The impact of a B-to-B container transferium on the sojourn time of inland container vessels

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Delft University of Technology

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Management summary

Inland container shipping The container transport business has been under stress since the global financial crisis of 2008. Because of the low profit margins, the competition between ports has become even more important. Staying ahead of the competition is crucial for a port. The large container ports in North-Western Europe compete trough hinterland connections rather than on their connectivity on the sea side; The performance of the connection between the port and its hinterland is key in the attractiveness of the port for shipping companies.

The Port of Rotterdam has set goals for the future of its hinterland connection, mainly by improving the connection by inland shipping. The Masterplan for the Maasvlakte focusses not only on facilitating the growth of inland shipping but also on the modality shift from road to inland waterway.

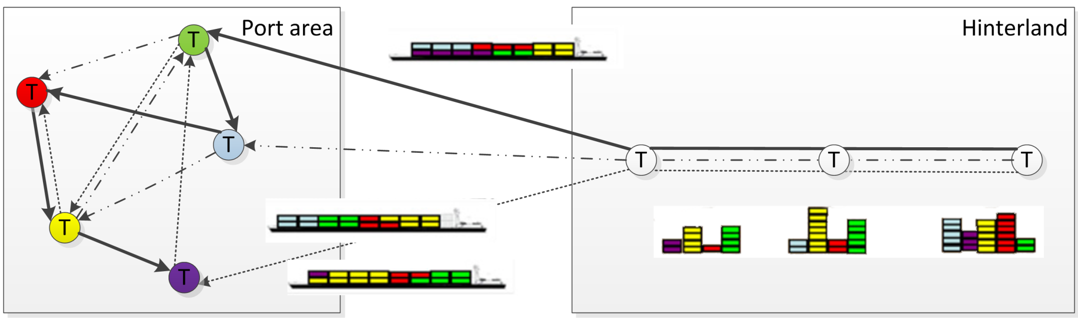

Figure 1: Inland shipping in the Port of Rotterdam

Problem situation The current situation is visualized in Figure 1. Inland vessels have a sojourn time of 24-36 hours of which half is spent waiting to be serviced. This problem is not unique to the Port of Rotterdam. The cause of the long sojourn time in Rotterdam lies in the coordination between inland shipping and terminals, specifically their willingness to work together. Both parties want to keep business information as private as possible for competition purposes.

One of the causes of long sojourn times is the lack of cargo exchange between inland vessels. 20 to 50% of the calls in the port by inland vessels are small call-sizes. Inland vessels must call on average at 6 terminals, upon which each terminal visit requires sailing time and waiting time, irrespective of the call-size. Waiting times at terminals are usually around an hour, but do sometimes increase to up to a day. This inefficient problem exists within logistical processes in ports for decades and no real solution has been implemented. Some terminals have begun with introducing a minimum call-size at their berths to counteract the small calls , the effects on the transport chain are not clear

The call-size can be increased by bundling small call-sizes of inland vessels by means of an transferium. Diverse types of transferium can be found in literature but few focus upon the use of inland vessels in the bundling process. The effects that a transferium has on the container transport chain depends on the configuration of the interaction between inland vessels and transferium.

This prompts the main research question of this report:

- ***"What are the effects of a barge-to-barge transferium on the hinterland connection performance of inland container shipping, in the Port of Rotterdam?"***

The effects of the transferium on the transport chain are investigated at three aggregation levels; Strategic, Tactical and Operational. The strategic level is concerned with overall performance, the tactical level with the specific terminals and the operational level with the interaction between transferium and inland vessel.

To get a different view on inland shipping in Rotterdam, other than from literature, a round-trip was made by the author on a "groot Rijnschip" with a capacity of 210 TEU. 30 hours sailing and talking with the crew proved valuable in understanding the challenges that the port is facing in the coming years, especially from an operational perspective.

A conceptual simulation model of the situation in the Port of Rotterdam was made, where inland vessels are the main component to transfer containers between hinterland and destination terminals in the port. This conceptual model has been implemented in a simulation model in Anylogic: an agent and java based software program to model discrete events. The assessment is done by means of a simulation model where the input and output variables of the interaction between a transferium and inland vessels are varied.

Transferium scenario The hypothetical transferium is located on the edge of the Rotterdam port area, near the Waalhaven. The transferium has no physical parameters other than transshipment speed. The interaction between transferium and inland vessels is visually presented in Figure 2.

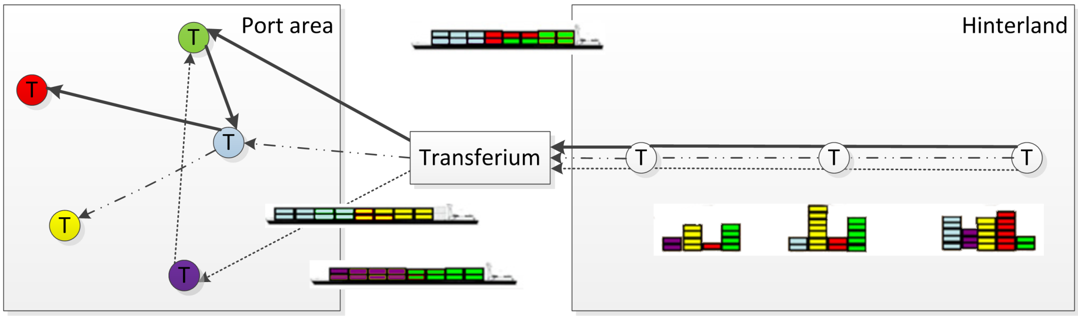

Figure 2: Transferium interaction variables

Three variables are distinguished within the simulation study:

- An input variable; the minimum call-size by which the transferium should not be used
- An output variable; the minimum number of terminal calls. Small call-size can only be dropped off at the transferium when the number of terminal calls does not go below the minimum number of terminal calls.
- Transferium stack size; which elaborates on the physical layout of the transferium.

Strategic aggregation level conclusions For cases where only small call-sizes are bundled, the transferium increases the performance of the inland shipping in the PoR. The container travel times and sojourn time of inland vessels are reduced. At a higher call-size minimum, the transferium gets congested and the transport chain efficiency reduces by increasing the container travel time.

Tactical aggregation level conclusions The effects on a tactical aggregation level differentiate between terminals, inland vessels and containers. Waiting times of inland vessels at medium terminals are reduced when the minimum call-size increases. Containers benefit at medium and large terminals and inland vessels at medium terminals. The individual terminals experience no negative changes, except when the transferium is congested in which case the throughput decreases.

Operational aggregation level conclusions The explored minimum terminal call as an output for the transferium scenario negates the negative effects that occur at higher minimum call-sizes, but does not improve the transport chain. A limited stack size mimics a smaller transferium and shows potential, but more selective input of containers should be considered. In general, more research is needed to identify other ways to use the variables surrounding to improve the interaction with the transferium.

General conclusion The introduction of a transferium into the transport chain in Rotterdam is an improvement to the hinterland performance of inland container shipping. The sojourn time of inland vessels is reduced in all variations, the container travel time is improved at terminals with long waiting times and the waiting times at terminals without large sea going vessels are improved.

The configuration of the interaction between inland vessel and transferium is key to the implementation success. However, the tested variables in this research are only a select base from a wide array of candidate variables, and a more sophisticated interaction with transferium is required to examine the benefits for each individual actor. Overall the effects are positive but require a more detailed model to fully understand the implications that come with a transferium for inland vessels.

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Chapter 1

Introduction: Container transport by inland shipping in the Port of Rotterdam

This thesis focuses on the inland container shipping in the Port of Rotterdam (PoR). First, an introduction on the European sea ports is given regarding competitiveness between sea ports, followed by a description of the hinterland connection in the PoR and the inland shipping in the PoR. Then the problem statement is elaborated, after which the research scope and research questions are given. This chapter concludes with the outline of this research.

1-1 Global container transport

Transport of containers is widely used across the world today. Containers brought a level of standardisation into the transport market, facilitating more efficient and faster transport. Figure 1-1 shows the transportation chain on a global scale. Shipping companies provide the backbone of container transport with their sea going vessels that visit ports all over the world. Nowadays, the largest container vessels available are Ultra Large Container Vessels (ULVC) that can transport up to 19.224 Twenty-foot Equivalent Unit's (TEU). Sea ports are typically connected by a variety of modalities (road, rail, inland waterway) to transport the containers to the hinterland directly or via inland terminals to warehouses, businesses and end users. The next sections will zoom in on the European ports and the hinterland connection from Rotterdam.

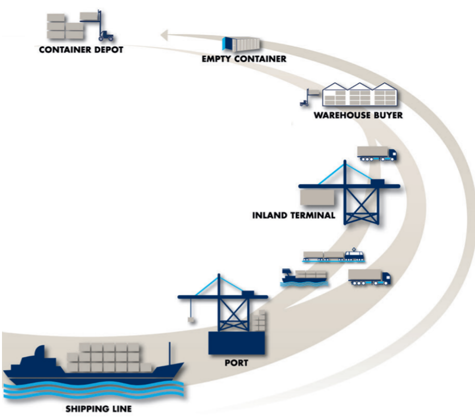

Figure 1-1: Adapted from [56]

1-1-1 Competitive European container market

Europe has a container market that produces and attracts 13% of the world wide TEU transport [52]. All container ports are connected by various shipping lines that operate their vessels via multiple routes. Figure 1-2 shows a graphical representation of routes in the North-West of Europe. That part of Europe is home to the largest container ports; Rotterdam, Antwerp and Hamburg. Combined the three ports had a throughput of 31 million TEU in 2014 [40].

Figure 1-2: North-West European container sea routes, www.shipmap.org

Container ports serve a hinterland area that can stretch out over multiple countries, for example the PoR hinterland reaches al the way too Switzerland and Austria. The hinterland areas of the three mentioned ports are situated relatively near each other and their hinterlands consequently overlap to a great extent (see figure 1-3). Both Antwerp and the port of Rotterdam have a substantial share of the market in France, furthermore Rotterdam has a dominant market share in the Netherlands and eastern Germany (Rhine area). Antwerp and Hamburg are not so much competing for each others hinterland market but rather with Rotterdam's.

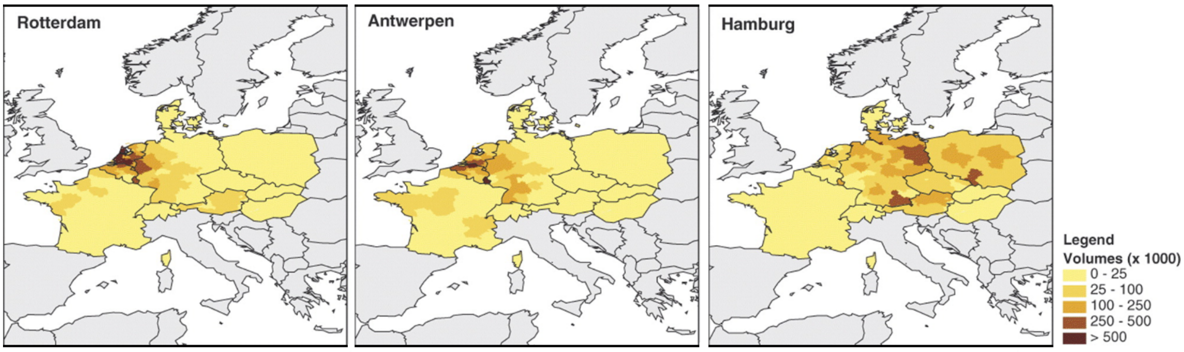

Figure 1-3: Hinterland area of Rotterdam, Antwerp and Hamburg. Adapted from [66]

Antwerp continues to catch up with the container volume of Rotterdam [61]. The recent figures show an increase in container throughput in Antwerp while Rotterdam shows a decrease [26] resulting in a capacity of respectively 10 and 12 million TEU [40]. The competition between these ports is partially influenced by aspects on the sea-side but mainly by aspects on the land-side. The seaside of a port has a limited sensitivity to competition [27] and is similar for the three ports. Which makes the hinterland connection key in the success within the competition between ports. Three main land-side factors on which a shipping company decides which port to use are:

- The size of the hinterland market [62]
- The availability of hinterland connections [62]
- The ability to serve markets in the hinterland efficiently (as cited from Welters 2003 in[9])

1-1-2 The Port of Rotterdam hinterland connection

The PoR is the largest container port in Europe, with over 7 million containers (equivalent to 12 million TEU) being transshipped every year [40]. Three modalities are used for transportation to the hinterlands: road, rail and inland waterway. These modalities are competitive and they vary in speed, reliability, costs and hinterland coverage. Road transport is the dominant transport modality in The Netherlands. Second is inland shipping which transports containers as far as Switzerland. Transportation by rail is the smallest modality [39]. The Netherlands has a vast infrastructure network to facilitate these modalities, which is ranked by the world forum for its competitiveness on the 6th place [63]. This is mainly influenced by the 1th place on port infrastructure, the Netherlands is one of the few countries that can use its inland waterways so extensively.

Table 1-1: Modal split overview, including masterplan goals PoR [39]

Modality	2009	2013	2014	2020 (goal)	2033 (goal)
Inland shipping	39%	34.8%	35.7%	41%	45%
Rail	14%	10.7%	10.9%	17%	20%
Truck	48%	54.6%	53.4%	42%	35%

Each of these modalities have different potentials for the coming years. Road transport causes congestion on highways and rail has a limited hinterland coverage as well as a limited capacity. Inland waterways have a moderate hinterland coverage and are less susceptible to congestion compared to transportation by trucks. Inland waterways have the capacity to support more traffic but were unable to increase their market share in the previous years, table 1-1 includes the recent figures on modality split. Noticeable is the decrease in market share of inland shipping after 2009. One of the reasons road transport has a larger percentage is that trucks are faster than inland vessels. Changing modality preference towards transportation by inland vessel requires an improvement of the characteristics, for example increasing the speed of inland vessels would bring the modalities closer together.

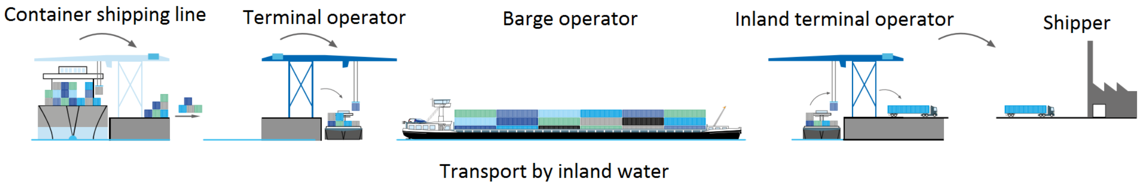

Figure 1-4: Hinterland transport chain of container inland shipping. Adapted from [10]

1-1-3 Inland shipping in the Port of Rotterdam

When container flows are increased, the infrastructure around Rotterdam will be subjected to a higher load and thereby increase the chances on congestion on all modalities. The port authority of Rotterdam acknowledges the current limitations and congestion, but also the prospect of more problems with an increasing container flow. The vision of the PoR is to engage the transport by inland waterways by increasing its market share and thereby accommodate a growth in transport flow. Contrary to road transport, inland waterways have the capacity to accommodate more traffic and affects the environment less. The modality goals are presented in table 1-1, the share of inland waterway transport needs to increase to 41% in 2020 and even further to 45% in 2035. One of the measures taken by the PoR is to contract new terminals to a minimum of 45% transportation by inland vessels [42].

1-2 Problem statement

The previous sections show that the PoR wants to remain competitive with other north-west European sea ports. Secondly, while keeping the port competitive it also wants to increase the share of inland waterway transport. There are still several problems that need to be faced. Increasing the use of inland shipping is a step to encourage improvement of inland container shipping although it does not guaranty an increase in the hinterland connection performance. Therefore improvements on inland shipping have to be made in order for the PoR to be able to accomplish it goals.

In order to have an efficient and well performing hinterland connection the coordination between the actors has to be efficient [27]. The most important coordination problems are defined as [57]:

- "Long sojourn time, many calls and small call sizes"
- "Insufficient terminal and quay planning with respect to the schedules of deep-sea and inland vessels"
- "Limited exchange of cargo"

These aspects will be described in more detail below.

Sojourn time Nowadays the sojourn time (the time an inland vessels is in the port) of inland container vessels is relatively long due to the many terminal calls and the small number of containers per call, this is referred to as the main problem. The container terminals in the PoR are spread out over a large area, causing at least 2-3 hours sailing time between the terminals furthest from each other. Moreover by visiting multiple terminals with small container call size the handling time is relatively long per terminal. In addition to the long handling times many inland vessels call at the same terminal, resulting in long waiting times [23]. An increase of inland vessels will probably only aggravate the current situation. Vessels already spent on average between 21 and 36 hours [19] in the port area and waiting times up to a day are not uncommon at terminals [20].

Round-trip planning Both terminals and barge operators want to remain autonomous, which leads to a difficult process when coordinating the round trip. The planning coordination between terminals and inland vessels is based on information sharing, both parties do not want to give or cannot give full disclosure on their part which results in a planning with large safety margins. This is caused by the fierce competition in the transport market and sharing too much information could give competition an advantage. Also both parties do not know exactly when the vessel arrives or how long the transshipment will take, this makes appointment planning more difficult. Furthermore there are no contractual relationships between barge and terminal operators which means that there is no contractual force to demand a certain level of service. However ULCV's, other sea going vessels and short sea vessels do have a contract with terminals operators and have a priority over inland vessels increasing the waiting times and sometimes causes the inland vessel to vacate the berth before transshipment is done.

Cargo exchange A tight planning could reduce the sojourn times of inland vessels significantly but coordination problems make it more difficult. Limited exchange of cargo reflects on the small container call sizes, interchanging containers between two vessels could reduce the sojourn time for both vessels since less terminals need to be visited. However, the inland shippers want to remain autonomous and the market is very competitive, this makes interchange of containers between actors difficult.

The inland container shipping in Rotterdam is in need of improvement. The current problems have to be addressed in order for the port authority to reach its goal of the hinterland master plan [42], remain competitive with other sea ports. However this problem does also exists in other ports like Antwerp and with other kind of cargo vessels. This thesis will discuss the handling problem of inland container vessels in the Port of Rotterdam.

1-3 Research scope

Coordinating the freight going through the PoR is shown to be challenging for inland vessels, especially with the anticipated increase of transport. The coordination problems with inland shipping cause the containers to be rather transported by other modalities, and thus inland shipping is not reaching it potential. This thesis aims to be an exploration research into the effects of a transferium on the container transport chain by inland vessels. Literature provides various solutions and improvements for coordination problems concerning ports. The most relevant topics discussed in literature concern: infrastructure, hardware and software [30]:

- Hardware: Improving equipment on inland vessels and tracking equipment on the supply chain.
- Software: Optimisation of routes, terminal visits. Inland vessel handling.
- Infrastructure: The improvement and building of (new) terminals and waterways.

1-3-1 Hardware: equipment

Hardware based solutions are focussed on equipment that allows users to interact better with other actors in the transport chain. For example, better navigational assistance, collision avoidance and real time data on the infrastructure could make it easier on-board of inland vessels. The problems stated in the previous section are most likely not affected by the hardware based solutions, since they do not resolve the planning or round-trip problems. Therefore, the hardware based solutions will be not taken into account in this research. An overview on hardware topics can be found in [30].

1-3-2 Software: route optimisation

As mentioned before in chapter 1-2, the way inland vessels now determine their route and make appointments is not efficient. The communication between terminals and inland vessel operators lacks a to-the-point approach. It is inefficient, incomplete and results in a round trip planning that is far from optimal due to the limited information sharing, lack of cooperation and conflicting interest. A central tool would be useful to optimise the route planning for all inland vessels. Currently a centralised tool for inland vessels is not available. And there are problems with a central system; a neutral party has to be owner of the system in order to have an objective and fair outcome to all actors. Furthermore, the competition between terminals and barge operators means that sharing information and giving up autonomy is not acceptable as it comes with the fear of losing their advantage over other actors.

Centralised approach In 2003 Schut et al. made an effort to the use of a decentralised rotation planning for inland vessels, based on a multi agent system with port terminals and inland vessels as agents [50]. It was used with an off line planning tool that connects agents to negotiate a rotation plan. A few years later in 2007 the port of Antwerp introduced the Barge Traffic System (BTS) that created a platform where barges and terminals could meet on-line and consult information on locks and request appointments at terminals [38]. Although the platform only functions as a place where information is centralised and the way appointments are made is still similar, it is an improvement in sharing information. The previous mentioned NextLogic has a similar project, called Brein, that is currently under construction in the Port of Rotterdam [34]. Brein is a neutral planning tool which can be used by actors that come in contact with the PoR in the transport chain of containers. The tool will make a comprehensive planning for inland vessels and keep track of the latest changes.

Decentralised approach In 2009 Douma developed an intelligent multi agent based planning system that could deal with real-time issues, such as dynamic nature and building on previous research [50]. He started with a protocol based on waiting time profiles [11]. In 2011 this model was further developed by the author with an extension of the model with service time profiles for vessels [13]. In the extended model he combined the waiting times and handling times in a service profile that enhanced the system accuracy. The model aims to reduce the time lost due to both parties taking into account extra time to be safe. The inland vessels promise to arrive within a certain time slot and in return the terminal guarantees that the beginning of the transshipment will commence within a set time. This research is addressing the problem of communication between terminal and vessel. Douma concludes that his multi agent based system reduces the waiting times of barges by 50 % to 10 hours in the best case. This includes the introduction of a transferium near Duisburg reducing the number of terminal calls from 7 to 2 per round-trip.

In 2015 a study on the vessel rotation planning problem suggests a bottom up approach. Using mixed-integer programming with distributed constraints optimisation [31]. This study uses the optimisation of vessels to find the optimal arrival/departure time and the optimal number of containers that have to be transported between terminals in order to minimize the round-trip time of vessels.

Within the software based literature solutions can be found to improve the sojourn time of inland vessels. However, one of the problems not dealt with, is the number of terminals that need to be visited in the round-trip. Douma shows in one of his extensions to his multi agent model that reducing the number of terminals visited could lead to a reduction of waiting times.

1-3-3 Infrastructure: B-to-B transferium

Infrastructure developments can be implemented in a wide variety of possibilities [30]. For example, improving the waterway infrastructure quality allows larger vessels or improves the availability of the waterways when during droughts . Other solutions could be introducing better and/or different terminals to the transport chain. The introduction of new terminals can be done in various places in the transport chain, anywhere between the sea port and hinterland is possible. This changes the characteristics of the whole transport chain. For example, a new terminal can be used to convert the incoming mixed container flows into uniform batches that continue further to their destination. Effectively changing from a point-to-point to a hub-and-spoke network irrespectively to the position of the terminal along the chain. However the implementation and impact will be different depending on the position in the transport chain [44].

Transferium A transferium is a terminal that is being used to combine container flows between hinterland and the port. Transferium do not have to be located away from the port area, Stegink (2002) [54] investigated the possibility of a transferium on the Maasvlakte and whether this could be beneficial to the transport chain. He specificity examined the possibility of using a new terminal for all inland vessels, from where the containers are transported to the destination terminals by an internal Maasvlakte transit system. By circumventing the deep sea terminals the waiting time for inland vessels was reduced. Inland vessels are no longer depending on the arrival of ULCV and thereby waiting times of inland vessels become more predictable. Zuidgeest (2009) [67] investigates if a new terminal at the second Maasvlakte could be beneficial to the terminals located there. In his research the containers are transported by the Multi Trailer System (MTS) to their destination. He concluded that using a dedicated berth for inland vessels is more effective for the waiting times than using berths for both inland vessels and sea going vessels.

Moving terminal Next to somewhat traditional ideas on terminals there are also other ideas to implement a intermediate terminal (transferium) into the transport chain. In 1994 Ottjes [35] researched the possibility of a sailing transferium (a self propelled platform). The transferium would sail between terminals on the Maasvlakte bringing containers from inland vessels to the sea terminals. By collecting the smaller call sizes the inland vessels have less terminals to visit, reducing the sojourn time as well as increasing the productivity at the berths. This concept is currently being used in Hong Kong where they use floating cranes to unload containers on inland vessels anchored next to the sea going vessels. Other possibilities could be delivering containers to customers in the port area that do not have a crane available, Mercurius vessels are currently providing this service [15].

There is much to gain by optimising the sojourn time by software solutions but the main problems identified in section 1-2 are currently not addressed at the PoR. Some hardware solutions are focus on both terminal calls and the call-size. For example adding a transferium can influence both, but there are different ways to implement it. Research on implementing a transferium system has only been done on a small scale, not taking into account the whole PoR and also without the second Maasvlakte finished. A study on the operational performance of an intermediate (transferium) is needed to asses the potential of the current state in the PoR.

1-4 Research questions

Section 1-1-2 showed that inland shipping poses is a threat for the future competitiveness of the PoR. Recent statistics show that the Port of Antwerp had a larger growth in container volume last year than Rotterdam [25]. It becomes clear from section 1-2 that the hinterland connection of Rotterdam is in need of improvement and that the connection by inland vessel is crucial to reach the goals set by the PoR. The economy is growing again and the container trade flows will probably follow. Improvement of inland container transport is necessary to facilitate the anticipated growth and to attract more containers to the PoR.

The main research question of this thesis is as follows:

"What are the effects of a barge-to-barge transferium on the hinterland connection performance of inland container shipping, in the Port of Rotterdam?"

In order to answer the main research question the following sub question have to be answered.

- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a strategic aggregation level?*
- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a tactical aggregation level?*
- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on an operational aggregation level?*

1-5 Approach & Outline

Figure 1-5 shows the outline of this report. This first chapter introduced the PoR and the hinterland connection performance and the problem statement. Chapter 2 will follow up by going into depth on solutions found in literature. The solutions are divided in three aggregation levels defined by Christiansen, et al. (2007) [6]. Each aggregation level adds a piece of the transferium design variables and the effects they have on the transport chain. Together they formulate the design variables for transferium at the end of Chapter 2. With the information gained from the literature review and the authors experience travelling on an inland container vessel a conceptual model is created in Chapter 3. The conceptual model makes a generic model that can be applied in any modelling language. The conceptual model is made to translate the problem through model requirements to a definition on what and how to model [46]. Four steps are followed as described by Robinson (2008) to create the conceptual model [46]: (1) The requirements and objective is determined. (2) The output is set to the performance indicators that are required to measure the hinterland connection performance obtained in the literature review. (3) The inputs that are needed to run the model and create the necessary outputs are defined. (4) The content of the model is described, scope and level of detail as well as the assumptions and simplifications. With the conceptual model a simulation model is made in Chapter 4. The model is not only described but also tested, validated and verified. Next the simulation results are explained and discussed in Chapter 5. The definition of the performed simulations is given, followed by a description of the transferium design variables as identified in Chapter 2. The closing Chapter contains conclusions on the work done and recommendations for future research.

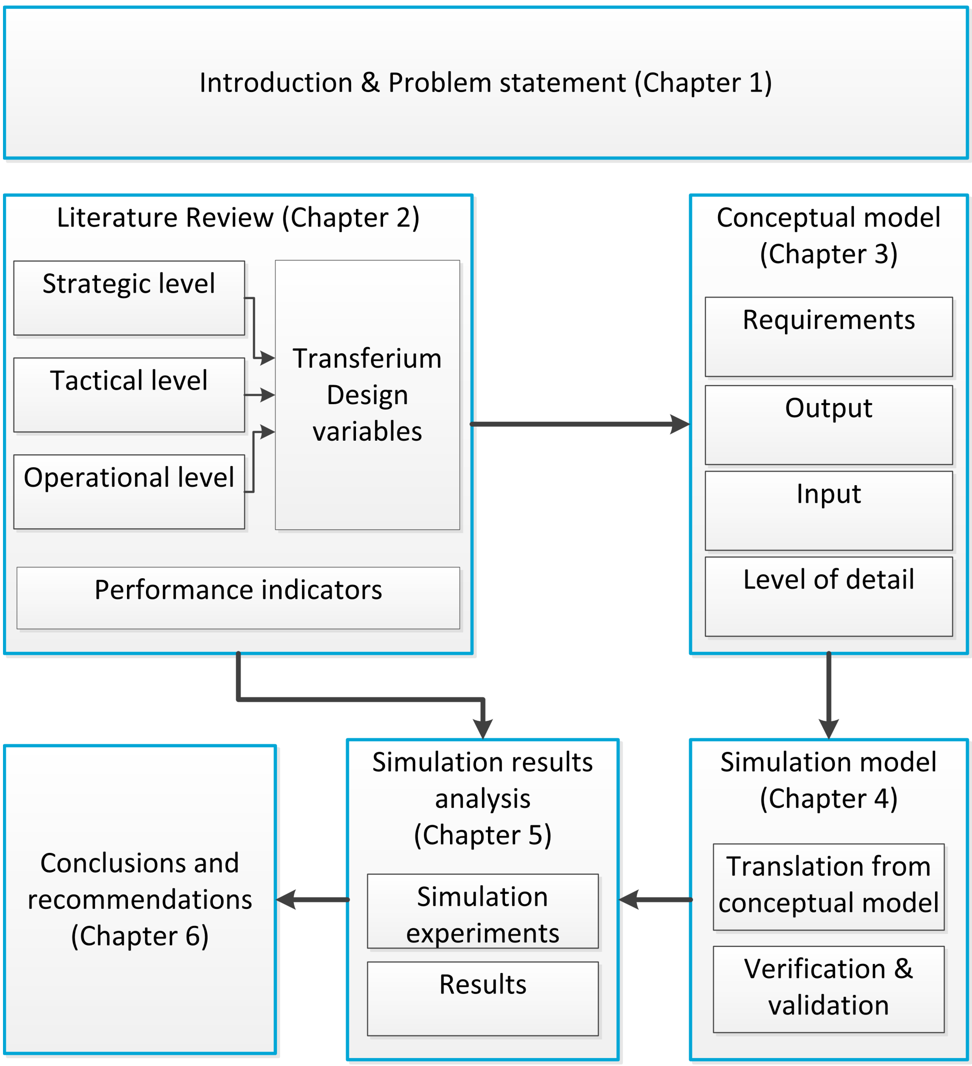

Figure 1-5: Report Methodology and Outline

Chapter 2

Literature review: Inland shipping on strategic, tactical and operational level

In this chapter, the latest findings from literature regarding to the sojourn time problem of inland vessels is discussed. Literature regarding transport on inland waterways can be divided into three aggregation levels: strategic, tactical and operational [6]. Each aggregation level will be discussed in relation to a corresponding sub-research question.

- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a strategic aggregation level?*
- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a tactical aggregation level?*
- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on an operational aggregation level?*

Using the structure of aggregation levels gives a top down approach which is a common approach in network design. The aggregation levels are time dependent and differentiated as discussed by Li, et al. (2015) [31]. Strategic solutions have a relatively long time frame of 5 to 10 years, topics include network design and supply chain. Tactical solutions concern routing and scheduling of vessels with a time frame of months. The lowest level considers operational solutions including decisions that can be changed from days to minutes. The performance indicators distinguish the same aggregation levels according to Flapper (1996) and van Groningen 2006 [16] [58].

2-1 Strategic aggregation level: IWW network design

Strategic level is the highest aggregation level of the IWW network. On the strategic level the main characteristics of the network are determined, the choices that are made are costly and have a lifespan of years. Every network is designed for a specific market and spatial distribution, keeping in mind the practical and economic viability. In this section the current network type of Rotterdam is compared (theoretically) with different network types. And finally, the function of a transferium and the change in network characteristics is discussed when introducing a transferium.

2-1-1 Network design types

Literature on the design of inland container shipping network is scarce, however the general characteristic can be compared to the design of a rail network [24]. Figure 2-1 shows five network designs. The networks are divided in two sub classes, with and without bundling.

Network types without bundling Point-to-point network is the most basic type of network. This type is best served by full loads and only one destination to maximise the use of capacity. For example, the connection between Antwerp and Rotterdam can be qualified as a direct link network. Large inland vessels travel between the ports calling only at a few terminals at a time.

Direct link networks work best on full loads and pure one-to-one connections, but they are not often found in inland shipping. However, line networks are similar and more common. A line network is one route with multiple stops from start to finish. A good example is the Rhine trade network. E.g. Alcotrans sails on the Rhine between Koln and Rotterdam, stopping at cities like Duisburg and Düsseldorf [1]. Inland vessels sail from the lower Rhine to Rotterdam and visit several terminals along the way. The main difference between trunk-feeder and line network is the number of transshipments that take place.

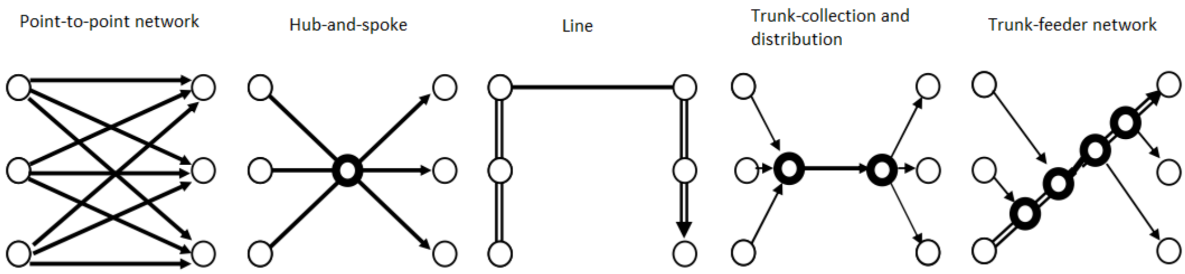

Figure 2-1: Rail network types, adapted from [24]

Network types with bundling Hub-and-spoke, Trunk-collection and distribution networks make use of bundling transport flows. The bundling takes place at a transferium that connects to all destinations. At the transferium the container flows are sorted to their destination.

The benefit of bundling in a network is to increase the utilisation of the network by reaching economies of scale and increasing the frequency of transport services. The downside of bundling is the transition from the trunk-collection to the distribution network, the transshipment needed in the transition is costly. However, routes can be longer but the time a container is waiting for further transportation increases with every bundling point. Bundling cannot be done by definition. According to Woxenius (2007) [65] there are five important factors influencing the effectiveness of bundling: transport distance, transport time demand, shipment size, characteristics of the product, the availability of goods along the route. In the Netherlands, there are various different transport chains that have different values for the factors Woxenius determined.

Inland shipping network in The Netherlands Inland shipping in the Netherlands uses multiple types of networks. The main network consists of two types, first the collection in the hinterland and second the distribution in the port area. Figure 2-2 gives an overview on the situation in the Netherlands. Hinterland is characterised as a line network where vessels sail past multiple inland terminals [22]. The distribution in the PoR is different from the types in figure 2-1. Each vessel visits multiple terminals and as discussed in the problem statement section (1-2) this type of distribution could be improved.

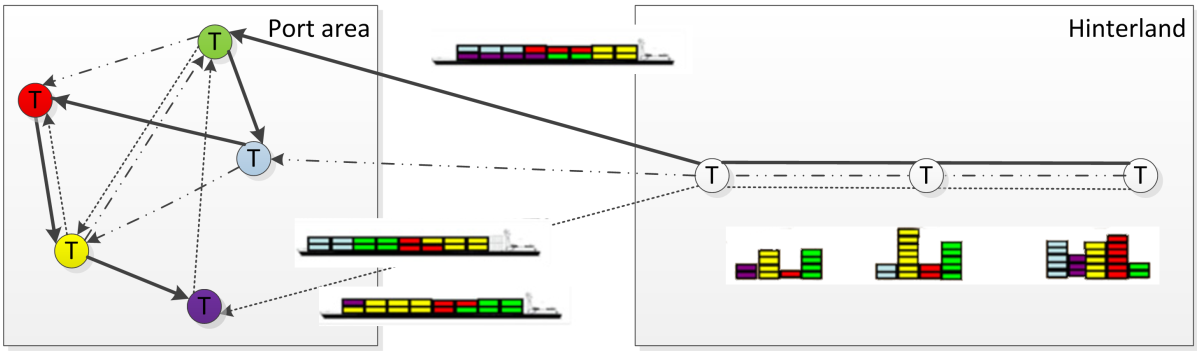

Figure 2-2: Schematic presentation of the inland shipping in the PoR, Adapted from [22]

2-1-2 Network design in the Netherlands

Network level changes are needed to tackle the problems with inland shipping in the PoR. Konings (2007) introduces a transferium to split the logistical chain of inland container shipping into a line network in the hinterland and a Trunk collection/distribution network in the seaport [20]. He concludes that splitting the transport chain will increase the competitiveness of the container transport by inland vessels. However, the performance of the network is dependent on the handling costs at the transferium and significant transport volumes are needed to ensure the feasibility of the network change.

Transferium location near hinterland The main function of the transferium is to bundle container flows but it needs centrality and intermediary attributes to be functional in the transport chain [21]. Located away from the port, a transferium would allow larger vessels to sail between port and hinterland, making use of economies of scale and reducing the transport costs [36]. Also, the investment of the terminal would be lower since the ground will be cheaper than in the Rotterdam area. Wormmeester, et al. (1996) investigates the improvement of inland shipping with the use of a 'revolutionary' automated transshipment system (transferium) for the container traffic on the Rhine [64]. The transferium is placed 100 km upstream from Rotterdam, where unsorted call sizes on push-barges can be bundled. Creating a network with hub-and-spoke characteristics for the container flows on the Rhine to Germany.

A 10 to 15% decrease in costs can be obtained with this concept [64]. However, this concept requires a complete fleet change from inland vessels to barges, which makes the transport chain more expensive. An important note is that in this research the concept only makes the transferium feasible if the container flow volume is large enough. Rooy (2010) notes that a hub-spoke does not necessarily results in costs benefits [59]. The hub and spoke transferium would be more beneficial if the terminal was located further away from the port. Although the service area of the terminal to the hinterland is greatly reduced. Also, van Rooy (2010) states that a general conclusion cannot be made because of the different factors involved and more research is needed [59]. The model he used is an excel model that calculates the logistical chain costs. He concluded that re-designing the chain to a hub-and-spoke centre will be a challenging task. Using a transferium can reduce overall costs for inland shipping and more transport can be steered away from truck transport to inland shipping.

Transferium location near port entrance Placing the transferium nearby the port entrance would increase number the container that can potentially make use of the transferium. It could function as a buffer of storage area for (empty) containers in peak periods [3]. In 2008, research was done to understand the potential of a transferium near the land side entrance of the PoR [17]. This transferium would function as a bundling point where trucks could drop their containers and inland vessels sail to the terminals, hereby releasing some of the congestion on the A15 highway. This transferium would shuttle high call sizes to the port terminals. The terminals would also benefit from this construction by having more inland vessels with a higher call size at their berths, although this has not been investigated by Froeling, et al. (2008) [17]. The transferium changes the network into a hub-and-spoke network for the last mile. The implementation of the intermediate terminal has far from reached its goal of 200.000 TEU [48]. The reason why the transferium is not working as intended is not explained. However, Froeling (2008) already suggested that more research is needed to see the effects of a transferium on sea terminals and that the reliability of the transport and integration in the transport chain are important to the success of the transferium [17].

Transferium location in the port area Locating the transferium inside the port area changes the possible usages. The transportation between transferium and port terminals can be done by an inter terminal transport system by land or by inland vessels. Stegink (2002) researches in his master thesis if a barge terminal on the Maasvlakte can be beneficial to the total logistical chain of container transport [54]. Terminals on the Maasvlakte are considered (disregarding city terminals). Overall waiting times are reduced at the terminals surrounding the transferium. However, 96% productivity on the berths is assumed which is very high and seems not realistic. Also 60 moves per hour are assumed due to a fast transshipment system. Furthermore, the costs are increased due to the extra transport and transshipment. Zuidgeest (2009) investigates a transferium at the second Maasvlakte [67]. The transferium would be located on the Maasvlakte and only inland container vessels are allowed. The dedicated barge-quay is beneficial to the waiting times, although the expectation is that there are no waiting times at the second Maasvlakte in the future. After his conclusion, the research followed up by a description of the effect of transshipping only small calls away from the deep-sea terminals. Every TEU that is handled on the transferium leads to a capacity increase of 5 TEU at the sea terminal, if all calls smaller than 25 TEU are handled at the transferium. A limitation to the research is that only one sea terminal is modelled, which limits the conclusions about the whole port area.

Caris, et al. (2009) researched the possibility of a transferium in the port of Antwerp [4]. The transferium would service inland vessels with small call-sizes in order to bundle flows, the definition of small call-sizes is not given. The port of Antwerp has a different geographical layout than the PoR, thus a general relation between the research and the PoR cannot be made. However, in some of the examined possibilities the turnaround time of inland vessels is reduced. The performance indicator used in by Caris, et al. are the turnaround time and waiting times of inland vessels. The time containers take to reach their destination in the port is not taken into account.

2-1-3 Performance on strategic level: Port of Rotterdam

The performance of the network is important in the design of a network. And on a strategic level the port performance is also important to the competitiveness of the port in relation to other sea ports. The performance indicators are based on the findings of van Groningen (2006) [58].

Table 2-1: Performance indicators on a strategic level. adapted from [58]

	Strategic aggregation level
Inland vessels	Sojourn time [minutes] Average call size [TEU]
Containers	Average container dwell time[minutes]

The sojourn time is defined as the time between entering and leaving the port area. It includes sailing time, waiting time and transshipment time. The dwell time of a container is defined as the time it takes from entering the port area on an inland vessel till it reaches the berths of its destination terminal. This indicator can be used to have an understanding on the individual container and is a measurement of congestion in the port. Long dwell times in relation to the time in port of inland vessels indicate congestion. In an individual case a container might be delayed but on average the time spend in port should be the same or better. The deviation on the time container spend in port indicates how large the number of container are that exceed the average. A large deviation on the average container time spend can be an indication of an inconsistent performance over time, resulting in a reduction of the competitiveness of the modality.

2-1-4 Conclusion strategic level

From this section conclusions can be drawn on a strategic level. First, a change in network type in the Netherlands is needed to improve the inland container shipping. Based on the introduction of a transferium could increase the effectiveness of the transport network. Reduce congestion for congested port terminals and faster sojourn times for inland vessels. When a transferium is introduced the network type changes into a trunk-distribution and choices have to be made. The location of the transferium has the most potential near the land entrance of the PoR, the available container flows are the largest here.

2-2 Tactical aggregation level: network operations

Tactical decisions are made on a medium-term horizon, on this level the allocation of existing resources is made as well as the design of the service network. In Crainic, et al. (1997) the importance of the tactical level in a transport network is emphasised, it is key in the design of a complex network [7]. On the tactical level decisions, must be made on the service provided between transferium and port terminals as well as the functionality of the transferium. This includes the routes of the inland vessels, round-trip or direct-connection with terminals, which terminals are visited in the PoR and in what sequence. Additionally the layout of the terminals, what equipment is needed how many cranes and the length of the quays.

2-2-1 Round-trip of inland vessels

The vessel rotation planning is part of the tactical level decisions in the transport network [31]. Finding the optimal berthing solution for all inland vessels is a process that has been researched on different occasions. Douma et al. researched the possibility of using a multi agent based method to optimise the arrival of inland vessels [13]. Their research has been done before the second Maasvlakte was concluded, in a time where terminals had a capacity shortage at the berths (up to 48 hours of waiting time for inland vessels). Focussing on the routing and scheduling problem of inland vessels in relation to the terminals, trying to integrate the planning of the inland vessels with that of the terminals. By facilitating a better connection between the schedules of the inland vessels and the terminals he closes the gap between them. The multi agent model is a distributed planning system. It is a system in which every agent represents an actor, every vessel separate. The agent makes decisions for the actor base upon its preferences, without consulting the actor for decisions. The benefit of such system is that information can be shared more efficient and without consulting the actor. The results are promising in reducing the sojourn time of inland vessels, most benefits can be gained if actors fully share their information which is difficult to accomplish even 10 years later.

Interaction with transferium The previous section determined that the location the transferium changes the influence it has on the transport chain. On the tactical level, different choices must be made that influence the interaction between vessels and transferium directly. Figure 2-3 shows that the transferium divides the transport chain in two sections, from hinterland to transferium and from transferium to the port area. The connection from hinterland to the transferium is done by the inland vessels, the link between transferium and port terminals can be organised in different ways. Pielage et al (2007), defines three logistical concepts that describe the link between transferium and port terminals [36]. Konings et al. (2013) generalises the logistical concepts and they are presented next [22]. The logistical concepts are added to the situation in Rotterdam, Figure 2-2 shows the situation in Rotterdam.

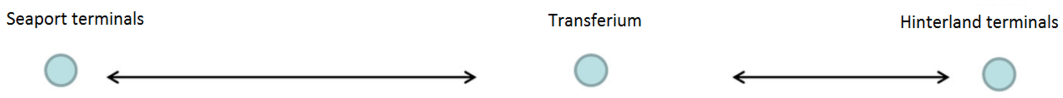

Figure 2-3: Introduction of a transferium in the transport chain, adapted from [22]

The logistical concept "Ongoing" uses inland vessels that sail from transferium to port area. Inland vessels drop small container calls at the transferium and pick up other small calls that have the same terminal destination as their large container calls that are still on-board of the vessel. The number of terminal calls is reduced but still multiple calls have to be made. The advantages of this concepts are the use of inland vessels between transferium and port area, there is no need for investment in a shuttle service. The downside is if small inland vessels are used the consolation reached will be small, this concept is thus best used with large inland vessels.

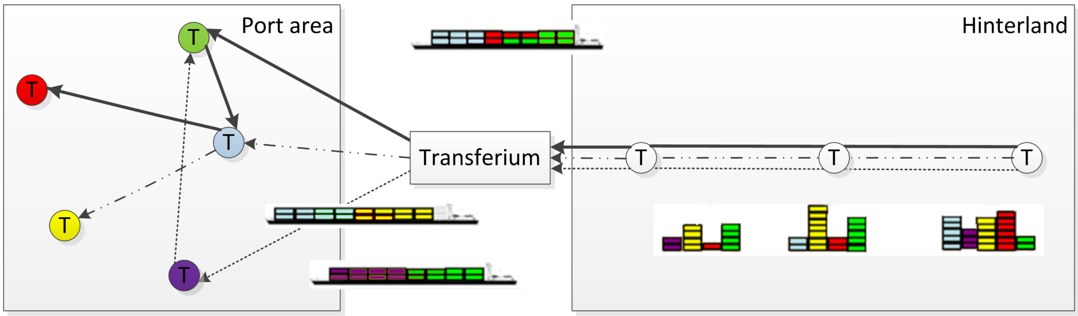

Figure 2-4: Schematic presentation of the logistical concept: Ongoing hinterland transport. Adapted from [22]

The next logistical concept is called "Dedicated", inland vessels visit the transferium and drop off all their containers destined for the port area. The vessels also pick up containers for the hinterland. The reduction of the sojourn time is maximal since it only requires transshipment at the transferium, however it requires a large transferium. Call sizes are not important on the hinterland side of the transferium, the distribution in the port can be done by a shuttle service. Konings et al. (2013) concludes that if the transferium is located further away from the port area larger shuttles can be used and economies of scale can be achieved. Close-by the port entrance smaller vessel have to used as shuttle but handling costs will weight more heavily on the total transport costs [22]. The disadvantages of this concept is the requirements of the transferium, when all containers are transshipped the transferium has to be large. Furthermore, a large stack is needed and the container transshipped twice at the transferium. There is also an investment needed for the link between transferium and port terminals.

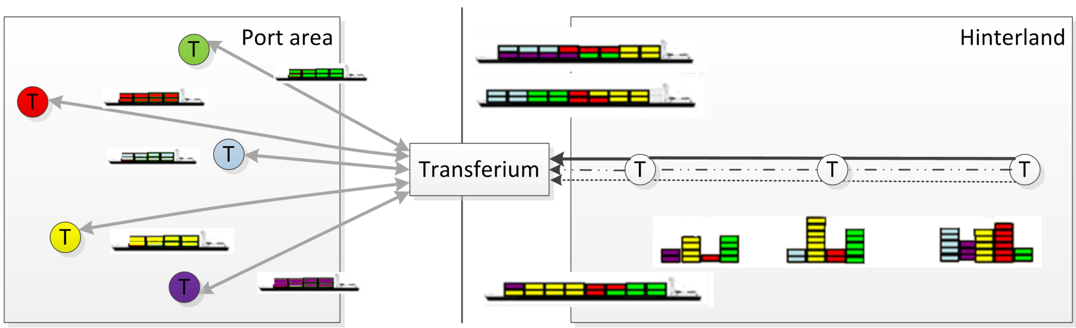

Figure 2-5: Schematic presentation of the logistical concept: Dedicated hinterland and port transport. Adapted from [22]

The last logistical concept is a combination of the previous two. Inland vessels drop off small call sizes at the transferium and continues to the port terminals. The number of terminal call can still be numerous. Before leaving the transferium the inland vessels can either supplement the call sizes still on board or continue without doing so. The benefit of only unloading is with a small call size limited, say up to 10 TEU for example. The interaction with the transferium is reasonable short and simple, and if terminals with large congestion can be circumvented the sojourn time can be reduced greatly.

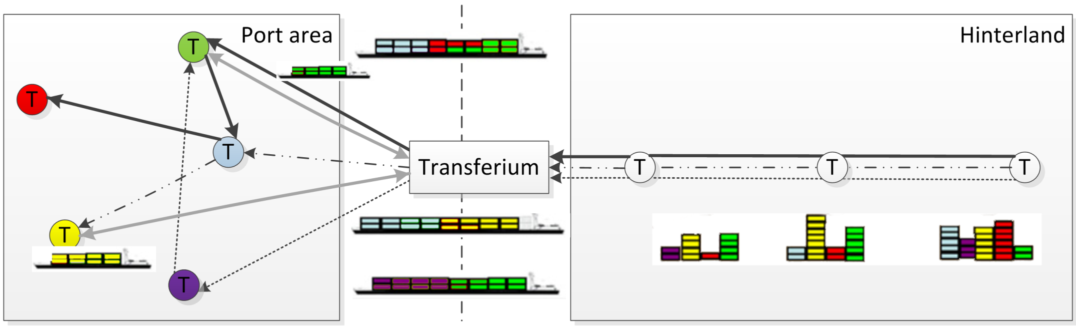

Figure 2-6: Schematic presentation of the logistical concept: Mixed operations. Adapted from [22]

The success of both ongoing and dedicated depends on the possibility to have different size vessels on both port area link as well the hinterland link. Economies of scale are possible for both sides. On the other hand reducing the sojourn time of inland vessels can be reduced by either of them and might be even more valuable. Konings et al (2013) conclude if there is no vessels size difference between hinterland and port area links than the ongoing concept can be the most interesting because the concept requires a low number of transshipment at the transferium [22]. Both dedicated and mixed operations also require the investment of new vessels, which is difficult in the current market situation. Pielage et al. (2007) did come to the same conclusion before Konings, and concluded that ongoing has the most potential, however much research is needed in further defining the logistical concepts and researching the transferium interaction with the transport chain [36].

2-2-2 Transferium operations

On the tactical level terminals determine layout and equipment. To understand the choices that need to be made we need to break down a terminal into basic elements. In Rotterdam container terminals are land areas that have: a container stack, land access, waterside access, quay with cranes. An example on a different approach is as follows: the general case in Rotterdam is that containers are always transshipped with cranes on the quays. An exception to the general case is a bulk vessel in the Waalhaven, it is used as permanent buffer with two mobile cranes to transshipment cargo. The concept of using mobile cranes in container transshipment is not new. For example, in the port of Hong Kong containers are directly transshipped from sea going vessels to inland vessels by mobile cranes to increase the capacity and avoid the container stacks on the terminals.

Mobility Pielage (2008) uses the idea of a mobile crane and applies it to sea going vessels that are berthed to decrease the berthing time [37]. He emphasises that the use of a mobile crane can have benefits to sea going vessels and terminals, but with inland vessels an extra transferium is needed at the edge of the land side entrance of the PoR. The transferium is needed to distribute the container from and to the sea going vessels over the inland vessels. A transferium does not have to be a terminal that is attached to land, as shown in the example. What was not mentioned in the example is that a transferium is not required to be stationary. In 1994 Ottjes [35] researched the possibilities of a sailing transferium (a self-propelled platform). The transferium would sail between terminals on the Maasvlakte bringing containers from inland vessels to the sea terminals. By collecting the smaller call sizes, the inland vessels have a reduced number of terminals that must be visited, reducing the sojourn time as well as increasing the productivity at the berths. In 23 year time, much has changes in the PoR therefore it is difficult to relate the results to the present. However, the conclusion that a transferium, and in this case a sailing terminal, would best be suited near the Waal/Eems (from now on W/E) location because of the small area and small container calls, reducing the sojourn time by 15%. Although this research is outdated small container call sizes are still a problem and by intercepting and bundling them at the transferium the sojourn time can be decreased. Malchow (2010) [32], makes a case in which he uses a similar idea to Ottjes (1994), a small sailing terminals (Port feeder barge) is used in ports. The patented Port Feeder Barge would be a benefit to the transport chain in a deep-sea port. They are versatile in use, for the collection of small call sizes, inter terminal transport and emergencies. A variation on the concept of Malchow are the Mercurius vessels in the PoR. An inland vessel is equipped with a crane and can transship its own containers. The crane allows the vessels to deliver containers at locations that have access to a waterway and quay but not to a crane, currently the vessels are transporting containers in the PoR to business that meet the criteria [15].

Figure 2-7: Transferium proposed in [32]

Equipment As discussed before the performance of the transferium is important to the success in the transport chain. In multiple studies a high transshipment rate is assumed. Wormmeester (1996) uses high transshipment rate with barges near the hinterland and Zuidgeest (2009) 60 moves/hour on the second Maasvlakte [67]. A small transferium with a low transshipment rate will have a small volume and thus will be most likely not feasible.

2-2-3 Performance on tactical level: operators

On the tactical level performance of the individual actor is important. Both terminal and inland vessel operators, transferium included, play an important role and are strongly dependent on each other.

Inland vessel operator The main objective of the barge operator is to minimise the delays in the pre-arrive determined schedule [58]. Van Groningen (2006) has done research by literature

Table 2-2: Terminal operator performance indicators on a tactical level

	Tactical aggregation level
Inland vessels	Waiting time per terminal [minutes] Terminal calls [calls]
Containers	Travel time to specific terminal[minutes] Time at transferium [minutes]
Terminals (transferium)	Containers at transferium [TEU] Calls at transferium [calls]

and questionnaires and determined four key performance indicators. However, these indicators are on the total barge operations and not the part this research is interested in, port area. The main objective of the barge operator still applies and with some assumptions it can still be measured. When considering all inland vessels, then the delay is the average time spend in port. If a vessel stays longer than the average sojourn time than chances are the vessel was delayed. The time in port can be broken down into three indicators that help in identifying the cause of the delay; Waiting time, travel time and transshipment time. Two more indicators are presented in table 2-2, terminal calls and container calls. These indicators help further identify the performance of the inland vessels and the system in general.

Terminal operator The objective of terminal operators is to utilise all the resources available thereby generating as much revenue as possible. The number of containers going through the terminal is an obvious indicator. Furthermore, the berth occupation is an indicator that shows the utilisation of the waterside of the terminal, this is defined as the time used by inland vessels divided by the available time (in minutes). Less important to the terminal operator are the waiting time and container call sizes of inland vessels. smaller call sizes can reduce the occupation and waiting times indicate whether the supply is constant. The goal of the transferium is to make the hinterland connection performance better by reducing the number of calls and enlarge the call sizes at port terminals. Therefore the difference in calls as shown in table 2-2 are needed to show the changes caused when implementing a transferium. The number of containers present on average at the transferium gives an indication on he required size of the terminal.

2-2-4 Conclusion tactical level

From this section several conclusions can be drawn. Routing solution can improve the round-trip and waiting time of inland vessels but fails to address the small container calls. The logistical concept for the interaction between inland vessels and the transferium can be divided into three types, of which the ongoing hinterland transport and mixed operations seem feasible. The Layout of the transferium can be done in a wide variety of ways, technically they are possible but in reality none have been implemented, yet. Due to the limitation of this thesis the focus will be on a transferium that is not moving and has the capacity of terminals currently existing.

2-3 Operational aggregation level

Operational decisions are made on a short time horizon and can be changed between minutes and days. Operational decisions in relation to terminals and inland vessels are e.g. the speed and trajectory of inland vessels and the use of 1 or 2 cranes. However, trajectories of inland vessels are too detailed for the scope of this research. Instead, the interaction of inland vessels and the transferium will be reviewed in this section.

2-3-1 Operational transferium interaction

Operational research on the interaction between transferium and inland vessels is limited. Pielage, et al. (2007) investigates the interaction with logistical concepts as has been explained in section 2-2-1. The focus of this research is the ongoing transport where inland vessels are used for both hinterland as port distribution. In order to explain the interaction between transferium and inland vessels a hypothetical example is given, made by the author of this report:

An inland vessel from the hinterland of the PoR is arriving with containers for multiple terminals are on board. Assumed is an inland vessel with 210 TEU capacity that has to visit 6 terminals. The vessel is partially loaded and the call sizes are 5-10-15-20-30-45 (total 125 TEU). Furthermore, the transferium has containers for all terminals in the port in its stack. The first step is to determine if the inland vessel must berth at the transferium. This input variable is called the "minimum call-size". All terminal call-sizes smaller that the minimum will have to be unloaded at the transferium. As mentioned before the ECT has introduced a minimum call size at their berths of 30 moves, which is roughly 19 TEU, and implement this limit for all terminals [2]. The calls 5-10-15 fall within the 19 TEU limit and will have to be unloaded. The remaining calls 20-30-45 are destined for three different terminals. If there are containers on the transferium with the same destination they will be loaded on the inland vessels till its capacity is reached. The inland vessel will then start its round-trip through the PoR.

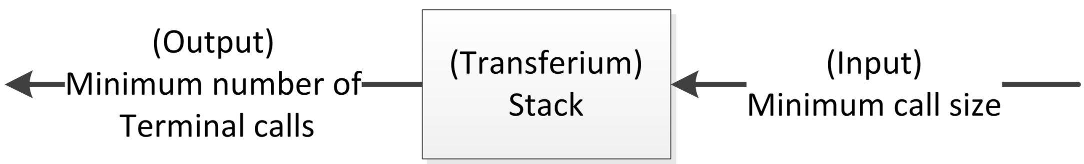

Figure 2-8: Transferium interaction variables

This is a basic example how the interaction with the transferium could be organised. Three elements of the interaction can be identified; (1) the input of the transferium (call size limit), (2) containers on the transferium (stack limit), (3) the number of port terminals that have to be visited. The call size limit can be varied to the needs of the terminals, increasing the call size limit will result in larger call sizes at the remaining vessels that berth at the terminal. Increasing the call size limit will also increase the number of containers that are allowed to pass through the transferium, which will set higher demands for the transferium. Pielage et al. (2007) report two examples for the minimum terminal calls; leave one destination on the vessel and consolidate, the distribution between transferium and port terminals becomes a line network, or leave two destinations [36]. The number of terminal calls also influence the number of containers that can go through the consolidation on the transferium, more terminal calls will lower the potential container number. Pielage, et al. (2007) conclude that leaving several destinations on the inland vessel has the most potential. However, they did a SWOT analyses to determine the possibilities and recommend an operational study for further research.

The interaction between transferium and inland vessels is elementary with the mentioned interaction variables. The input variable is based on the cargo of the inland vessel, but it could be more efficient to the total transport chain to look at it from a destination perspective. For example, when a terminal is congested it could be beneficial to use the transferium as a buffer, the inland vessels can use the transferium to remove the congested terminal from its round-trip reducing sojourn time. However, the containers destined for the congested terminal will still be delayed and extra handling has to be performed.

2-3-2 Conclusion operational level

The operational interaction variables that determine the role of the transferium is an area of research that has not yet been explored in detail. Assumptions can be made on the effects the variables but the effects on the transport chain have not yet been investigated.

2-4 Conclusion

In this chapter conclusions are given for the three research sub- questions based on the previously considered literature about the influence of a B-to-B transferium on the hinterland performance of inland container shipping for the three aggregation levels.

- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a strategic aggregation level?*

From literature it becomes clear that on a strategic level, changing the distribution network type by introducing a transferium in the PoR has the potential to improve the inland shipping performance. However, the details on how to implement a transferium in the container transport chain has no consensus yet in literature. Several papers suggest implementing a transferium in/near the port area, where they either focus on transferring the containers from inland vessels to trucks, an inter terminal transport system or vice versa.

It has been shown that a dedicated transferium for inland vessels, which is located outside the PoR closer to the hinterland has the potential to reduce the overall transportation costs. Meanwhile, locating a transferium in Alblasserdam can reduce the road congestion on the A15 by transferring containers from trucks to inland vessels. Furthermore, it has also been shown that in other port areas, such as Antwerp, the introduction of a transferium with a shuttle service in the port area can reduce the turn-around time of inland vessels. The previous shows that the characteristics of the transferium determine the effects on the hinterland performance of the container transport chain. While there is a consensus in literature that a transferium can have a positive effect on the hinterland performance of inland container shipping, it depends on the configuration and role of the transferium within in the container transport chain.

- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a tactical aggregation level?*

On a tactical level, literature on both logistical concepts for a transferium and routing of inland vessels have been reviewed. Improving the routing of inland vessels by software related solutions aside from using a transferium can reduce the waiting times for inland vessels in the port area. However, it does not address the issue of inland vessels having to visit multiple terminals with small call-sizes. Therefore, a logistical concept of a transferium that reduces the number of small call-sizes would still be needed. In literature, diverse designs for logistical concepts of a transferium are proposed, based on the size, location, mobility of the transferium and required interaction between the transferium and inland vessels. The logistical concepts on the interaction between inland vessels and transferium can be divided into three types; dedicated transport, ongoing transport and mixed operations. Ongoing hinterland transport and mixed operations seem the most feasible since minor changes to the fleet must be made, reducing the investment. Furthermore, the transferium must have a high transshipment performance in to minimize the delay containers and inland experience when using the transferium. The interior of the transferium is not considered in this research, the design of the transferium is determined by the performance need and interaction with inland vessels.

- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on an operational aggregation level?*

Literature on influence of a transferium within the port area on an operational aggregation level is still limited and has not yet been explored into detail. Setting a minimum number of terminal calls in the port area can limit the throughput of the transferium, which is especially needed with the capacity of the transferium is limited. Furthermore, the input variable of a transferium can be done by setting a minimum call-size for all terminals in the port, which is a very basic way of selecting containers and inland vessels that make use of the transferium. In conclusion, this research will focus on the effects of a transferium that is located on the land side entrance of the PoR. Since no other vessels are used for the distribution in the port are, the location away from the port does not cause economic of scale benefits. Both on a tactical and operational level the logistical concepts have several variables that define the measure of consolidation which have not been addressed in previous literature. Investigating the logistical concept and the variables give inside the in the effects they have on the sojourn time of inland vessels in the PoR. The further to be used in- and output variables in this research are shown in Table 2-3.

Table 2-3: Transferium input and output variables

Input variable transferium	output variable transferium
Minimum call size [TEU]	Minimum terminal calls [Calls]

Chapter 3

Modelling the Barge-to-Barge transferium: Conceptual simulation model

In this chapter a conceptual model is made to facilitate the process of building a simulation model. Robinson (2008) determines four elements that have to addressed in the development of a conceptual model [47]. The first subject is to understand the problem, this has been done in the previous chapters. The second step is to determine the objective, requirements and scope of the model. The third step is the identification of in- and outputs. And finally the model content is determined, which includes level of detail, assumptions and simplifications.

3-1 General simulation model requirements

In this section the conceptual model will be elaborated upon. The objective will be introduced as well as the models requirements. Furthermore the scope of the model will be determined.

3-1-1 Model objective

The objective of the model is to create a conceptual model that can be used to run simulation with that turn examines the use of a B-to-B transferium in the PoR. The objective of the model is based upon the research objective and refers to the purpose that the model serves. By doing so different variables can be compared on an operational level, this will create insight into the relation between the variety of scenarios and the current situation.

3-1-2 Model requirements

The requirements for a model should be established before it is built, that way the modal can be tested when build if the intended model is built. Two kinds of requirements can be distinguished. The model has requirements that describes the working of the model. Secondly the software has requirements which states the functionality that is needed.

Model requirements The round-trip of inland container vessels in the PoR is influenced by various aspects which the simulation model should be able to variate in these aspects. The variations should be relative easy to apply to determine the effect of the variations without rebuilding large portions of the model. Furthermore, many inland vessels must be modelled as well as individual containers to keep track of the performances of these entities. The entities should have the same variables as properties as well as the same behaviour. The vessels and containers arrive at different times in the model and should be able to be in their own state, for example, the first vessel is berthed at a terminal on the Maasvlakte and the 10th vessel is just arriving and determining which route to sail. The model should have a clear data input and be well documented so that in can be reproduced in any simulation program. The route choice for inland vessels must be possible in the model, a similar algorithm to the Dijkstra algorithm is needed. Finally, the model must be able to mimic the situation in the PoR.

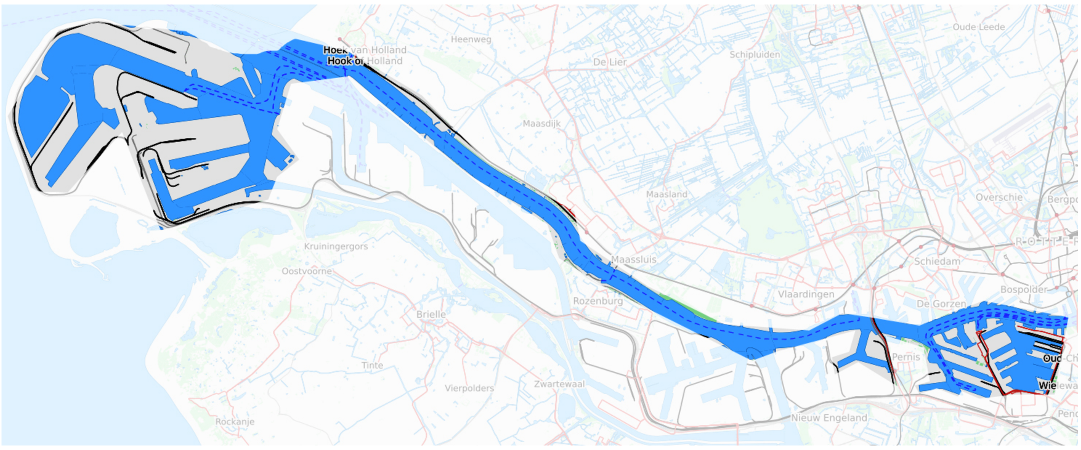

Figure 3-1: Model boundary, Adapted from google.maps.com

Software requirements For the user, it is important that the software is transparent, allowing checks and reviews of the model when it is being build. Extensibility, the input of external data into the program is required to load schedules and other data sets. For example, excel files that contain terminal opening and closing times. Furthermore, the arrival of inland vessels can be seen as events and a discrete type of model is required. The time scope of this thesis requires the model to be efficient and the runtime must be kept in bounds. The model should also be able to generate statistics on all the entities that are modelled, for example, the time individual containers take to reach their destination terminal has to be recorded. The use of a Dijkstra algorithm is required to decide the route for the inland vessels.

Scope of the model The scope of the model has been introduced in Chapter 1, figure 3-1 shows the boundary schematically. The highlighted area represents the Port of Rotterdam area, the focus area of this research. On the left side of the figure sea going vessels enter the PoR area and in the bottom right corner the inland vessels enter the model area. The grey areas are land volumes on which the terminals reside, figure 3-2 shows the locations of the terminals. The blue area are the waterways.

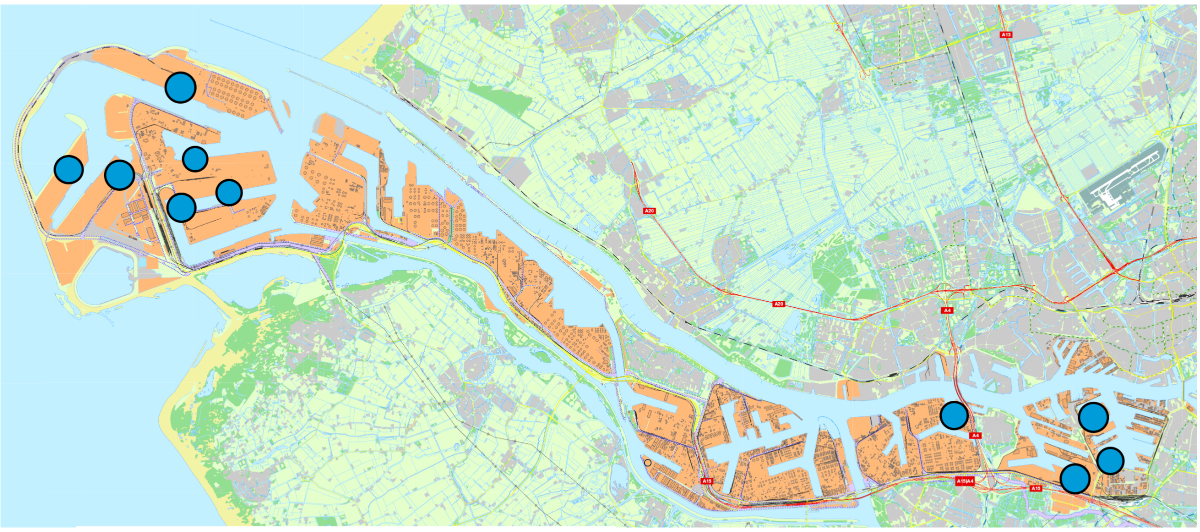

Figure 3-2: Container terminals of the Port of Rotterdam, [41]

3-2 Model input & output

A model needs in- and output variables in order to function. First the output is discussed from which can be determined what is needed in the input.

Model output The output of the model can be related to the performance indicators that are given in Chapter 2. Table 3-1 shows the output variables and their units.

Table 3-1: Overview model output variables

Strategic aggregation level	Number of terminal calls [Calls] Container travel time differentiated per terminal [Minutes] Waiting time inland vessel differentiated per terminal [Minutes]
Tactical aggregation level	Sojourn time vessels [Minutes] Container travel time [Minutes]
Operational aggregation level	Transferium throughput [TEU] Container time transferium [Minutes]

The sojourn time of inland vessels is specified into three sub parameters; waiting time, travel time and if applicable time spent on the transferium. It is important to know the differences between the time spent on the vessels in relation to the time on the transferium, since this gives inside in the changes the transferium causes when introduced to the transport chain.

Table 3-2: Overview model input variables

	Strategic	Tactical	Operational
PoR - system	Waterway network	Sea going vessels arrival pattern Sea going vessels berth time	
Terminal operator	Terminal locations	Terminal quay lengths Number of terminal cranes	Transshipment speeds
Inland vessel operators		Inland vessel arrival pattern Inland vessel call size distribution	Inland vessel speed Inland vessel capacity

Model input The trade flow data is used to generate the container flows between hinterland and port area, including inland vessel services frequency. Furthermore trade flow data the container exchange between terminals and vessels is quantified. The inflow of containers from sea going vessels are also taken into account in this data. PoR area data defines the wet/dry infrastructure, including terminal capacities and possible inland vessel routes. Table 3-2 shows the input variables.

3-3 Conceptual model

Chapter 2 showed two parts to the situation in the Port of Rotterdam: and operational and a physical part. In the conceptual model the relation between the two is further defined and explained. The physical parts interact with each other in a way that is determined by the operational concepts as will be shown. The introduction of a transferium in the logistical chain will be proposed, therefore the most important part of the model is the interaction of the vessels with the transferium. Second to that is the interaction of the transferium with the total logistical chain.

3-3-1 Model level of detail

Not enough detail could lead to a model from which it is difficult gain the needed results, conclusions could be too generic. To much details could make the model unnecessarily difficult leading to large computational times and results that are too complex. The level of the model gives information about the temporal and spatial resolution in which the model should be confined. A usable model should have an aggregation level that follows the objective of the model. For example, inland vessels and containers need to be tracked individually in order to observe a differentiation in behaviour between scenarios.

Temporal resolution The temporal resolution of the model needs to be long enough for the inland vessels to move through the port area, call at container terminals and then leave the port area again. However the sea going vessels occupy a large percentage of the berth time at the terminals and therefore have to be taken into account as well. The temporal resolution must also be long enough to facilitate the stay of sea going vessels. But the temporal resolution also needs to be small enough to show differentiation in handling of containers, for example the transshipment of only a few containers will require only a fraction of the total time in port of inland vessels. The model should have a large enough resolution to cope with sea going vessels but also detail enough to notice the container transshipment.

Furthermore the data used in making the model should be fairly recent because of the rapid chances that happen in the port area. Latest data is preferable

Spatial resolution Another way to determine the level of detail in a model is the spatial resolution. Again how detailed should the model be. The goal of this research is to determine the effect of a barge-to-barge transferium on an strategic level, which means that operational decisions made on the spot are not taken into account. This includes the processes that happen on the terminal/transferium grounds, and therefore the terminals can be a black box in the model. Furthermore the strategic level does not include hour to hour influences like wind force and tidal currents. Figure 3-3 shows the three main entities and their attributes that are needed to model the transferium in the PoR.

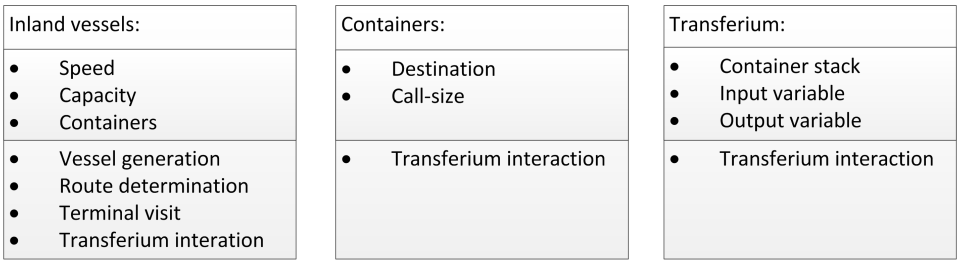

Figure 3-3: Model objects with attributes and processes

3-3-2 Model processes

Process 1: Vessel generation The generation of inland containers vessels is the arrival of a vessel at the edge of the PoR considering the arrival pattern. The arrival pattern is influenced by the closing times of port terminals, inland terminals and working hours on vessels. The vessel creation mimics the reality situation where vessels arrive in the PoR with containers destined for port terminals. The agent determines the size of the vessel and number of terminals that must be visited. After which a unique set of terminals is added to the travel list, which terminals are chosen come from a distribution based upon the terminal size. The last step is the determination of the call size per terminal. The method used in the generation of the inland vessels is similar to the method used in Zuidgeest (2009) [67]. However, the difference lies the route generation, Zuidgeest models one terminal and can discard the vessel if that terminal is not visited thereby excluding the influence on the whole port system. Furthermore is the transferium used only for unloading containers.

Result: Vessel creation
Create agent of type vessel;
Get *vessel size* from distribution;
Get *Terminal visits* from distribution;
while *Terminal visits* > *travel list* **do**
  Get Terminal Number;
  if *Unique number in travel list* **then**
    add terminal number to travel list;
  else
    Get new terminal number;
  end
end
for *Each terminal in Travel list* **do**
  Get *Call size* from distribution;
  Add *Call size* to *call size list*;
end

Algorithm 1: Vessel creation

Process 2: Route determination The route determination is done after the vessel has been created and requires a route through the port. Vessels get a schedule from their company which provides a route and time slots where to arrive at what terminal, the company makes the appointments at the terminals. In case the vessel misses an appointment must be made, this can be done either by the company or the captain of the vessel. The generation of the route consist of combining requirements and limitations. The route should pass all the required terminals once, in other words a travelling salesman problem (TSP). This is different from reality since vessels can visit terminals twice (as experienced by author) depending on the availability of terminals, cranes and cargo. In a conversation with the captain of an inland vessel the route choice was explained. The company that owns the vessels has a department that makes appointment for all the owned vessels. The route is mostly determined on the availability of free terminal spots, but since there is no transparent overview on the slots it takes multiple calls to establish route. The route determination in the model should represent the efficiency as well as the inefficiency of the route planning. An optimal route is not representative of the situation in the PoR. The vessels only sail once between Maasvlakte and city terminals, it is a 2,5 to 3-hour trip that would costs too much time and fuel if sailed twice. The model does not consider the costs the vessels so the limitation of sailing the Maasvlakte-city route only once (this means once in both directions). The route is determined by determining the first possible timeslot in which the inland vessels can be processes at a terminal, all terminals are compared and the first terminal is selected. A processing slot is the time of arrival plus the time needed to tranship containers. Transshipment time is chosen as a constant similar as in Douma (2008) and [12]. The transshipment of containers is variable due to various reasons, old equipment, sea cranes instead of inland vessels cranes, crew changes. The transshipment speed is 30 moves an hour, the number is acquired from the conversation with the captain of the inland vessel. The end time of the first slot is used to determine as starting point for the remaining terminals, the new processing slots are determined and the process repeats itself.

Result: Round-trip route without transferium
Get *travel list*;
Get *call size list*;
...;
for *Each terminal in Travel list* **do**
    Get *travel time*;
    Add *travel time* to *travel time list*;
end
Get *travel time list*;
while *travel list is.Empty is false* **do**
    for *Each entry in Travel list* **do**
        Get *travel time*;
        Find earliest possibility to fit call size at berth;
        Add begin time to sorting list
    end
    Find lowest entry in *sorting list*;
    Add to *Final travel list*;
    Remove from *sorting list*;
end
Add exit point at the end of *Final travel list*;
Use *Final travel list* to start round-trip;

Algorithm 2: Vessel arrival in Port area

Process 3: Terminal visits The third process happens each time an inland container vessels arrives at a terminal. The vessel arrives at the terminal and must wait till the designated berth is free. Then the vessel can moor at the berth, mooring is defined as the manoeuvring of the vessel in the correct position and attaching cables to the quay. The mooring time is determined between 5 and 15 minutes [8] [12]. The number of containers that are offloaded are equal to the loaded containers, this assumption is made because there is no data freely available on the ratio per terminal. Furthermore, it can differ between terminals and shipping companies making it more difficult to make a guess. After the mooring the transshipment can begin and the vessel stays there until it is completed. No delays due external factors like technical problem and weather are considered.

Result: Round-trip
for *Each terminal in Final travel list* **do**
    Sail to terminal;
    Wait till berth is free;
    Moor vessel;
    Wait for container transshipment is complete;
    Departure vessel;
end

Algorithm 3: Round-trip vessels

Process 4: Round-trip with transferium visit The determination of the route with transferium is for the most part the same as normal route choice therefore only the added lines are given in the pseudo code. The dots show where in the round-trip code of algorithm 2 the transferium visit is added. The transferium visit will always be in the beginning and at the end of each route. The necessity of the visit is determined by the minimum call size, if container calls smaller than the minimum are present on the vessel a visit to the transferium is mandatory. The model determines how many containers must be moved to the transferium but there must always remain a minimum of terminal call on the vessel, this is an assumption made to have all vessels enter the port. The number of minimum terminal calls can be varied to test it effects on the system. After the containers are transferred to the transferium new containers are added to the remaining terminal calls. If possible all remaining calls are equally enlarged till the capacity of the vessel is reached or if the container stack of the transferium is empty. The vessel is filled to its capacity because otherwise chances are that smaller terminals serviced. After the transshipment is completed the statistics of the vessel are updated and the route is further determined. This addition to the round-trip algorithm is similar to what is used in [67].

Result: Round-trip route with transferium
...;
if *Call size list containes call sizes smaller than call minimum* **then**
    Move to transferium;
    Wait until arrived at transferium;
    while *call size list* > *minimum terminal calls-1* **do**
        Add all calls smaller than *minimum terminal calls* to *transshipment*;
        Add containers to transferium stack;
        Wait *transshipment*;
        Remove containers from *call size list*;
    end
    Update *Travel list*;
    Update *Call size list*;
end
...;

Algorithm 4: Vessel arrival in Port area with transferium visit

Chapter 4

Simulation model of a B-to-B transferium

In this chapter the conceptual model is implemented using the building block given in the conceptual model of chapter 3. First, the modelling program is discussed. Secondly, the transition from conceptual model to simulation model will be elaborated. Thirdly, the verification and validation of the model is done together with the sensitivity analysis.

4-1 Discrete modelling program: Anylogic

The system described in the previous chapters can be modelled with different simulation software. The most obvious choice is discrete modelling due to the nature of the system and the ability to use stochastic algorithms. Literature discussed in chapter 2 mostly uses discrete event simulations, but there are exceptions. A queuing model is used by Evers (2004) [14] and Caris et al. (2011) [4] use Arena which is a discrete model based on a queuing model. Discrete simulation makes use of events that instantaneous occur and may change the state of the system [29]. An event can make an inland vessel change its state and undertake action, after which the state remains until the next event has taken place. The total state of the system is determined by all the entities in the system. The simulation is also object orientated: the simulation consists of objects that intact with each other during the simulation. An object has characteristics that describe the state of the object. There are multiple simulation software programs that can facilitate the simulation. The software packages that are available on the university and support discrete event simulation are Matlab, Simio, Arena and Anylogic.

Introduction Anylogic Anylogic is a simulation tool not widely known in The Netherlands therefore a small introduction is needed. Anylogic is an agent based modelling program that can use multiple simulation techniques, it can be used for continues or discrete models. Agent based means that elements in the model, for example inland vessel, all belong to the class

"Vessels" and hold the same variables but the values although differ for each element. Agents can be created or destroyed during a simulation run. A benefit is that Anylogic consists of standardised blocks that can be used in building a model such as, variables, arrays, lookups, and also graphs are ready to be used. To have precisely control standard block are used in JavaScript. Using scripts, the blocks are linked and influence each other if necessary. With Anylogic it is also possible to visualise the agents using a network of poly-lines and nodes.

Software choice The four software packages that are available have different characteristics. Section 3-1-2 describes the requirements for the software and all four software packages comply with the requirements. One of the requirements is the use of a travelling salesman algorithm to determine the route of inland vessels. In a consultation with simulation expert the suggestion was made to use a program that allows full control over the simulation and travelling salesman algorithm. Both Simo and Arena do not provide this control and make it more difficult to implement such an algorithm, therefore both programs have not been used.

Matlab provides full control over the simulation but lacks the graphical presentation. This leaves only Anylogic that suffices for this research. Anylogic uses pre-made blocks but still allows the user to have sufficient control over the simulation to implement a travelling salesmen algorithm. It also supports graphical presentation of the model.

4-2 Translation from conceptual to Anylogic model

In section 3-3 the conceptual model is presented. From this generic model an Anylogic specific model needs to be made to run experiments. In this section the conceptual model will be translated to the Anylogic model. In order to do that assumptions, data requirements and processes need to be defined.

4-2-1 Model structure

Anylogic is a Java based program that is object oriented class based language. The model is divided into six blocks that are all Active Object Classes in Java.

The objects (1) Vessel, (2) Container, (3) Terminal and (4) Transferium are modelled as agents. Thereby the objects can be duplicated with the same characteristics but different variable values. Furthermore, objects can follow a state chart to specify the behaviour during the simulation. Figure 4-1 shows the different objects of the model with a short explanation on important functions it contains.

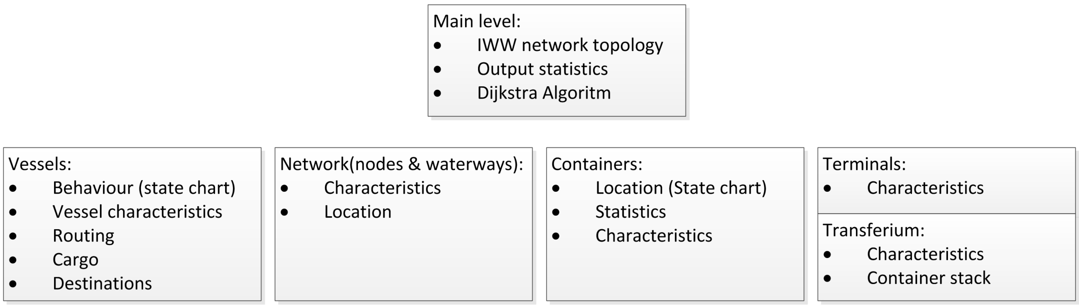

Figure 4-1: Anylogic levels overview

4-2-2 Model processes

As been identified in the conceptual model in section 3-3, there are four processes that determine the model; Vessel generation, Route determination, Terminal visit and Transferium interaction. Each process will be elaborated upon in order to get a better understanding of it workings. The relation between the processes are given in Figure 4-2.

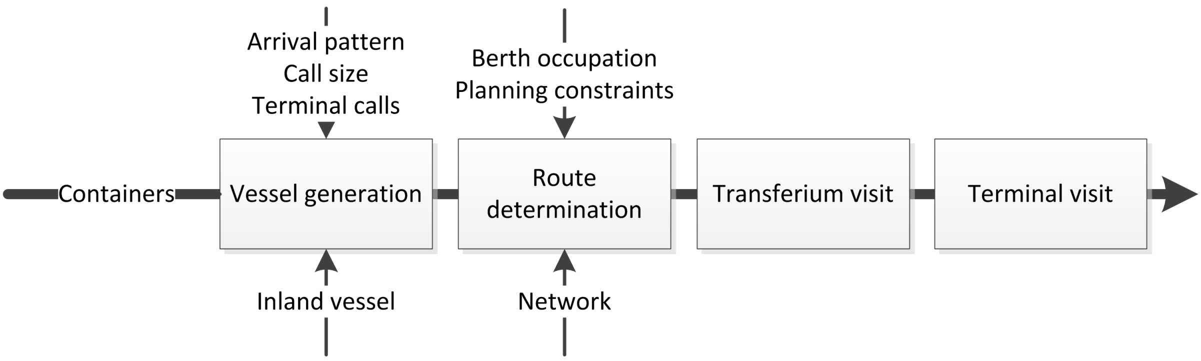

Figure 4-2: Anylogic levels connected to each other

Vessel processes Figure 4-3 shows the state chart for the inland vessel. Every inland vessel has a unique state chart, allowing for specific time interactions for every inland vessel in the simulation model. Each inland vessel starts at the enter_port_area in the grey box. The box represents the pre-arrival of the vessel and its destinations, cargo and round trip route are calculated. The "Transferium" state is only reached if the scenario that allows the use of it is activated. At the "Transferium" box the containers that meet the call size limit for using the transferium are determined. After the pre_arrival the inland vessel starts its round trip by sailing to the first terminal on its destination list. As shown in the network of the model the vessel passes several nodes that are intermediate nodes, when passing through such node the list with route nodes is updated. If the node is a terminal the state chart continues with the arrival and transshipment at the terminal. If an inland vessel arrives too early for its appointment, and there is no berth available, the vessel will wait at the terminal. After the transshipment the vessel will continue its voyage, when all terminals are visited the vessel will start Sailing_back. While leaving_port_area the statistics of the vessel are updated.

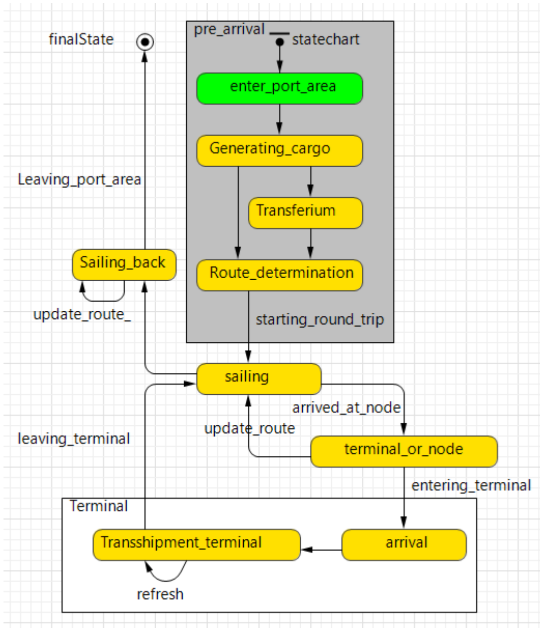

Figure 4-3: State chart of the agent vessel

Route determination & Berth occupation When the inland vessel reaches this state it already has a list of terminals and a corresponding container call sizes list with it. Now the actual route must be determined. The route is determined with a Dijksta algorithm. From the starting point in the network the travel times to the terminals are calculated. Then the closest terminal is selected, the vessels will then find the earliest free berth to use and save this to a temporary list. This is done for all terminals in the original terminal list. When finished, all terminals are in both lists. The list contains times when the inland vessels can start transshipment (considering travel time as well). The terminal that can be used the earliest will be first on the destination list and removed from the original one. This process is repeated until the original terminal list is empty. When the final list is done the berths that are needed for the transshipment are marked as occupied for the needed time.

No variation in transshipment time is used due the fact that terminals have different equipment and no detailed information is available on how they are used. For example, a deep-sea crane has a higher transshipment rate for sea going vessels but a lower speed for inland vessels due to the height difference. Furthermore, older cranes can be slower or have a smaller reach which can cause the vessels to move at the berth in order to give the crane full access. Not knowing what the transshipment rates will be one rate is picked for the whole port. In an interview with the captain aboard of an inland vessel the difference in transshipment times becomes more clear. The transshipment time is depended on: crew changes, technical issues, weather, equipment age, skill of the operator and more. Douma (2008) uses 20 moves a hour which seems low, but he acknowledges that in reality the transshipment speed varies [12]. Froeling (2008), et al. also estimated 20 moves a hour [18]. In 2013 Rijkswaterstaat estimated 25 moves a hour [43]. The interview on-board an inland vessel was taken in 2016 and the captain confirmed the various transshipment rates but estimated that the current rate is at 30 moves a hour. There is an increasing in transshipment rate over the years, therefore the rate for this model is set at 30 moves a hour.

Transferium interaction Before the vessel reaches the state of route determination the content of the vessels is tested to the minimum call-size variable, when call-size smaller than the minimum are present the vessel will enter the transferium state. In the transferium state the process as determined in algorithm 4 takes place. First the vessel moves to the transferium, there are no waiting times at the transferium. Enough capacity is assumed to process the vessels, the transshipment rate is 20 TEU per hour as well. The containers are transshipped and the vessel continues to the route determination.

4-2-3 Model variables

Sea vessels generation The sea going vessels are generated at the beginning of the model to simulate the limited availability of berths to inland shipping. The model requires a distribution on the size and the time spend in port, with this data the model can occupy berths to simulate transshipment of sea going vessels.

The website of marine traffic is used to collect data regarding two months of departures from the PoR. The website distinguishes the MV and W/E area as well as the inland vessels and sea going vessels. However the data is raw and needs to be processed before it can be used. For example the vessels are sometimes counted as two arrivals when hopping between terminals and the differentiation between inland container or bulk vessels is not always present. The data collected contained the following information: Time spend in port, Name of the vessel, Length, Capacity in TEU.

The first step in generating the sea going vessels is the determination of the destination terminal. Based on Table A-2 a distribution is made, terminals with a high capacity have a higher chance in the distribution. The table can be found in Appendix A-3 The second step is the determination of vessel size. Figure 4-4 shows the data gained from the marine traffic website for large seagoing vessels departing from the MV by size and time spent in port. The groupings are based on the berth time, length of vessels and by the grouping from the PoR [40].

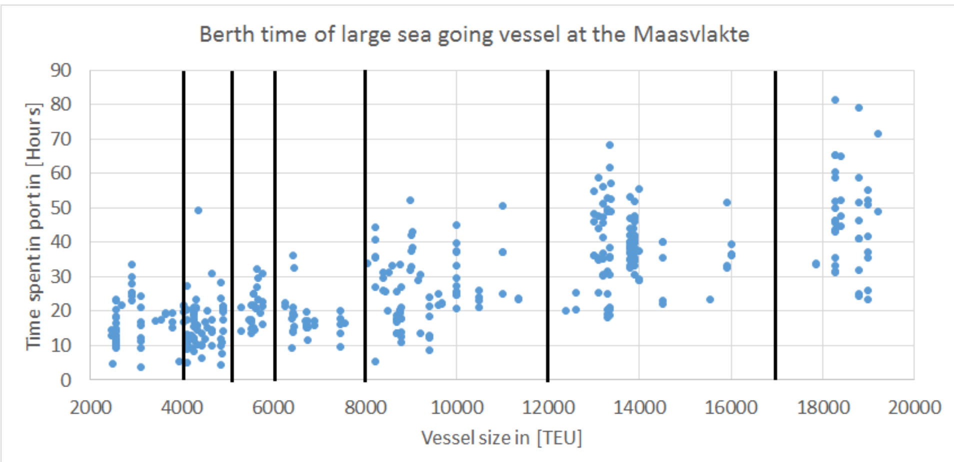

Figure 4-4: Large sea going vessels time spend in port in relation to vessel size, made from Marine traffic data

The third step is determining the berths time of the vessel. Per group in Figure 4-4 a new distribution is made from which the time spent in port can be determined. Figure 4-5 shows to graphs taken from Anylogic, it illustrates the distribution of the size of the sea going vessel in the left graph and the time spent in port in the right graph. Both distribution are based on a scale from 0 to 100, the model randomly selects a number and returns the corresponding size (left graph) and duration in port (right side). The duration in port graph is give for vessels between 6000 and 8000 TEU. These graphs are also made for the W/E area and for small sea going vessels for both W/E and MV and can be found in Appendix B.

Smaller sea going vessels call at more than one terminal each time they visit the PoR. However, the data from marine traffic is not detailed enough to register these hops, therefore the vessels visit only one terminal and will stay there the whole time.

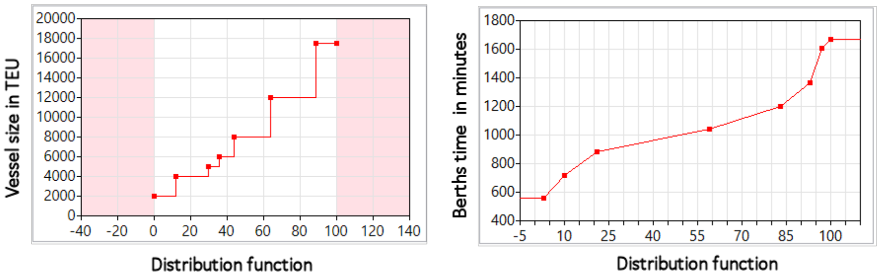

Figure 4-5: Vessel size and time spent in port distributions, from Anylogic model

The same data provides the number of vessels that arrive each day. Together with data from the PoR [40] four discrete uniform distributions are made, one for each class and location.

Arrival of Inland vessels rate Data concerning the arrival of inland vessels is scarce, barge companies sometimes have a schedule on their website but these are generic, no times are specified. Furthermore the data is regarded as competitive data and not shared easily. From different sources and observations a arrival pattern is constructed.

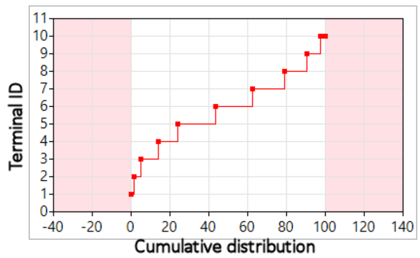

Figure 4-6: Number of terminal calls distribution, as in Anylogic

Inland vessels arrive in Rotterdam 24/7, Maasvlakte terminals are always open but some Waal/eem terminals close during the night and on Sunday. Observations are made on how many inland container vessels are present in the Port of Rotterdam. During a period of 3 weeks the number of vessels in the harbour have been counted via the website marinetraffic.com. On average 35 vessels where counted, varying between 28 and 45 vessels. The counts were done between 10:00 and 16:00 and can be found in Appendix B. The marinetraffic data indicates that the arrival pattern during the day differs between MV and W/E terminals, as expected when looking at the opening times the arrival pattern for MV is more or less constant while at the W/E arrivals pike around noon and are lowest around midnight [33]. Because the MV and W/E area are together the Port of Rotterdam an over al pattern is needed. Assumed is that inland vessels arriving in the PoR will visit the first terminal available and will fit the W/E terminals in their round trip where possible. Which makes the somewhat continues rate of arrival of the MV a good estimation for the whole port.

Contrary to the arrival per day the arrival per week differs in the weekend [33]. However not enough data can be collected in order to give an good estimation on the reduced arrival rate. In [67] an arrival pattern is used for 2005 in which a weekly pattern is multiplied with a grow factor, from that weekly pattern can be reduced that Saturdays have a 81% and Sunday a 57% arrival rate in relation to the weekly rate. These numbers seem to match with the little data marine traffic provides, and are used in the generation of inland vessels. A poisson distribution is used to determine the inter arrival time of inland vessels, for weekdays an average of 35 vessels a day is used and for Saturday and Sunday respectively 28 and 20 a day.

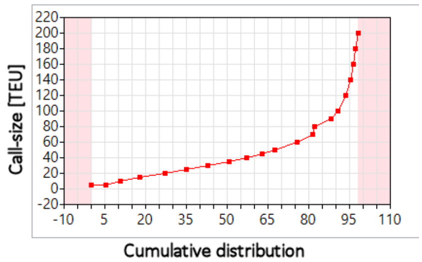

Figure 4-7: Call size distribution, as in Anylogic

Number of Terminal calls The number of terminals that need to be visited by an inland vessel differ per type. In [34] the terminal call size is differentiated in vessel length, inland vessels between 86 and 111 meter call on average at 5.8 terminals while vessels longer than 111 meter call 7.0 times in 2014. Same as with the arrival rate, specific data is not available freely due competitiveness of the data. For both lengths a triangular distribution is made with and average of respectively 5.8 and 7.0 between 1 and 10 terminals. From the previous mentioned observations of the number of vessel in the PoR at one time, 151 unique vessels have been identified. 31% is larger than 111 meters.

For both inland vessels as sea going vessel a distribution is made on what terminal is visited. This distribution is made on the theoretical capacity given by the terminals on their website or from the port authority [40]. By using this method the market position of the terminals is lost, but without any detailed information this would be impossible to determine in an other way. The table can be found in Appendix A

Container call size The container call size can differ between ship type and length, inland vessels from Antwerp tend to have larger container call sizes than domestic and Rhine trade [36]. However data elaboration on the difference is not freely available. Nextlogic presents a graph on container call sizes throughout the PoR per terminal, making a distinguishing between the MV and W/E area [19]. Again due to the competitiveness of the data no specific terminal is shown. From the data can be seen that the smaller container call sizes are more frequent in the W/E area. Two important side notes are needed with the data. Firstly the AMP-2 and RWG terminals on the second MV were not yet operational at the time. Secondly the ECT Delta terminal is divided into multiple section, explaining the 7 terminals at the MV. For both MV and W/E area one distribution each is made from the data in figure 4-8. Kramer terminal on the MV gets the same distribution as the W/E terminals since it has a similar function.

The interaction of the transferium is initiated if there are call-sizes on a vessel smaller than the minimum call size. The variation on the minimum call-size is determined as 5-10-15-20-25-30-45-50. The range is based on statements of terminals. ECT terminal already has set a limit

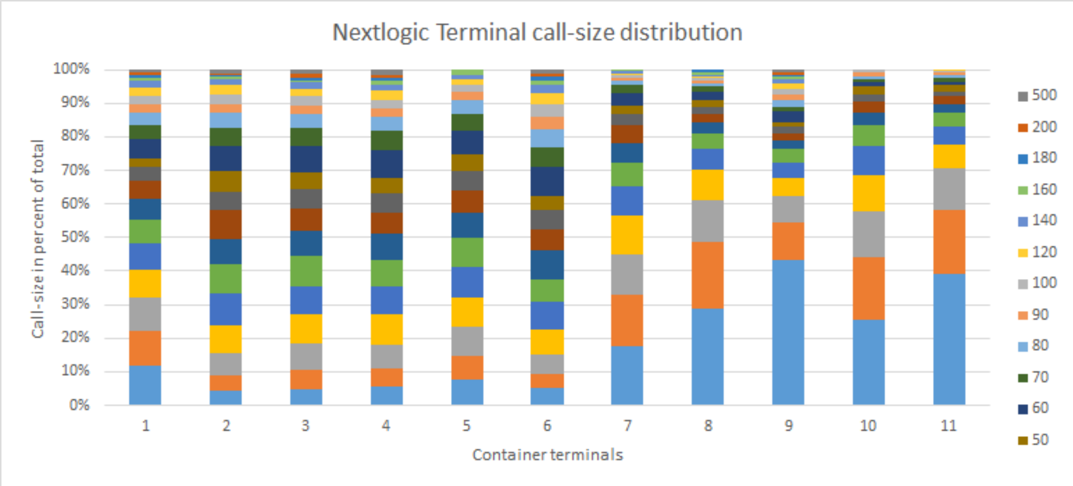

Figure 4-8: Distribution of container call size by Nextlogic [19]

for some berths at 30 TEU and is planning on increasing the number to 50 [2]. The smaller call-sizes up to 30 TEU are interesting since those are part of the problem in the PoR. 45 TEU is added to give some contrast with the 50 TEU. Ideally smaller steps and more steps are used as parameters, but due to the length of one simulation the number of parameters is limited to 8.

4-2-4 Assumptions

Data given to vessels is deterministic, when the route is made it will not change over time. The destination of containers can change (as the author experienced). When a terminal slot was missed by the inland vessel the next opportunity would take hours of waiting, the planning department of the company determined that it was best to unload the container at the terminal of the company and another vessel would take it to the destination. Inland vessels visit terminals only once. And the terminals give the accurate time a berth is available. No safety margins are used. Furthermore, the handling of inland vessels is not interrupted. Inland vessel plan their round-trip when generated, there cannot be two vessels at the same time planning.

All inland vessels have the same speed. The speed is limited to the maximum speed inland vessels can sail in the port area. The speed is set to 13 km/h. The speed difference due to the currents are not considered. Inland vessels routing is based on time instead of distance due to the waiting times. Furthermore, deadlines for delivering certain containers are not considered, also the preferences of the captain are neglected. The arrival of sea going vessels is determined before the inland vessels enter the system.

Entities in the model do not experience break downs, technical issues or malfunctions. Capacity of the terminals is fixed; no cranes are added or removed on any instant during the model runtime. Some terminals have closing times. Closing times are hard lines, if a vessel does not fit before closing it must visit another terminal first or wait till the terminal opens. When inland vessels make an appointment at a terminal it will arrive and stay the time it has claimed. All berths are used for both sea going vessels as well as inland vessels. The start of transshipment before closing and finishing after the terminal reopens is not possible. The in and out going container flows are the same. Inland vessels load as much containers as they unload.

Run length & warm up period

First of all the length of the simulation needs to be determined. The run-length needs to be long enough that all possible events can occur and a steady state of the system is reached. A round-trip from the hinterland to the port area can take between days to weeks. A round-trip to lower Rhine area can take up to 2 weeks. The model time of 30 days is chosen to allow inland vessels to have at least 2 round-trips.

The warm up period is needed because the model starts with an empty system. The warm up time is defined as the time needed to get the system into a steady state, if there is such state possible within the model. There are different ways to determine the warm up period, one of the simplest and frequently used methods is graphical [28]. The idea is based on making a number of independent replications with a large enough run time to let the simulation reach a steady state and from a visual representation the steady state can be recognised. The graphical representation of this model is given in figure 4-9. The model seems to reach a steady state at around 20.000 minutes model time into the simulation, this gives the total run time of 63.200 minutes.

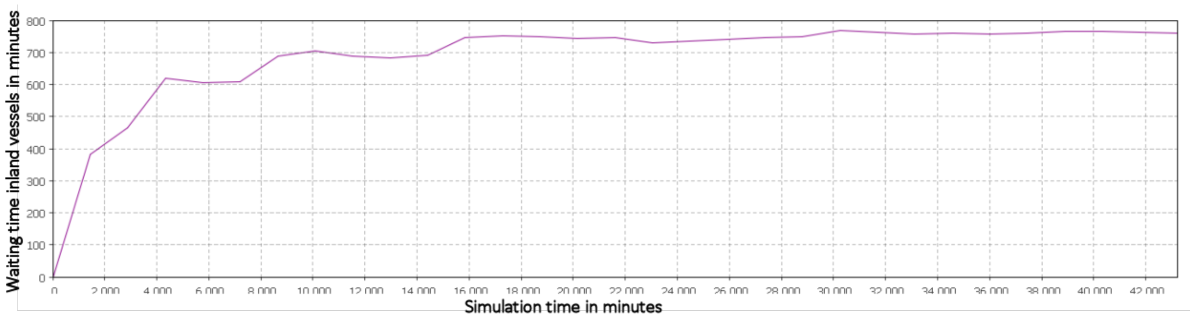

Figure 4-9: Waiting times inland vessels in Anylogic over time

Replications

Simulation runs need to be replicated in order to cope with the effects of variation in the model. Each replication is simulated with a different random seed that results in a somewhat different output per run. The default random number generator of Anylogic is used. It is an instance of the Java class Random, which is a Linear Congruential Generator (LCG). The LCG is known to be quick and requires a minimum memory usage. To determine the replication three methods are usable [29]. (1) A graphical method is used to plot the cumulative mean of a PI over multiple runs and the number of replications is then determined visually from the graph and confidence interval method. (2) the rule of Tumb, it states that a simulation experiment has to be replicated between 3 and 5 times. (3) Confidence interval method (CI) uses a defined estimation on the tolerated error on the mean for the experiments.

Both graphical method and the rule of thumb do not have a measured precision that determines the number of replications, and are therefore subjective. For this reason the method of confidence interval is used. In this method the level of certainty is chosen on forehand. Using the CI method, half the CI width of any performance indicator must be smaller than the defined boundary of the cumulative mean. In this model a 95% certainty interval has been chosen. Also the half width of the CI can not be larger than the 5% of the cumulative mean. The CI method states that if a performance indicator exceeds this limited another run must be added until all the indicators are within the required limit.

The formula used to determine the number of replications [45]:

$$d_n = \frac{100 t_{n-1,\alpha/2} \frac{S_n}{\sqrt{n}}}{\overline{X}_n}$$

The performance indicators where used to test the number of replication needed. The replications needed are shown in table 4-1.

Waiting time	23
Sojourn time inland vessel	10
Average container time in port	7

Table 4-1: Replications needed to reach a certainty of 95%

4-3 Verification & validation

In this chapter the verification and validation is performed. First the verification is done, after which the validation.

4-3-1 Verification

Verification is to determine if the model is working properly, verification is defined as "ensuring that the computer program of the computerized model and its implementation are correct" [49]. The model functioning has to be verified in respect to the goal of the model.

Building the model was a continuous verification process, in the version used (6.6 educational version) no debugger was present. However there are three ways to verify the ongoing progress; code check, visual aids and tracers. (1) Every new written piece of code can be checked by 'building' the model, which only takes several seconds, and shows if the written code it correct. The meaning 'correct' has to be taken literally, the code is checked whether or not it is reachable, the names of the variables are correct and if the commands are consistent with the used language. A correct written code does not translate directly to a preferred behaviour. After a piece of code is written it has to be verified to the behaviour it creates in the model. This can be done by visual aids. (2) The visual aids take form as graphs, movement of agents, variables and statistics. An animation of the PoR is made in Anylogic, inland vessels(agents) can be visually tracked throughout their stay in the model. While the vessels are moving through the model the state chart can be viewed at the same time, making it possible to check the progress of the inland vessel. Furthermore variables, arrays and collections show the individual state of a vessel. In the Main level graphs and other statistics can be visualised in order to keep track of the global progress in the simulation. It has to be mentioned that while Anylogic contains the building blocks for the visual aids it has to be programmed from scratch in order to make it work. (3) Checking the model while running required to build in so called 'tracers' that output a value or sentence if triggered. These tracers are used to check if the model is using the intended functions and right values and at what time.

4-3-2 Validation

"the substantiation that a model within its domain of applicability possesses a satisfactory range of accuracy consistent with the intended application of the model" [49].

The validation of the model has been done by means of historical data validation. Table 4-2 shows the PI from the model and the ones obtained from other sources.

	Model values (averages)	External source values (averages from 2014)
Inland vessel through system [vessels/month]	1075 per month	35 observed per day (1050 per month)
Sea going vessels [vessels/day]	20,1 on average	19,8 on average [40]
Containers [TEU/year]	320.000 per month, 3.84 million	4.2 million [5] [40]
Occupation inland vessels [%]	69 small inland vessels, 53 for large inland vessels	65 % for all inland vessels [53]
Waiting time [Hours]	32,6	between 24-72 (2007)[12]
Sojourn time [hours]	45,9	between 21 and 36 [34]
Call size [TEU]	30,7	35 (2007) [36]

Table 4-2: Values comparison between model and external sources

The arrival of the sea going vessels is a little higher than the average found for 2014. This means that the larger terminals will receive more sea going vessels which can cause a higher occupation rate than in reality. If this is the case the waiting times of inland vessels are higher and container travel times as well. The number of containers is lower than the monthly average and this will reduce the throughput of terminals and lower the occupancy of inland vessels. This is confirmed by the lower occupation observed in the model, unfortunately there is no data available to differentiate between large and small inland vessels.

Waiting time is in the range given by the historic data, but that data is a decade old. For this research the number of inland vessels in the port was counted. The counts were done with regular interval of around 24 hours. Inland vessels regularly showed up on two counts with 24 or more hours between counts. However, this where only a few per count and therefore it can be assumed that the waiting times of 32 hours is too high. The cause for the high waiting time can be allocated to the inflexibility of the model. Inland vessels determine their route hours before they arrive in the port area, if there is no available terminal the vessel can reduce speed and save fuel. Furthermore, the estimation of the time sea-going vessels spent in port is to high. The data to predict the time in port comes form the MaritimeTraffic website, vessels are registered as in port when they are still mooring or even turning into one of the Maasvlakte basins. The compensation of the time in port would require to explicitly go through every vessel and figuring out the precise moment of unloading, which would take too long for the scope of this research.

The sojourn time consist for a large part of waiting time, with the waiting time to high the sojourn time is as well. There is no indication on how much lower the sojourn time will be if the waiting time is reduced since the interaction with terminals determine this as well.

In conclusion; the model seems to imitate the system in the PoR. However, the results can not be used directly since some values are very different than from historic data. Meaning that results can only be interpret as trends and cannot be use numerical.

4-4 Sensitivity analysis

A sensitivity analysis can be defined as an set of experiments on how uncertain a model is in its output attributed to different sources of the model input [51]. With the experiments the input parameters can be tested on they sensitivity towards the system, also the robustness of the scenario's can be put to the test.

A commonly used method is to test the sensitivity of a model with means of OAT, 'one-at-a-time'. Several PI are selected but only one is altered each time to see the influence of that indicator on the model. It is a strait forward method that suits the need of this sensitivity analysis. The most uncertain input parameters are chosen for the analysis.

The number of inland vessel arriving in the PoR will be tested for two reasons; the data used to calculate the arrival pattern is not complete. Secondly the trade flow of containers has to be sufficient in order to support the use of a transferium, the question is what happens if the current modelled flow is less or more. The transshipment rate for inland vessel containers is a variable that is assumed for all cranes in the model area. However it is not clear if the rate represents the whole system and needs to be tested. The number of terminal calls. Due to limited time only these three have been tested.

A sensitivity analysis of the call size distribution per terminal would have been interesting to test since it is an assumed variable that can have large influence. Other studies like Douma (2008) [12] and Staalduinen (2014) [60] concluded that more information on the call size distribution would improve the simulation. However, they also concluded that the data accessible on the call size distribution is very limited. The data of Nextlogic is the only free available source that has and full distribution and not only a few averages [34].
The transshipment rate is a constant in this simulation but in reality something that can change over time, transshipment times will likely reduce in coming years as it has done in previous years. The arrival of inland vessels determine not only the number of vessels but also the throughput of containers in the system. With a differentiation in arrival rate the system is tested what happens if more vessels arrive with the same occupation rate. The sensitivity analysis can be found in Appendix D.

Chapter 5

Results analysis of the simulations

In this chapter the experiments are performed and the results presented. First the design of the experiments is given. And after that the experiments are elaborated.

5-1 Experiment design

The experiments conducted are the base scenario and transferium scenario. In this section the design of the experiment are given. The following scenarios are performed:

- Base scenario
- Transferium scenario
    - Minimum call-size limit
    - Minimum terminal calls
    - Limited transferium stack size

5-1-1 Base scenario

In the base scenario the PoR is simulated as described in Chapter 4. Figure 5-1 shows the general idea on how the inland vessels travel through the port.

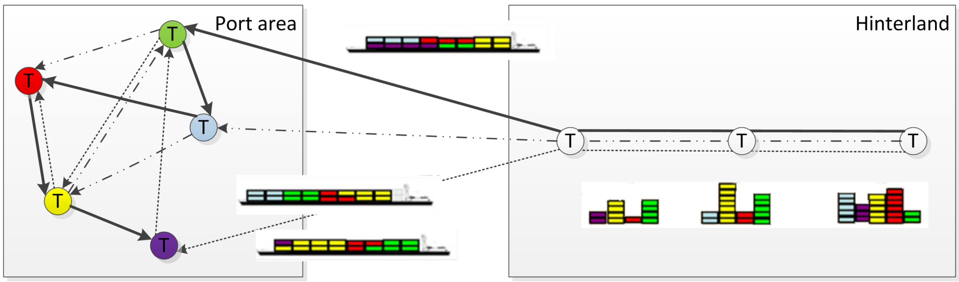

Figure 5-1: Transferium interaction variables

5-1-2 Transferium scenario

Two sets of experiments are performed in the transferium scenario, both sets are given in Table 5-1. Due to the limited time frame of this research only minimum call size can be investigated as an input variable. The calls size minimum ensures that call sizes smaller must be delivered to the transferium. In the first set the output variable minimum terminal calls is tested. The minimum terminal calls represent the minimum number of terminals that must to be visited in the port area after the transferium is visited. The logistical concept used in this research is "ongoing transport" which means that the inland vessels need to have at least one terminal call on-board when leaving the transferium. The average terminal call of an inland vessels is 5.8 and the goal of the transferium it to reduce the number of terminal calls, therefore the minimum terminal call is examined up to 5 calls. The second set of experiments is focussed on the stack size of the transferium, having a to large buffer could lead to containers staying to long on the transferium. The stack limitation of 125 TEU represents the maximum number TEU that can be present on the transferium for one terminal, in total 1250 TEU can be stored on the transferium. The first value of the stack limit was 500 [TEU] to explore the variable since not much is known. After the first experiment the stack limited of 500 [TEU] seemed to large and was cut in half twice.

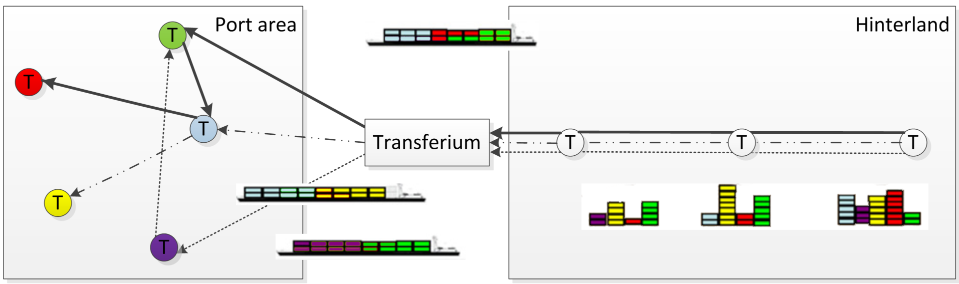

Figure 5-2: Transferium interaction variables

In Table 5-1 three specific combination of variables are filled in with the specific name for the experiment, e.g. Minimum call size 10 and minimum terminal call of 1 will be referred to as 10|1 and minimum call size 50 with a limited transferium stack of 250 [TEU] will be 50|250.

Table 5-1: Experiments overview set 1 and 2

Minimum call size	Minimum terminal call				
	1 #	2 #	3 #	4 #	5 #
5 [TEU]					
10 [TEU]	10|1				
15 [TEU]					
20 [TEU]					
25 [TEU]				25|4	
30 [TEU]					
45 [TEU]					
50 [TEU]					

Minimum call size	Limited transferium stack		
	125 [TEU]	250 [TEU]	500 [TEU]
5 [TEU]			
10 [TEU]			
15 [TEU]			
20 [TEU]			
25 [TEU]			
30 [TEU]			
45 [TEU]			
50 [TEU]		50|250	

First the ongoing operations with the the minimum call-size and at least 1 terminal call is evaluated in the next section. This is done to give a general overview of the effects the transferium has on the container transport chain before alterations to the initial concept are introduced. Then the minimum terminal calls are expanded to 5 and discussed. Finally the transferium stack size limit is discussed.

5-2 Experiment: Base scenario

In order to compare the scenarios a base scenario is created. As presented in chapter 4 multiple runs are needed to ensure 95% reliability, the averages of the KPI's presented in Chapter 2 of 27 runs are presented in table 5-2. The results are made by the Anylogic model.

Table 5-2: KPI for the base scenario

Sojourn time inland vessels [Minutes]	Container travel time [Minutes]	Waiting time inland vessels [minutes]	Terminal call [#]	Average container call-size [TEU]
2627 minutes	707 minutes	1742 minutes	6.6 Calls	29.8 TEU

Figure 5-3 shows a box plot with waiting times of the inland vessels visiting the PoR. The plot clearly shows the deviation of waiting times in the port, longest waiting times are almost 4300 minutes (71 hours). Long waiting times (more than a day) are extreme cases in which multiple terminals are fully being used by ULCV's, causing delays for inland vessels. After some of the runs the model was reviewed and shows that in the cases with extreme waiting times one or two terminals were congested. Waiting times for the individual terminal are observed as high as 2500 minutes, no individual terminal data was saved by the model.

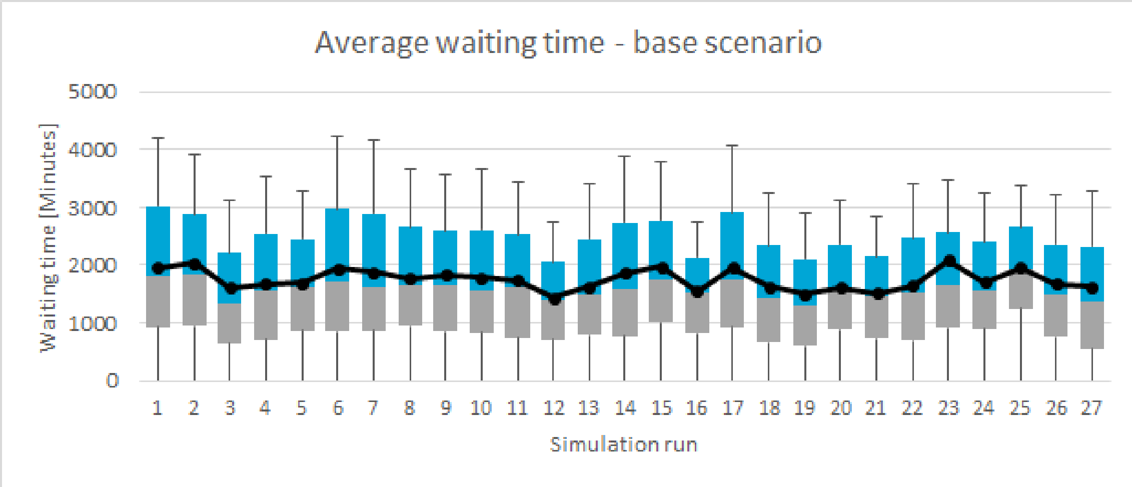

Figure 5-3: Average waiting time for inland vessels for multiple base scenario model runs

To visualise the vessels stay in the port a graph of waiting, travel and total time in system is presented in figure 5-4. The graph shows a random simulation run of the base scenario. Every vessels modelled has three coloured dots that represent travel time (green), waiting time (red) and time in system (orange). From the figure some behaviour of the model can be seen. Starting with the travel time, the size of the inland vessel determines the number of terminal calls it has to make since there are two types of vessels in the model two horizontal patterns can be seen in the green dots. The waiting time (in red) shows a descending pattern, this is caused by one or two terminals that are to congested also known as bottleneck terminals [12]. Douma (2008) concluded that the total waiting time in the port depends on the waiting times at bottleneck terminals, this figure underpins this behaviour. The anylogic model supports this, the highest waiting times are caused by mainly three terminals (Euromax, ECT Delta, APMT-2 and short sea shipping). Average waiting time is 5 to 6 hours for these terminals and the average waiting time per terminal is 3 hours The average waiting times It has to be mentioned that the data from the graph is collected when a vessel leaves the system, which causes the descending pattern to be grouped.

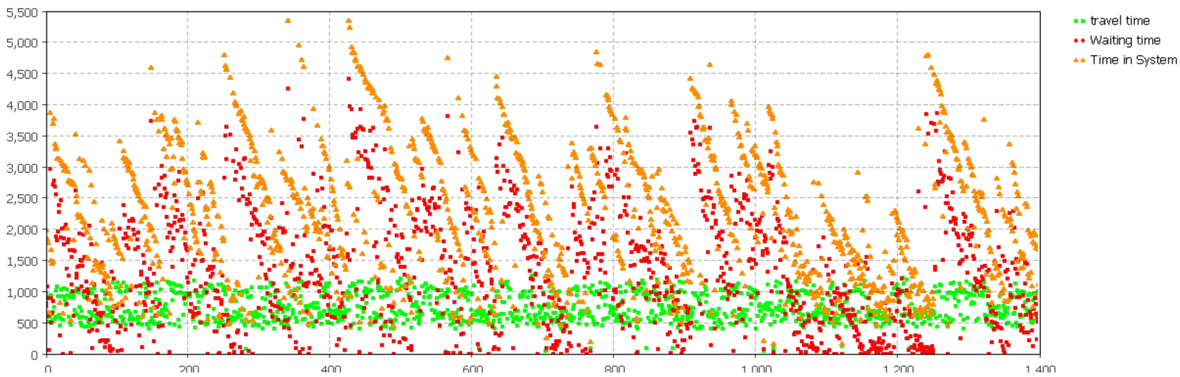

Figure 5-4: Model output for inland vessels

5-3 Experiment: Transferium scenario

In this section the results of experiments regarding the transferium scenario are given. First the minimum call-size and minimum one terminal visit is elaborated upon. Second the number of minimum terminal calls is raised between 2 and 5. Third the limited transferium stack size is given.

5-3-1 Minimum call-size & 1 terminal visit

Table 5-3 shows the strategic performance indicators that are determined in section 2-1-3. The sojourn time of inland vessels is decreasing as the minimum call size increases, at call size 50 TEU the reduction of the sojourn time is more than 60%. The average number of calls of inland vessels in the port is also reduced by increasing the minimum call-size. The 50% reduction is reached around 20 call size limit which is much sooner in relation to the sojourn time. The introduction of a transferium can reduce the sojourn time of inland vessels significantly, however the container travel time shows something different. At first the container travel time is reduced up to 8.3% at call size minimum of 15 TEU, but when the minimum call size increases the travel time increases as well. The container travel time is almost doubled at minimum call size 30 TEU.

Table 5-3: Overview of strategic performance indicators

Minimum call-size	Minimum terminal call = 1					
	Sojourn time inland vessels [Minutes]	Difference with base scenario [%]	Container travel time [Minutes]	Difference with base scenario [%]	Number of calls [#]	Difference with base scenario [%]
Base scenario	2726	-	707	-	6.1	-
5 [TEU]	2506	-8.1	675	-4.5	5.2	-14.8
10 [TEU]	2376	-12.8	650	-8.0	4.3	-29.5
15 [TEU]	2315	-15.1	648	-8.3	3.4	-44.2
20 [TEU]	2185	-19.8	661	-6.4	3.1	-49.4
25 [TEU]	1915	-29.8	777	9.9	2.9	-52.4
30 [TEU]	1782	-34.6	1248	76.5	2.4	-60.6
45 [TEU]	1174	-56.9	7252	925.8	1.6	-73.6
50 [TEU]	1026	-62.4	9233	1205.9	1.4	-76.4

The increasing container travel time is caused by containers that are dropped off at the transferium and not picked up. Bundling the container flows cause the average terminal calls to lower and less inland vessels call at port terminals overall. This mechanism is needed to bundle the cargo flows, but when the output of the bundling point is smaller than the inflow congestion occurs making the bundling point a bottleneck in the transport chain. By reducing the absolute number terminal calls in the port the outflow of the bundling point is reduced, container time on the transferium is increased and eventually containers do not reach their destination. Table 5-4 shows the increase in transferium time for containers and the number of container on average on the transferium. The time spend on transferium increases rapidly after minimum call size 20 TEU. The number of containers increases slightly when the minimum call-size increases but note that container time on transferium is only counted when containers leave, thus when the stockpile grows the containers time grows not as fast. The leaving containers are selected on the first-in first-out principle (FIFO).

Table 5-4: Time containers spend on the transferium and average number of TEU in the transferium stack

Minimum call-size	Average time containers spend at transferium [minutes]	Average number of containers on transferium [TEU]
5 [TEU]	258	30
10 [TEU]	252	51
15 [TEU]	293	106
20 [TEU]	397	238
25 [TEU]	943	847
30 [TEU]	2352	3306
45 [TEU]	17993	42345
50 [TEU]	23293	57676

Figure 5-5 shows that the percentage of inland vessels visiting the transferium increases with the increase of the minimum call-size. It also shows that the occupation of the vessels drop after 30 TEU, which matches the previous table and underpins the result that containers do not reach their destination at high call-size minima. Furthermore, the smaller inland vessels show a reduction of occupancy while the larger vessels show an increase before the 30 TEU call-size minimum. The larger vessels are filled up at the transferium with containers of smaller vessels, this is because the larger vessels visit more terminals on average and thus have a higher chance of loading containers at the transferium. After the 30 call size limit both drop significantly because of terminals that are not visited any more.

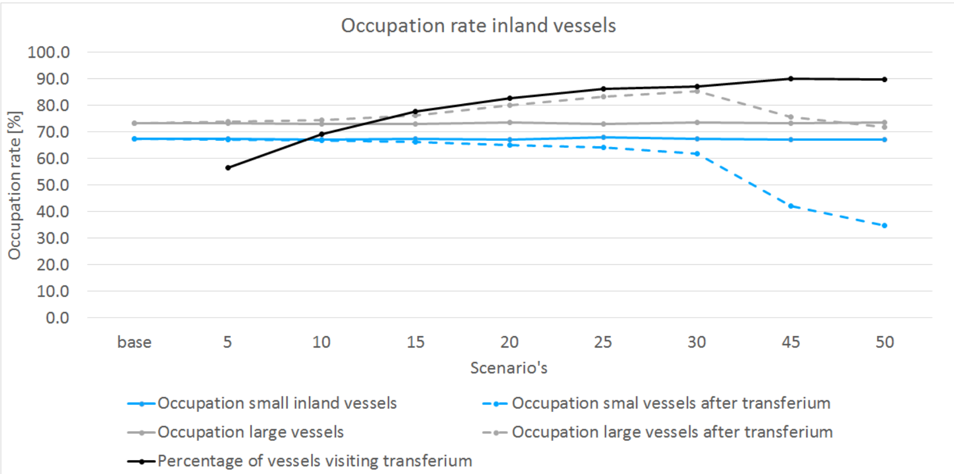

Figure 5-5: Occupation rate of inland vesselss

Performance of inland vessel at different terminals Figure 5-6 shows the waiting times of inland vessels at the individual terminals. The solid (red) lines are terminals on the MV, these terminals are large size terminals that are visited by both inland vessels as well as sea going vessels. The average waiting time is higher in the model than other terminals but is not affected by the minimum call size up to 20 TEU, from 25 TEU and on the waiting times drop due to the decrease in vessel calls. The long dotted lines (red and blue) are medium size terminals, located at both MV and W/E areas and can be visited by the smaller sea going vessels and inland. These terminals have a smaller waiting time at the base scenario but and immediately after the introduction of the minimum call size the waiting times go down for W/E terminals but the waiting times at the MV terminal only drop after the 30 TEU minimum call-size. The difference is due to terminal characteristics which will be discussed in the next paragraph. The last set of terminals are the small size terminals in the fast dotting lines (black), these terminals are located in the W/E area of the port and only inland vessels can berth. Same as like the medium terminals, when the minimum call-size is introduced the waiting times reduce. However, the reduction in waiting time for inland vessels is reduced on a more even basis as the graph shows.

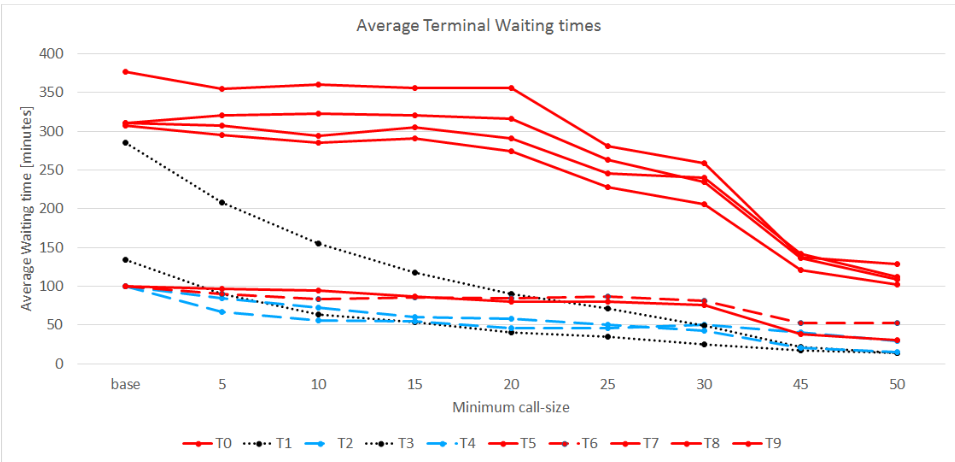

Figure 5-6: Average terminal waiting time for minimum call size scenario

Call-size distribution on terminals Previous section 4-2-3 shows that port terminals have different sizes and number of berths, the previous paragraph shows that the characteristics of a terminal influence the waiting time of inland vessels. Table 5-5 shows a relation between call-size distribution of inland vessels that call at the terminals and the implementation of a transferium with minimum call-size. The table shows the change in travel time of containers related to the base year. The observed relation is when the call-size minimum nears the call-size distribution average of a terminal the travel time of containers increases rapidly. Although this is not the case on every terminal, as the table shows, thus other factors might be of influence as well.

The call size distribution of inland vessels that call at small and medium size terminals are on average 24 TEU, large terminals have an average of 44 TEU. The tipping point for container travel time on large terminals is clearly shown in table 5-5 between 30 and 45 TEU. The exact tipping point is not known due to the step size in call-size minimum, however the increase is significant. The small and medium terminals show for the most part the same behaviour, 3 out of 5 terminals have an increase in container travel time between 20 and 25 TEU minimum call-size. However, the relation is not uniform to all terminals, the second medium terminal shows a tipping point between 25 and 30 TEU. And the third medium terminal's tipping point starts at 25-30 and increases after 45 TEU. The small and third medium terminal have two things in common, first sea going vessels do not call at the terminals and second the waiting times are already low (between 10-30 minutes on average). But tipping points are still visible near the distribution average of 24 TEU.

Thus in general containers destined for terminals with low waiting times do not benefit from using the transferium to reduce the travel time. Containers destined for terminals with a higher waiting time benefit from the transferium put to the point that the average of the call-size distribution on board inland vessels is reached.

Table 5-5: Changes in the container travel time per terminal in [%] of the base scenario

Call-size minimum	Small terminal		Medium terminal			Large terminal				
5 [TEU]	8	3	-6	-5	0	-5	-3	-9	-9	-3
10 [TEU]	10	5	-6	-7	1	-7	-10	-13	-13	-3
15 [TEU]	25	8	-6	-12	5	-12	-11	-13	-18	-3
20 [TEU]	60	19	4	-16	12	-16	-14	-13	-19	1
25 [TEU]	140	117	168	-18	31	-18	-20	-24	-23	11
30 [TEU]	885	528	614	16	73	-1	-18	-23	-18	65
45 [TEU]	5206	1576	1371	752	2017	751	449	655	736	2104
50 [TEU]	5457	1746	1372	887	2242	887	1008	944	899	2484
Terminal size [%]	2.0	2.0	5.9	5.9	4.0	13.6	25.2	16.5	13.3	11.6
Number of berths [#]	2	1	12	8	2	12	30	12	12	14

5-3-2 Minimum call size & terminal calls 2-5

Adding minimum number of terminal calls for inland vessels after they have visited the transferium changes the sojourn time and container travel time, Figures 5-7 and 5-8 show the changes. The sojourn time of inland vessels increases as the number of minimum calls increases, the large minimum call-sizes are more influenced than the smaller as 5-7 shows. However, the container time of minimum call-size 30-45-50 TEU is still enormous in comparison to the base scenario. Figure 5-8 shows the reduction of the container travel time when the minimum number of terminal increases.

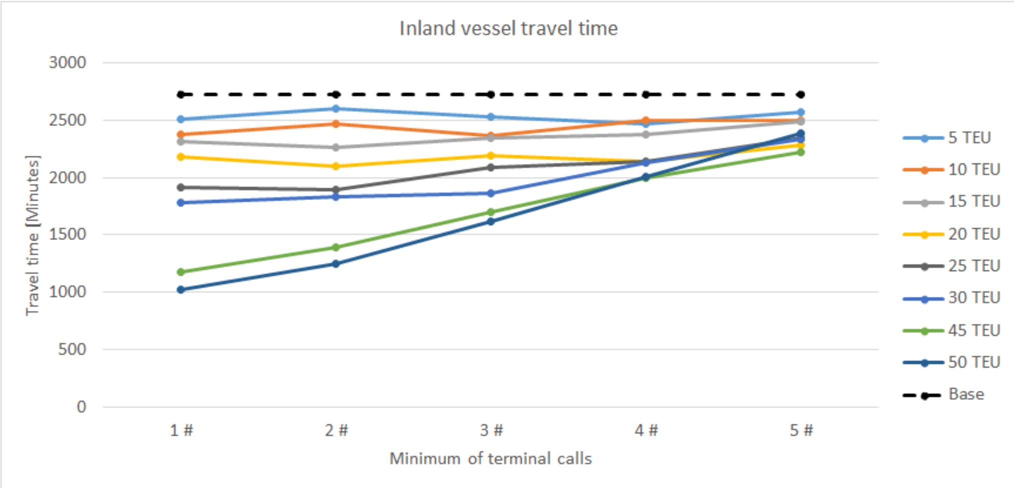

Figure 5-7: Container travel time with minimum number of terminal calls

The container travel time for minimum call-size 45-50 TEU are in a steady decline in Figure 5-8. At a minimum of 5 terminal calls both lines are still three times as large as the base scenario container travel time. Call-size 25-30 TEU are steady lines across all the minimum terminal calls, respectively around 800 and 1200 minutes, which is both higher than the base scenario of 707 minutes. Smaller than 25 minimum call-sizes are steady around 650 minutes.

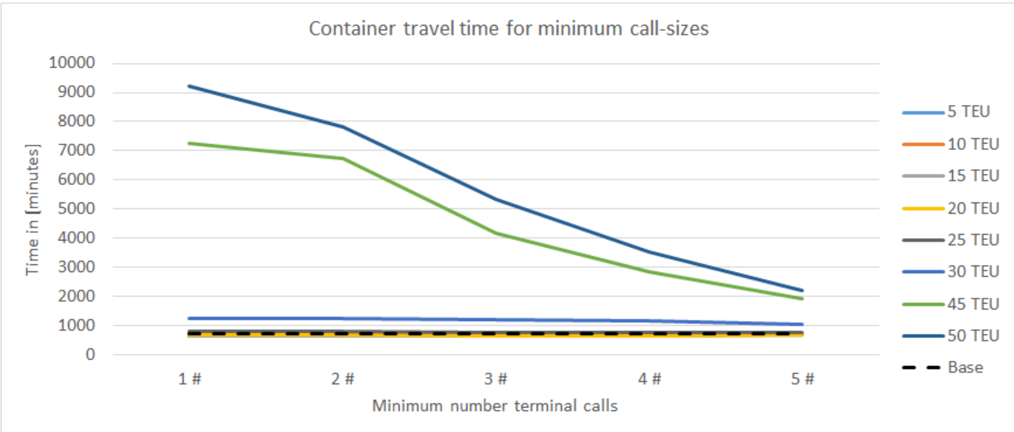

Figure 5-8: Container travel time with minimum number of terminal calls

Table 5-6 shows the increase in number of terminal inland vessels visit on average. For minimum call sizes 5-10 TEU the number of terminal calls does not change much, for the higher minimum call-sizes the average terminal call increases as the number of terminal calls increase. The increase in terminal calls accounts for the increase in sojourn time for inland vessels, more terminal calls cause more travel time, waiting time and thus sojourn time increases.

Only the inland vessels that visit the transferium will be subjected to the minimum number of terminal calls. Vessels that do not meet the input variable threshold (minimum call size) sail past the transferium. Table 5-6 shows the effect of minimum number of terminal call has on the actual number of terminal calls inland vessels make on average. Increasing the minimum terminals visited after transferium will still result to a reduction of calls in comparison with the base scenario (6.1 calls).

Table 5-6: Number of terminal calls for inland vessels

Base scenario 6.1 calls	Minimum terminal call				
Terminal calls	1 #	2 #	3 #	4 #	5 #
5 [TEU]	5.2	4.9	5.0	5.0	5.1
10 [TEU]	4.3	4.5	4.5	4.5	4.7
15 [TEU]	3.4	3.9	3.9	4.1	4.3
20 [TEU]	3.1	3.4	3.4	3.6	4.1
25 [TEU]	2.9	2.9	3.1	3.4	3.9
30 [TEU]	2.4	2.6	2.7	3.2	3.8
45 [TEU]	1.6	1.7	2.2	3.0	3.8
50 [TEU]	1.4	1.6	2.1	2.9	3.8

The minimum terminal calls do not change the container travel time of the small-medium-large terminals for call-size minimum of 5-30 TEU. At 45 and 50 TEU the container travel time for all types of terminals decrease in relation to minimum 1 terminal call, but this change is not significant.

5-3-3 Minimum call size & limited transferium stack size

The introduction of a transferium in the container transport chain and the minimum call-size as input for the transferium show that when the minimum call-size increases the transferium gets congested. The consequences are for minimum call-size 25 TEU and higher are an increase in container travel time. A solution could be to limit the transferium, by limiting the transferium containers cannot be stored over a certain number. Inland vessels that arrive at the transferium with call-sizes smaller than the minimum will not be unloaded if the maximum stack size is reached. Leaving the transferium only the remaining call-sizes larger than the call-size minimum will be supplemented with containers of the transferium. Adding containers to all remaining destinations is not done due to the simplifications made in the model, but would be an addition worth investigating in the interaction with the transferium.

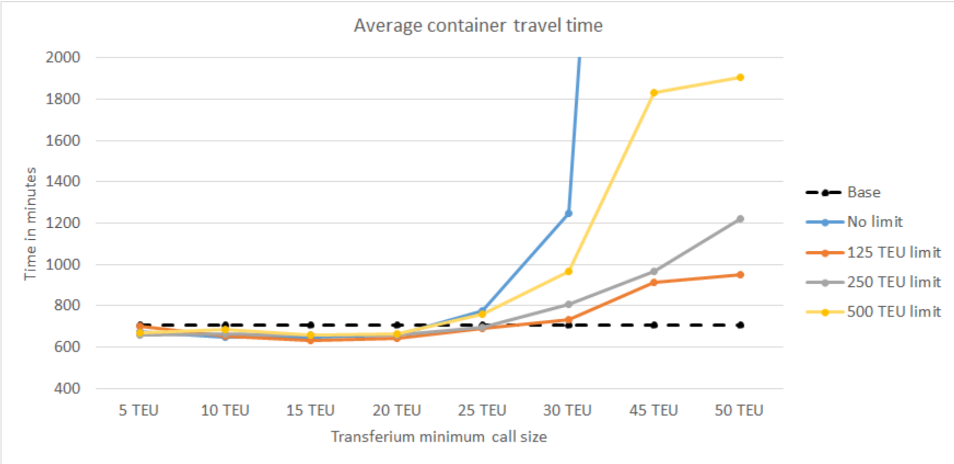

Figure 5-9: Container travel time
for limited transferium capacity scenario

Stack limitations 1250-2500-5000 TEU have been tested. Figure 5-9 shows the container travel time after the limitation is added to the transferium. The limitation starts to have an effect on the container travel time after minimum call-size 20 TEU, at 25 TEU the difference between the variation becomes clear. The highest line (blue) in the graph shows the container travel time without a transferium limit, 45-50 TEU are not shown but are 7000 and 9000 minutes. The stack limitations shows a decrease in container travel time relative to the no limit variation. The 25 TEU call-size minimum shows that the 125-250 TEU limit are still an improvement to the base scenario, however the improvement does not carry to the larger call-size minimum.

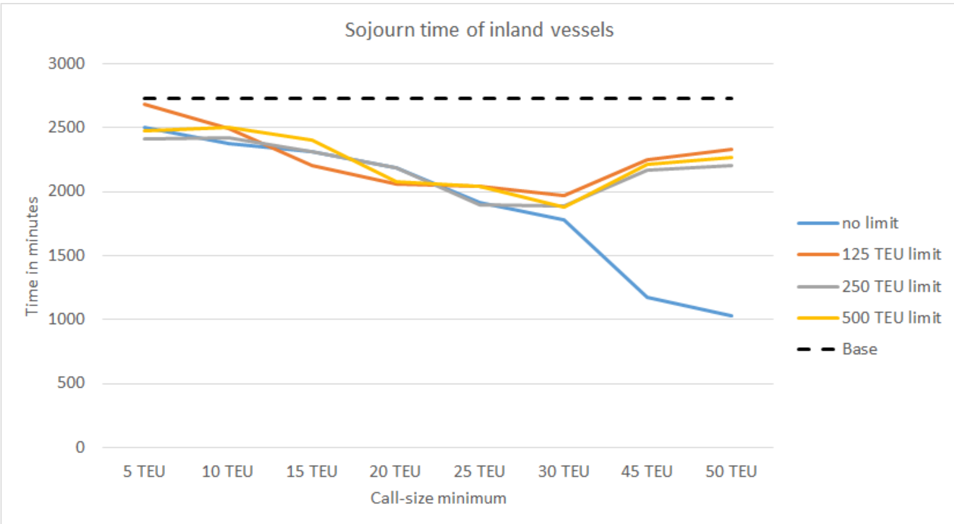

Figure 5-10: Inland vessel waiting times for limited transferium capacity scenario

The limited stack on the transferium has no effect on the different size terminals in relation to the first variation were at least 1 terminal is visited. An overview of data collected can be found in Appendix E.

5-4 Conclusions: Result overview

Table 5-7 shows the overview of the scenarios and the variation within of the container travel time. It clearly shows that that both the minimum terminal calls and limited transferium stack have influence on the higher minimum call-sizes. However, they improve the already negative effect of the higher call-size minimum.

Table 5-7: Overview of the container travel time for all experiments

Base scenario: Container travel time	Minimum terminal call					Limited transferium		
Minimum call-size	1 #	2 #	3 #	4 #	5 #	125 [TEU]	250 [TEU]	500 [TEU]
5 [TEU]	-5%	-3%	-7%	-6%	-5%	-7%	-7%	-6%
10 [TEU]	-8%	-5%	-6%	-5%	-7%	-7%	-6%	-5%
15 [TEU]	-8%	-9%	-7%	-8%	-5%	-9%	-7%	-7%
20 [TEU]	-6%	-6%	-8%	-8%	-5%	-9%	-7%	-6%
25 [TEU]	10%	15%	8%	9%	6%	-3%	-1%	8%
30 [TEU]	76%	73%	67%	65%	46%	3%	14%	37%
45 [TEU]	926%	850%	488%	299%	170%	29%	37%	159%
50 [TEU]	1206%	1007%	655%	396%	211%	34%	73%	170%

Table 5-8 shows the sojourn time over al experiments. The inland vessels benefit of the minimum call-size irrespective of the number of TEU. However, when a limited stack size is introduced the benefits are reduced.

Table 5-8: Overview of the sojourn time of inland vessels for all experiments

Base scenario: Container travel time	Minimum terminal call					Limited transferium		
Minimum call-size	1 #	2 #	3 #	4 #	5 #	125 [TEU]	250 [TEU]	500 [TEU]
5 [TEU]	-8%	-4%	-7%	-9%	-6%	-2%	-12%	-9%
10 [TEU]	-13%	-9%	-13%	-8%	-8%	-9%	-11%	-8%
15 [TEU]	-15%	-17%	-14%	-13%	-9%	-19%	-15%	-12%
20 [TEU]	-20%	-23%	-20%	-22%	-16%	-24%	-20%	-24%
25 [TEU]	-30%	-31%	-23%	-22%	-14%	-25%	-30%	-25%
30 [TEU]	-35%	-33%	-31%	-22%	-15%	-28%	-31%	-31%
45 [TEU]	-57%	-49%	-38%	-27%	-18%	-18%	-21%	-19%
50 [TEU]	-62%	-54%	-41%	-27%	-12%	-14%	-19%	-17%

Chapter 6

Discussion, Conclusions and Recommendations

In this chapter the discussion is presented, after which the conclusions for the sub- and main research questions are drawn and the recommendations for future research are given.

6-1 Discussion

In this section, will be reflected on the model that has been used in the research and the various research methods that have been used.

Simulation model The conceptual and simulation model used in this research comes with several assumptions and simplifications. The assumptions reduce the degree in which the model represents the real world. For instance, not all coordination mechanisms between inland vessels and terminal operators are modelled. The route generation in the model is based upon the full knowledge when berths are available. On the other hand, terminals also have full knowledge on when the vessel arrive. The interaction between the inland vessels and the terminals contain uncertainties that are not presented in the model.

Furthermore, the route choice in the model is deterministic. After the route is determined no changes can be made, no interruptions during transshipment and no flexibility. The deterministic approach removes the planning uncertainty but on the other hand the flexibility as well. If a (too) small window exist for an inland vessel to unload a few containers, the model will reject the possibility for transshipment. However, in reality the vessel can be squeezed in, resulting in a minimal delay for the second ship but a major benefit for the first vessel. Another option is to deliver the containers to terminals from where the containers are transported by truck-/vessels to their destination. The priority container has not been considered. Some containers have a limited time frame to get to the destination terminal, these containers could possibly be delayed by going through the transferium. Including this in the simulation model requires more detailed information.

The model does not consider the transport costs of containers, small gains in travel time can be negated by the extra costs of transshipment at the transferium. The performance of the hinterland connection is also depended on the costs of transport, if the transferium would increase the costs of transport then the travel time should negate the extra costs for the transferium to be an improvement.

Simulation input The reliability of some of the data is uncertain. The call size distribution at the terminals is the most uncertain and most influential variable. Furthermore, the data of the terminals is estimated, the real capacity could be influenced by other factors than only the number of cranes. Next to that the terminals maximum capacity dictates the distribution for arrival of the inland vessels as well as the sea-going vessels, this is influenced by contracts and alliances.

The model gives an estimation that resembles the current reasonable well, but some substantial changes have been made to the PoR since the data was collected. New terminals on the Maasvlakte are opened and a city terminal closed.

The arrival pattern of sea going vessels is obtained from data of one month. Seasonal effects are not considered and data on a whole year (or multiple) will give more accuracy in modelling the scenarios.

Simulation results The simulation by Caris, et al. (2009) suggests that the introduction of a transferium will reduce the waiting times at terminals [4]. This model has shown different results before the drop-in throughput. This may be since the model has not modelled the irregularities, when the route is determined no changes can be made. While the appointments can be missed due to external effects.

Discussion of methods used The model required between 5 and 45 minutes for one simulation run, the more extensive use of the transferium results in a longer computational time. A newer version of the software could solve some inefficiencies that where not circumventable in the current version. Furthermore, the model could only work on one CPU core and a maximum of 4GB of ram. With less runtime or simultaneous runs, more variables and a more dens variety of parameters could have been tested.

Anylogic provided a good base to model the inland shipping in the PoR. The level of customization with the built-in modules and components made it a program that was pleasant to work with. The main disadvantage was the lack of overview in the coding added to various parts in the model, which made finding errors in behaviour difficult from time to time.

6-2 Conclusions

Before the main research question can be answered, the sub-questions must be addressed. In chapter 2 the sub-question where answered based on existing literature, the same questions can be answered with the results from chapter 5. Combining the answers to these questions will formulate an answer on the main research question.

Strategic aggregation level

- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a strategic aggregation level?*

The cases where only small call-sizes are bundled (before the tipping point) the transferium increases the performance of the inland shipping in the PoR on a strategic level. The container travel times and sojourn time of inland vessels is reduced. When the transferium gets congested by too many containers, the transport chain efficiency reduces by increasing the container travel time.

On the strategic aggregation level the sojourn time and container travel time are the two key performance indicators and both are reduced by the introduction of a transferium. A large part of the sojourn time of inland vessels is due to waiting times at terminals. Reducing the number of terminal calls by bundling containers through a transferium, results in a decrease of terminal visits and sojourn time. All experiments show that the sojourn time of inland vessels will reduce.

The container travel time is the other key indicator, when the travel time for containers increases, the benefits of a transferium to the transport chain diminishes. The container time is defined the time on an inland vessel plus the time on the transferium, when the transferium gets congested the total container travel time increases. As the input of containers to the transferium increases the changes on congestion increase, in the model a tipping point was found after which the container travel time drastically increases. The terminals experience minor change in their daily business, the occupation rate on the berths stay the same, possibly the number of total calls is reduced if the throughput stays the same. When the transferium is congested the throughput of the terminals decreases.

Tactical aggregation level

- *How can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a tactical aggregation level?*

The individual terminals themselves experience no negative changes, except when the transferium is congested, then the throughput decreases. Waiting times for inland vessels at medium terminals are reduced when the minimum call-size increases. The effects on a tactical aggregation level varies between terminals, inland vessels and containers. Containers benefit at medium and large terminals and inland vessels benefit at medium terminals. Terminals itself have little to none benefit. The ongoing transport logistical concept works for small minimum call-sizes, increasing the minimum call-size requires a different approach than has been used in this research.

On the tactical aggregation level the effects on the individual terminals and their container travel time is examined. The results of the model show that the three sizes of terminals experience different consequences with the transferium in the transport chain.

The reduction in container travel time to terminals is different for each size terminal. Containers for small terminals experience a negative effect on their travel time. The occupation of berths at these small terminals is low in the model, which makes the conclusions questionable, but container travel time to smaller terminals tends to be less. When the minimum call-size increases and reaches the average call-size of inland vessels, the container travel time increases drastically. The container travel time to medium sized terminals decreases for minimum call-sizes less than the average call-size of inland vessels. After the tipping point a rapid increase in the travel time is reached when the minimum call-size is increased over the average call-size. The container travel time to larger terminals show the largest decrease up to the tipping point, the reduction can be as great as 24%.

For all terminals alike, the occupation rate at the berths does not change when the call-size minimum is raised. The waiting times for large and small terminals stays the same when the throughput stays the same. However, the waiting times for medium sized terminals improve. Their waiting time decreases as the minimum call-size increases.

Operational aggregation level

- *how can the hinterland performance of inland container shipping be influenced by introducing a B-to-B transferium on a operational aggregation level?*

The explored variations on the transferium scenario negate the negative effects on higher minimum call-size input but do not improve the transport chain. The limited transferium stack size could help improve the transport chain when a small limit is used. In general, more research is needed to identify other ways to use the variable surroundings to improve the interaction with the transferium.

On the operational aggregation level the interaction between transferium and inland vessels is examined. The input and output variables determine the interaction with inland vessels as well as the effects on the transport chain.

The variables used for the in- and output of the transferium are elementary, since little research has been done on the operational level of a transferium as suggested in this research. The effects of the minimum call-size input seem to correlate with the call-size distribution on the inland vessels. When the minimum call-size limit approaches the average call-size, the transferium receives more containers than are distributed, thereby increasing the number of container in stack and creating an unbalanced system. As a result, the system stalls and the throughput at terminals drops.

The output of the transferium is regulated by the minimum number of terminal calls. The effects are clear; when the number of terminal calls increase the travel times reduces and travel time of inland vessels increases. But these measures influence the negative effects of the transferium when congestion occurs and does not contribute to improving the transport chain. Like the minimum terminal calls, the introduction of a limited stack size decreases the negative effects that occur when the call-size minimum rises over the average call-size.

General conclusion Now that the sub-research questions have been answered the main research question can be answered.

"What are the effects of a barge-to-barge transferium on the hinterland connection performance of inland container shipping, in the Port of Rotterdam?"

The introduction of a transferium into the transport chain in Rotterdam is an improvement to the hinterland performance of inland container shipping. The sojourn time of inland vessels is reduced in all variations, the container travel time is improved for terminals with long waiting times and the waiting times at terminals without large sea going vessels is improved.

The configuration of the interaction between inland vessels and transferium is key to the implementation success. However, the tested variables in this research are elementary and more sophisticated interaction with transferium is required to examine the benefits for each individual actor. Overall the effects are positive. Though a more detailed model is required to fully understand the implications that come with a B-to-B transferium.

This model provides an overview on the general choices that should be made when implementing a transferium. Also, it examines a set of choices and its effects.

6-3 Recommendations

The variables used as input and output are simple variables, there are other options thinkable to test the interaction of the transferium. E.g. only serve certain terminals, only serve containers destined for the congested terminals, only serve low priority containers. A more dynamic interaction algorithm between transferium and inland vessels should be investigated to get a better understanding of the factors that influence the transferium. It should help identify external factors like the relation between average call-size and the minimum call-size found in the results of this research.

Differences between the influence of the transferium on terminals in the Maasvlakte and Waal/Eem area are found in the results. Decoupling the two areas in a different interaction algorithm could accommodate the needs for both areas, increasing the effectiveness of the transferium.

The results show that the number of containers at the transferium is small, but still the time spend on the transferium is over 3 hours. To reduce the container travel time more, a small shuttle service between transferium and terminals could be a solution. Also in other variations of the experiment could a shuttle help improve the transport chain. E.g. when the transferium receives too many containers for a specific terminal a shuttle can be used to reduce the travel time for that specific terminal.

Before the tipping point, only smaller call-size minimum, the number of TEU on the transferium is around the capacity of an inland vessel of 210 TEU on average. This means that the transferium does not have to be a large terminal, of course the 210 TEU is an average over a months time but it indicates that smaller transferium are worth investigating. A few small sailing transferium could potentially have enough capacity to facilitate the transport chain.

Considering the costs of transport will allow a better overview of the effect the transferium has on the competitiveness of the inland shipping modality.

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Appendix A

Container transport on Dutch inland waterways

A-1 Container trade flow

The main transportation of containers per inland waterways, can be categorized in three parts; Rhine trade (to Germany), Rotterdam-Antwerp trade and domestic trade. Figure A-1 shows the container flows on Dutch waterways for the year 2014. In 2014 a total of 5.3 million TEU was transported over Dutch inland waterways. When looking further into the Rhine trade three areas of Rhine trade can be identified; lower, middle and higher Rhine [20]. Every part of the trade has its characteristics of trade flow, the lower parts of the Rhine will take two weeks to make a round-trip, while areas near the Dutch-German border can have two trips every week. Furthermore the sizes of vessel are related to the CEMT class of the waterways, large waterways like the Rhine can be sailed by larger vessels than smaller waterways in domestics trade.

Table A-1 shows the important trade flows between Rotterdam and the hinterland. Domestic trade is by far the largest flow of container by inland vessel. The flow between Rotterdam and the province Zuid Holland (ZH) is around 150.000 TEU. It is unlikely that containers with destination Rotterdam are transported via waterways, thus the flow of containers is most likely part of multi-modal transport. The transportation from ZH to the EU hinterland is 111.000 TEU which is a combination of produced goods in ZH and goods imported from the PoR. From these numbers we can deduce that there is a flow of containers being moved from sea terminals, via a (inland) terminal in ZH, to the hinterland. The share of the 110.000 TEU that is part of the inter-modal transport is unclear for the CBS data [5]. In 2015 the transferium of Alblasserdam has been opened

Trade flow	Quantity (x Million)
Rotterdam - NL	1.80
Rotterdam - DE	1.02
BE - DE	0.97
Rotterdam - BE	0.70
Rotterdam - ZH	0.15
ZH - EU	0.11

Table A-1: Main trade flows on Dutch inland waterways in 2014

Figure A-1: Container trade flow on Dutch inland waterways 2014

for both road and water transport, the change on the inland waterways by this transferium is not visible in the data from CBS but will have influence on the system. Although in a recent news post they state that the terminal is far from reaching its goals of begin a transferium for inland vessels [55].

A-2 Inland container vessels

The Dutch waterways are populated by multiple types of container vessels, sailing under different flags. In 2014 container vessels under the flags of Belgium, France, Germany, Switzerland and The Netherlands could be found on the Dutch inland waterways [5]. Around 5000 vessels are sailing the inland waterways yearly [5]. The Dutch BVB (Bureau Voorlichting Binnenvaart)

[10] shows three types of inland container vessels used on the Dutch waterways. Only the 200 TEU and 500 TEU vessels are used in the model.

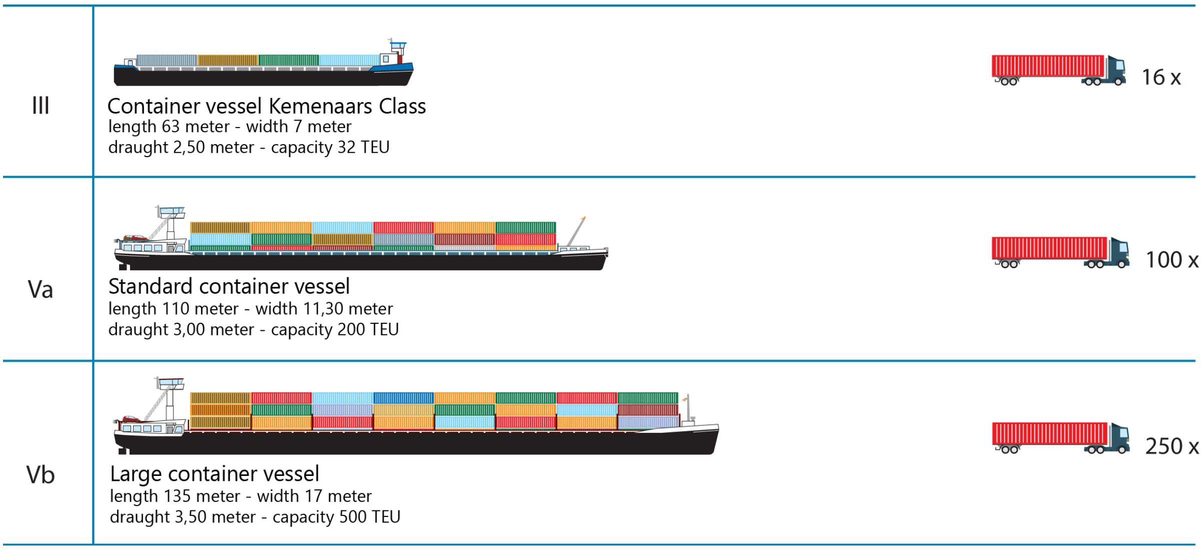


Figure A-2: Types of inland containers vessels found on Dutch waterways

A-2-1 Inland vessels visiting the Port of Rotterdam

The transportation of containers over inland waterways requires organisation between multiple actors. Figure A-3 shows the communication interaction between actors in the PoR. The figure shows the communication from a viewpoint of inland vessels. There are multiple actors in contact with the barge operator. When an inland vessel is visiting container terminals in the PoR it has to make appointments for transshipment, the appointment can be made by the shipper himself or by the company that employs him. The barge operator knows which terminals and in what order the terminals have to be visited before entering the port area. In the case that a barge operator enters the port ahead of its first appointment he can either wait, or call terminals asking if they have the opportunity to expedite the appointment. Waiting is economical not optimal but carries little risk for the operator. However, being to late for an appointment at a terminal carries consequences for the entire round trip of the vessel. If a window is missed by the operator the sensible solution is to try to fit a new appointment in the time that is scheduled for the round trip in the port, but the chances of succeeding are little since not all terminals are flexible enough to facilitate this. Resulting in an increased round trip time for the barge operator. Missing an appointment can happen at any terminal and is more likely when more terminals have to be visited. A small malfunction or error at the terminal can cause the barge operator delays that will result in a longer round trip time because of the tight schedule. There are uncertainties when making appointments since both the transporter and terminal operator can have irregularities. The uncertainties are the cause that time is wasted since both parties will include a safety factor in their appointments.

The size and draught of a inland vessel determines the waterways it can sail and influences also the round-trip time in the PoR. Vessels smaller than 85 meter have on average a round-trip time of 21 hours while larger vessels up to 111 meter average 36 hours [34]. Larger vessels can

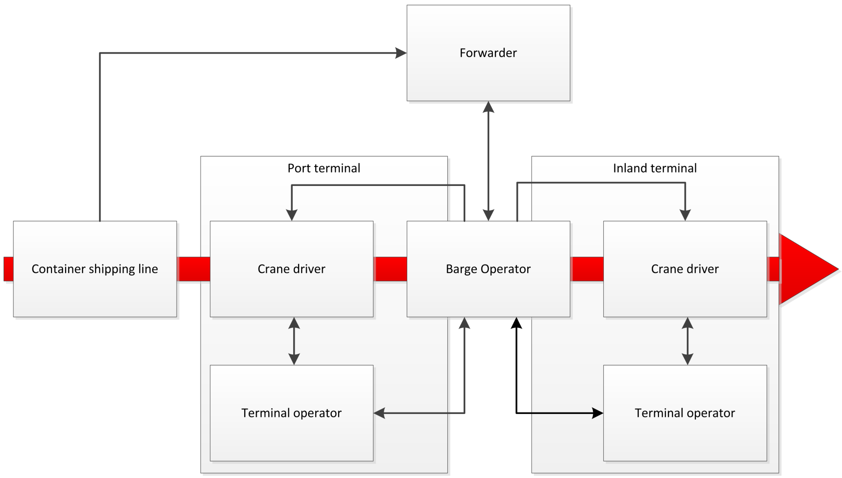


Figure A-3: Container shipping chain from sea vessel to inland terminal

carry more containers which would take a longer time to transship but if more terminals are visited more waiting time is also included.

A-3 Container terminals in the PoR

Name terminal	Capacity [TEU]	Size	Berths [Number]	capacity in [%] of total	Terminal Number
UniPort	1,200,000	M	8	6.1	T1
Barge Centre	200,000	S	1	1.0	T2
Short Sea Shipping	1,440,000	M	12	7.3	T3
CTT	200,000	S	2	1.0	T4
ECT Delta	5,100,000	L	30	25.8	T5
Kramer	500,000	M	2	2.5	T6
Apm-1	3,350,000	L	12	16.9	T7
Apm-2	2,700,000	L	12	13.6	T8
RWG	2,350,000	L	14	11.9	T9
ECT Euromax	2,750,000	L	12	13.9	T0

Table A-2: PoR container terminal capacity as used in the Model

Appendix B

Data collection

Table B-1: Nextlogic call-size distribution

	1	2	3	4	5	6	7	8	9	10	11
5	12.0	4.4	4.9	5.6	7.8	5.1	17.6	29.0	43.2	25.6	39.1
10	10.3	4.6	5.8	5.4	7.1	4.4	15.4	19.7	11.2	18.6	19.2
15	9.9	6.7	7.8	7.1	8.5	5.7	12.1	12.3	7.8	13.4	12.2
20	8.4	8.3	8.5	9.2	8.8	7.5	11.3	9.2	5.6	10.9	7.3
25	7.5	9.5	8.4	8.2	9.0	8.3	8.7	6.2	4.4	8.8	5.2
30	7.3	8.5	9.0	8.0	8.6	6.6	7.4	4.6	4.2	5.9	4.4
35	6.2	7.5	7.5	7.5	7.6	8.4	5.7	3.2	2.4	3.8	2.2
40	5.3	8.9	6.6	6.4	6.6	6.4	5.2	2.7	2.2	3.3	2.4
45	4.2	5.3	5.9	5.7	5.9	5.7	3.5	2.1	2.2	2.4	1.5
50	2.6	6.2	5.0	4.7	4.8	4.4	2.5	2.0	1.2	2.2	1.9
60	5.7	7.5	7.8	8.1	7.3	8.4	3.6	2.4	3.1	1.5	1.0
70	4.3	5.4	5.4	5.7	4.9	5.9	2.4	1.5	1.5	1.0	1.2
80	3.7	4.4	4.1	4.2	3.9	5.3	1.5	1.0	2.0	0.7	0.8
90	2.4	2.4	2.4	2.7	2.5	3.7	0.8	0.9	1.7	1.0	0.6
100	2.3	3.2	2.7	2.5	2.1	3.7	0.9	0.8	1.7	1.0	0.5
120	2.7	2.7	2.2	2.9	1.9	3.5	0.3	0.5	1.7		0.5
140	2.1	1.7	1.9	1.6	1.2	2.3	0.7	0.5	1.0		
160	0.8	0.8	0.8	1.1	1.5	1.5	0.5	0.5	0.7		
180	0.7	0.6	0.5	0.8		1.0		1.0	0.8		
200	0.8	0.5	1.4	0.9		1.0			0.5		
500	0.9	1.0	1.2	1.7		1.1			1.0		
Average call	39	44	46	47	38	51	24	20	24	18	15
Smaller calls %	20.5	8	10	9.8	13.7	8.5	30.1	35.7	52.6	10.1	54.3

Table B-2: Inland vessel count

		Total	Apm-2	RWG	Yangteze kanaal	Europa	Amazone	hartel	Seine	Eem	Waal top	underway
Wednesday	27/07/2016 -1000	31	4	2	5	4	4	0	0	4	5	3
Wednesday	03/08/2016 -1000	34	0	0	2	3	4	1	1	6	7	11
Wednesday	17/08/2016 -1000	38	3	3	7	1	6	0	1	3	10	4
Thursday	18/08/2016 -1100	37	7	3	5	4	6	0	1	2	6	3
Sunday	21/08/2016 -1530	39	7	2	5	9	5	3	0	3	4	1
Monday	22/08/2016 -1030	37	0	0	2	3	6	1	1	6	7	11
Tuesday	23/08/2016 -0930	28	3	1	1	2	7	2	0	6	4	2
Thursday	25/08/2016 -1055	36	4	4	5	6	4	0	0	5	5	3
Tuesday	30/08/2016 -1030	28	3	2	3	0	1	0	0	5	7	7
Wednesday	31/08/2016 -1600	45	8	1	4	1	4	0	2	3	5	17
Thursday	1/09/2016 -1020	41	8	3	2	1	7	1	1	7	2	9
Friday	02/09/2016 -1000	38	7	2	3	1	6	2	0	3	4	10
Monday	05/09/2016 -1000	30	6	1	3	0	3	1	1	4	7	4
Tuesday	06/09/2016 -1130	30	4	4	1	1	5	2	1	2	5	4
Wednesday	07/09/2016 -1110	37	4	2	4	1	5	3	0	4	4	10
Thursday	08/09/2016 -0930	35	3	2	3	2	12	1	0	3	3	6
Saturday	10/09/2016 -1000	34	0	0	2	3	4	1	1	6	7	11
Monday	11/09/2016 -1600	36	5	2	3	1	6	2	0	3	4	10
Tuesday	12/09/2016 -1130	28	3	1	1	2	7	2	0	6	4	2
Wednesday	13/09/2016 -1530	36	6	3	4	2	7	2	0	5	5	2
Thursday	14/09/2016 -1100	37	7	3	5	4	7	0	1	2	5	3
Friday	15/09/2016 -1200	36	5	4	1	2	5	3	1	2	7	6
		35.0	4.65	2.15	3.2	2.3	5.65	1.3	0.55	4	5.30	6.25

Appendix C

Anylogic

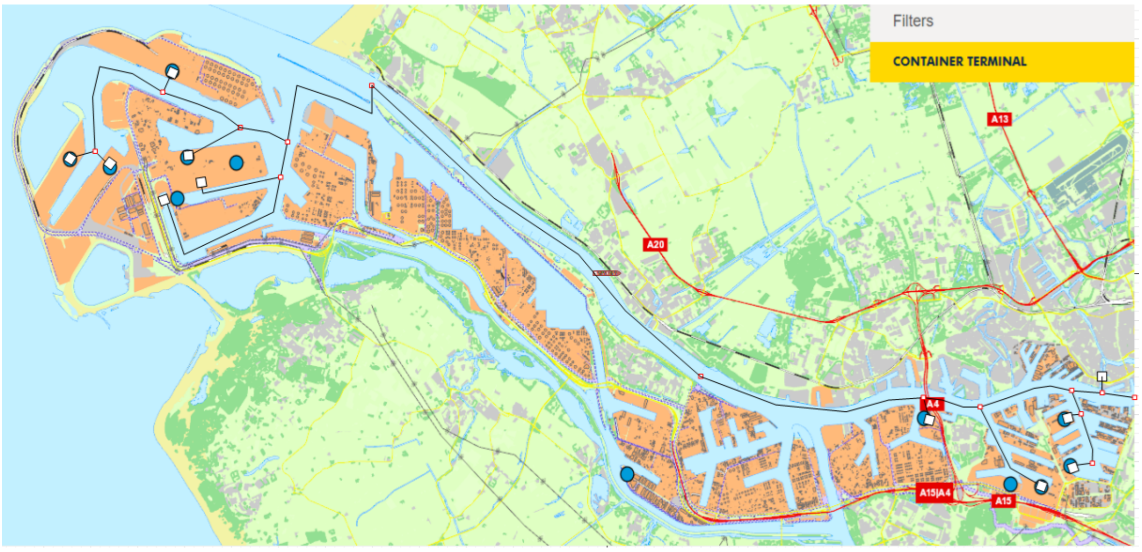
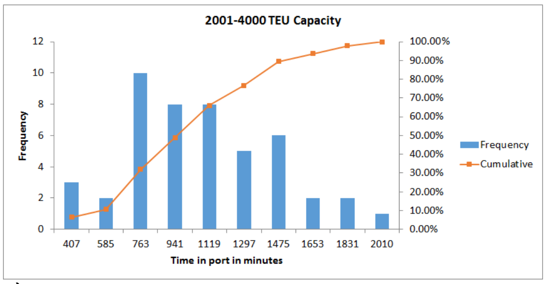


Figure C-1: Network overview as seen from Anylogic

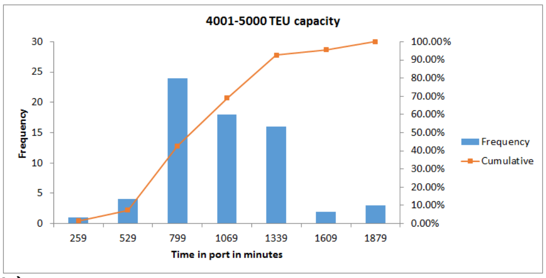
C-1 Time in port sea going vessels Maasvlakte

In this section the port time distributions for sea going vessels calling in Maasvlakte are given

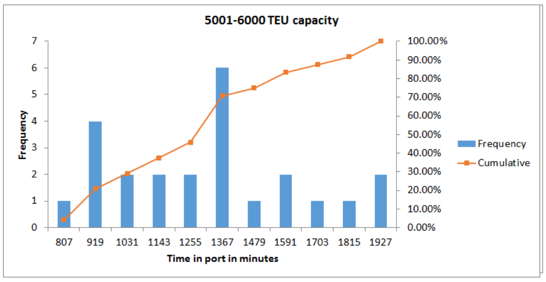
Figure C-2: Time in port distribution for Large sea going vessels calling at MV



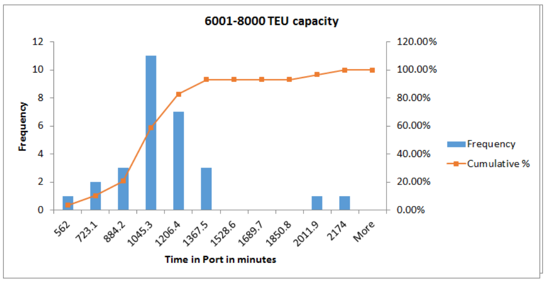
(a) Time in port distribution between 2000-4000 TEU



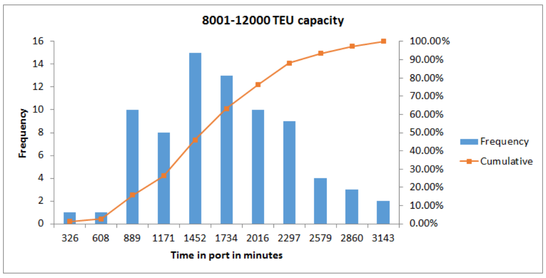
(b) Time in port distribution between 4001-5000 TEU



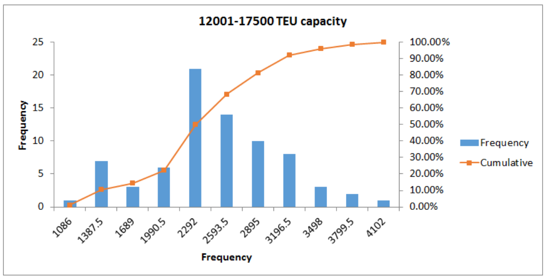
(a) Time in port distribution between 5001-6000 TEU



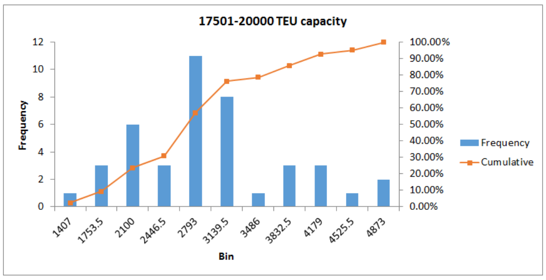
(b) Time in port distribution between 6001-8000 TEU



(a) Time in port distribution between 8001-12000 TEU

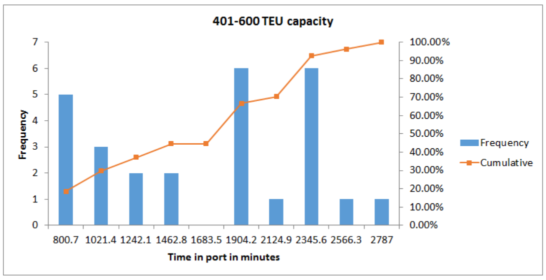


(b) Time in port distribution between 12001-17500 TEU

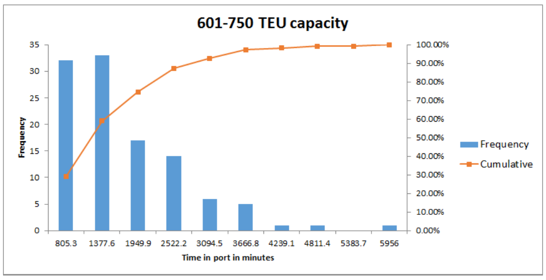


(a) Time in port distribution larger than 17501 TEU

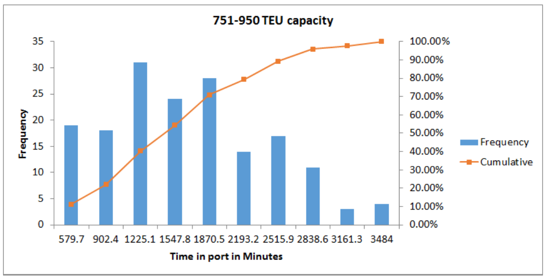
Figure C-6: Time in port distribution for small sea going vessels calling at MV



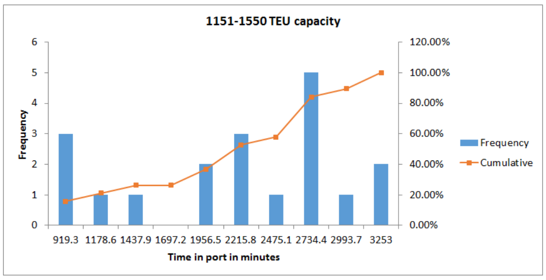
(a) Time in port distribution between 401-600 TEU



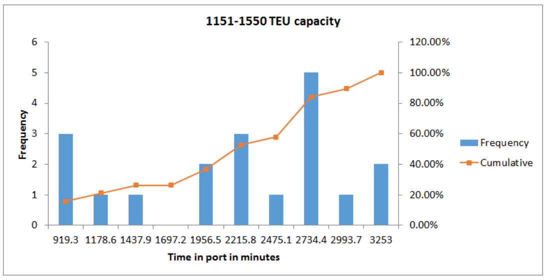
(b) Time in port distribution between 601-750 TEU



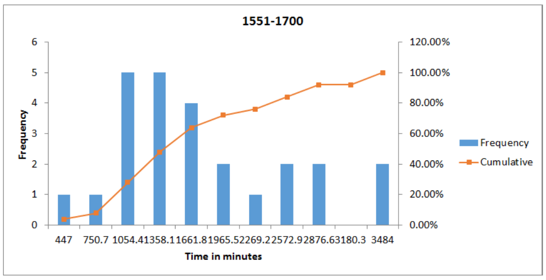
(a) Time in port distribution between 751-950 TEU



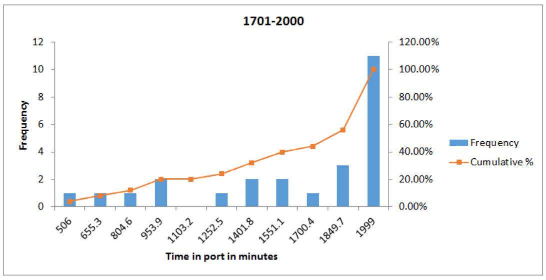
(b) Time in port distribution between 951-1100 TEU



(a) Time in port distribution between 1101-1500 TEU



(b) Time in port distribution between 1501-1700 TEU

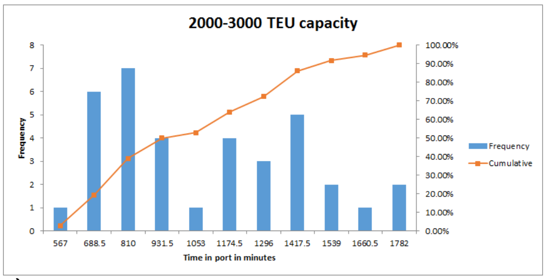


(a) Time in port distribution between 1701-2000 TEU

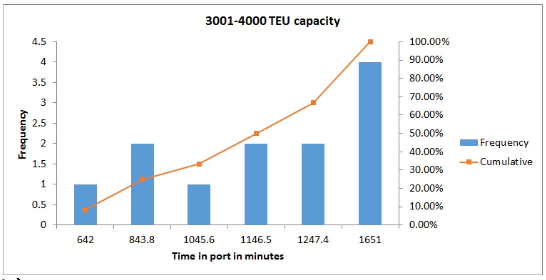
C-2 Time in port sea going vessels Waalhaven- Eemhaven

In this section the port time distributions for sea going vessels calling in the Waalhaven and Eemhaven are given

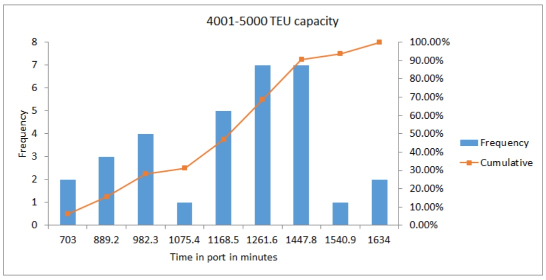
Figure C-10: Time in port distribution for Large sea going vessels calling at Waalhaven- Eemhaven



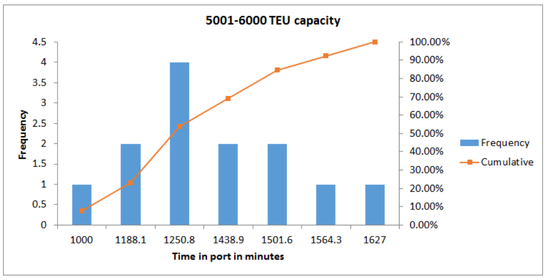
(a) Time in port distribution between 2000-4000 TEU



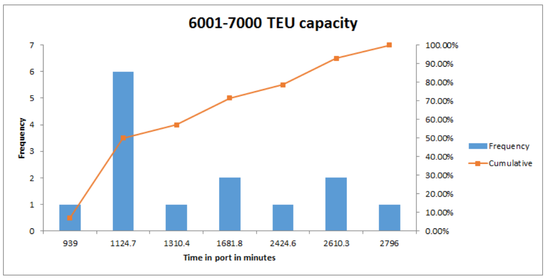
(b) Time in port distribution between 3001-4000 TEU



(a) Time in port distribution between 4001-5000 TEU

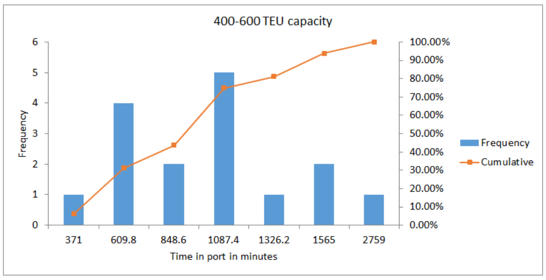


(b) Time in port distribution between 5001-6000 TEU

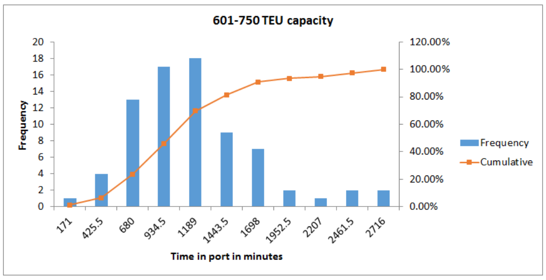


(a) Time in port distribution between 6001-7000 TEU

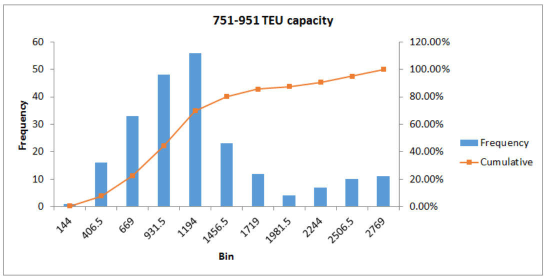
Figure C-13: Time in port distribution for small sea going vessels calling at Waalhaven - Eemhaven



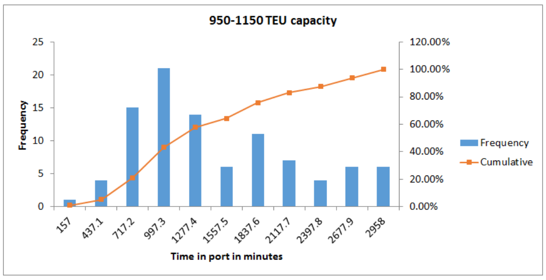
(a) Time in port distribution between 401-600 TEU



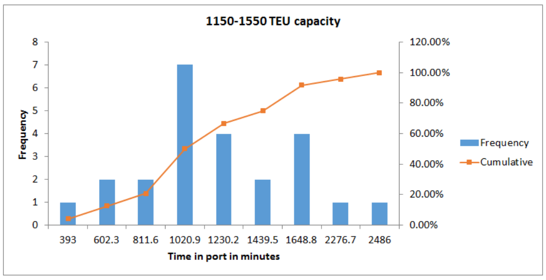
(b) Time in port distribution between 601-750 TEU



(a) Time in port distribution between 751-950 TEU



(b) Time in port distribution between 951-1100 TEU



(a) Time in port distribution between 1101-1500 TEU

Appendix D

Sensitivity analysis

Inland vessel arrival rate

Figure D-1 shows the waiting time, port time and the container time. The x-axle of the graph shows the variation of the All indicators show an insensitivity in relation to the reference line. With an increase of 20% arrival rate only 5% more waiting time is shown. This could mean that the model is not yet saturated with vessels and that there is enough available berth time to facilitate more vessels before congestion occurs. In a more saturated scenario the waiting time should increase rapidly when the arrival rate exceeds the service time.

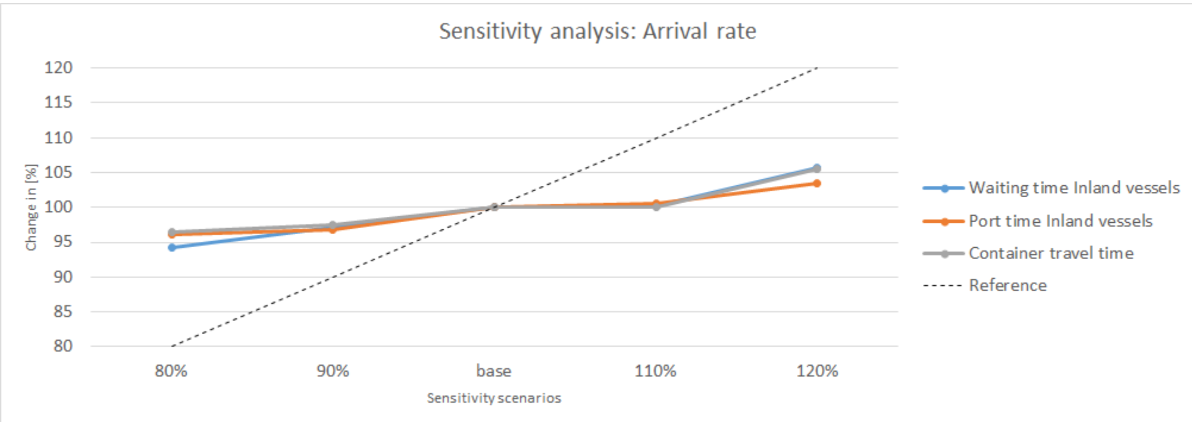


Figure D-1: Arrival rate sensitivity results

Transshipment rate

Figure D-2 shows the change in transshipment rate. A higher rate causes the inland vessels to be faster done at the terminals which in turn reduces the waiting time for other vessels and also the average time containers need to reach their destination terminal. The change in the transshipment parameter is also not very sensitive to change. A 20 % increase in transshipment rate causes only 10 % reduction of waiting time and same goes for 20% reduction.

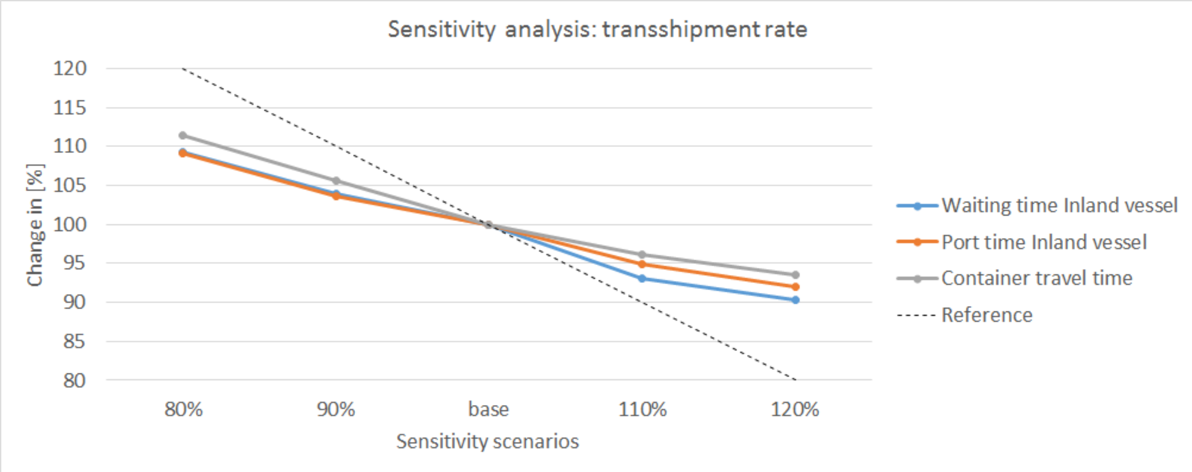


Figure D-2: Transshipment sensitivity results

Number of terminal visit

In the base scenario the terminal visit are determined by a triangle distribution. In the sensitivity analysis this is change to a normal distributed function. Both distributions are displayed in Figure D-3. The differences between the scenarios were negligible.

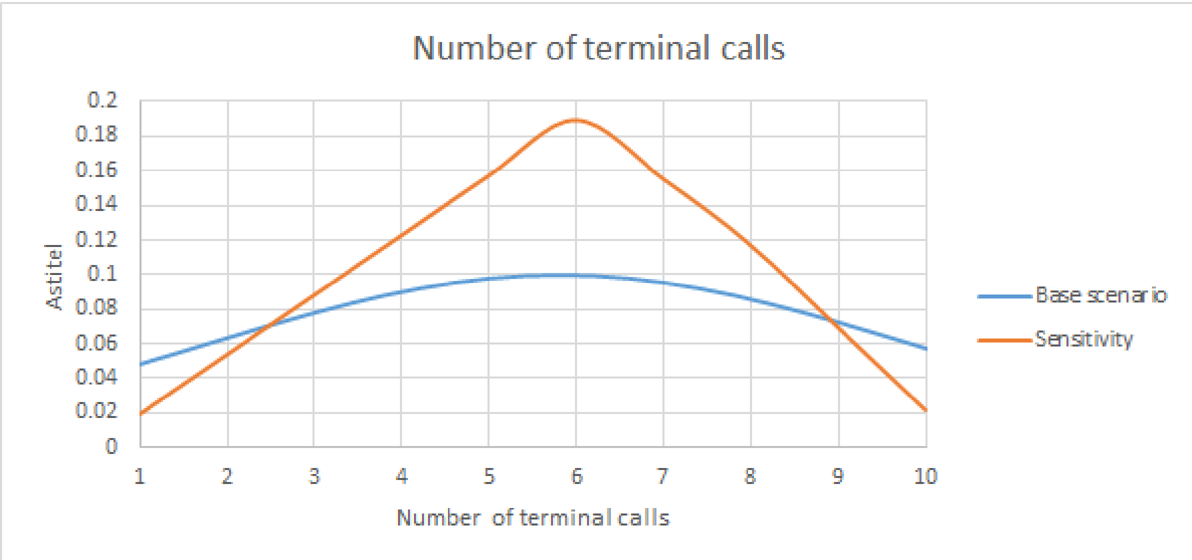


Figure D-3: Number of terminal calls distributions

Appendix E

Results

In this appendix the results are presented in tables.

Table E-1: Sojourn time inland vessels

Base		Minimum terminal call					Limited transferium		
Throughput		1	2	3	4	5	125	250	500
	5 [TEU]	5424	5498	5428	5262	4821	5491	5508	5551
	10 [TEU]	9477	9843	9464	9078	7772	9422	9723	9692
	15 [TEU]	17123	17466	17193	15790	13395	17391	17436	17114
	20 [TEU]	28208	29076	27771	24677	19361	28716	28782	29193
	25 [TEU]	41147	40958	38240	32714	23906	38336	40183	39800
	30 [TEU]	53339	54377	48450	38930	27842	46307	50544	51508
	45 [TEU]	92504	87706	70616	52549	36537	44231	40107	45710
	50 [TEU]	102439	95549	78779	55696	37547	40234	43415	39631

Throughput		Minimum terminal call					Limited transferium		
Transferium [%]		1	2	3	4	5	125	250	500
	5 [TEU]	2.2	2.2	2.2	2.1	1.9	2.2	2.2	2.2
	10 [TEU]	3.8	3.9	3.8	3.6	3.2	3.8	3.9	3.9
	15 [TEU]	6.9	7.1	6.9	6.4	5.4	6.9	7.0	6.9
	20 [TEU]	11.5	11.6	11.1	9.9	7.7	11.4	11.6	11.7
	25 [TEU]	16.6	16.4	15.3	12.9	9.6	15.3	16.0	16.2
	30 [TEU]	21.6	21.3	19.4	15.6	11.1	18.6	20.3	20.5
	45 [TEU]	37.3	34.7	28.5	21.2	14.5	17.8	16.3	18.3
	50 [TEU]	41.3	37.9	30.7	22.4	15.1	16.3	17.6	15.8

Table E-2

(a) Sojourn time inland vessels

Base	2726	Minimum terminal call					Limited transferium		
Sojourn time		1	2	3	4	5	125	250	500
	5 [TEU]	2506	2607	2527	2469	2569	2683	2411	2479
	10 [TEU]	2376	2473	2368	2494	2495	2490	2425	2499
	15 [TEU]	2315	2267	2348	2371	2487	2201	2312	2404
	20 [TEU]	2185	2096	2188	2136	2282	2062	2188	2079
	25 [TEU]	1915	1893	2088	2138	2341	2043	1895	2043
	30 [TEU]	1782	1830	1869	2130	2331	1970	1885	1875
	45 [TEU]	1174	1396	1699	1993	2223	2246	2165	2213
	50 [TEU]	1026	1248	1618	2003	2385	2332	2206	2271

(b) Waiting time inland vessels

base	1743	Minimum terminal call					Limited transferium		
waiting time		1	2	3	4	5	125	250	500
	5	1603	1704	1621	1630	1651	1763	1510	1571
	10	1514	1480	1501	1580	1606	1622	1553	1628
	15	1492	1437	1490	1528	1622	1373	1485	1574
	20	1401	1302	1320	1319	1424	1268	1399	1286
	25	1156	1125	1303	1317	1474	1262	1127	1281
	30	1057	1060	1091	1310	1456	1191	1129	1128
	45	595	689	929	1158	1324	1380	1293	1355
	50	494	546	852	1168	1474	1444	1331	1381

Table E-3

(a) Container travel time

Container travel time: 707		Minimum terminal call					Limited transferium		
Minimum call size		1	2	3	4	5	125	250	500
	5 [TEU]	675	684	659	666	672	699	657	667
	10 [TEU]	650	675	665	671	661	656	662	684
	15 [TEU]	648	642	659	651	671	631	657	657
	20 [TEU]	661	662	649	651	668	646	656	663
	25 [TEU]	777	816	765	771	746	689	697	761
	30 [TEU]	1248	1226	1182	1169	1030	731	806	967
	45 [TEU]	7252	6715	4155	2824	1912	915	966	1833
	50 [TEU]	9233	7827	5337	3507	2196	950	1220	1909

(b) Container transferium time

Transferium time		Minimum terminal call					Limited transferium		
		1	2	3	4	5	125	250	500
	5 [TEU]	258	247	254	249	250	262	258	264
	10 [TEU]	252	256	244	252	254	248	249	246
	15 [TEU]	293	291	291	286	301	290	294	283
	20 [TEU]	397	397	409	396	404	348	408	419
	25 [TEU]	943	1164	937	983	893	459	587	816
	30 [TEU]	2352	2297	2304	2693	2564	577	862	1414
	45 [TEU]	17993	17281	11937	9746	7955	1119	1354	4707
	50 [TEU]	23293	21865	16967	13915	10627	1310	2384	5633