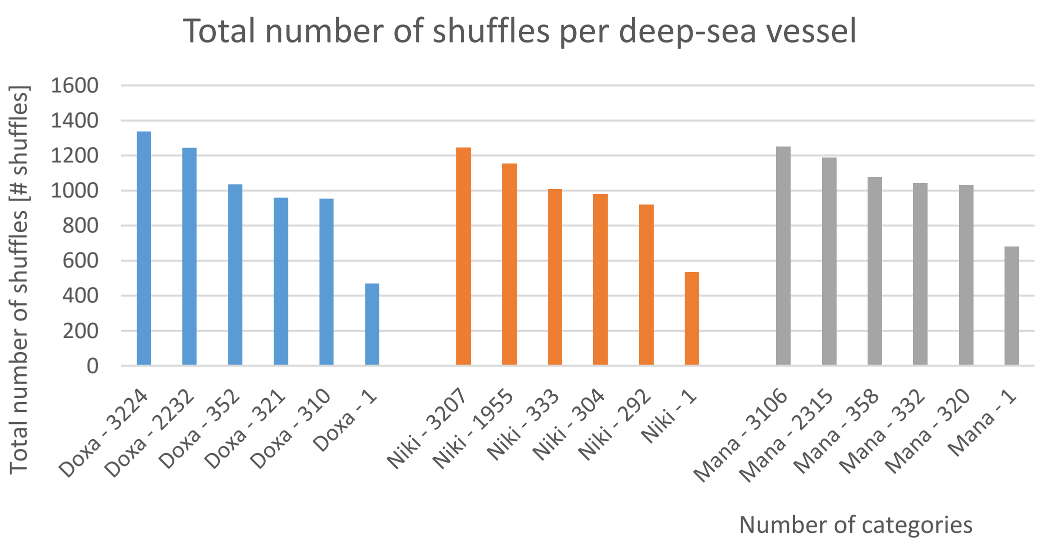


Figure 28 - Graphics number of shuffles

Waiting time of the AGV: The results for the waiting time of the AGVs show a comparable trend with the number of shuffles, the less categories the shorter the calculated waiting time. This is a logical cause of the decreasing number of shuffles, as the waiting time of the AGV strongly depends on the number of shuffles in the simulation model. A small part of the waiting time is caused by the change on a landside move on busy moments of the ASC, but this is comparable to the current situation and will not influence the scenarios.

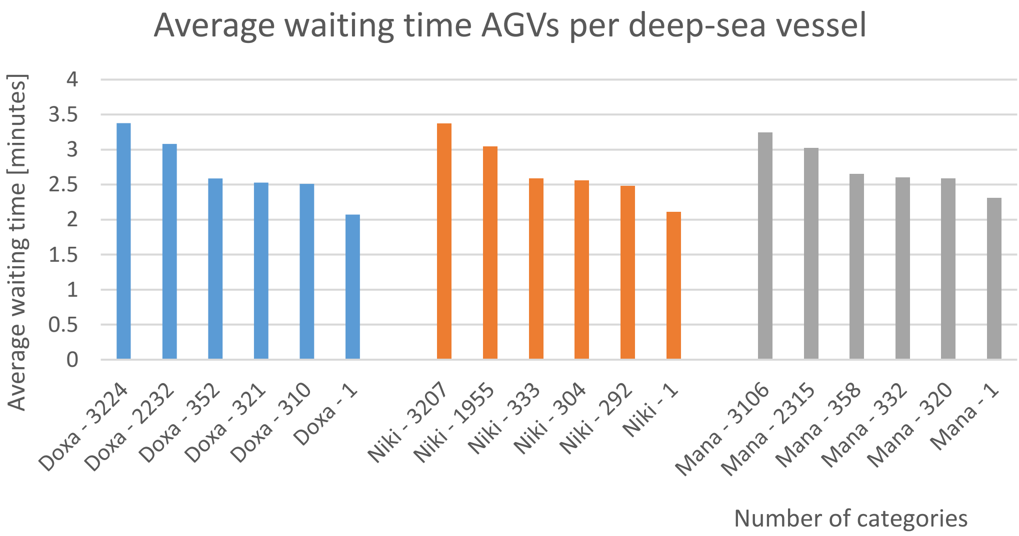


Figure 29 - Graphics waiting time AGV

Utilization QC: An increasing trend can be seen in utilization of the quay crane when less categories are added, and a higher utilization is more desirable. This trend is partly the result of the shorter waiting times at the stack and partly of the dynamics of the AGVs. The dynamics of the AGVs are aggregated considered in the simulation model, the routes and driving times are the same for a specific container in the stack since the position of a container in the stack is always the same in the applied dataset. However, due to the selection process at the stack the containers will arrive at the QC at different times for the different scenarios, caused by shorter waiting times at the stack and the effects through the process of this. This leads to a higher utilization when the stack-output is higher. As already showed, the stack output does not change that much, where the number of shuffles decrease caused by the reduced number of categories. The combination of the distribution over the stacking yards and the less shuffles that contribute to a shorter waiting time for the AGVs at the Transfer Points at the stack causes less idle time for the Quay Crane. Taking into account the boundaries of the system for this thesis, a large reduction in shuffles have to take place to increase the utilization of the QC a few percent. For example, the Thalassa Doxa has a reduction of 868 shuffles to achieve an increase of 5% in the utilization of the Quay Crane.

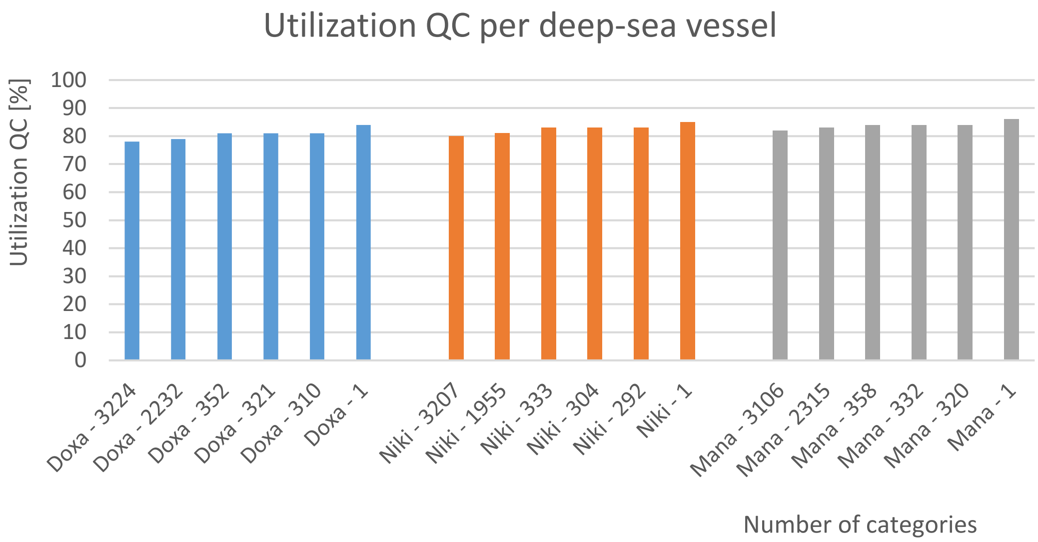


Figure 30 - Graphics utilization QC

Overall service time: As a result of the higher performance of the Quay Crane, the total service time of the deep-sea vessels decreases when less categories form the input for the simulation model. Both KPIs have a direct link, but since the loading time is a valuable indicator they are presented separately.

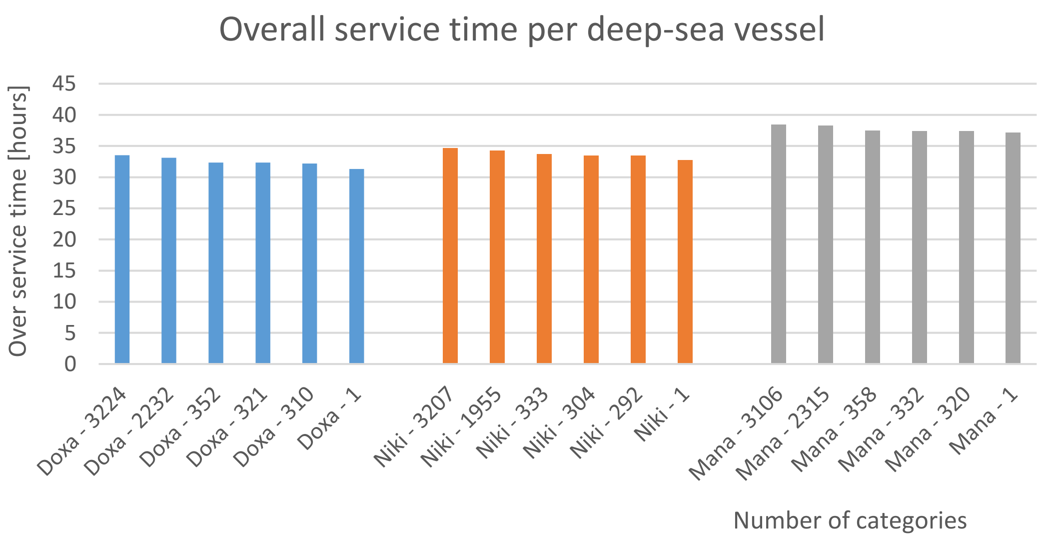


Figure 31 - Graphics overall service time

The overall goal of a container terminal is to handle their clients, the deep-sea vessels, as fast as possible. In the first place it is shown that changing the way of selecting the containers, based on shuffles and workload, leads to a shortage of over an hour to more than two hours. Which is respectively 6.5%, 5.4% and 3.6% for the Thalassa Doxa, Niki and Mana. This shortage is achieved in the situation when it does not matter which characteristics belong to the containers (destination, size, weight, special or not), except the crane which will load the container. All containers belong to the same category. Since this is not realistic, because of the requirements of the weight distribution of the deep-sea vessels, the special containers and the desires for the location of the containers for the next stops of the deep-sea vessel, the containers are split in categories. It can be seen that distributing the containers in these categories also shows an overall shorter loading time, but this is less than when the characteristics of the containers are not taken into account. Classifying only empties in categories shows a result of 0.4% (Mana), 1.1% (Niki) and 1.2% (Doxa), where when also classifying the full containers in categories of 5 tonnes shortage of respectively 3.6%, 2.7% and 2.4% for the Doxa, Niki and Mana is achieved.

5.3 Changes in the loading process by implementing Category Loading

Changing the way of loading according the (automated) equipment includes a change in the control of the equipment. Moreover, the processes of the loading of the deep-sea vessel will be affected and will be discussed in this section.

5.3.1 Change in control of the equipment at the container terminal

A change in the control of the loading process will be applied in the software of the Terminal Operating System. In the current situation the TOS makes decisions based on the exact loading sequences that is formed according to the stowage of the deep-sea vessel. When the category loading concept will be introduced the system will receive a set of containers from which the best reachable container has to be chosen. This set of containers will be selected on a few characteristics; defined as its category. The best container is the container that has the lowest penalty points. Penalty points are assigned based on the number of shuffles that have to be made to reach the container and the number of orders that is assigned to the ASC. To apply this way of working all categories need to be defined and appointed to the containers. This requires a software change and the way of working for the planners of the terminals.

5.3.2 Change in the way of working

In the current way of working the planner receives a rough stowage or pre-stow from the central planner of the shipping line. This rough stowage is used to make a detailed stowage after the cut-off moment between the ship operator and the terminal. After this moment it is not allowed to change the loading list anymore. In the case of category loading, it is not necessary to form a detailed stowage. Possibilities will arise around the cut-off moment between the shipping lines and the terminal. As no detailed stowage need to be formed anymore, the cut-off moment can be moved to a closer time to the arrival time of the deep-sea vessel. Containers that are late in the current situation will not be late anymore, which might lead to increase of service for the end-costumers.
Furthermore, before the loading starts the first officer of the deep-sea vessel gives his approval on the detailed stowage. When category is applied, no detailed stowage is formed on forehand and the first officer cannot agree anymore on the way his vessel will be loaded. This demands the trust of the first officer about the way of loading. Overall a new way of loading demands new agreements between the shipping lines and the container terminal. The processes that will be changes are highlighted in red in **Figure 32**.

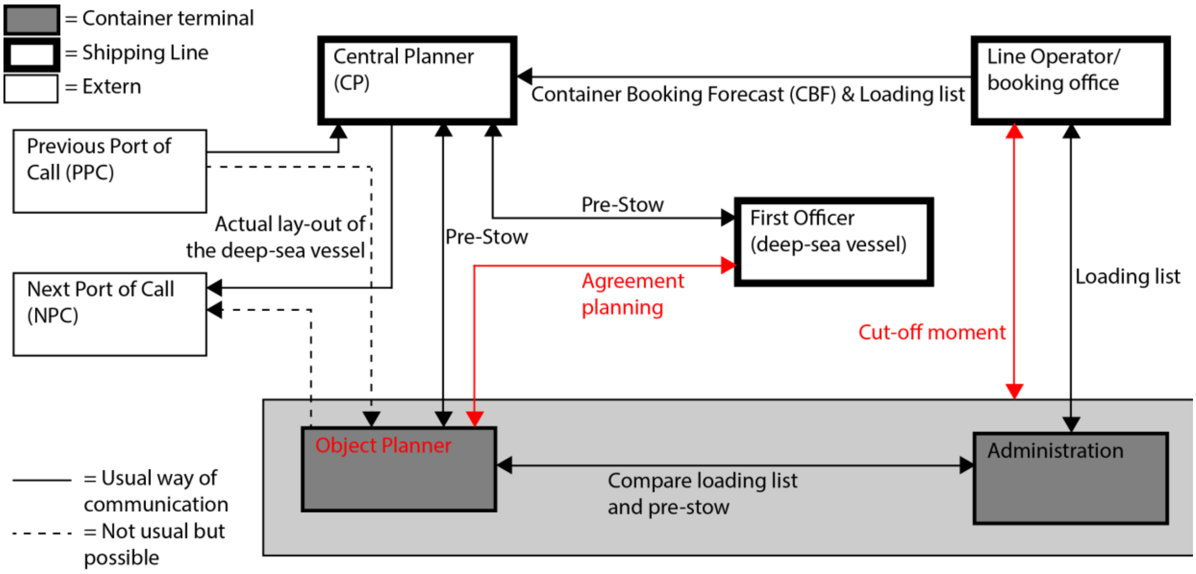


Figure 32 - Changes in the loading process

6 Conclusion and Recommendation

In the last chapter of this thesis conclusions on this research will be drawn. Furthermore, the limitations of this research will be discussed followed by recommendations for further research.

6.1 Conclusions

The main question of this thesis is '*What is the operational influence of the category loading concept on the service time for deep-sea vessels at a container terminal?'*. Several sub questions have been used to grasp the entirety of the research question. The combination of these sub questions form the answer to the main research question. The sub questions will be addressed first, followed by the answer to the main question.

SQ1: What does the current process of loading deep-sea vessels entail?

In this thesis, first, the current situation of the loading process at the terminal has been explained. A configuration of stacking yards, equipped with Automated Stacking Cranes, Automated Guided Vehicles for the horizontal Transport and manned Quay Cranes are used. Because of the complexity of the loading of the containers on board of deep-sea vessels, only this part in taken into account. The discharging of container during the handling process of the vessels does not face such a complexity and is therefore not taken into account. The focus of the research is set to the bottleneck at the output of the stacking yard. At this location, containers from the stacking yard are handled by the Automated Stacking Crane to be placed on an AGV. Of influence on this bottleneck are the containers that are loaded according a specific loading sequence. This means that when a container is required and it has containers on top of it or the ASC that has to facilitate the order is very busy, the AGV has to wait at the transfer point at the stack. Further on in the loading process the Quay Crane has to wait for the AGV and will not perform maximal.

SQ2a: What is considered the state of the art of the loading of deep-sea vessels?

This sub question is used to research the literature about the problems and the solutions of the loading of deep-sea vessels. Shortly, it turned out that an optimal solution for the loading process is not found yet. This is caused by the complexity and the number of different variables that have to be optimized in one process. Different situations as loading an airplane or truck and the handlings in warehouses offer partly solutions to the loading process of deep-sea vessels. These solutions are helpful in a way of identifying important influences, like the reachability of goods in warehouses and the different moments of arrivals of goods which cause problems with the loading sequence of the transport means. Research into the loading process in literature offers a promising concept of loading containers classified in categories. An improvement of 5% in performance of the utilization of the quay crane during the loading process is mentioned, but only one way of classifying a random set of containers is investigated. Furthermore, nothing can be found about the influence on the process of a container terminal by changing the way of loading. Therefore, this gap in the literature is investigated further on in this thesis.
Furthermore, the Key Performance Indicators are identified using the literature:

- Output of the stack [containers/hour]
- Total number of Shuffles [#shuffles]
- Waiting time AGVs at the stack [minutes]
- Utilization Quay Crane [%]
- Overall service time [Hours]

SQ2b: What is Category Loading?

It is found that, because of the complexity of the loading process, an optimal solution to the whole process is not found yet. However, for one of the bottlenecks (the output of the stacking yard) in the process, the concept of category loading is mentioned by Duinkerken et al., (2001). The concept offers more flexibility during the loading. A potential of 5% improvement in utilization of the QC is given. In the research of Duinkerken et al., (2001), no specification of the categories is given and only one way of classifying the containers is tested. Moreover, in 2001 the vessels were smaller than the vessels that are handled nowadays at container terminals and the process around the loading is not taken into account. According to this research the concept of category loading will be investigated further on. The concept of category loading can be explained as follows: instead of a specific loading sequence, a container from a certain category is requested when a next container is required. The decision for the next job is made on the moment that an order for a container is assigned to an AGV. The Terminal Operating System has to make a choice between different container that are classified in the category, and does this based on the current workload of the corresponding ASC of the containers and the number of shuffles that have to be made to reach the container. Improve the number of shuffles and a better distribution of the workload for the ASCs could contribute to the solution for the bottleneck at the output of the stacking yard.

SQ3: What is the current performance of the loading process of the ECT Delta terminal?

To investigate the loading concept, the current situation is simulated first. An overview of the performance according the KPIs is given in **Table 20**. Of importance is the aggregation of the dynamics of the AGVs while driving at the quay and the influences of other vessels or landside operations.
The data of the loading process of three deep-sea vessels Thalassa Doxa, Thalassa Niki and Thalassa Mana from container terminal ECT is used. These vessels are part of a weekly service at the ECT Delta Terminal at Rotterdam. The cycle times of the equipment during the loading process and the validation of the model is done by using data from the ECT Delta Terminal Rotterdam. The aggregation cause differences between the real data and the simulated results. For the objective of this thesis, to provide an advice about the potential of category loading, these differences have to be kept in mind, but the model will be useful to compare the different situation to each other.

SQ4a: Which scenarios can be formulated for implementing the Category Loading concept at a container terminal?
SQ4b: What is the impact of different scenarios of implementing Category Loading at a container terminal?
SQ4c: Which people that are involved in the loading process will be affected by a change of loading concept and how?

To test the category loading concept, all containers are classified in the same category at first. This results in a clear improvement of the performance of the loading process. The total loading time decreases. According to the data analysed, this decrease lies between the 3.6% and 6.5%. Furthermore, the number of shuffles decreases by 35% to 64% for the analysed data. Additionally, the output of the stack shows a higher number of containers per hour and the waiting time of the AGVs at the stack is decreased. As such, all KPIs show a clear improvement.
Since it is not realistic to classify all containers in the same category, due the weight distribution of the deep-sea vessels, the special containers and the desire for convenient locations of the containers that have to be unloaded at the next stop, the containers are split in more categories. The following scenarios were defined:

- One category only

- Only empty containers in categories
- Empty containers in categories and full containers split in two weight categories
- Empty containers in categories and full containers split in thee weight categories
- Empty containers in categories and full containers split in six weight categories
- Current Situation

It is tested whether the concept of category loading could improve the output of the stack, and could therefore decrease the overall service time for deep-sea vessels at the quay of a container terminal. Only the categories of the containers and the corresponding loading sequence per Quay Crane are changed in the scenarios.
It can be seen that distributing the containers over the categories shows an overall shorter loading time, but less than when the characteristics of the containers are not taken into account. Classifying only empties in categories shows an improvement of the results of 0.4% (Mana), 1.1% (Niki) and 1.2% (Doxa). Where by classifying the full containers as well in categories of 5 tonnes shortage of service of respectively 3.6%, 2.7% and 2.4% for the Doxa, Niki and Mana is achieved. An overview of all results can be found in **Table 20**.

Apart from a change in software, the processes around the loading will have to be adjusted too. Most important are the changes in the planning of the deep-sea vessel. In the case of category loading no detailed stowage can be made. This is an opportunity to pull back the moment of closing the loading list for changes; no time is required for the detailed planning anymore. Beside this opportunity the agreement of the first officer of the deep-sea vessel on the detailed stowage could impose a difficulty on the process. In the category loading situation this is not possible anymore. The first officer has to trust the concept before it can be used at the terminal.

Answer to the main research question
Concluding, it can be said that the operational impact of implementing the category loading concept provides a shorter overall loading time. Especially, the number of shuffles is reduced by applying the concept. It turned out that the higher availability of the containers, based on the required shuffles and workload of the ASC, during the process leads to a more efficient output of the stacking yard. Noticeable are the small changes in the stack output, defined as the average number of containers per hour. This indicates that, given the reduced number of shuffles, the distribution of the workload for the ASC is improved. The concept of category loading can therefore be classified as interesting and the promising results of Duinkerken et al., (2001) can be partly confirmed by this research. Partly because the classification of the containers has to be done in more detail. Special containers cause more categories and therefore less improvement than stated by the former research. Moreover, the improvement can be confirmed in the case of using a set of real data of containers that have to be loaded. Moreover, changing the way of loading cause a lot of changes in the processes of a terminal. Contractual agreements have to be adjusted and the control of the equipment have to be changed. The shipping lines, ship operators, planners of the container terminal and other people involved have to reach a new agreement when the concept of loading will be changed.

The promising results of the concept of reducing the number of categories can be of interest for container terminals. However, it is important to be aware of the shortcomings of the used simulation model by drawing these conclusions. Moreover, several aspects that are not taken into account could contribute or counteract to the results of this research. In the next sections the shortcomings of the simulation model will be discussed, followed by a discussion about further research on the theory of reducing the number of categories during the loading of containers to deep-sea vessels at container terminals.

6.2 Limitations of the research

Before the decision of further research or implementation of category loading at container terminals it is important to discuss the limitations and the shortcomings of this research.

First of all, the data used is based on the loading process of three deep-sea vessels at the ECT Delta Terminal Rotterdam. These three vessels have been chosen because data of the locations of the containers in the stack could be provided. It would be useful to research more vessels and compare the characteristics and results of more loading processes.
Furthermore, the cycle times in the simulation model are set values that are determined during the loading of the deep-sea vessels. For example, disruptions are not taken into account. These extreme values can influence the data.
Lastly, other influences on the system that are not simulated and outside the boundaries of this research could be:

- The position of the shuffled containers. When a container is picked from the stack and one or more containers have to be removed to reach that container, the positions of the removed containers change. In this model the time that is needed to remove these containers is taken into account, but the next position of the containers is not considered. It is assumed that, when the target container is handled, the other containers remain in their position. Only the number of containers above the shuffled container change and therefore the number of shuffles is updated to the new situation.
- The influence of other moves by the Automated Stacking Crane. In this research the output of the stack is delayed on busy moments, which is based on the change that the waterside outbound is disrupted by another move that has a higher priority. But the moves that the ASC makes if it has no orders, for the simulated vessels, are not taken into account.
- The dynamics of the AGVs controlled by the Terminal Operating System. In the real system AGVs do not only receive orders based on the next container, but more variables are taken into account, this includes their position or other vessels that have to be served.
- Failures. Technical issues can be refuelling of an AGV, or failure of an AGV or a crane. When an ASC is out of order and containers from that stack is needed the process can be delayed.

These influences can be an interesting additional aspect in category loading. Therefore, several recommendations for further research are proposed in the next section.

Table 20 - Overview results

Deep-sea vessel	Number of categories	Output Stack (average)	Number of shuffles (total)	Waiting time AGV at stack (average)	Utilization QC	Overall service time
Current Situation						
Thalassa Doxa	3224	3,54 containers/hour	1338	03:23 minutes	78%	33:31 hours
Thalassa Niki	3207	3,37 containers/hour	1245	03:22 minutes	80%	34:37 hours
Thalassa Mana	3106	2,95 containers/hour	1252	03:14 minutes	82%	38:24 hours
Categories of empties and six weight categories full containers						
Thalassa Doxa	351	3,60 containers/hour	1036	2:35 minutes	81%	32:20 hours
Thalassa Niki	333	3,47 containers/hour	1010	2:35 minutes	83%	33:40 hours
Thalassa Mana	358	3,00 containers/hour	1076	2:39 minutes	84%	37:29 hours
Categories of empties and three weight categories full containers						
Thalassa Doxa	320	3,60 containers/hour	960	2:32 minutes	81%	32:21 hours
Thalassa Niki	304	3,47 containers/hour	981	2:34 minutes	83%	33:29 hours
Thalassa Mana	332	3,00 containers/hour	1044	2:36 minutes	84%	37:24 hours
Categories of empties and two weight categories full containers						
Thalassa Doxa	309	3,60 containers/hour	953	2:31 minutes	81%	32:18 hours
Thalassa Niki	292	3,47 containers/hour	919	2:29 minutes	83%	33:25 hours
Thalassa Mana	320	3,00 containers/hour	1031	2:35 minutes	84%	37:25 hours
Categories for empty containers only						
Thalassa Doxa	2231	3,49 containers/hour	1244	3:05 minutes	79%	33:07 hours
Thalassa Niki	1955	3,37 containers/hour	1153	3:02 minutes	81%	34:14 hours
Thalassa Mana	2315	2,92 containers/hour	1188	3:01 minutes	83%	38:14 hours
One category						
Thalassa Doxa	1	3,71 containers/hour	470	2:04 minutes	84%	31:20 hours
Thalassa Niki	1	3,57 containers/hour	536	2:06 minutes	85%	32:45 hours
Thalassa Mana	1	3,00 containers/hour	681	2:19 minutes	86%	37:07 hours

6.3 Recommendation for further research

In this research the potential of category loading is investigated. This is done by providing a simulation model. Because of the size and the complexity of the loading process of deep-sea vessels the process is only partly simulated. Furthermore, the classification of the containers is done by splitting the containers according to their characteristics. Other ideas on how to investigate the concept of category loading are given below.

First, the classification of the container. In this research the characteristics are taken into account and containers have been divided into different categories in accordance with these characteristics. However, some categories may only contain one container. The influence of the partition of the containers taking into account the size of the categories can be of interest. For example, flexible definitions of the weight distribution could be a solution to enlarge the number of container per category. Then, containers that are classified differently, for example tanks, have their unique category in this thesis, but the possibilities for this container to fit into one of the existing categories can be of interest to reduce the number of categories.
Lastly, the property of the crane that have to load a specific container could be modified. This will be influences by the distribution of the containers over the available spots at the deep-sea vessel, but can be of interest.

Secondly, some additions to the current model can be offer more insights, like the dynamics of the AGVs controlled by the operating system. This issue is already mentioned as shortcoming of the current simulation model. The routing of the AGVs from and to the Quay Cranes, including the interaction between other AGVs, are of interest for the category loading.
Another shortcoming of the model is the influence of failures in the process. In case of category loading, other containers from the same category that are placed in another stack can be reached during the time an ASC is unavailable caused by a failure. It was shown that the distribution over the stacks was favourable, so therefore taking into account this aspect might lead improved results.

Thirdly, the influences from the control of terminal processes from outside the scope of this thesis can be investigated. An example is the way of stacking and restacking the containers, especially the distributions of the containers from categories over the different stacks. Furthermore, the influence of the loading concepts of dual cycling and twin lifting by the Quay Crane can also be considered in further research.

Lastly, at the moment the concept of reducing categories would be implemented, it is importance to investigate the process around the loading. The ship operator has to trust the system, otherwise the vessel will not call anymore at the terminal. Of interest is how the ship operator or the shipping lines can be involved in the process to reach the goals of both parties.

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Appendix A - Input parameters

On the x-axis the number of times an AGV is waiting the shown time at the y-axes. The data of all three deep-sea vessels is taken into account.

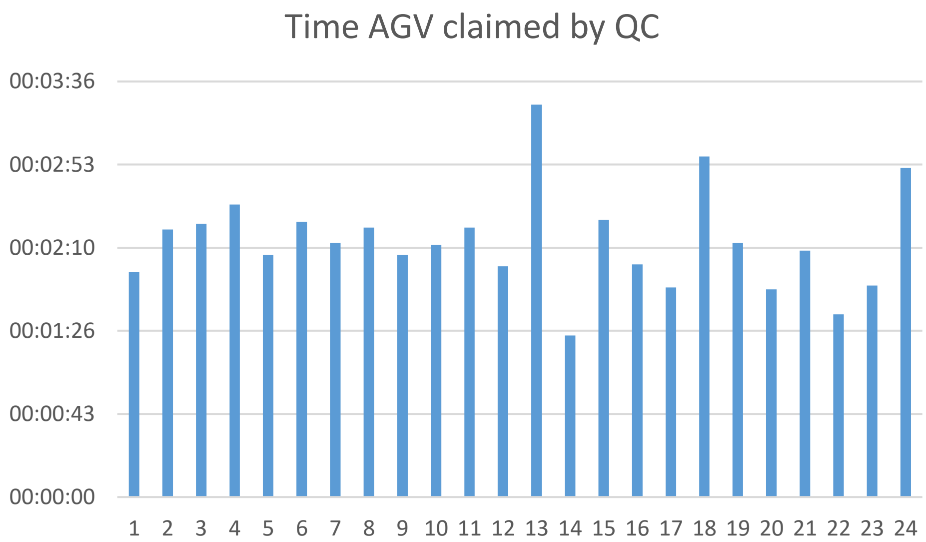


Figure 33 - Time AGV claimed by QC

On the x-axis the cycle times of the ASC are presented. On the Y-axis the number of containers that are handled that time are indicated. The data consist of all ASC cycle times of the three deep-sea vessels.

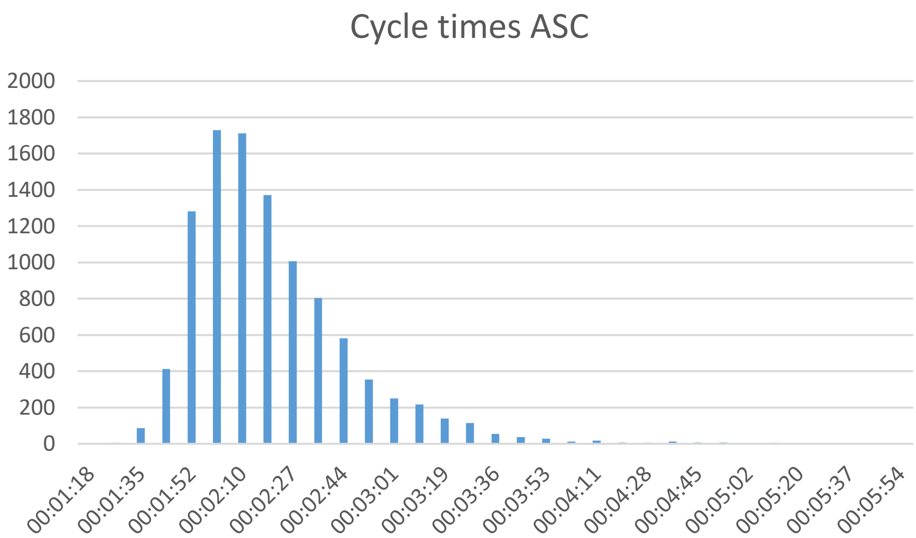


Figure 34 - Cycle times ASC

The cycle times of the Quay Crane are presented on the x-axis. The number of containers that are handled in the indicated times are presented on the Y-axis. The data is presented per deep-sea vessel.

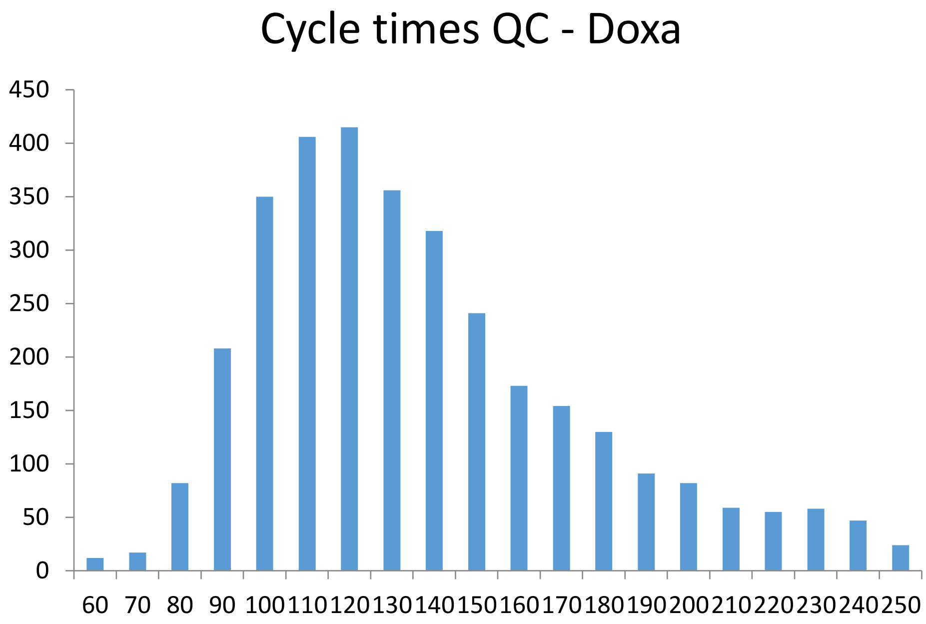


Figure 35 - Cycle times QC Doxa

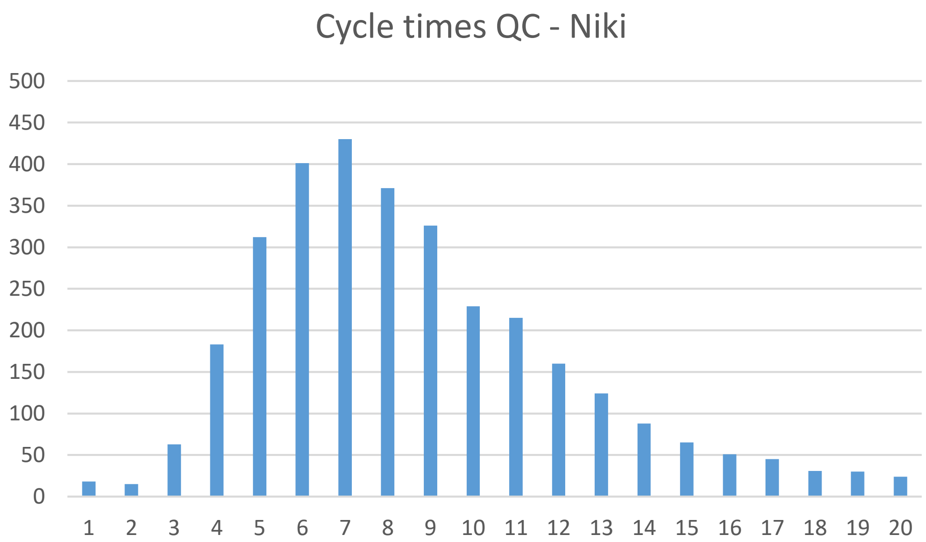


Figure 36 - Cycle times QC Niki

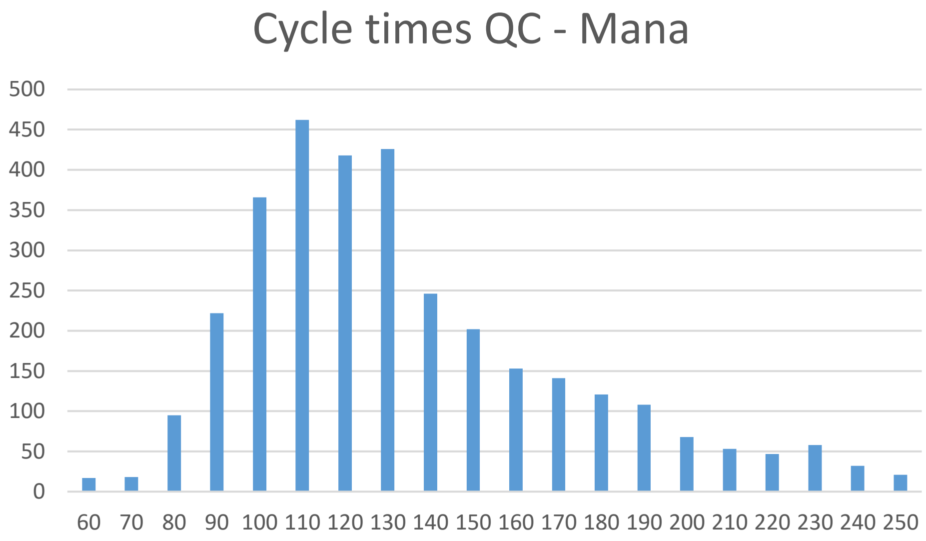


Figure 37 - Cycle times QC Mana

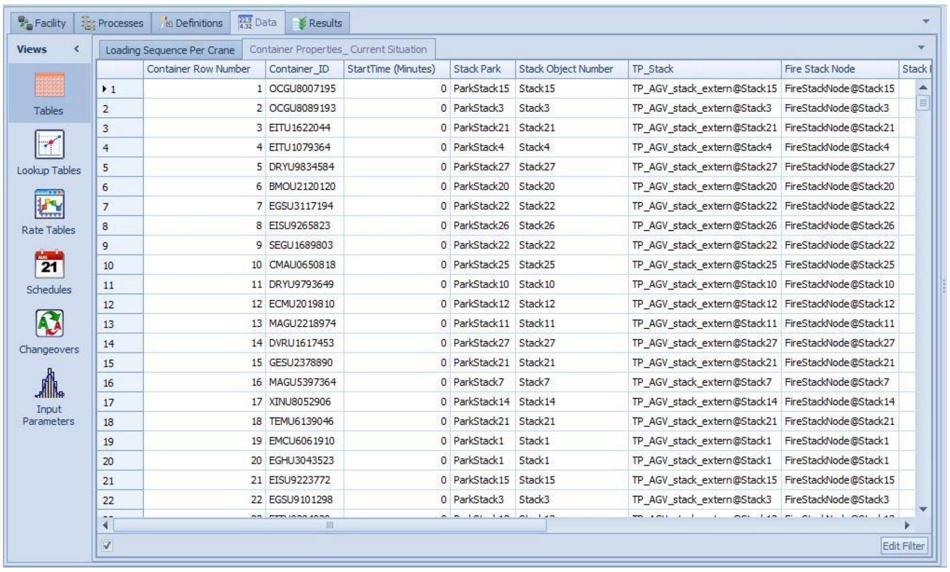
Appendix B - Simulation model

The development of the simulation model of the loading process of containers on board of a deep-sea vessel at a maritime container terminal will be described in three steps. The first step includes the start of the simulation run. In the second step the logic of the model will be described and in the last step the output and the end of the run will be explained. This explanation makes it possible to reproduce the model or to understand the build-up of the model to use it and develop it further on.

Start of the simulation run

The simulation run of the model starts at the moment that the model is manually started and the first order for a container will be assigned to an AGV. Therefore, orders have to be available, AGVs have to be accessible and the containers have to be positioned in the stacking yards.
Containers are modelled as entities and are passive. The entities are coupled to a table that is added to the simulation program. This table contains all the containers that have to be loaded during a call of a deep-sea vessel. The characteristics of the container are in the table as states that can be used by the model. When the containers are created as entities in the model, these characteristics are assigned as states to the container entities (see **Figure 39** 'state assignments'). In the current situation, every container has its own category. Because a table is used to define the containers that enter the model, different sets of containers can be added easily. Real data of containers can be used, but also fictional sets can be added. An example of the table can be seen in **Figure 38** and in

Table 21 an overview of all states of the containers is given.



	Container Row Number	Container_ID	StartTime (Minutes)	Stack Park	Stack Object Number	TP_Stack	Fire Stack Node
1	1	OCGU8007195	0	ParkStack15	Stack15	TP_AGV_stack_extern@Stack15	FireStackNode@Stack15
2	2	OCGU8089193	0	ParkStack3	Stack3	TP_AGV_stack_extern@Stack3	FireStackNode@Stack3
3	3	EITU1622044	0	ParkStack21	Stack21	TP_AGV_stack_extern@Stack21	FireStackNode@Stack21
4	4	EITU1079364	0	ParkStack4	Stack4	TP_AGV_stack_extern@Stack4	FireStackNode@Stack4
5	5	DRYU9834584	0	ParkStack27	Stack27	TP_AGV_stack_extern@Stack27	FireStackNode@Stack27
6	6	BMOU2120120	0	ParkStack20	Stack20	TP_AGV_stack_extern@Stack20	FireStackNode@Stack20
7	7	EGSU3117194	0	ParkStack22	Stack22	TP_AGV_stack_extern@Stack22	FireStackNode@Stack22
8	8	EISU9265823	0	ParkStack26	Stack26	TP_AGV_stack_extern@Stack26	FireStackNode@Stack26
9	9	SEGU1689803	0	ParkStack22	Stack22	TP_AGV_stack_extern@Stack22	FireStackNode@Stack22
10	10	CMAU0650818	0	ParkStack25	Stack25	TP_AGV_stack_extern@Stack25	FireStackNode@Stack25
11	11	DRYU9793649	0	ParkStack10	Stack10	TP_AGV_stack_extern@Stack10	FireStackNode@Stack10
12	12	ECMU2019810	0	ParkStack12	Stack12	TP_AGV_stack_extern@Stack12	FireStackNode@Stack12
13	13	MAGU2218974	0	ParkStack11	Stack11	TP_AGV_stack_extern@Stack11	FireStackNode@Stack11
14	14	DVRU1617453	0	ParkStack27	Stack27	TP_AGV_stack_extern@Stack27	FireStackNode@Stack27
15	15	GESU2378890	0	ParkStack21	Stack21	TP_AGV_stack_extern@Stack21	FireStackNode@Stack21
16	16	MAGU5397364	0	ParkStack7	Stack7	TP_AGV_stack_extern@Stack7	FireStackNode@Stack7
17	17	XINU8052906	0	ParkStack14	Stack14	TP_AGV_stack_extern@Stack14	FireStackNode@Stack14
18	18	TEMU6139046	0	ParkStack21	Stack21	TP_AGV_stack_extern@Stack21	FireStackNode@Stack21
19	19	EMCU6061910	0	ParkStack1	Stack1	TP_AGV_stack_extern@Stack1	FireStackNode@Stack1
20	20	EGHU3043523	0	ParkStack1	Stack1	TP_AGV_stack_extern@Stack1	FireStackNode@Stack1
21	21	EISU9223772	0	ParkStack15	Stack15	TP_AGV_stack_extern@Stack15	FireStackNode@Stack15
22	22	EGSU9101298	0	ParkStack3	Stack3	TP_AGV_stack_extern@Stack3	FireStackNode@Stack3

Figure 38 - Containers in the simulation model

Table 21 - States containers simulation model

Container Row Number	Container_ID	StartTime	Stack Park	Stack Object Number	TP_Stack	Fire Stack Node	Stack Row	Stack Column	Shuffles	Crane Number	Crane Location	Category	Queue Waiting State
1	OCGU8007195	0	ParkStack15	Stack15	TP_AGV_stack_extern@Stack15	FireStackNode@Stack15	5	52	0	1	EnterQueueCrane_Input@QuayCrane1	1	WaitingStack15
2	OCGU8089193	0	ParkStack3	Stack3	TP_AGV_stack_extern@Stack3	FireStackNode@Stack3	3	80	1	1	EnterQueueCrane_Input@QuayCrane1	2	WaitingStack3
..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..
..	..	..	..	..	..	..	..	..	..	..	..	..	..
n	UACU8305955	0	ParkStack3	Stack3	TP_AGV_stack_extern@Stack3	FireStackNode@Stack3	2	48	1	2	EnterQueueCrane_Input@QuayCrane2	3224	WaitingStack3

The attributes of the model will be added to the entity on the moment the entity is created. The moment of creation is defined on time zero. This means that all containers will be produced on the moment the model starts running, the settings of the arrival mode are set to 'table arrival'. See **Figure 39**.

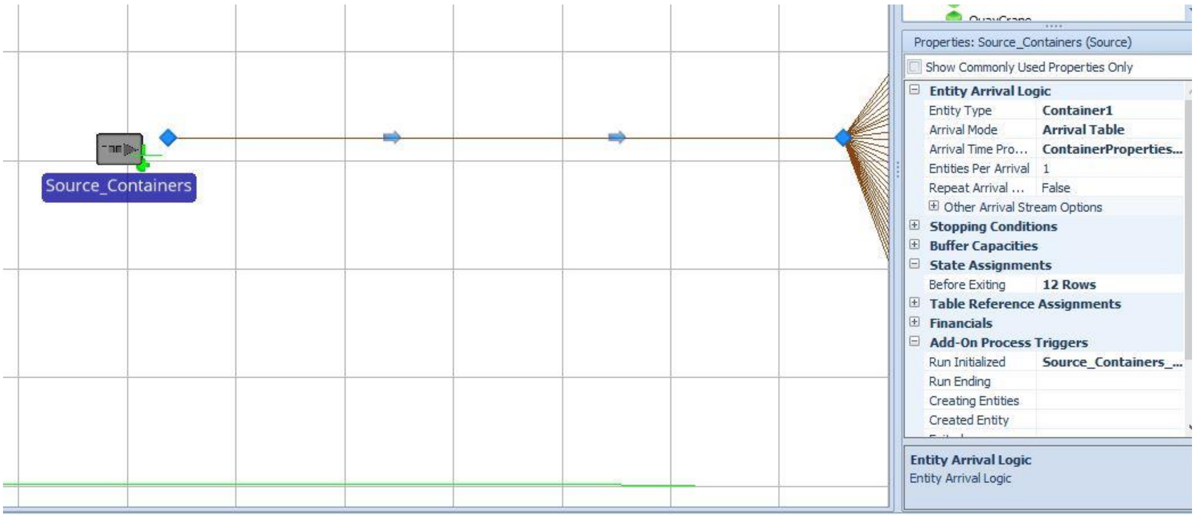


Figure 39 - Settings source containers

Then, the containers that have to be loaded are organized in stacking yards that are close to the location of the deep-sea vessel at the quay. Approximately 28 stacks are used per call, these are all equipped with Automated Stacking Cranes.
Because the simulation starts on the moment of the first request for a container, all containers have to be available in their stacking yards, as is in the given situation at the ECT Delta terminal. The start time assigned to the containers is therefore zero and all containers are created and placed in the yards immediately. The start time of the containers can be adjusted.

In the real system the orders for containers are made by the Terminal Operating System (TOS). The TOS creates a planning for half an hour forward, this means that orders are available at any time during the during the loading process until all containers are loaded. In the model these orders are placed in a queue. On the moment the order is made, it is placed at the back of the queue. The orders are modelled as entities and the properties category and crane number are assigned on the moment the orders are created. These properties are assigned according the loading sequence that is specified per crane. For the start of the simulation model, 15 orders per crane are created, in this way all AGVs can start working and the situation is comparable to the real situation taking into account the planning for half an hour. After the first creation of orders, a new order is created on the moment that the quay crane has handled an order, to do this, a second source is added in the simulation model, see **Figure 40** and **Figure 41**.

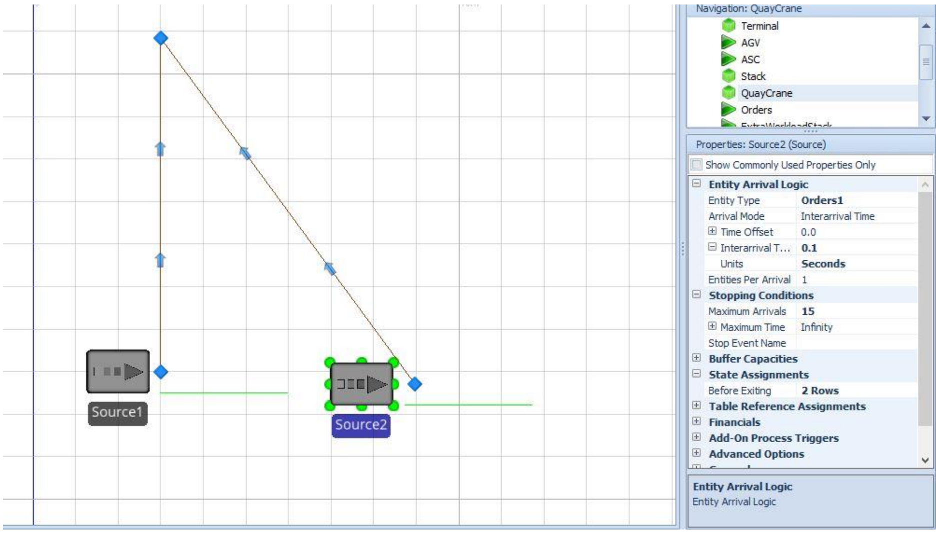


Figure 40 - Create orders start simulation run

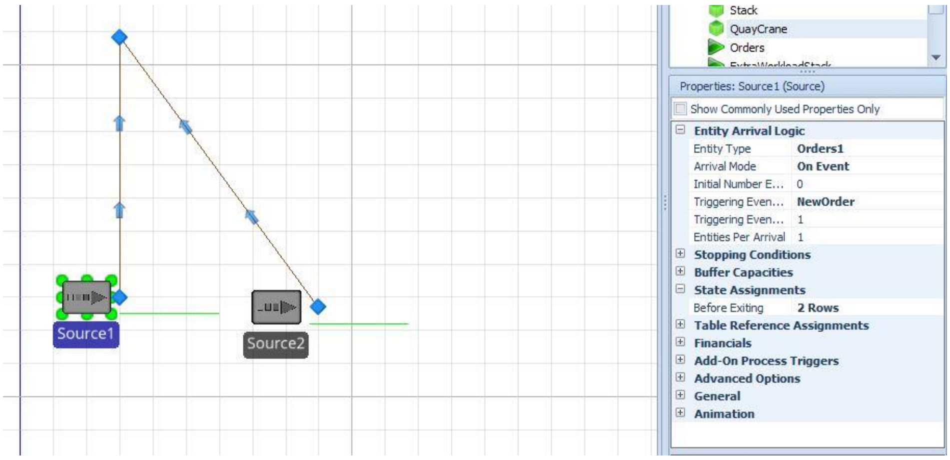


Figure 41 - Create orders during loading

Every stack owns one Automated Stacking Crane and these cranes are modelled as entities. The automated stacking crane can be seen in **Figure 42**, the green triangle represents the ASC. At the start of the run all ASCs are created by its source and will be waiting for jobs. On the moment a container arrives, the ASC will become active. The stack is not taken into account as object, but modelled as a waiting area without any characteristics, represented by a green line in the simulation model. This makes it possible to search to specific containers and the position of the container is assigned as property to the container entity. Other characteristics of the stack are outside the scope of this research and therefore not taken into account.

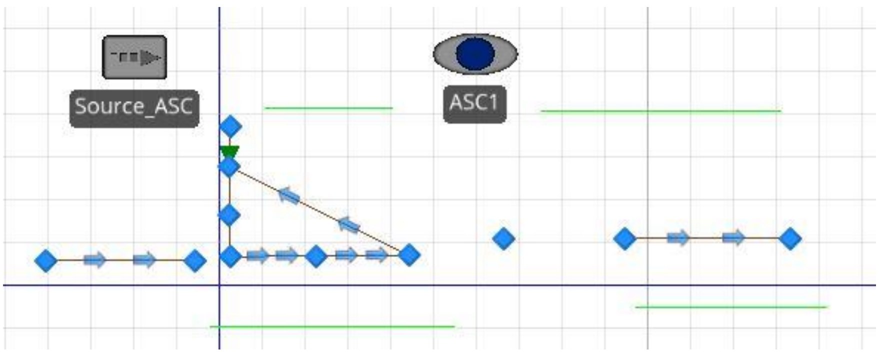


Figure 42 - ASC and stack

The AGVs that takes care of the horizontal transport are assigned to the deep-sea vessel that is simulated and only serve this boat during the run. The number of AGVs that are used per boat depends on the number of Quay Cranes; 42 AGVs in total are used. The AGVs are not dedicated to a crane, but serve all cranes. The AGVs in the simulation model are also modelled as entities. On the moment of creating the AGVs the attribute average speed is added to the entities. The number of vehicles that will transport containers during the run can be set. This can be useful whether a different number of AGVs is available for example. See **Figure 43** for the AGV and the AGV source of the simulation model

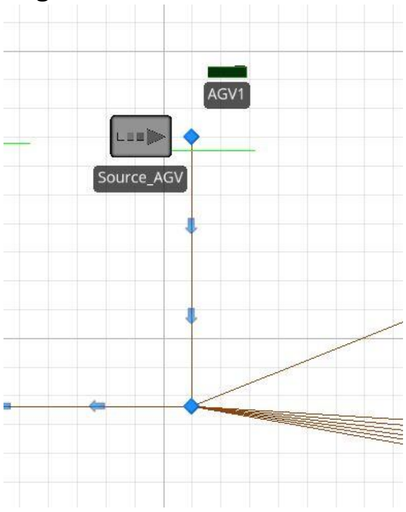


Figure 43 - AGV and source AGV

Lastly, the Quay Crane is modelled as a resource. A needed container can claim the QC and will be handled. Six cranes are modelled in the simulation model in a sub model, depending on the situation the number of cranes can be adjusted. In xx one QC of the simulation model is represented.

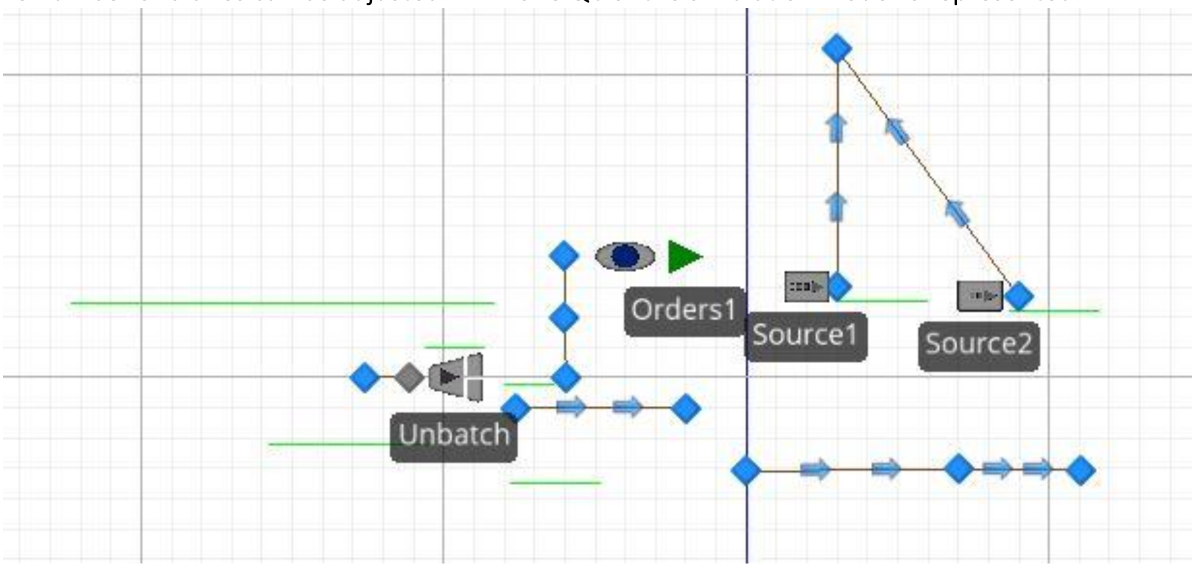


Figure 44 - Quay Crane simulation model

In the next section, all the mentioned aspects will be explained according the logic of the simulation model.

Logic of the simulation model

After the start of the simulation run the first orders are in the queue, all containers are in the stacking yards and the ASCs are created, the AGVs start signing up for jobs. For this, they drive to a specific point in the model. This point will be defined at the end of the route under the Quay Cranes and the first point after the source of the AGVs. The point is indicated by a red circle in **Figure 45**.

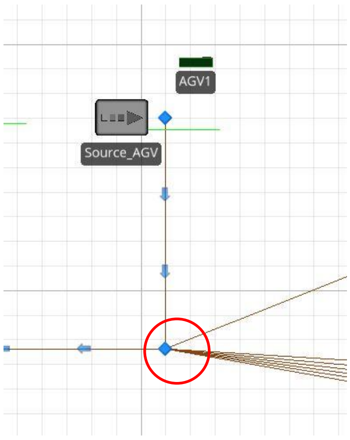


Figure 45 - New order assigned to AGV

The point can be on both sides of the ship in the real system, dependent on the drive direction of the specific AGV lane. In the simulation model one only point is modelled, because the driving times to this point are the same caused by the passage possibilities for the AGVs. This situation is presented in Figure 46, were the black dots represent the end of the AGV lane under the quay cranes and black squares the passage areas to the stacks.

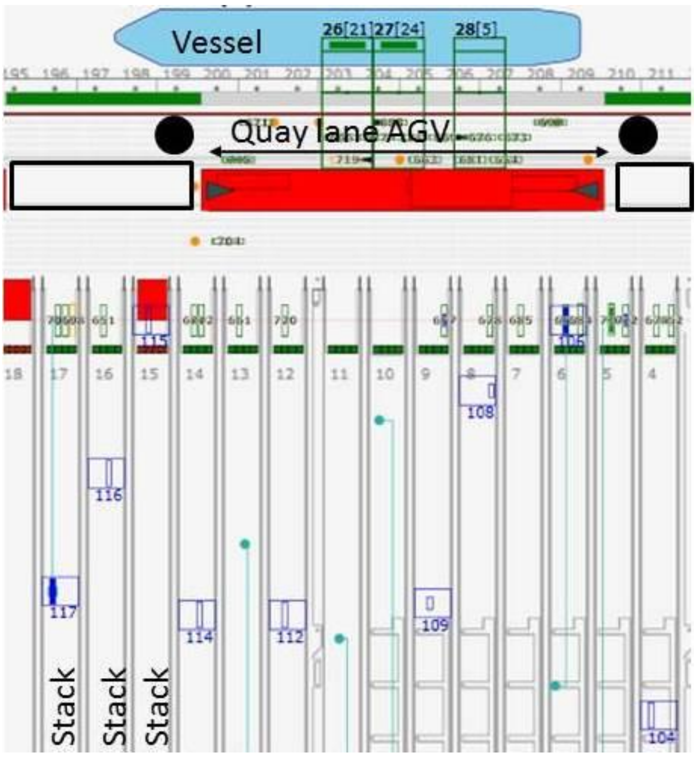


Figure 46 - Quay lane AGV

On the moment of arriving at the end of the quay lane, the AGV will check of a next order is available. This is done by checking for orders in the order queue. When no order is available the AGV will be released for other jobs at the terminal and disappear from the simulation model. In the case an order is available, the job is assigned to the AGV. The location of the container in the stack and the crane that requested the container are assigned to the AGV and the vehicle starts driving to the assigned stacking yard. See also **Figure 57**.

5 3 2 1

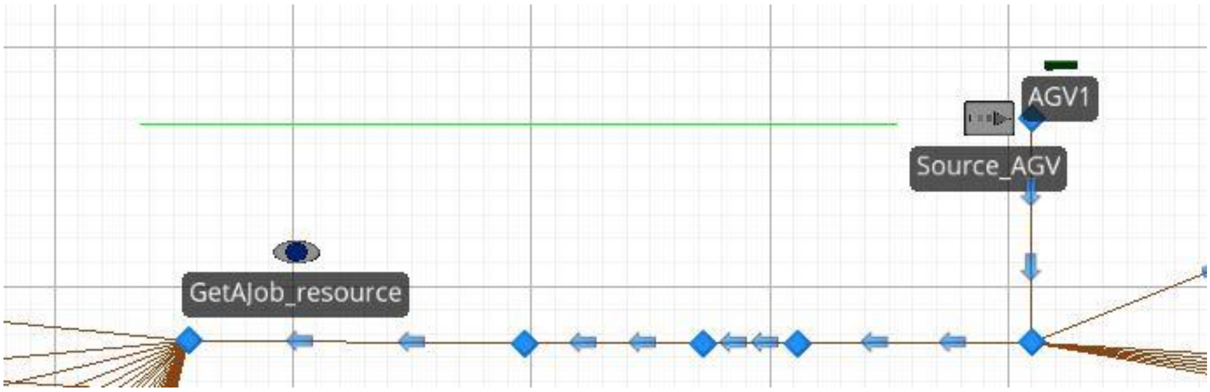


Figure 47 - Assign jobs to AGVs

In the first node that will be visited by the AGV (node 1, **Figure 57**) there will be decided whether a next order is available or not. See **Figure 48**. Firstly, the resource 'GetAJob' will be seized. This is done in order no other AGV can start the process until the current AGV is going through this process. In case no order is available, the AGV will leave the model and the resource will be released.

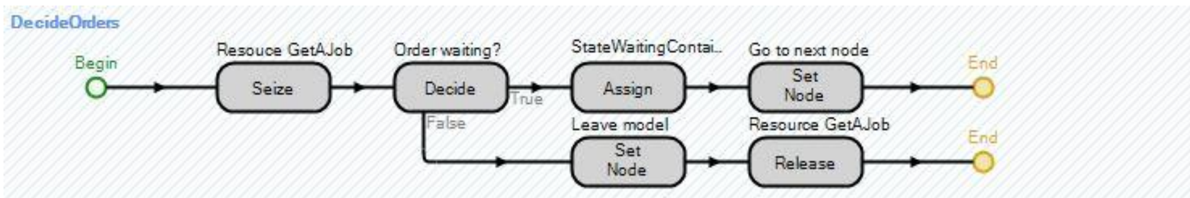


Figure 48 - Decide next order simulation model

In case an order is available the AGV leaves to node 2 (**Figure 57**) and the resource 'GetAJob' stays seized. The process presented in **Figure 49** shows how the first order in the row is selected by a search module and how the crane number and category number are added to general states of the simulation model. After this, the order entity is removed from the queue and transferred to a sink. The reason that the crane number and category number are assigned to general model states is that states of different entities cannot be assigned to each other directly.

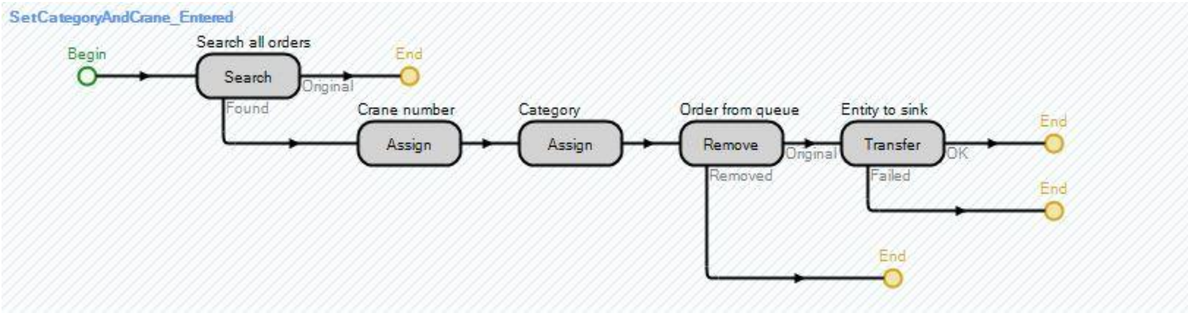


Figure 49 - Set crane number and category to AGV

In node 3 (**Figure 57**), the first selection of containers will be done. In case of the current situation, the choice for a container will be consist of one container, because every container has its own category. In case of more containers per category the choice will be bigger. In **Figure 50** the process is presented. In a general queue (which is a virtual queue that contains all containers that are not loaded yet), all containers that satisfy the requirements of the order (category and crane number) will be selected. To ensure that all containers are taken into account an extra decide module is used after the search module. From all selected containers the row in the table of the containers is set. One column of this table contains the state of the stacking yard of the container. This state represents the current number of orders that is waiting to be handled by the corresponding ASC. The number of the waiting orders and the number of shuffles that have to be made for the container are assigned together in the penalty point state of the container. After updating the state of the container, it will be put in a temporary waiting queue and removed from the general queue. When all containers of the requested category and crane number are selected the AGV is fired and moves to the next node.

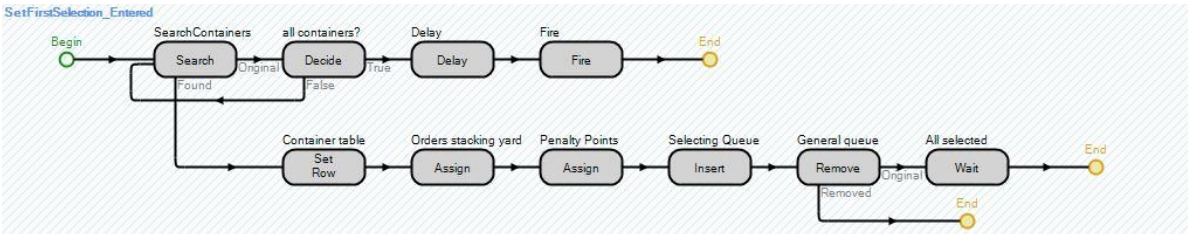


Figure 50 - First selection containers

The order contains a category number and a crane number. On the moment a container from a category is requested, all containers that fit that category are selected. From this selection the container that contains the lowest number of shuffles and is positioned in the stack that has the lowest workload on that moment is chosen. The number of shuffles and the workload together represent the number of penalty points of the container. In the current situation, each container owns its own category, therefore only one container is selected and chosen.

In case of more containers per category, the best container has to be selected and the other containers have to be placed back in the general queue to be available for a next order. This will be done in node 4 (**Figure 57**). The first part of this process is presented in **Figure 51**.

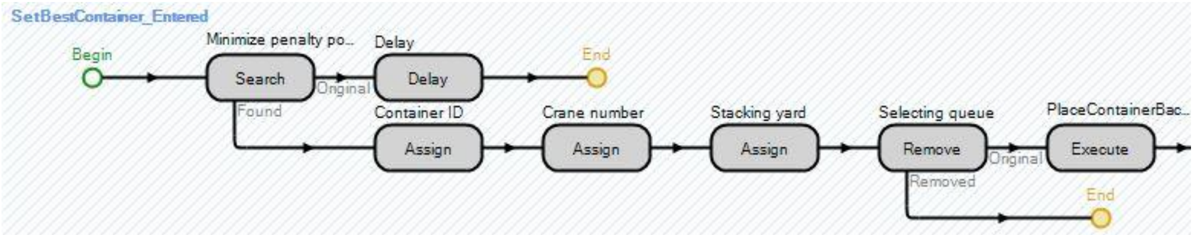


Figure 51 - Set best container process part 1

Firstly, the container that has the least penalty points will be selected by the search module. The ID number (can be found in the container table), the corresponding crane number and stacking yard number are assigned to general states (as also was done for selecting the containers in the first place). Then, the selected container is removed from the temporary selecting queue followed by a sub process (the execute module) to place the other containers back in the general queue, see **Figure 52**.

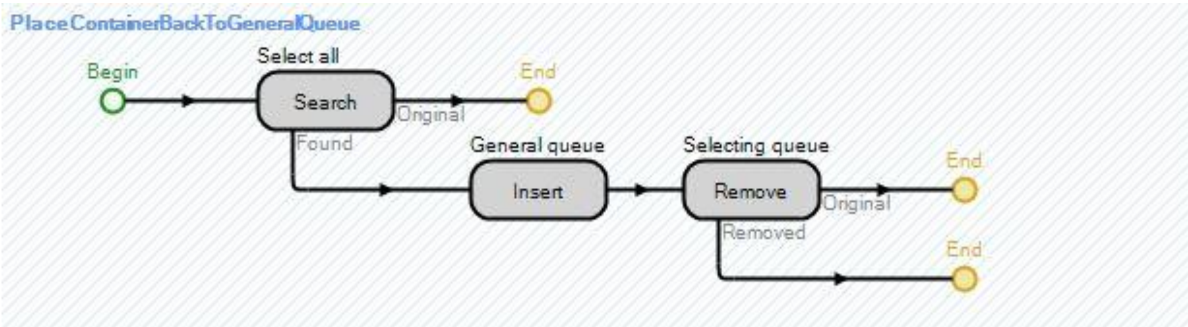


Figure 52 - Place containers back in general queue

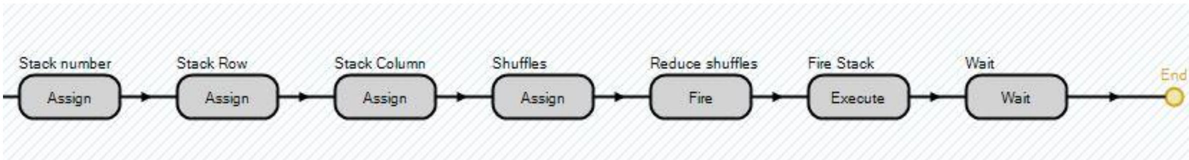


Figure 53 - Set best container process part 2

After placing the other containers back in the general queue, the stack number, stack row and stack column in the stacking yard and the number of shuffles of the chosen container are assigned to general model states. After assigning the states the 'Reduce shuffle' process is fired. This process accomplishes the reduction of shuffles for containers that are positioned below the chosen container. See **Figure 54**.

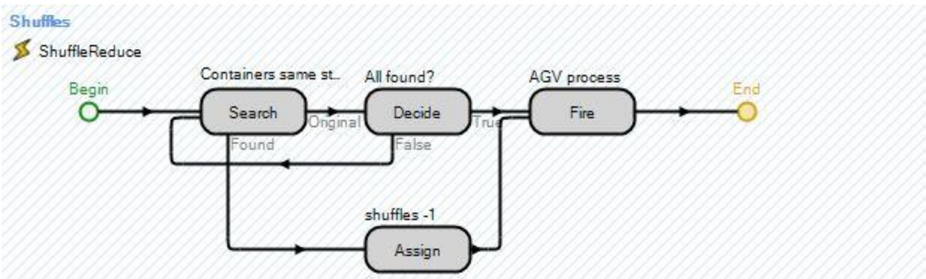


Figure 54 - Reduce shuffles

After reducing the shuffles, the AGV process of **Figure 53** continues by the fire at the end of the shuffle reduction process. The reduction of the shuffles is followed by the activation of the ASC of the connected stack of the chosen container. The container is 'parked' in the model at its own stacking yard and is transferred from this parking to the queue of the ASC.

Figure 55 - Fire ASC

Before moving on to the stacking yard and the ASC, the AGV arrives is the last node of **Figure 57**, node 5. In this node the general states that contains the information of the container ID, the stacking yard and the crane update this information to the AGV and the direction to the stack is set. Lastly, the 'GetAJob' resource is released, the next AGV can enter the process, see **Figure 56**. The whole get a job process is executed in 0.2 seconds.

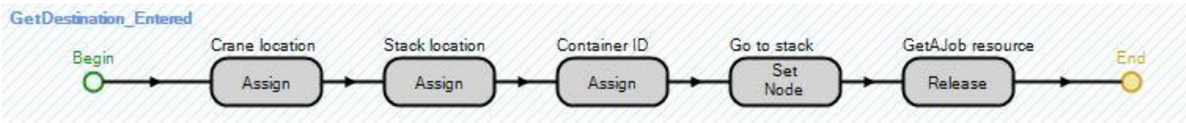


Figure 56 - Set destination AGV

On the moment the AGV starts driving to the stacking yard the ASC is activated for the order. In the most perfect situation the ASC can pick up the container directly and will arrive at the Transfer Point of the stacking yard on the same moment the AGV arrives. The perfect situation is unfortunately not always the case. For example, when a container has other containers on top of it, one or more shuffles have to take place. Moreover, other containers can be in the order queue of the ASC and the new order is placed in the back of that queue. The AGV has to wait until its container is handled. Lastly it is possible that the ASC has to handle a landside container. In that case the waterside move had to wait. On the moment of a delay, caused by a land side move, other orders for the waterside or shuffles, the AGV has to wait at the Transfer Point (TP) of the stacking yard. See **Figure 57**.

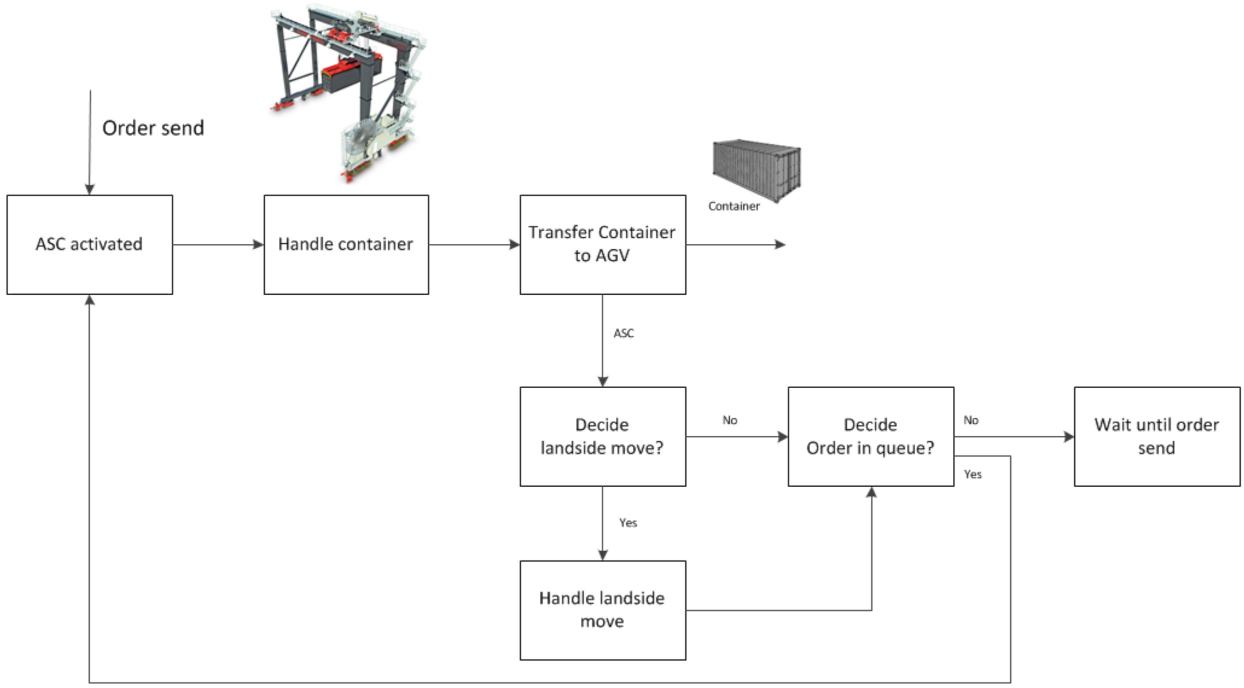


Figure 57 - Stack process

In the simulation model the container enters the order queue of the of the stacking yard. In **Figure 58** a situation of the stacking yard and ASC with containers of the stacking yard can be seen.

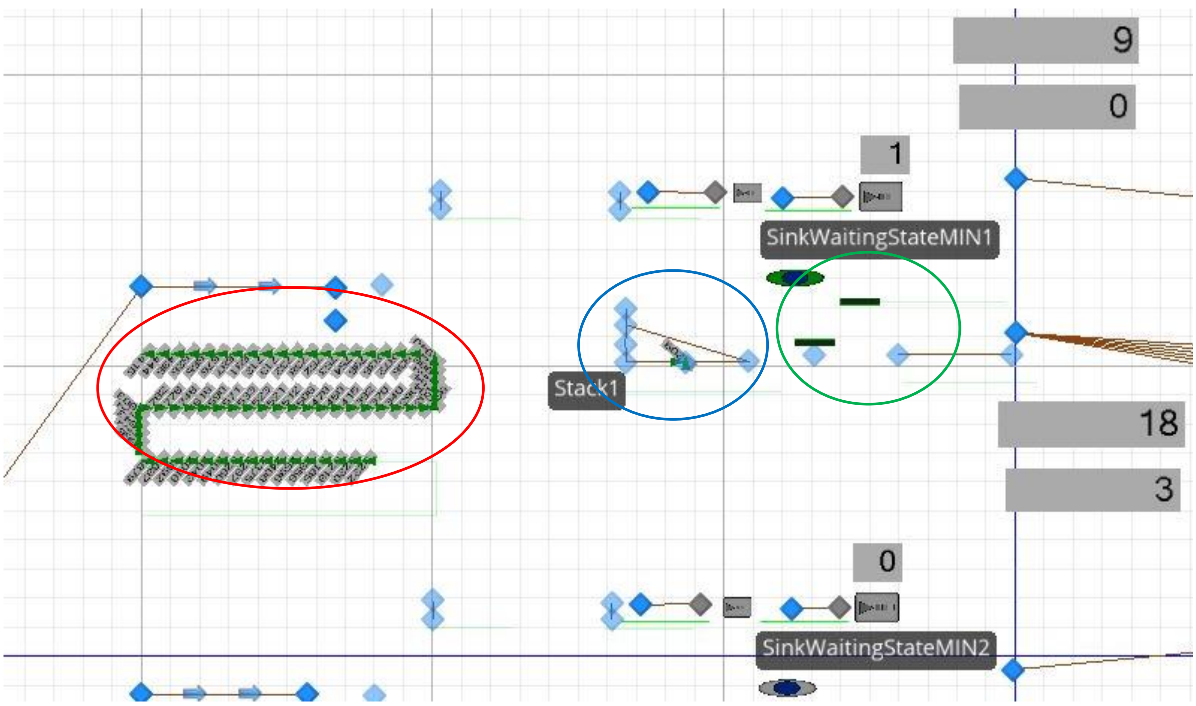


Figure 58 - Stacking yard

In the red circle, all container that are in the stack are represented by green triangles. On the grey label the category of the container is presented. The blue circle is the ASC and the green circle are waiting AGVs.

On the moment a container is transferred from its parked position in the model to the stack it enters the stack processes. First the number of shuffles of the container is assigned to a general system state that keeps track on the total number of shuffles made during the loading of a deep-sea vessel. Then the chosen container is searched picked from the queue of all containers in the stack and inserted in the order queue of the ASC.

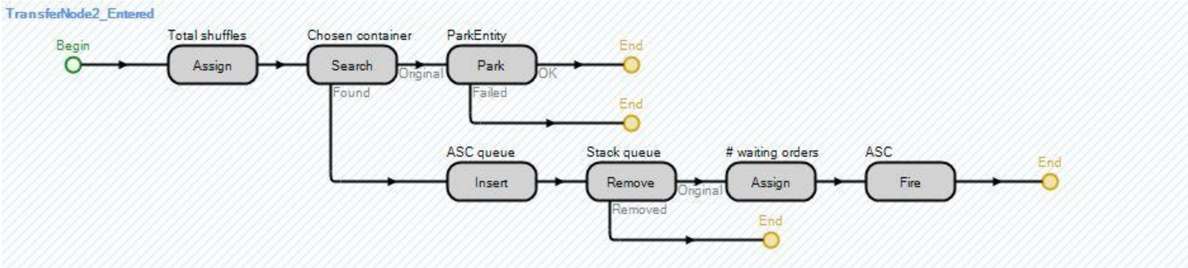


Figure 59 - Fire stack process

The workload of the stack is measured as the number of orders that have to be handled by the ASC. Moreover, a landside move is also counted for the workload of the stack. After that these states are updated the process will fire the ASC, which is waiting for its next job. See **Figure 59**.
The fired ASC leaves for the container, the ASC will be delayed for the time that is needed to reach the container, see **Figure 60**.

Figure 60 - Go to container

When the ASC reach the container, the ASC and container will be batched in the simulation model and the container will be removed from the order queue. The state of number of containers waiting will be updated and the ASC drives to the Transfer Point at the end of the stacking yard, see **Figure 61**.

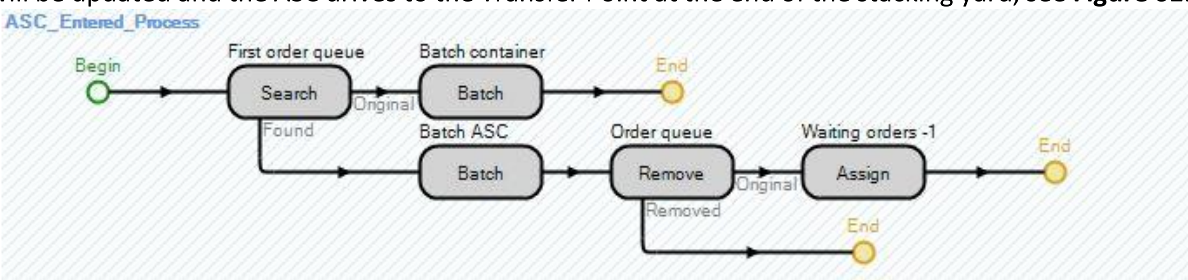


Figure 61 - Batch ASC and container

The process time of the ASC handling the container consist of different steps. First a minimum delay is modelled, followed by a varying, depending on the location of the container in the stack. If any shuffles have to be made, the ASC is delayed for the number of shuffles. After all the delays, the ASC is batched to the container again to be delivered at the Transfer Point. See **Figure 62**.

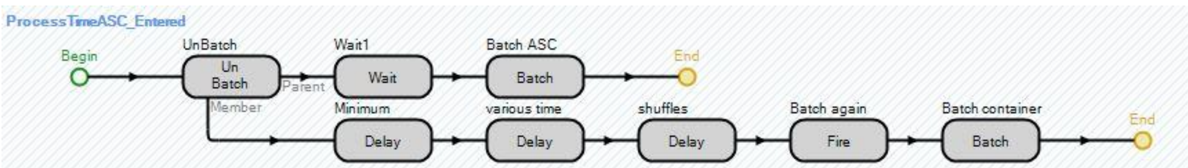


Figure 62 - Process time ASC

The ASC arrives at the Transfer Point, the container and ASC will be unbatched and the ASC leaves for a next job. The container is put in a queue, the corresponding AGV will be activated and will pick up the container from the queue. This last handling will be done in zero time. See **Figure 63**.

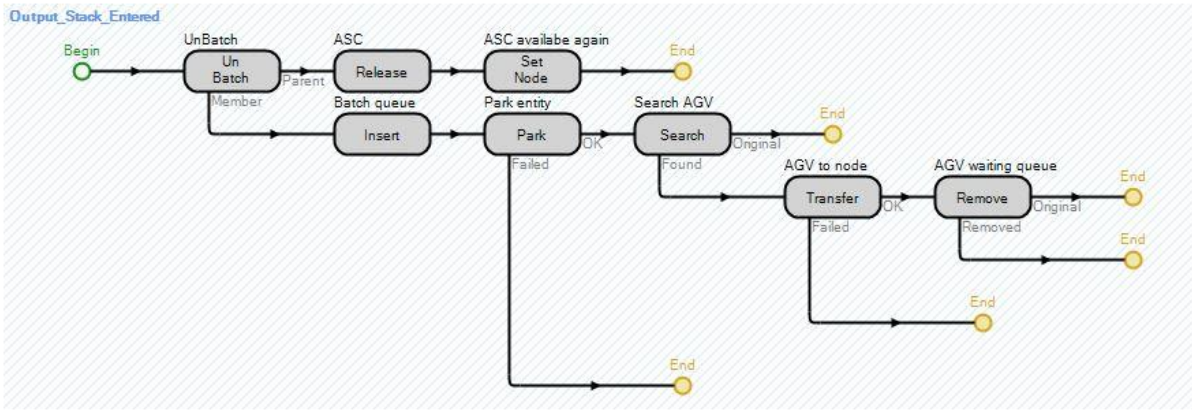


Figure 63 - Container to AGV

The ASC leaves to its 'home node' and will check for a next order or an order for the landside. In the case no landside moves or next order are waiting the ASC will wait for the next order. In the case a next order or landside move is available the ASC will keep processing the orders.

After the container is loaded to the AGV starts driving to the assigned QC. In **Figure 64** the routes from the general point, the point where AGVs get their jobs, to the stacks and the routes of a few stack to the cranes can be seen. The stacks are indicated by the red square, the point of assigning jobs to AGVs by the blue square.

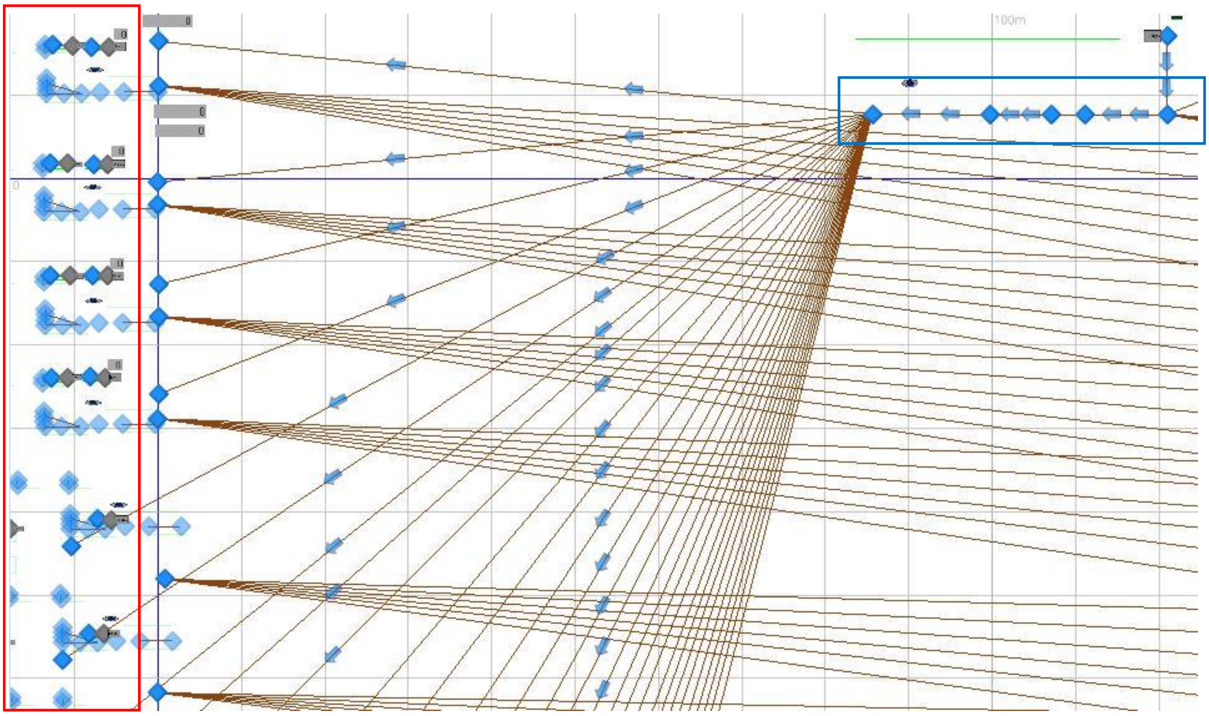


Figure 64 - Routes

Because of the set directions of the paths at the terminal and the fixed routes, the AGV needs a certain driving time from the stack to the entrance of the QC lane (the driving lanes under the cranes, parallel to the vessel). The QC lane can only be entered at a few places. In the model possible delays, caused by congestion at this entrances and at other point during driving, are included in the driving time.

After entering the QC lane, the driving time depends mainly on the waiting time under the QC. In the model an exclusive lane for each crane is used, therefore the AGV can only be delayed by an AGV that has to deliver a container to the same crane. The QC lanes are one way lanes. In **Figure 65** can be seen how the AGVs could arrive at the six QCs of the model. The QC are indicated by the green square.

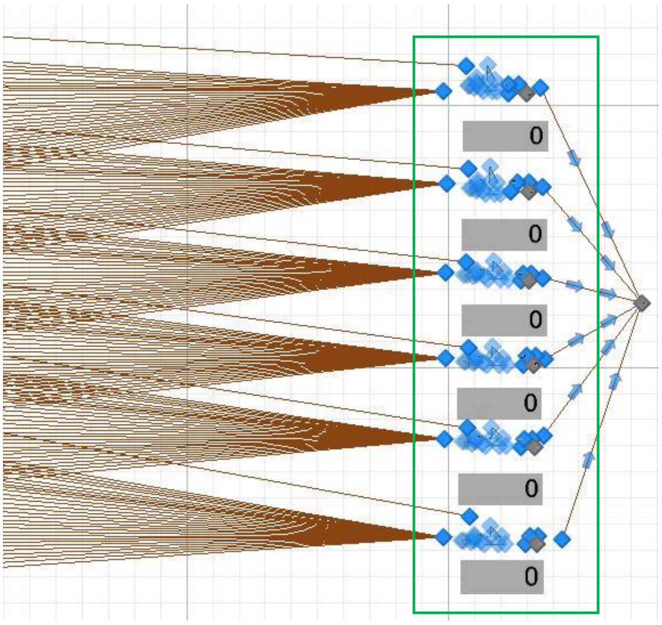


Figure 65 - Arrival QCs

The QC is pictures in **Figure 66**.

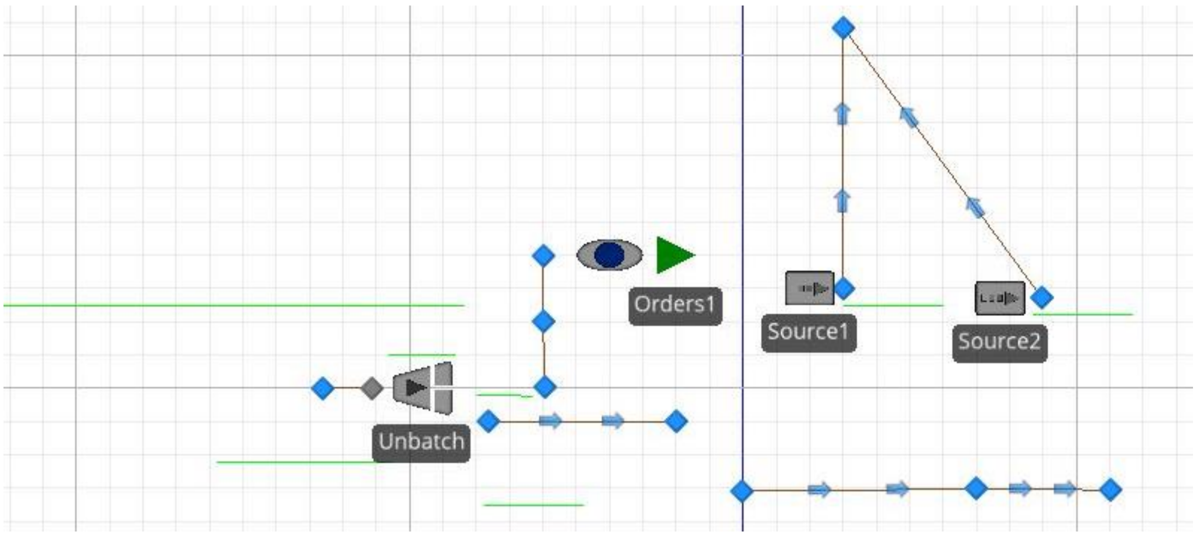


Figure 66 - QC simulation model

When the AGV arrives at the QC, the AGV and container will be unbatched first. The container seizes the QC resource after leaving the unbatch module and a fire for a next order will be send to the order queue, characterized with the needed category and crane. The order of categories is stored per crane in a table and the next row will be used every time. The AGV leaves the unbatch module and will be parked in a waiting queue. See **Figure 67**.

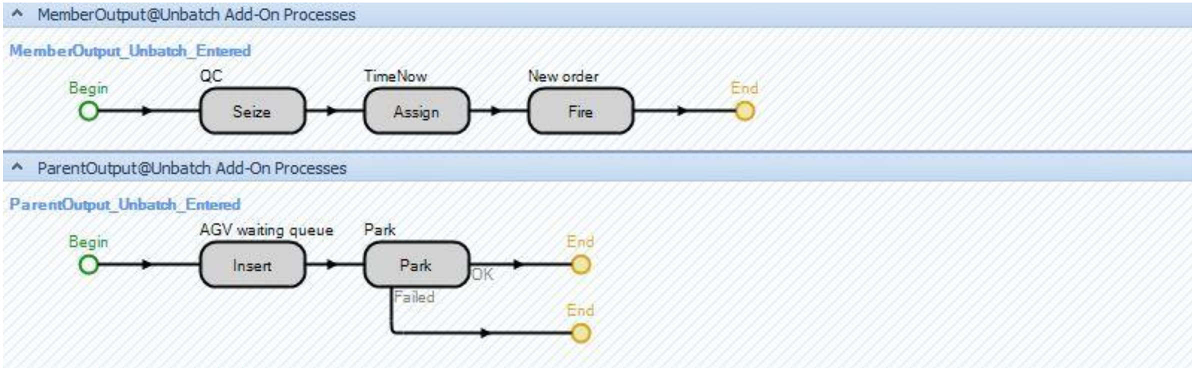


Figure 67 - Output unbatched AGV and container

The container moves on to the next node, in this node the next process is started. First a delay for the first part of the handling time of the container is done, after this delay the AGV is released by removing it from the queue. Then, the second part of the delay of the handling time of the container by the QC will be done. Moreover, a general model state is updated to record the time that the QC is in use, see **Figure 68**.

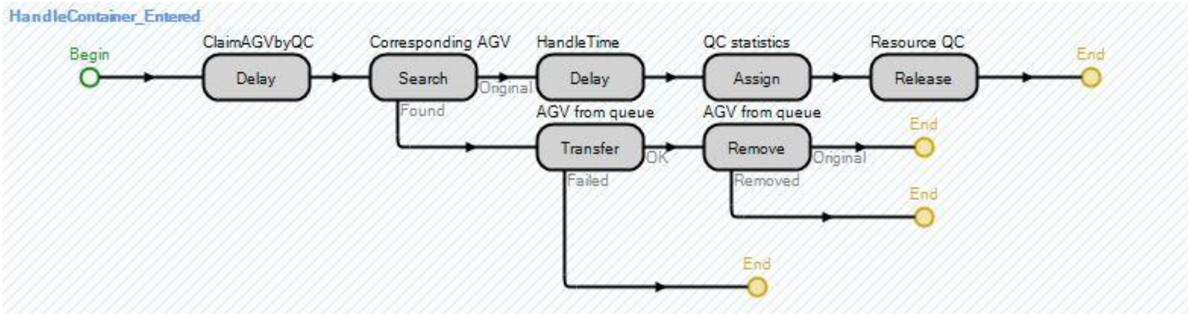


Figure 68 - Handling container by the QC

After delivering its container and the first delay, the AGV drives to the end of the quay lane and will check for a next job and the logic starts again.

Lastly, several states are updated during the processes and resource are included. The resource is used for two reasons. The first reason is to avoid that different jobs can influence each other when AGVs are following up very close. The second reason is that the time a resource is seized can be measured well and the output of this measurement can be used.

Output and end of the simulation run

When the last order is assigned to an AGV and ASC the order queue of the model will be empty. The AGV that arrives at the end of the quay lane will be sent to a sink in the model and will be destroyed. On the moment the last container is handled by the QC the run will end. At the end of the run the results will be presented in the software program.

An important aggregation of the loading system is the driving time from the stacking yard to the QC by the AGV. The dynamics of the AGVs, which include interactions between the vehicles, congestion and the dispatching of the AGVs that in the real system not only work for one loading process are important simplifications of the system and have to be taken into account in the conclusions about the concept of category loading.

Appendix C - Validation

Shuffles: the determination of the number of shuffles per container. The stacks that are used during the loading process from the moment of the loading starts until the vessel is leaving are taken into account.

Doxa

Table 22 - Shuffles per container Thalassa Doxa

ASC	Waterside	Landside	Shuffles	Total Outbound	Shuffles per container
268	121	3	76	124	0,61
269	116	4	67	120	0,56
270	153	6	110	159	0,69
271	123	6	79	129	0,61
272	138	6	102	144	0,71
273	141	8	81	149	0,54
274	159	5	96	164	0,59
275	123	4	62	127	0,49
276	132	5	80	137	0,58
277	140	9	65	149	0,44
278	142	7	58	149	0,39
279	161	7	102	168	0,61
280	153	4	76	157	0,48
281	155	5	75	160	0,47
282	152	3	59	155	0,38
283	160	4	81	164	0,49
284	152	5	96	157	0,61
285	169	5	98	174	0,56
286	162	4	66	166	0,40
287	145	13	74	158	0,47
288	163	13	87	176	0,49
289	154	16	92	170	0,54
290	163	5	89	168	0,53
291	154	6	101	160	0,63
292	147	7	77	154	0,50
293	151	13	91	164	0,55
294	159	17	90	176	0,51
295	73	7	31	80	0,39
Total	**4061**	**197**	**2261**	**4258**	**0,53**

Niki

Table 23 - Shuffles per container Thalassa Niki

ASC	Waterside	Landside	Shuffles	Total Outbound	Shuffles per container
268	135	16	151	107	0,71
269	162	6	168	100	0,60
270	155	11	166	112	0,67
271	146	19	165	110	0,67
272	156	13	169	108	0,64
273	170	10	180	90	0,50
274	170	9	179	105	0,59
275	146	9	155	58	0,37
276	144	21	165	69	0,42
277	141	8	149	77	0,52
278	158	11	169	80	0,47
279	158	12	170	108	0,64
280	170	12	182	103	0,57
281	168	15	183	94	0,51
282	163	4	167	84	0,50
283	164	9	173	67	0,39
284	150	15	165	116	0,70
285	141	31	172	79	0,46
286	155	16	171	85	0,50
287	162	7	169	92	0,54
288	151	19	170	77	0,45
289	154	23	177	102	0,58

290	158	19	177	93	0,53
291	156	12	168	93	0,55
292	159	20	179	107	0,60
293	159	16	175	112	0,64
294	148	27	175	115	0,66
295	270	10	280	30	0,11
Total	**4469**	**400**	**4869**	**2573**	**0,53**

Mana

Table 24 - Shuffles per container Thalassa Mana

ASC	Waterside	Landside	Shuffles	Total Outbound	Shuffles per container
269	144	8	91	152	0,60
270	151	21	100	172	0,58
271	143	16	89	159	0,56
272	139	3	77	142	0,54
273	154	9	83	163	0,51
274	159	6	73	165	0,44
275	147	1	66	148	0,45
276	141	7	47	148	0,32
277	138	4	51	142	0,36
278	142	12	59	154	0,38
279	139	4	75	143	0,52
280	141	9	69	150	0,46
281	143	9	67	152	0,44
282	133	5	56	138	0,41
283	148	3	48	151	0,32
284	132	6	64	138	0,46
285	141	4	62	145	0,43
286	135	8	54	143	0,38
287	149	1	52	150	0,35
288	152	4	49	156	0,31
289	143	7	56	150	0,37
290	153	5	75	158	0,47
291	141	8	56	149	0,38
292	142	6	53	148	0,36
293	159	3	49	162	0,30
294	159	1	61	160	0,38
295	212	1	51	213	0,24
296	136	0	56	136	0,41
Total	**4116**	**171**	**1789**	**4287**	**0,42**

Waiting time AGVs: the time AGVs are waiting at the stack and receive a container. Below the waiting times of the AGV of the Thalassa Doxa, Niki and Mana are presented. Moreover the average waiting times after removing all values above the 20 minutes are given.

Table 25 - Reduced waiting times AGVs

Deep-sea Vessel	**Reduced average waiting times AGVs**
Thalassa Doxa	04:01 minutes
Thalassa Niki	03:50 minutes
Thalassa Mana	04:13 minutes

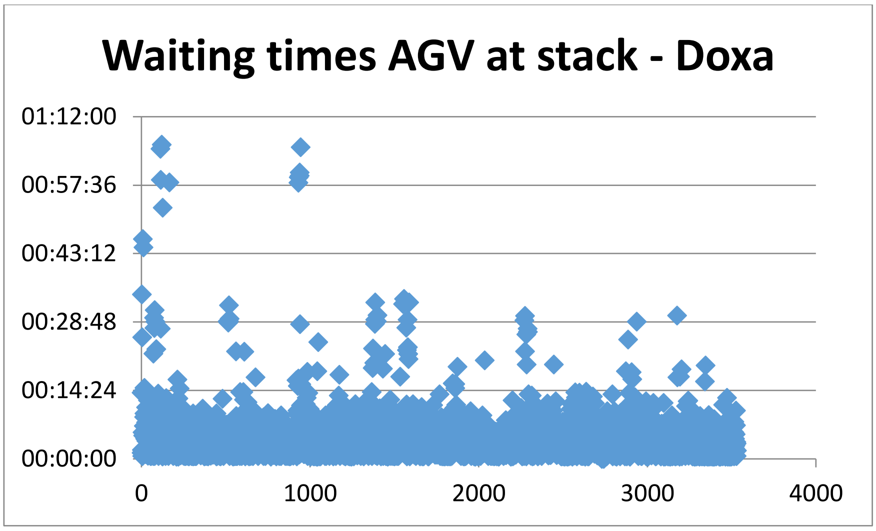


Figure 69 - Waiting times AGV at stack - Doxa

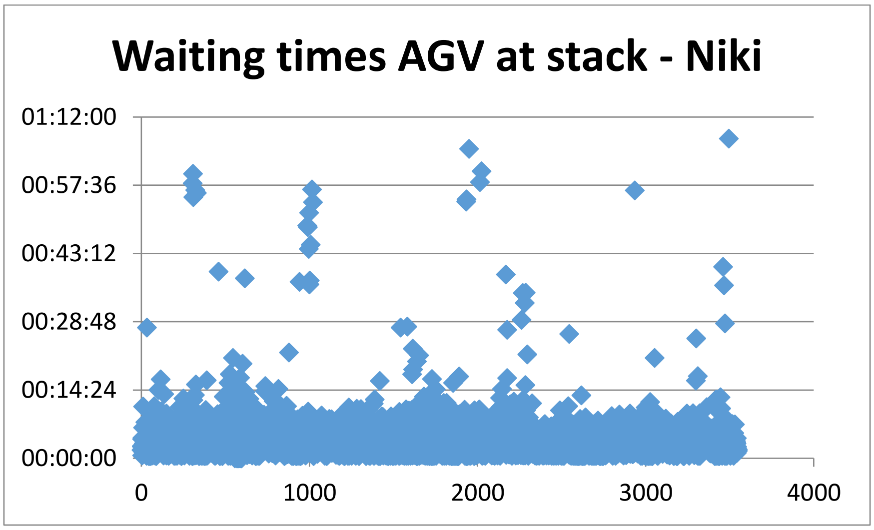


Figure 70 - Waiting times AGV at stack - Niki

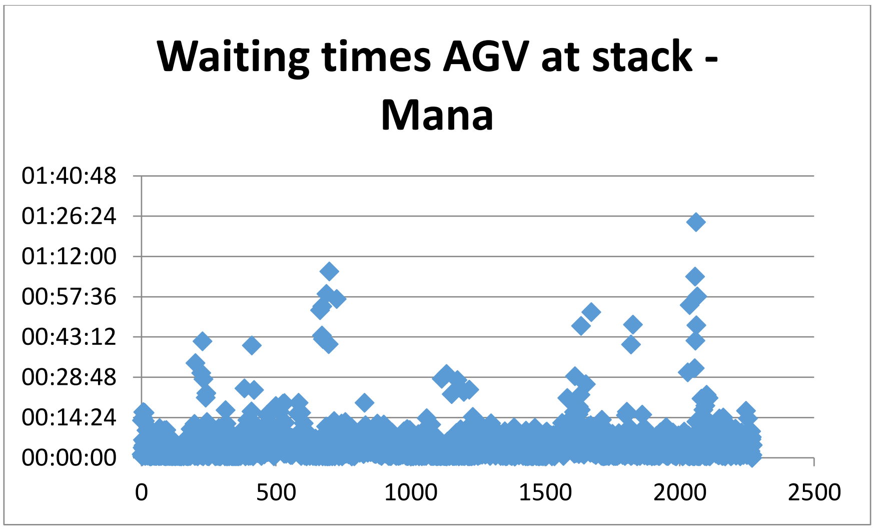


Figure 71 - Waiting times AGV at stack - Mana

Appendix D - Categories

Categories empties only

Below an overview of the classification of the containers of the deep-sea vessel Thalassa Niki and Thalassa Mana are presented.

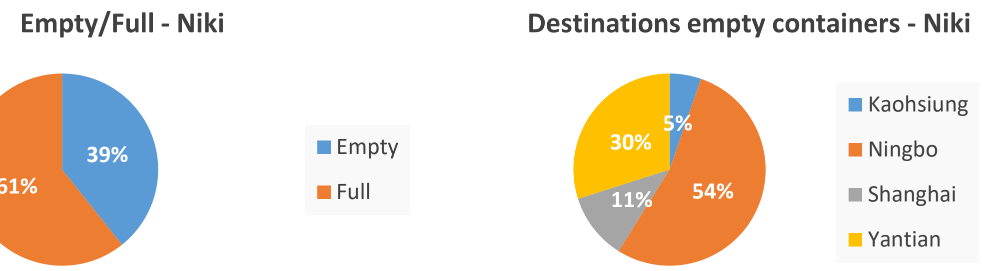


Figure 72 - Categories Empties Niki

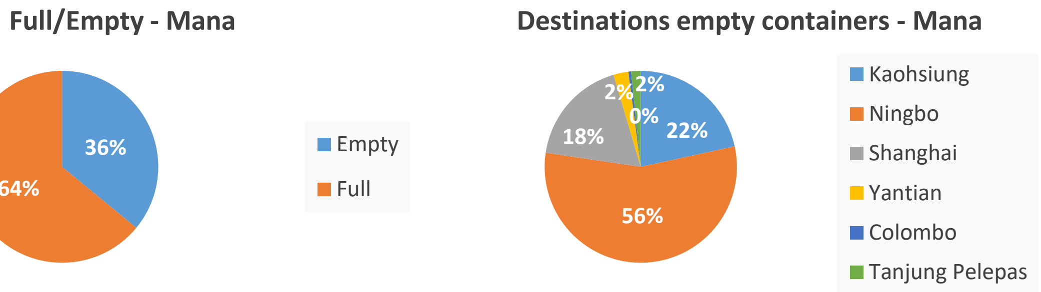


Figure 73 - Categories Empties Mana

An overview of all defined categories in this scenario is presented below.

Table 26 - Categories Empties

Categories		**Containers**		
		Doxa	Niki	Mana
Full and special containers (all own categories)		*2223*	*1947*	*1994*
Kaohsiung	20 feet	139	-	139
	40 feet	63	67	102
	45 feet	12	-	-
Ningbo	20 feet	3	5	29
	40 feet	125	670	594
	45 feet	-	-	-
Shanghai	20 feet	215	118	151
	40 feet	51	23	51
	45 feet	-	-	-
Yantian	20 feet	-	331	2
	40 feet	393	39	2
	45 feet	-	7	24
Tanjung	20 feet	-	-	18
	40 feet	-	-	-
	45 feet	-	-	-
Categories empty containers		**8**	**8**	**10**
Total number of categories		**2231**	**1955**	**2315**

Categories empties and full containers

An overview of the destinations of the deep-sea vessels Thalassa Niki and Thalassa Mana are presented below.

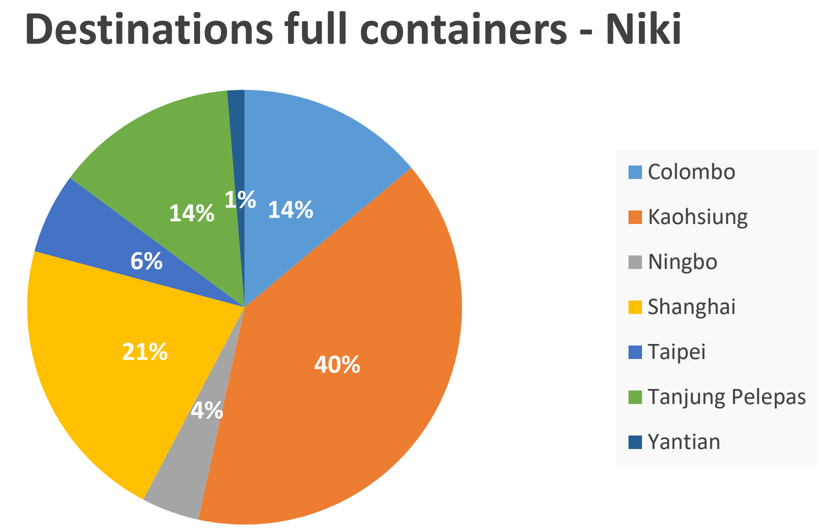


Figure 74 - Destinations full containers Niki

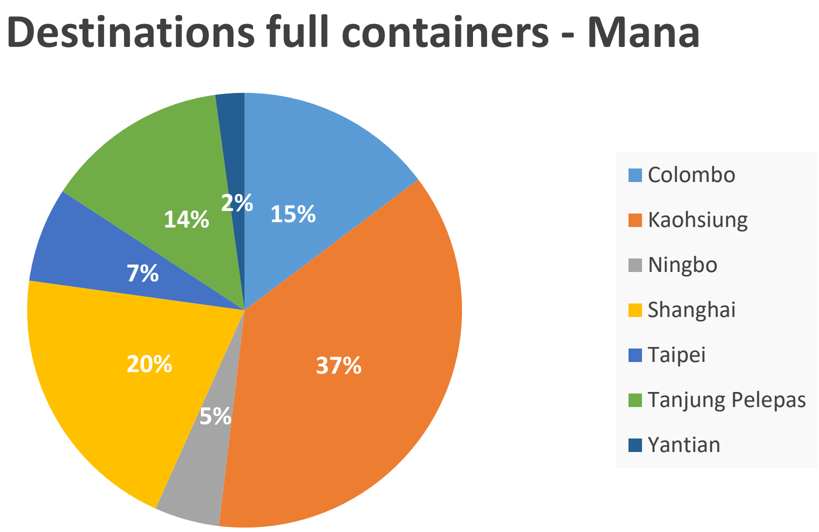


Figure 75 - Destinations full containers Mana

The distributions of the weight of the containers that will be loaded during the simulation of the loading process are presented in the figures below (**Figure 76, Figure 77** and **Figure 78**) per deep-sea vessel. On the vertical axis the number of containers is presented and on the horizontal axis the weight in tonnes. For is first scenario that includes categories for full containers, containers a distinction is made between containers less than 20 tonnes and containers of 20 tonnes and more. The reason to split the container at that point is that the heaviest containers is 35 tonnes and the weight of empty containers is 4 or 5 tonnes. Therefore, 2 categories of 15 tonnes, one from 5 to 20 and one from 20 to 35 tonnes are defined. There have to be mentioned that a few containers are less than 5 tonnes, this can be for example mistakes in the registration. These containers are categorised in the under 20 tonnes category.

The weights in tonnes are presented on the x-axis and the number of containers on the y-axis.

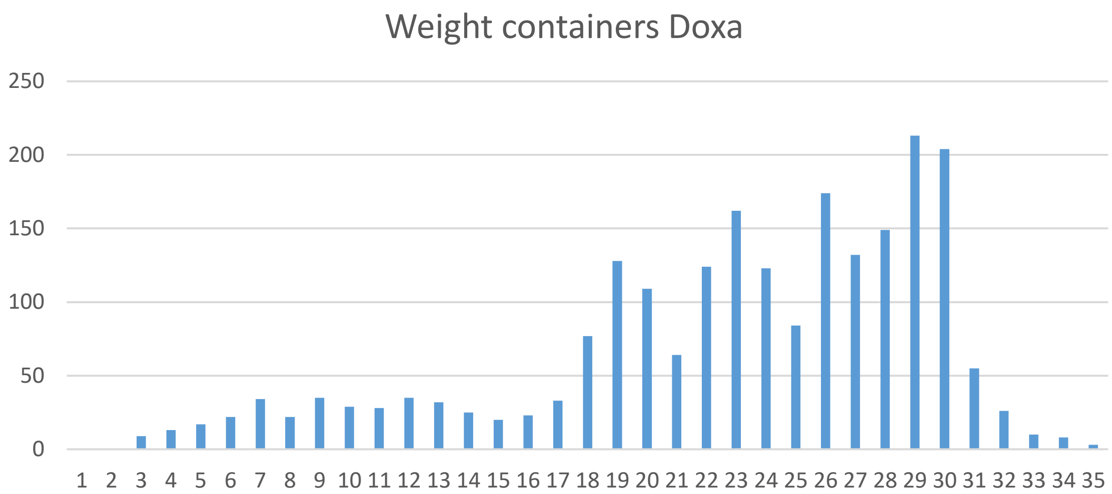


Figure 76 - Weight containers Doxa

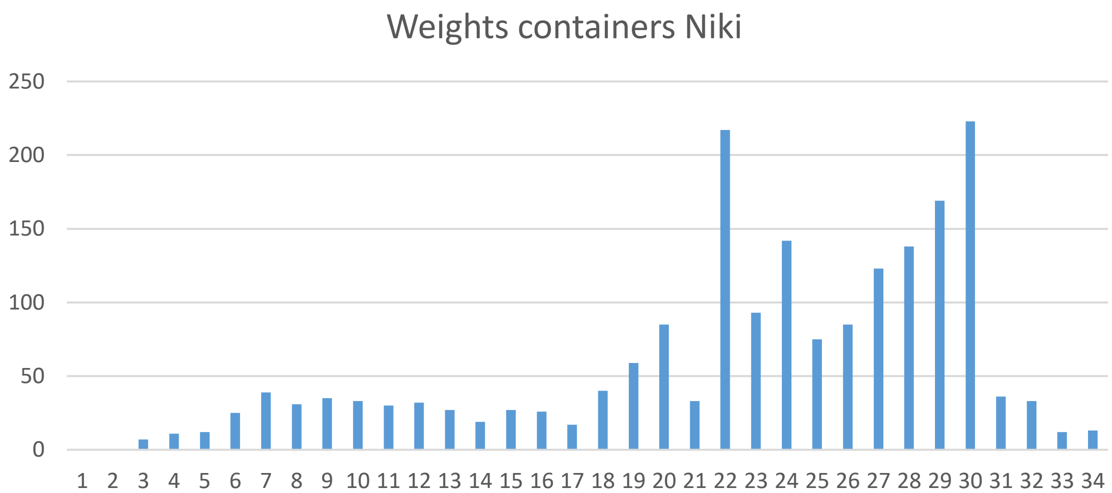


Figure 77 - Weight containers Niki

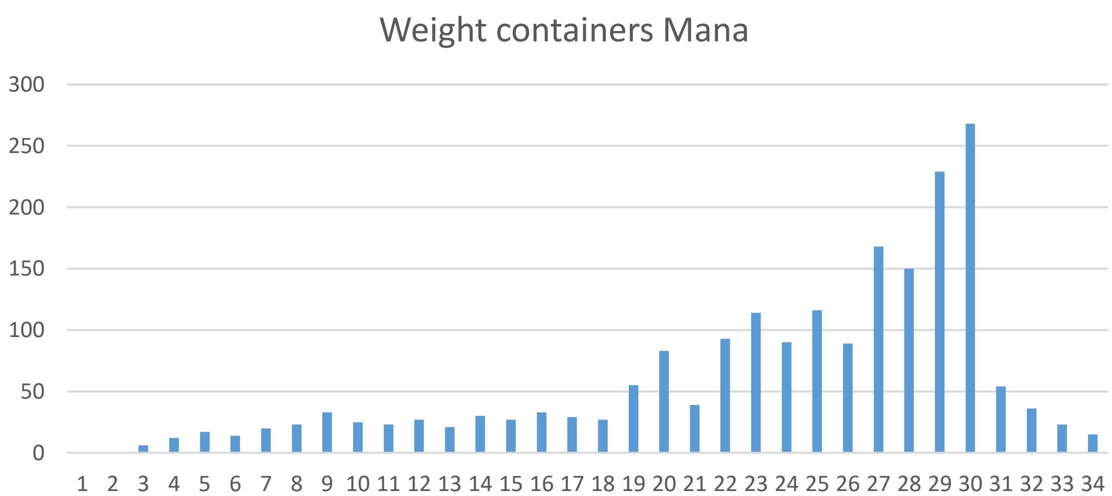


Figure 78 - Weight containers Mana

Table 27 - Categories 2 categories full containers

Categories			**Containers**		
			Doxa	Niki	Mana
Special containers			*276*	*255*	*283*
Empty Containers			*9*	*8*	*10*
Colombo	20 feet	<20 tonnes	37	30	38
		>= 20 tonnes	123	64	80
	40 feet	<20 tonnes	43	44	27
		>= 20 tonnes	147	84	91
	45 feet	<20 tonnes	-	-	-
		>= 20 tonnes	-	-	-
Kaohsiung	20 feet	<20 tonnes	121	69	64
		>= 20 tonnes	160	228	135
	40 feet	<20 tonnes	46	43	44
		>= 20 tonnes	367	337	406
	45 feet	<20 tonnes	-	-	-
		>= 20 tonnes	-	-	-
Ningbo	20 feet	<20 tonnes	3	3	-
		>= 20 tonnes	7	25	34
	40 feet	<20 tonnes	31	6	3
		>= 20 tonnes	73	44	54
	45 feet	<20 tonnes	-	-	-
		>= 20 tonnes	-	-	-
Shanghai	20 feet	<20 tonnes	75	76	58
		>= 20 tonnes	106	80	67
	40 feet	<20 tonnes	100	80	79
		>= 20 tonnes	133	120	129
	45 feet	<20 tonnes	-	-	-
		>= 20 tonnes	-	-	-
Taipei	20 feet	<20 tonnes	13	11	8
		>= 20 tonnes	35	55	32
	40 feet	<20 tonnes	15	11	14
		>= 20 tonnes	30	34	82
	45 feet	<20 tonnes	-	-	-
		>= 20 tonnes	-	-	-
Tanjung Pelepas	20 feet	<20 tonnes	24	14	10
		>= 20 tonnes	48	24	75
	40 feet	<20 tonnes	8	30	20
		>= 20 tonnes	191	156	112
	45 feet	<20 tonnes	-	1	-
		>= 20 tonnes	-	-	-
Yantian	20 feet	<20 tonnes	-	1	1
		>= 20 tonnes	-	1	15
	40 feet	<20 tonnes	-	2	1
		>= 20 tonnes	11	19	24
	45 feet	<20 tonnes	-	-	-
		>= 20 tonnes	-	-	-
Total categories full containers			*25*	*29*	*27*
Total number of categories			**310**	**292**	**320**

Table 28 - Categories scenario empty containers and three categories full containers

Categories			Containers		
			Doxa	Niki	Mana
Special containers			*276*	*255*	*283*
Empty Containers			*9*	*8*	*10*
Colombo	20 feet	<15 tonnes	26	18	14
		>=15 and <25 tonnes	83	24	46
		>= 25 tonnes	51	52	58
	40 feet	<15 tonnes	33	35	18
		>=15 and <25 tonnes	53	46	20
		>= 25 tonnes	104	47	80
	45 feet	<15 tonnes	-	-	-
		>=15 and <25 tonnes	-	-	-
		>= 25 tonnes	-	-	-
Kaohsiung	20 feet	<15 tonnes	39	35	36
		>=15 and <25 tonnes	219	217	131
		>= 25 tonnes	23	45	32
	40 feet	<15 tonnes	33	29	32
		>=15 and <25 tonnes	64	60	57
		>= 25 tonnes	316	291	361
	45 feet	<15 tonnes	-	-	-
		>=15 and <25 tonnes	-	-	-
		>= 25 tonnes	-	-	-
Ningbo	20 feet	<15 tonnes	3	3	-
		>=15 and <25 tonnes	1	2	10
		>= 25 tonnes	30	23	24
	40 feet	<15 tonnes	5	5	2
		>=15 and <25 tonnes	2	9	1
		>= 25 tonnes	73	36	54
	45 feet	<15 tonnes	-	-	-
		>=15 and <25 tonnes	-	-	-
		>= 25 tonnes	-	-	-
Shanghai	20 feet	<15 tonnes	37	45	36
		>=15 and <25 tonnes	131	91	77
		>= 25 tonnes	13	20	12
	40 feet	<15 tonnes	38	59	49
		>=15 and <25 tonnes	98	63	67
		>= 25 tonnes	97	78	92
	45 feet	<15 tonnes	-	-	-
		>=15 and <25 tonnes	-	-	-
		>= 25 tonnes	-	-	-
Taipei	20 feet	<15 tonnes	10	11	5
		>=15 and <25 tonnes	22	43	28
		>= 25 tonnes	16	12	7
	40 feet	<15 tonnes	10	7	6
		>=15 and <25 tonnes	19	20	31
		>= 25 tonnes	16	18	59
	45 feet	<15 tonnes	-	-	-
		>=15 and <25 tonnes	-	-	-
		>= 25 tonnes	-	-	-
Tanjung Pelepas	20 feet	<15 tonnes	12	11	8
		>=15 and <25 tonnes	32	14	7
		>= 25 tonnes	28	13	70
	40 feet	<15 tonnes	5	19	18
		>=15 and <25 tonnes	48	54	14

		>= 25 tonnes	146	113	100
	45 feet	<15 tonnes	-	-	-
		>=15 and <25 tonnes	-	-	-
		>= 25 tonnes	-	1	-
Yantian	20 feet	<15 tonnes	-	-	1
		>=15 and <25 tonnes	-	2	-
		>= 25 tonnes	-	-	15
	40 feet	<15 tonnes	-	2	-
		>=15 and <25 tonnes	-	1	12
		>= 25 tonnes	11	18	13
	45 feet	<15 tonnes	-	-	-
		>=15 and <25 tonnes	-	-	-
		>= 25 tonnes	-	-	-
Total categories full containers			*36*	*41*	*39*
Total number of categories			**321**	**304**	**332**

Table 29 - Categories empties and six weight categories full containers

Categories			**Containers**		
			Doxa	Niki	Mana
Special containers			*276*	*255*	*283*
Empty Containers			*9*	*8*	*10*
Colombo	20 feet	<=10 tonnes	16	11	11
		>10 and <= 15	12	9	7
		>15 and <= 20	13	13	27
		>20 and <= 25	75	17	24
		>25 and <= 30	44	43	49
		>30	-	1	-
	40 feet	<=10 tonnes	17	20	6
		>10 and <= 15	17	16	17
		>15 and <= 20	12	10	5
		>20 and <= 25	46	49	13
		>25 and <= 30	73	32	64
		>30	25	1	13
Kaohsiung	20 feet	<=10 tonnes	26	27	25
		>10 and <= 15	14	10	13
		>15 and <= 20	121	68	52
		>20 and <= 25	98	148	78
		>25 and <= 30	22	44	31
		>30	-	-	-
	40 feet	<=10 tonnes	25	25	24
		>10 and <= 15	9	8	8
		>15 and <= 20	18	15	16
		>20 and <= 25	67	60	67
		>25 and <= 30	283	259	316
		>30	11	13	19
Ningbo	20 feet	<=10 tonnes	2	3	-
		>10 and <= 15	1	-	-
		>15 and <= 20	-	1	-
		>20 and <= 25	2	1	14
		>25 and <= 30	29	23	20
		>30	-	-	-
	40 feet	<=10 tonnes	4	3	2
		>10 and <= 15	1	3	1

		>15 and <= 20	2	-	-
		>20 and <= 25	4	13	3
		>25 and <= 30	67	29	50
		>30	2	2	1
Shanghai	20 feet	<=10 tonnes	21	27	26
		>10 and <= 15	18	20	10
		>15 and <= 20	56	34	42
		>20 and <= 25	80	57	38
		>25 and <= 30	6	18	9
		>30	-	-	-
	40 feet	<=10 tonnes	25	34	25
		>10 and <= 15	18	28	37
		>15 and <= 20	60	25	18
		>20 and <= 25	47	39	52
		>25 and <= 30	74	69	75
		>30	9	5	1
Taipei	20 feet	<=10 tonnes	9	9	5
		>10 and <= 15	2	2	-
		>15 and <= 20	5	5	6
		>20 and <= 25	19	45	22
		>25 and <= 30	13	10	7
		>30	-	-	-
	40 feet	<=10 tonnes	2	3	4
		>10 and <= 15	8	4	2
		>15 and <= 20	6	5	13
		>20 and <= 25	13	19	21
		>25 and <= 30	14	14	55
		>30	-	-	1
Tanjung Pelepas	20 feet	<=10 tonnes	11	5	5
		>10 and <= 15	2	9	3
		>15 and <= 20	15	-	2
		>20 and <= 25	17	9	7
		>25 and <= 30	26	10	68
		>30	1	-	-
	40 feet	<=10 tonnes	2	9	1
		>10 and <= 15	3	2	17
		>15 and <= 20	16	10	4
		>20 and <= 25	39	41	29
		>25 and <= 30	124	102	66
		>30	15	10	15
	45 feet	>25 and <= 30	-	1	-
Yantian	20 feet	<=10 tonnes	-	-	1
		>10 and <= 15	-	-	-
		>15 and <= 20	-	1	-
		>20 and <= 25	-	1	-
		>25 and <= 30	-	-	15
		>30	-	-	-
	40 feet	<=10 tonnes	-	2	-
		>10 and <= 15	-	-	-
		>15 and <= 20	-	1	1
		>20 and <= 25	1	14	20
		>25 and <= 30	10	-	4
		>30	-	4	-
Total categories full containers			*67*	*70*	*65*

Total number of categories	**352**	**333**	**358**