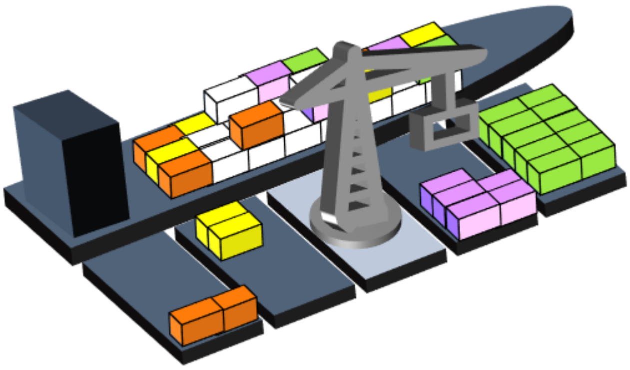
An analysis of the potential locations for Modular Mobile Terminals

Case study for the ports of Rotterdam and Antwerp



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Research Assignment

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An analysis of the potential locations for Modular Mobile Terminals

Case study for the ports of Rotterdam and Antwerp

By

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Research Assignment

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List of Abbreviations

IWV	Inland Waterway Vessel
MMT	Modular Mobile Terminal
CEMT	Conférence Européene des Ministres des Transport
RWS	Rijkswaterstaat
PL	Potential Location
DST	Deep Sea Terminal
MT_sail	Sail time between MMT and deep-sea port (incl. mooring/unmooring at port and MMT)
IX_sail	Sail time between import and export MMT

Summary

Long waiting times in ports for inland vessels to load and unload containers are a serious problem. The European project NOVIMOVE researches the inefficiencies and suggests solutions. One of the solutions for reducing waiting times in ports is the placement of Modular Mobile Terminals (MMTs). The focus of the research will be on the ports of Rotterdam and Antwerp.

In this research assignment, three questions are addressed. The first question is: What are the criteria that a potential location must meet to be able to place one or more MMTs?
The second question is: Which potential locations for the placement of MMTs in the ports of Rotterdam and Antwerp provide the highest time savings compared to the situation without MMTs?
The last question is: What are the most suitable locations for MMTs based on the combination of the pre-defined criteria and the expected time savings?

In order to be able to give answers to these questions, qualitative research will first be carried out on the basis of predefined criteria. Then, a quantitative research is done with a static time-saving model.

The results of both the qualitative and quantitative research indicate that for the port of Rotterdam location 1 is the most suitable for the placement of MMTs. For the port of Antwerp, location 1 and location 2B are identified as the most suitable.

Based on this investigation, a conclusion can only be drawn based on the qualitative and quantitative results. Follow-up research will be necessary to determine if there are changes when a dynamic time saving model is used. Follow-up research is also needed to include the economic aspects in the determination of the most suitable locations.

1. Introduction

Waiting for days in the port for a place at the deep sea container terminal to load and unload containers [1][2]. That is the harsh reality for IWVs. On 8 June 2022, it was determined that an IWV has to wait approximately 46 hours in the port of Antwerp and 83 hours in the port of Rotterdam [3]. This has to do with the fact that larger container ships get priority at the deep sea container terminals [4]. Also, there are backlogs due to the measures in place to prevent the further spread of Covid-19 [5]. This study focuses on the ports of Rotterdam and Antwerp. Both ports are in the top 25 of the largest container terminals in the world and are leading the ranking for the largest container ports in Europe [6]. IWVs are defined as all container barges up to and including CEMT class Va or RWS class M8 [7].

For the port of Rotterdam, IWVs are responsible for 38% of the containers transported from the Maasvlakte further into the hinterland. The ambition of the port is to grow to 45% IWV container transport by 2030 [8]. The port of Antwerp has the ambition of having 42% of the total container traffic being transported via IWVs by 2030 [9].
These aspirations can only be realised if the waiting times for IWVs for loading and unloading containers at deep sea container terminals can be drastically reduced; at the moment it can amount to approximately 60% of the time IWVs spend in the port [10]. This time consists of sailing between the different deep sea container terminals and waiting for loading or unloading [10]. The European project NOVIMOVE aims to identify these kinds of inefficiencies in Inland Waterborne Transport (IWT) and to come up with solutions [11]. One of the solutions devised for the long waiting times of IWVs in ports is the Modular Mobile Terminal (MMT) [12]. These are terminals that can be placed at open water in the port and where IWVs can load and unload their containers.

The operation of an MMT is as follows: the IWV moors at the import MMT and then the containers destined for one of the connected deep sea container terminals are unloaded. These are sorted by the MMT per deep sea container terminal on different barges, so per connected deep sea container terminal there is one barge available on which the containers can be loaded. As soon as the IWV is empty, it can sail to the export MMT. Here, the barges are already fully loaded with containers from the deep sea container terminals that need to be loaded onto the IWV again. As soon as the IWV is fully loaded, it can set off again for the hinterland to deliver all the containers and collect new ones. As soon as the barges of the import and export MMTs are empty or filled, they return to the respective deep sea container terminals to unload the containers and collect new ones [13]. Because IWVs make use of these specific MMTs and therefore do not have to sail past all the different deep sea container terminals, it is expected that the waiting times in the ports will be significantly reduced.

In this research assignment, the following research questions are explored:
1. What are the criteria that a potential location must meet to be able to place one or more MMTs?
2. Which potential locations for the placement of MMTs in the ports of Rotterdam and Antwerp provide the highest time savings compared to the situation without MMTs?
3. What are the most suitable locations for MMTs based on the combination of the pre-defined criteria and the expected time savings?

In order to answer the first question, research is done to find out which criteria apply to the locations. This is done by means of a literature study and then the criteria is validated by Scandinaos, the company that designs the MMTs. Based on these criteria and feedback, it is determined which criteria can be used to test the locations in a qualitative way. For the second question, a time-saving model is used to investigate the possibilities of the MMTs. With this, a quantitative investigation can be done into the influence of the different locations on the possible time savings that can be achieved with the use of MMTs compared to the time needed in the port without MMTs [14]. The last question combines the answers from the previous research questions. An analysis will be made to compare the results of both investigations. With this, it can be determined which locations in the ports of Rotterdam and Antwerp are the best for the placement of MMTs.

2. Methodology

This chapter is divided into two parts. The first part contains the criteria that have been drawn up, which a potential location for an MMT should meet and how these are used in a qualitative way in the investigation. Also a review of the criteria is given. This part of the research will be used to answer the first research question. The second part give a short explanation of the mathematical time savings model and the modifications that have been applied as well as how this model contributes to the investigation in a quantitative way. This part of the research forms the basis for answering the second research question.

2.1 Criteria

To determine which potential locations are suitable for the placement of MMTs, the following criteria have been formulated.

Waiting location
A waiting location is a place in the port where an IWV moors to wait until a place at the deep sea container terminal becomes available for loading and unloading. These locations are indicated on the port maps [15] [16] [17]. The MMTs cannot be placed at waiting locations. For each location, it is necessary to check the map of the port in order to verify that the location has not been designated as a waiting location.

(Main) waterways
The MMTs cannot be placed in the sailing routes used by other water users. For this, the shipping routes within the ports and the buoyage must be considered. In order to determine which shipping routes are used, use can be made of the RIS, which indicates per ship which route is being used [18]. Signs indicate the main waterways and where an MMT can certainly not be placed [19]. For each location, the map of the port must be checked to ensure that the location is not in the (main) waterway. Furthermore, it must be taken into account that ships passing by cause wave action, see further the criterion of wave action.

Area
The space st the location must be large enough to accommodate an MMT and IWV. Furthermore, the space to manoeuvre should be taken into account for both the barges of the MMT and the IWV. This can be divided into the amount of surface and water depth that a MMT and IWV need, including manoeuvring space. Yet also in the amount and types of environmental factors that are present that can influence the placement of MMTs. The influence of these factors are briefly discussed below.

- *Surface and water depth*
  This sub-criterion depends on the dimensions of the MMT and IWV. In addition, sufficient space must be taken into account for the manoeuvring of barges and IWVs.

  - MMT
    The composition of the MMT is modular, so the dimensions of the total MMT can be adjusted. The crane module of the MMT is 52 m long and 17 m wide. The modules each have a length of 55 m and a width of 17 m [20]. If the configuration is taken with 4 barges and 1 crane module, as shown in Figure 1, the MMT itself covers an area of 85 m by 55 m. The design draft of the modules are 2.5 m.

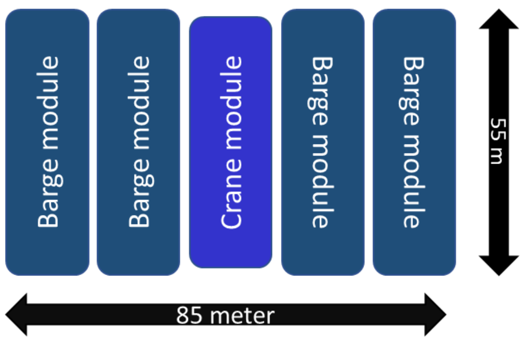

Figure 1: Dimensions MMT [20]

  - IWV
    The IWVs are divided into so-called CEMT-classes or RWS classes [7]. The most frequent vessel that will use the MMT is taken as a starting point, here it is the IWV CEMT-class Va or RWS-class M8 vessel. If this vessel fits, smaller vessels will fit as well. CEMT-class Va has a maximum length of 110 m and is 11.4 m wide. In addition, this type of vessel has a draught of 3.5 m when loaded [21].

- *Manoeuvre*
  The vessels and barges within the MMT need space to manoeuvre and berth. It was decided to work with 1.5 times the length of the IWV in order to have enough space to moor and sail away. For the width it was decided to use the total width of the IWV plus 2 times the length of the barge module [22], see Figure 2.

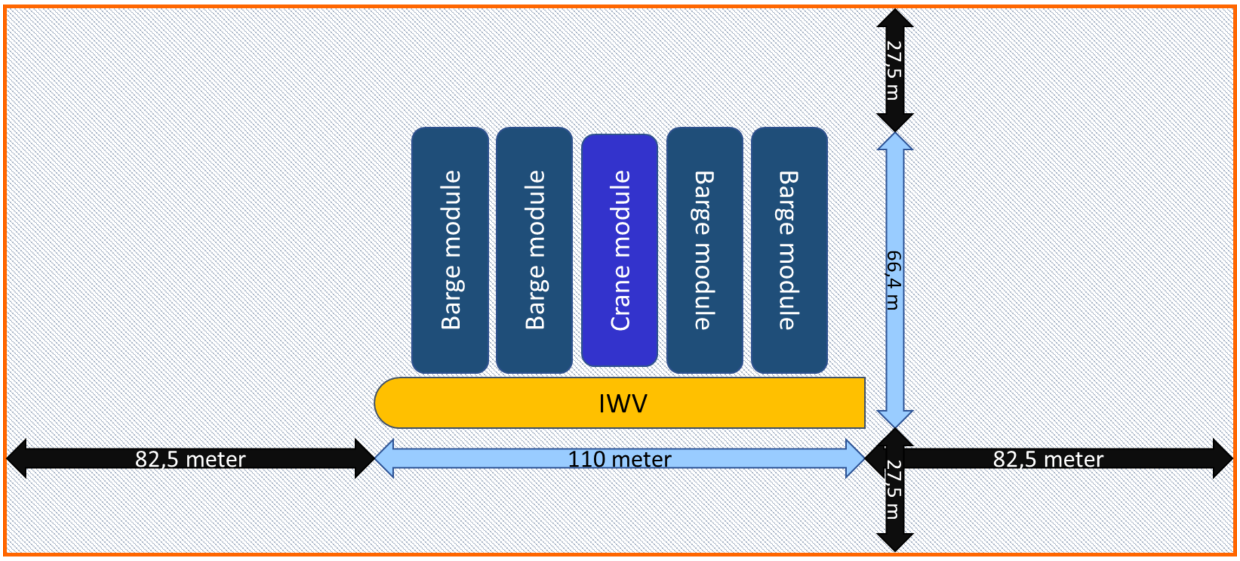

Figure 2: Space needed for MMT and IWV to manoeuvre [22]

In short, it can be said that a minimum depth of 3.8 m and an area of 275 m by 121.4 m is required to accommodate at least one MMT with IWV.

- *Multiple MMTs*

It may also be considered whether the potential location is suitable for the placement of multiple MMTs. It should therefore be considered whether the potential location is wide and long enough to accommodate multiple MMTs.

- *Environmental factors*

This includes matters that may affect the amount of space available. One can think of docks, sandbanks, inlets in the port or shore terminals that must remain accessible to other ships. The more these types of environmental factors are present, the more difficult it is to place a MMT.

Distance to the different deep sea container terminals
For both ports, the deep sea container terminals have been identified. The distance from the potential location to each of these deep sea container terminals can be determined. With this distance and the average sailing speed of the barges of the MMT, the sailing time can also be determined. The larger the distance between the MMT location and the various deep sea container terminals, the longer it takes to sail up and down and the more barges are needed. This criterium will be used for the quantitative research part.

Safety
The potential location must meet the prescribed safety regulations. Here, one can think of, for instance, the accessibility of the emergency services or fire safety

Emissions
The port of Rotterdam is currently the most polluting port in Europe, immediately followed by the port of Antwerp [23] [24]. The emission of nitrogen oxide, fine dust and CO_2 is partly caused by the diesel generators used by ships [25]. For this, the solution devised in the port of Rotterdam is to connect the ships that are moored to the shore power and no diesel generator is needed anymore [26]. A similar plan can be found for the port of Antwerp [27]. Access to such alternatives must be considered on a site-by-site basis.

Noise pollution
The port of Rotterdam is divided into noise zones to limit the nuisance [28]. It has to be examined whether the noise produced by the loading and unloading of containers falls within the set decibels. It must also be considered whether other activities of the port in the vicinity of the MMT do not already cause the maximum number of decibels, otherwise the MMT may not be placed there.

Spud poles/anchor placement
To secure the MMT, spud poles or anchors are used. In the port of Rotterdam there are rules regarding the use of spud poles, this is because these poles can cause damage to the pipelines running along the bottom of the port. Areas have therefore been designated within the port where spud poles may be used [29]. There are also areas where mooring with anchors is allowed. It must be investigated whether an exemption can be granted if the MMT nevertheless wishes to make use of spud poles in a place that is not designated as a spud pole location. Furthermore, it must be examined whether spud poles can be used in all types of bottom. In addition, the depth of the water at that location must not be deeper than the spud pole can reach. The insertion depth of the spud pole is leading in how deep the water may be [30].

Weather condition: Wind
The port can be affected by various weather conditions. Here, only the factor of wind is considered. As soon as there is a storm, all port activities are suspended [31]. The operational criteria of the MMT should be looked at to determine the maximum wind force allowed so as not to hinder the process of the MMT. For the locations, it can be looked at whether the potential locations are sensitive to the wind or more sheltered so that the process is less affected by the wind. Another way is to analyze the wind measurements of the past years to be able to make a statement about the wind at that specific location.

Water conditions
Tides
The ports of Rotterdam and Antwerp both have to deal with tides. In the port of Rotterdam, the differences between low and high tide are small, approximately 1.5 m [32]. In addition, the port of Rotterdam sometimes has to deal with double low tides, which can cause the water level to drop much further than normal [33]. In the port of Antwerp, there are larger differences of about 5 m between low and high tide [34]. However, in some parts of the port, use is made of a tidal dock, which is a dock in the port that can be closed off with lock gates to have less impact from the tides. For the use of spud poles, it is important to know how large the tide differences are.

Stream
Where there are tides, currents also develop [35]. The influence of currents on the process of transferring containers and the role of the location must be considered.

Swell (or wave stroke)
In addition, there are waves in the port, which are partly caused by the ships passing by [36]. These waves cause nuisance to the process of the MMT. The busier it is with passing ships, the more nuisance is experienced. This criterion can therefore be linked to that of the (main) waterway. The main waterways are used by the most ships, so a location right next to a main waterway can experience a lot of nuisance from wave action.

Review of the criteria
The list of criteria was presented to Bengt Ramne of Scandinaos. He came up with a number of solutions for criteria about which there is very limited information. These are discussed below.

For example, a solution to reach lower emissions is to load container aggregates on the barges that have a methanol drive. This allows the IWV moored to an MMT to be supplied with electrical power. These gensets can run on renewable methanol, reducing the carbon footprint and meeting the strictest SOx, NOx and PM emission levels for sea and land applications.

A solution has also been devised for spud poles and anchorages. If buoys are placed at the locations where the MMTs will be present, the MMT and IWV can moor to them. The use of spud poles and anchors is then no longer necessary. This criterion could then possibly be changed into which locations it is possible to place buoys.
With the assumption of mooring to buoys, the criterion with regard to the tides is also solved. There will no longer be any influence of the tides because the buoys will rise and fall along with the water level. Due to the fact that the buoys move along, the MMT and IWV will also move along without this having any consequences for the transhipment process.

To this point, there is not enough information available to test the locations against the criteria related to safety, noise and wind.

Only the following criteria will therefore be considered in the qualitative analysis of this study: Available surface, Depth of water, Distance to (main) waterway and Environmental factors.

2.2 Mathematical model

This subchapter is divided in two parts. The first part of this subsection presents the adjustments to the mathematical model. The second part gives a brief explanation of the implementation in Python.

2.2.1 Adjustments mathematical model

The mathematical model is used to perform a quantitative investigation of the potential locations. It investigates how the potential location contributes to time within the total system.
In this research, two cases are compared with each other. The first is the base case. In this case no MMTs are used and the IWVs have to go to all deep sea container terminals to load and unload containers.
The second case is where MMTs are used [14]. The import MMTs pick up the right containers from the IWV and place them on the barges of the deep sea container terminals in question, once these barges are full they sail to the deep sea container terminals to unload the containers there and subsequently load the containers that need to be shipped to the hinterland. The barges then sail to the export MMT where there is an IWV that needs to be loaded again with containers for the hinterland. The containers are therefore collected and distributed via the MMT and the IWV no longer has to go to the deep sea container terminals that are connected to the MMTs.

The original mathematical model can be found in Appendix 1. The changes to this mathematical model will be discussed below. Table 1 shows the parameters added in the modified model.

Table 1: Parameters adjusted model

Parameter	Unit	Description
$t_{MS\_01}^{sail}$	hr	Sailing time between location 1 and sea port area
$t_{MS\_02}^{sail}$	hr	Sailing time between location 2 and sea port area
$t_{MS\_03}^{sail}$	hr	Sailing time between location 3 and sea port area
$t_{MS\_04}^{sail}$	hr	Sailing time between location 4 and sea port area
MAX_MMT	-	Maximum number of MMTs available

Formulas

The following equations are formulated to add to the mathematical model. Equation 1 indicates the number of MMT pairs available. A pair contains one import MMT and one export MMT. This depends on which locations are used per port. Equation 2 shows the adjustment made to $T_t^{M,sail}$ from the original model. A distinction is made for the different MT_sail times of the different locations.

$$Number\ of\ MMT\ pairs = \frac{MAX\_MMT}{2} \qquad (Eq.1)$$

$$T_t^{M,sail} = \left(a * t_{MS_{01}}^{sail} + b * t_{MS_{02}}^{sail} + c * t_{MS_{03}}^{sail} + d * t_{MS_{04}}^{sail}\right) \sum_{i \in I} \frac{z_{it}}{Number\ of\ MMT\ pairs} \qquad (Eq.2)$$

- Where a, b, c and d are the number of MMTs at that specific location.
- $T_t^{M,sail}$ is the weighted average of the sailing times based on the locations and amount of MMTs.
- Z_{it} represents the total number of shuttles between MMTs and terminal *i* for month *t*.

Constraint

Equation 3 indicates the constraint that is added. This constraint ensures that the number of MMTs required by the model is not exceeded by the maximum number of terminals available.

$$(x_t^{in} + x_t^{ex}) \leq MAX_{MMT} \qquad (Eq.3)$$

- Where x_t^{in} represents the number of import MMTs operated during month t.
- And x_t^{ex} represents the number of export MMTs operated during month t.

2.2.2 Python model

The original mathematical model, without the modifications for this study, has been converted to a Python model.
The choice has been made to modify the model at a few points so that it is possible to work with different MMT locations. The modified Python model can be found in Appendix 2, where the modifications in comparison with the original model are indicated with yellow marks. The original lines of code are visible with strikethrough lines. Explanations of the modifications to the Python model can be found in Appendix 3.

It is important to note that only the number of MMTs per location and the MT_sail times, defined as the sailing time between the location of the MMT and the deep sea container terminals, per location to the different deep sea container terminals, have been considered. MT_sail is the sailing time including mooring and unmooring at the terminal and MMT. It is chosen to take 0.25 hours as a margin, so this is already added to the MT_sail times. The MT_sail times themselves are determined based on a route planner with the assumption that a barge sails at approximately 5 km/hour. The overview of the MT_sail times can be found in Chapter 3.1 Overview of the Potential Locations Table 2 for the port of Rotterdam and Table 3 for the port of Antwerp.

Furthermore, the model works with pairs of one import MMT and one export MMT at the same location. As a result, IX_sail, defined as the sailing time between the import and export MMT, can be considered as a constant. Here it is assumed that IX_sail = 0.25 hours.

In addition, this investigation is only done for the static case.

3. Case study: Ports of Rotterdam and Antwerp

This chapter consists of three subsections. In the first section, an overview is given of the potential locations. Furthermore, in this part the qualitative analysis is done based on the criteria. In the second part, the results from the model are discussed. With this, the quantitative analysis can be done. The last subsection contains the discussion.

3.1 Overview of the Potential Locations

This subsection provide background information on the various potential locations. The potential locations have been identified from other studies carried out by NOVIMOVE [13]. First, an overview is given of the potential locations and the deep sea container terminals that exist in the port of Rotterdam, 3.1.1, and in the port of Antwerp, 3.1.2. Here, the MT_sail times are also investigated. Subsequently, in 3.1.3 the locations in the port of Rotterdam are analysed and subjected to the qualitative analysis. The same is done in 3.1.4 for the port of Antwerp.

3.1.1 Port of Rotterdam

In the port of Rotterdam, four potential locations have been identified by NOVIMOVE [13] that will be assessed against the criteria. The locations are indicated in Figure 3.

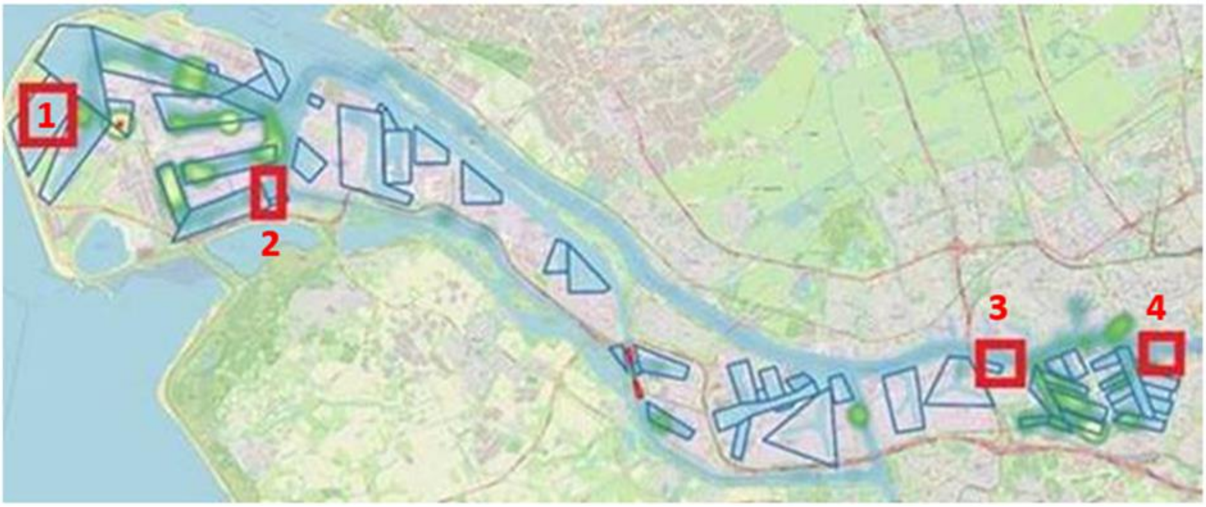

Figure 3: Potential locations Port of Rotterdam [13]

The various deep-sea container terminals in the port of Rotterdam [37] have been given a number so that it is clear which one is being referred to. The indications are shown in Figure 4.

- DST 1. Rotterdam World Gateway container terminal
- DST 2. APM Terminals Maasvlakte II
- DST 3. Hutchison Ports ECT Euromax
- DST 4. APM Terminals Rotterdam
- DST 5. Hutchison Ports ECT Delta

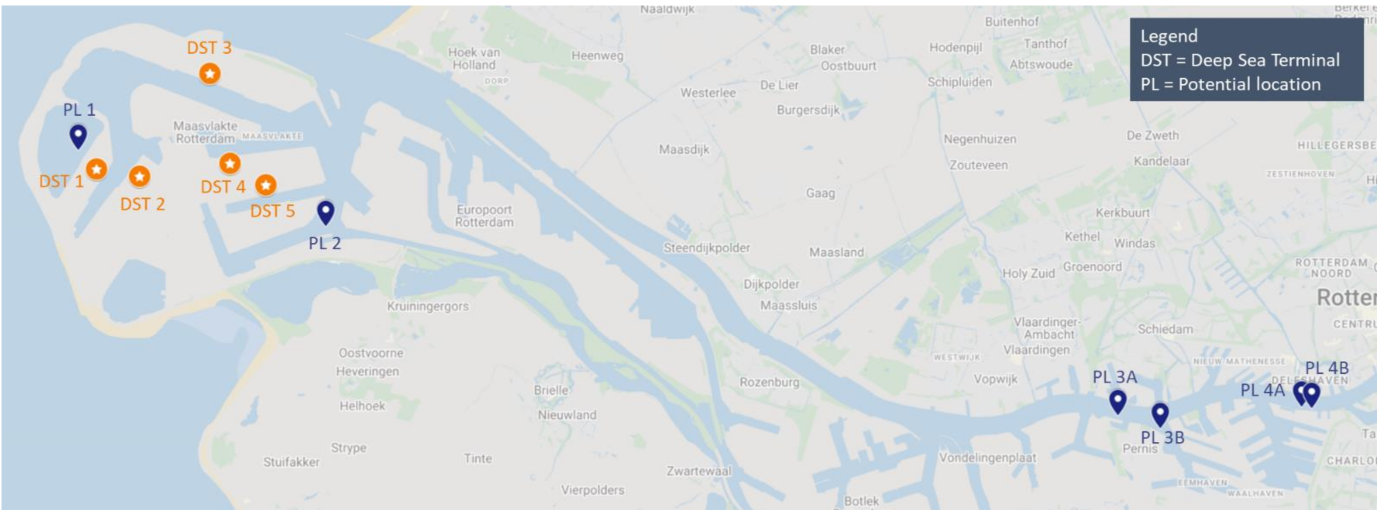

Figure 4: Deep-sea container terminals (DST) and Potential Locations (PL) in the Port of Rotterdam [37]

The distances from the potential MMT locations to the deep sea terminals are rounded off to 0.5 km. In addition, it is chosen to take the distances to about halfway the terminal's quay, the actual distances to specific terminal locations may therefore be slightly different. Also, it is assumed that there is an average sailing speed of 5 km/h and that 0.25 hours are needed for manoeuvring and berthing.
Table 2 shows the MT_sail times, taking into account the sailing speed and manoeuvring time, for the different potential locations to the different deep sea container terminals.

Table 2: MT_sail times Port of Rotterdam

Deep sea container terminals / Potential Locations	1. Rotterdam World Gateway	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta	Average MT_sail [hr]
1	1,15	1,15	1,25	2,05	2,65	1,65
2	2,35	2,35	1,45	1,25	0,85	1,65
3	6,95	5,95	6,95	5,75	5,75	6,27
4	7,95	6,95	7,95	6,75	6,75	7,27

3.1.2 Port of Antwerp

In the port of Antwerp, three potential locations have been identified by NOVIMOVE [13] that will be assessed against the criteria. The locations are indicated in Figure 5.

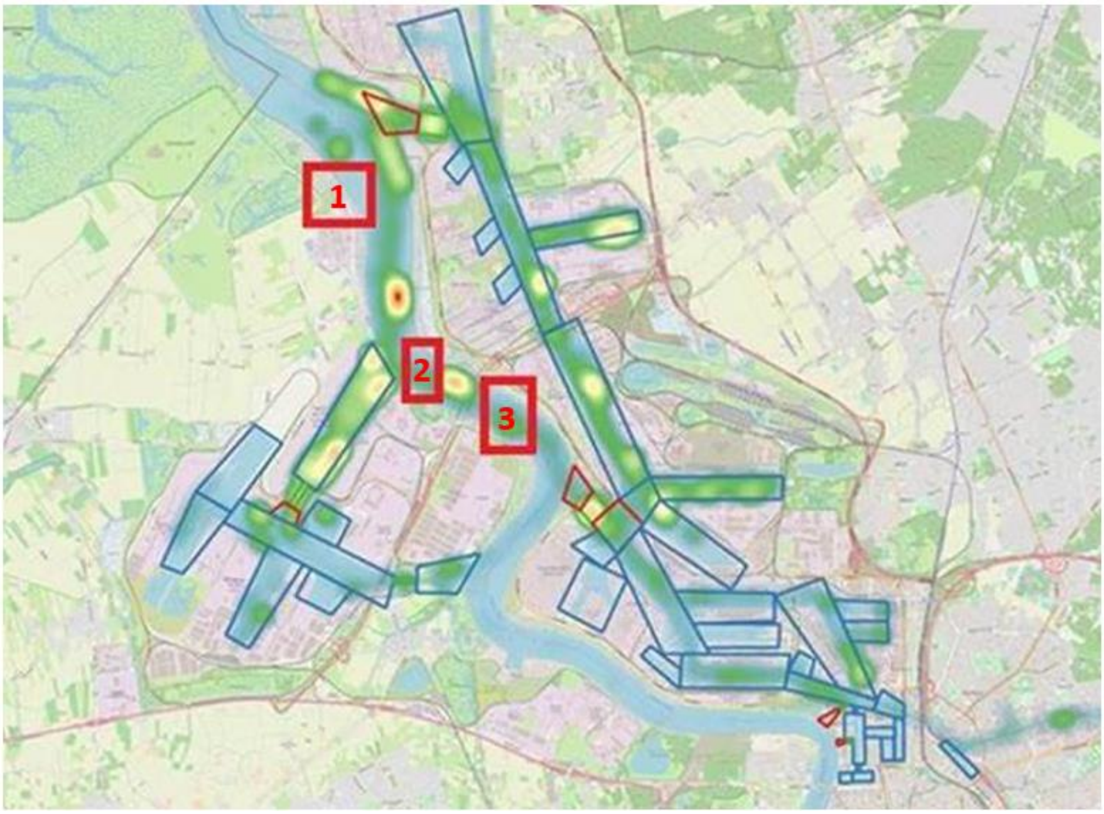

Figure 5: Potential locations Port of Antwerp [13]

The various deep-sea container terminals in the port of Antwerp [38] have been given a number so that it is clear which one is being referred to. The indications are shown in Figure 6.

The different deep sea container terminals have been given the following numbers;

- DST 1. MPET K1742
- DST 2. MPET K1718
- DST 3. AG K1700
- DST 4. PSAA K913
- DST 5. PSAA K869

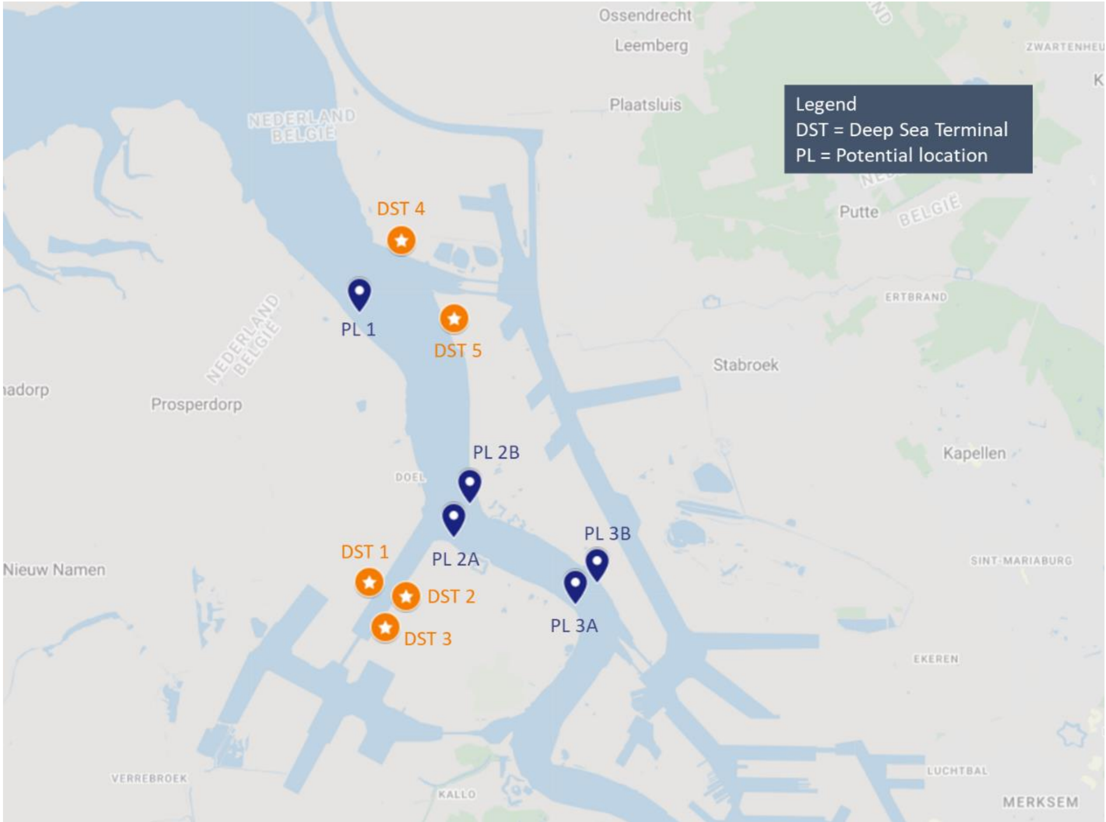

Figure 6: Deep-sea container terminals (DST) and Potential Locations (PL) in the Port of Antwerp [38]

The same assumptions as for the port of Rotterdam regarding the rounding off of distances and sailing speed also apply here. Table 3 shows the MT_sail times, taking into account the sailing speed and manoeuvring time, for the different potential locations to the different deep sea container terminals.

Table 3: MT_sail times Port of Antwerp

Deep sea container terminals / Potential Locations	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869	Average MT_sail [hr]
1	1,55	1,75	1,55	0,55	0,55	1,19
2A	0,65	0,85	0,65	1,45	1,15	0,95
2B	0,75	0,95	0,75	1,25	0,95	0,93
3A	1,25	1,45	1,25	1,95	1,65	1,51
3B	1,35	1,55	1,35	1,85	1,65	1,55

3.1.3 Port of Rotterdam; detailed analysis per location

Location 1

This location is in a sheltered part of the harbour where there is less shipping, so there will be less trouble from passing ships or other weather and water conditions. The available piece of land is located on the right side of the sandbank, see Appendix 4: Figure 14. There are already activities of another company on the left side of the sandbank, so it is not possible to place MMTs on the left side of the sandbank. The depth of the sand bank is sufficient to meet the minimum depths for placing MMTs and IWVs, see Appendix 4: Figure 15, Figure 16 and Figure 17. There is a passageway that is deep enough to reach the right-hand side of the sandbank, however it should be taken into account that no MMT can be placed at that spot.
The piece of available space that is sufficiently deep therefore comes to 275 m by 1250 m. This is large enough to accommodate eight MMTs, see Figure 7. This is meant to provide an image of a possible configuration of the different MMTs at this location. However, many variations are possible.

Figure 7: MMTs at location 1 Port of Rotterdam [39]

Location 2

This is in the middle of a zone where it is forbidden to anchor, see Appendix 5: Figure 18 the purple circle with the cross through the anchor. Slightly outside this zone there is sufficient space for the placement of MMTs. Since this location is in a busier part of the harbour than location 1, more passing ships and possibly therefore more nuisance must be taken into account. The depth of this location does meet the minimum depth for both MMTs and IWVs, see Appendix 5: Figure 19. However, there is a mooring quay for another company close to this location, so there should be enough space left to allow ships to moor there, see Appendix 5: Figure 20. Taking this into account, it can be stated that there is a piece available of 125 m by 825 m. This is large enough for the placement of two MMTs, see Figure 8.

Figure 8: MMTs at location 2 Port of Rotterdam [39]

Location 3
This can be divided in two parts where possibly MMTs can be placed, see Appendix 6: Figure 21.

Location 3A is located between the Beneluxtunnel and the entrance of the Madroelhaven. This is right next to the main waterway of the port of Rotterdam, which means that there are many passing ships. In addition, there are ships passing by that have to enter the Madroelhaven and therefore may have to maneuver. Because of this, there may be hindrance to the process of the MMT.
The MMT and IWV should be placed a couple of meters from the quay side, as it is not deep enough on the quay side, see Appendix 6: Figure 22. Furthermore, the arriving and departing ships of the adjacent company must be taken into account. The available space of location 3A is approximately 125 m by 340 m, so one MMT fits here, see Figure 9. However, it must be stated, that this is a very tight location.

Location 3B is a little further away at the entrance to Eemshaven. This is a little further away from the main waterway but at the entrance of a busy part of the port. Because the bottom depth at the quay is not enough for MMT and IWV, they have to be placed a few meters from the shore, see Appendix 6: Figure 23. However, sufficient space must be left open for passage so that other ships can continue to pass. Furthermore, account must be taken of the dock present at this location, as a result of which there must be space for mooring at this dock. If these points are taken into account, it appears that there is approximately 125 m by 340 m available, which is sufficient for one MMT, see Figure 9.

A total of two MMTs can be placed at location 3, which is the combination of locations 3A and 3B.

Figure 9: MMTs at location 3 Port of Rotterdam [39]

Location 4
This location must also be divided into two separate spots, as there must be enough space to moor at the dock of a company already present there, see Appendix 7: Figure 24. However, both locations are situated on the main waterway of the port of Rotterdam, so there is a lot of ship passing. Location 4A is located on the left-hand side of the jetty. In addition to the dock, the water depth must also be taken into account; it is too shallow at the quay. A few metres from the quay the depth is sufficient for the MMT and IWV, see Appendix 7: Figure 25. The available location is approximately 125 m by 340 m, which is enough for the placement of one MMT, see Figure 10.

Location 4B is on the right-hand side of the dock. The water depth should also be taken into account here, see Appendix 7: Figure 25. Furthermore, this location is also on the main waterway, so there are many passing ships. It should also be taken into account that there is sufficient space for ships to moor at the existing jetty and to turn into the Robbenoordsehaven. Taking all this into account, a piece of 125 m by 300 m is available. Although this location is very tight, one MMT can fit on this location. It may be necessary to look at how busy the dock and the Robbenoordsehaven are to decide if and how an MMT can be placed. For now, it is assumed that it is possible to place one MMT there, see Figure 10.

Location 4, which is the combination of locations 4A and 4B, will be able to accommodate two MMTs in total, although with some difficulty.

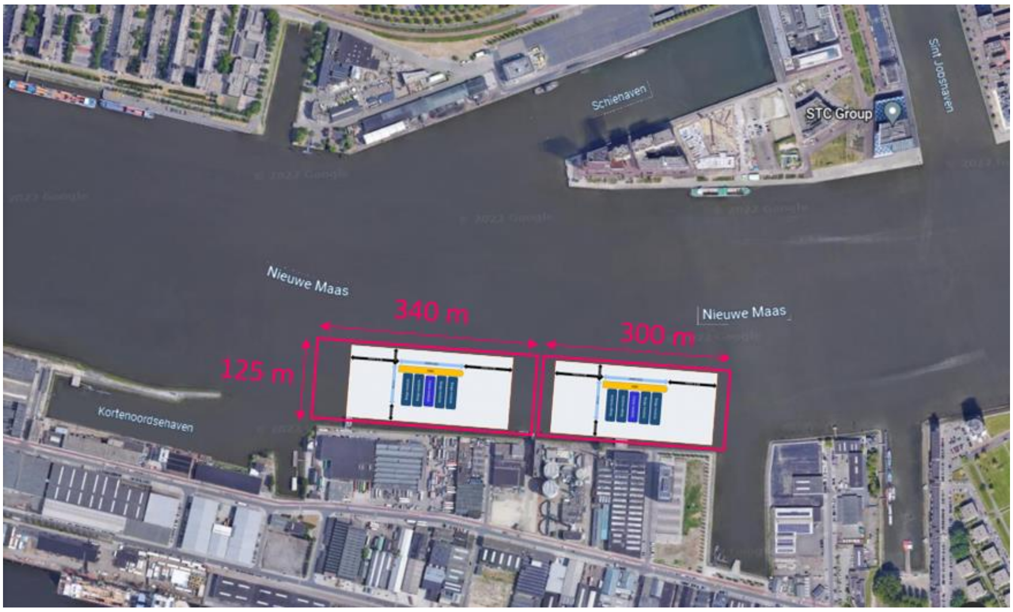

Figure 10: MMTs at location 4 Port of Rotterdam [39]

Criteria results Port of Rotterdam

It can be established that there can be placed fourteen MMTs in total if all potential locations are used in the port of Rotterdam.

Based on the abovementioned observations the following overview, see Table 4, can be drawn up for the criteria considered in the quantitative assessment. It was decided to include locations 3A and 3B together in the analysis as a combined location, namely location 3. This has been done because the analysis shows that the differences between the sub locations are very small. In this way, exactly one MMT pair fits at the location. The same applies to locations 4A and 4B, which together form location 4.

Table 4: Overview criteria Port of Rotterdam

Criteria / ***Location***	**Available surface**	**Depth of water**	**Distance to (main) waterway**	**Environmental factors**
1	+++	+	+++	+
2	+	+++	+	-
3	-	++	---	---
4	-	++	---	---

It follows from this that locations 1 and 2 are the most attractive for the placement of MMTs. Location 3 and 4 have the biggest disadvantages. As these lie nearby the main waterway and because there are many environmental factors that must be taken into account.

3.1.4 Port of Antwerp; detailed analysis per location

Location 1

This location is on a sandbank, the Doel plate (''Plaat van Doel''), in the port of Antwerp. The bottom depth here varies from 2 m deep near the shore to 10 m at the end of the sandbank towards the main waterway, see Appendix 8: Figure 26 and Figure 27. It should therefore be carefully examined at which location a MMT can be placed.

It is located next to the main waterway which means that there are many passing ships. Opposite this location are the Berendracht and Zandvliet locks, so it must be assumed that there will be ships turning nearby to enter or exit the lock, which can be seen in Appendix 8: Figure 28. If it is examined where the sandbank is deep enough and the other passing water traffic is not hindered, it comes down to approximately a piece of 130 m by 1100 m which is large enough for four MMTs, see Figure 11.

Figure 11: MMTs at location 1 Port of Antwerp [39]

Location 2

Location 2 is divided into locations 2A and 2B, see Appendix 9: Figure 29. Location 2A lies on one side of the Schelde and location 2B lies on the other side of the Schelde in line with location 2A.

Location 2A

This location is on the edge of a sandbank, which means that it has to be carefully examined where it is deep enough to place the MMT and IWV, see Appendix 9: Figure 30. Furthermore, it is located next to a docking station, so arriving and departing ships have to be taken into account. It is also located next to an entrance to the deep sea container terminals, so ships turning in should also be taken into account. Finally, this location is next to the main waterway, so there are many passing ships. Taking all this into account, there is a piece of 125 m by 340 m available, which is large enough for the placement of one MMT, see Figure 12.

Location 2B

This location is on a sandbank called the Lillo plate (''Plaat van Lillo''). Because of this, the bottom depths vary. At the edge of the sandbank the depth is 8 m to 10 m, which is deep enough for the MMT and IWV, see Appendix 9: Figure 30. Furthermore, there are other jetties on both sides of the potential site, so there should also be room for arriving and departing ships. In addition, the location is next to the fairway, which means there are many passing ships. The bottom line is that there is approximately a 125 m by 1050 m area available. This is large enough for the placement of three MMTs, see Figure 12.

Location 2, which is the combination of locations 2A and 2B, can accommodate a total of four MMTs.

Figure 12: MMTs at location 2 Port of Antwerp [39]

Location 3
Location 3 is divided into locations 3A and 3B, see Appendix 10: Figure 31. Location 3A is on the same side as location 2A. Location 3B is on the other side of the Scheldt in line with location 3A.

Location 3A
This location is on a sandbank and in front of a nature reserve, because of the sandbank the depths vary between 2 m and 10 m, as can be seen in Appendix 10: Figure 32. The MMTs will therefore have to be placed some distance from the shore to ensure that it is deep enough. Furthermore, it is located in a bend of the river, which means that there are many passing ships. It is also located next to a number of mooring buoys, which means that other ships have to take into account the space needed for mooring at these buoys. There is a piece of approximately 125 m by 850 m available, which is large enough for three MMTs, see Figure 13.

Location 3B
The location is on a sandbank, which varies in depth between 2 m and 10 m. At the edge of the sandbank it is deep enough, between 5 m and 10 m, to be able to place an MMT and IWV, see Appendix 10: Figure 32. Furthermore, this location is situated in the main waterway of the port of Antwerp and passing ships have to be taken into account. In addition, it is located near the entrance to the Boudewijn lock, therefore ships may be waiting to enter the lock. It comes down to a piece of 125 m by 870 m which is large enough for the placement of three MMTs, see Figure 13.

Location 3, which is the combination of location 3A and 3B, can accommodate a total of six MMTs.

Figure 13: MMTs at location 3 Port of Antwerp [39]

Criteria results Port of Antwerp

It can be established that there can be fourteen MMTs placed in the port of Antwerp if all locations are used.

The following overview, see Table 5, can be drawn up for the criteria that can be assessed quantitatively. Here, the choice has been made to keep the locations that consist of several parts separate. This has been done because these sub locations differ substantially from each other.

Table 5: Overview criteria Port of Antwerp

Criteria / ***Location***	**Available surface**	**Depth of water**	**Distance to (main) waterway**	**Environmental factors**
1	+	-	-	+
2A	-	+	--	--
2B	+	++	--	+
3A	++	+	--	--
3B	++	++	--	--

It can be concluded from this that all locations are next to the main waterway, which means that there will be nuisance from the waves of passing ships. Locations 3A and B score very well in terms of surface area and water depth, but it must be considered whether this outweighs the locations in a bend and close to a lock. Location 2A scores significantly less well than location 2B, this is mainly due to the fact that location 2A is located in a busy area where there are many environmental factors that need to be taken into account. Location 2B is less affected by this, although the jetties and buoys on both sides must be taken into account. Location 1 has the biggest disadvantage that it is located next to a sandbank which means that MMTs can only be placed quite a distance from the shore. Because of this, the MMTs are close to the main waterway which causes a lot of wave action. Furthermore, location 1 is opposite the entrance of a lock, with the result that many ships will manoeuvre near the MMTs.

3.2 Experimental results

This subsection will first discuss where the results can be found and which formulas are used to analyse the results. Subsequently, 3.2.2 zooms in on the quantitative results for the port of Rotterdam. In 3.2.3, the same is done for the port of Antwerp.

3.2.1 Formulas used in results

All the results obtained by modifying the model can be found in Appendix 11: Tables 10 till 24 for the Port of Rotterdam and Appendix 12: Tables 25 till 31 for the Port of Antwerp.
It was decided to present a smaller overview in this chapter so that the results can be compared easier, see Table 6 for the Port of Rotterdam and Table 7 for the Port of Antwerp.

The first column, of Table 6 and Table 7, indicates which location(s) is/ are used in the specific port. The second column indicates how many MMTs can potentially be placed, if more than one location is taken at the same time then the number of potentially placeable MMTs of all locations are added up. The third column is the number of MMTs that are needed according to the model, so this can differ from the value of column 2. Column 4 shows the total number of hours required in the base case. Furthermore, column 5 shows the total number of hours with MMTs. The 6th column shows how many hours are saved on average by using the total time with MMTs compared to the base case (without MMTs). The formula, see Equation 4, behind this is:

$$Total\ time\ base\ case\ [hr] - Total\ time\ with\ MMTs[hr] = \ Time\ saved\ [hr] \qquad (Eq. 4)$$

The total time base case (without MMTs) and the total time with MMTs are both without the time spent in the hinterland. This is done because this is a constant value that does not change and covers most of the time in the total system. As this study focuses on the total time in port, the time in the hinterland is less relevant.
For the results with multiple locations the average total time in the port with MMTs and the average time saved are used. This is calculated by adding up the total time in the port for each configuration of locations and dividing it by the number of deep sea container terminal locations (in both ports there are five deep sea container terminals). The same is done for the amount of time saved.

The last column contains the percentage of time saved using MMTs compared to the base case. The formula, see Equation 5, used is:

$$(Total\ time\ saved / \ Total\ time\ base\ case) * 100 \ = \ \%\ Time\ saved \qquad (Eq. 5)$$

3.2.2 Quantitative results Port of Rotterdam

See Table 6 for an overview of the most important results for the port of Rotterdam. Between 2.80% and 19.85% time in the port can be saved. The results show that especially potential location 1 plays a significant role in how much time can be saved within the system. In all cases when potential location 1 is used there is a time saving of at least 16.62%. If potential locations 1 and 2 are both used then this will result in the highest percentage of time saved, namely 19.85%. Potential location 4 will result in the least time saving, 2.8%. Furthermore, not all potentially placeable MMTs are used to save the most time.

Table 6: Model results Port of Rotterdam

Potential location(s)	Potential MMTs	Max MMTs used	Total time base case [hr]	Average total time with MMTs [hr]	Average time saved [hr]	% Time saved
1	8	8	346768	280854	65914	19,01%
2	2	2	346768	330246	16522	4,76%
3	2	2	346768	336108	10660	3,07%
4	2	2	346768	337068	9700	2,80%
1&2	10	10	346768	277936	68832	19,85%
1&3	10	10	346768	284245	62523	18,03%
1&4	10	10	346768	285539	61229	17,66%
2&3	4	4	346768	305768	41000	11,82%
2&4	4	4	346768	307160	39608	11,42%
3&4	4	4	346768	313591	33177	9,57%
1,2&3	12	10	346768	283235	63533	18,32%
1,2&4	12	10	346768	284317	62451	18,01%
1,3&4	12	10	346768	289124	57644	16,62%
2,3&4	6	6	346768	297055	49713	14,34%
1,2,3&4	14	10	346768	287662	59106	17,04%

3.2.3 Quantitative results Port of Antwerp

Table 7 gives an overview of the most important results for the port of Antwerp. It shows that between 11.42% and 12.63% time in the port can be saved when MMTs are used. When all potential locations are used, the most time can be saved. From the fourteen potential MMTs that can be placed, only twelve will be needed. The second highest efficiency can be achieved if only potential locations 1 and 2 are used and only eight MMTs are needed.

Table 7: Model results Port of Antwerp

Potential location(s)	Potential MMTs	Max MMTs used	Total time base case [hr]	Average total time with MMTs [hr]	Average time saved [hr]	% Time saved
1	4	4	245783	217426	28357	11,54%
2	4	4	245783	216706	29077	11,83%
3	6	6	245783	217716	28067	11,42%
1&2	8	8	245783	215297	30486	12,40%
1&3	10	10	245783	216401	29382	11,95%
2&3	10	10	245783	215678	30105	12,25%
1,2&3	14	12	245783	214739	31044	12,63%

3.3 Discussion

In the first part, the discussion focuses on the results of the port of Rotterdam. In the second part, the results of the port of Antwerp are discussed.

3.3.1 Port of Rotterdam

The largest time savings in the system occur when using potential locations 1 and 2. When looking at the time savings per potential location, it can be seen that this is mainly due to potential location 1. Despite the fact that the MT_sail times of potential locations 1 and 2 are equal on average, the qualitative investigation clearly shows that location 1 can place more MMTs and that location 1 does not suffer from the environmental factors that do play a role with location 2. Where location 1 is not situated along a (main) waterway and there are no other terminals in the area that need to be taken into account, this will be the case for location 2. This location is next to the waterway and close to a turning area for ships. There are also other terminals present which must remain accessible. In addition, location 2 only has space for 25% of the MMTs, namely two, which can be placed on location 1. Location 1 does have a point for attention in that it only has one passage opening where it is deep enough to cross the sandbank.

If location 1 and 2 are both used then a time saving of 19.85% will be achieved for which ten MMTs are needed. Compared to the time savings of only location 1, namely 19.01% which is achieved with eight MMTs, it can be concluded that the difference in time savings amounts to 0.84% for a difference of two MMTs. A more detailed evaluation must be made to determine whether it is profitable to open a location with two MMTs for this extra 0.84% saving. Yet as such and adding the fact that location 2 qualitatively has a number of environmental factors that have a strong influence on the operation of the MMTs, it can be stated that the additional time saving of 0.84% is not profitable.

The time savings that are achieved with location 1 in combination with one of the other locations are significantly lower than what can be achieved when only location 1 is used. This is mainly due to the amount of MMTs that can be placed at these other locations and the MT_sail times for locations 3 and 4.

What is also striking about the results of the model for the combinations of different potential locations is that not all potentially placeable MMTs are always used. It is plausible that only the potential locations with the lowest MT_sail times are used.

It is striking here that for the result where potential locations 1,2 and 3 are used which gives a time saving of 18.32% and where only ten of the twelve potentially placeable MMTs are used. It is assumed that the MMTs with the highest MT_sail time are not deployed, in this case the MMTs on location 3. However, if only locations 1 and 2 are used, Table 6 shows that this results in a time saving of 19.85%. This is a difference of 1.53% in time saving.

The reason for this lies in the formulation of the model with which the results are obtained for the different configurations of locations. If several locations are taken but not all of them are used, the model still assumes that the MT_sail time of the unused location must be counted in $T_t^{M,sail}$, see Equation 2. So the model itself does not decide which locations are included and which are excluded. This can be seen in the results for time sailing between MMT and port. On average for location 1 and 2, see Appendix 11: Table 14, the time sailing between MMT and port is 10866 hours. For locations 1, 2 and 3, where it is plausible that location 3 is not included because of the high MT_sail times, the time sailing between MMT and port is 15129 hours, see Appendix 11: Table 20. This contributes to a longer time within the system, so the percentage of time saved is lower.

The same findings can be made for the remaining results involving multiple potential locations, but where the maximum number of placeable MMTs differs from the maximum number of MMTs required by the system for optimisation.

Potential locations 3 and 4 are the sites that will be the most affected by passing ships. In addition, both potential sites have many peripheral issues, such as other shore terminals, accesses to other parts of the port and jetties. Add to this the fact that the MT_sail times for these locations are very disadvantageous compared to potential locations 1 and 2, then it is recommended not to place MMTs here. After all, according to the model, it does not save much time.

In a nutshell, it can be stated that especially location 1 is the most attractive for the placement of MMTs. This location has the least negative points according to the qualitative analysis and saves the most time according to the quantitative analysis.

3.3.2 Port of Antwerp

For the port of Antwerp, it is somewhat more difficult to say which location emerges best from the results. Quantitatively speaking, the highest percentage of time savings is achieved when all three locations take part. There would be twelve MMTs of the possible fourteen MMTs used which gives a time saving of 12.63%. However, it can also be seen that if only location 1 and 2 are used, only eight MMTs are used and this results in a time saving of 12.40%. The difference between the two configurations is that placing and using four additional MMTs results in an additional time saving of 0.23% compared to only opening location 1 and 2. The consideration here can be whether it is profitable to place so many more MMTs for a minimal additional time saving. Despite the assumption that at the location where the MT_sail times are the highest, the least MMTs will be placed, there is still no unambiguous conclusion about which location is the least attractive. Looking at the results it can be concluded that the number of MMTs at a location is related to the deep sea container terminal that has to be served. The location with the highest MT_sail time to a specific deep sea container terminal will have the least MMTs. As an example it is helpful to look at the results in Appendix 12: Table 31. Here it can be seen that the MT_sail times for deep sea container terminals 1. AG K1700, 2. MPET K1718 and 3. AG K1700 are the highest for location 1. However, for deep sea container terminals 4. PSAA K913 and 5. PSAA K869, these MT_sail times are the highest for location 3. Thus, it can be concluded that no unequivocal conclusion can be drawn about which location is the least attractive when all three locations are used. However, it can be concluded that it is not profitable to place four additional MMTs when the time saving only increases by 0.23%.
The results of the quantitative study also show that location 3 saves less time than locations 1 and 2. Furthermore, location 3 has many environmental factors, such as the lock and the curve, that have to be taken into account. All this together makes location 3 the least attractive location to place MMTs, even though this is the location where most MMTs can be placed.

Looking further into the results of the qualitative research, it can be stated that location 2A, with room for 1 MMT, is less attractive. It is located in a busy part of the port and there are many environmental factors that cause nuisance and which must be taken into account. Location 2B, on the other hand, is a very attractive location because there are few environmental factors and there is enough space to place 3 MMTs. Location 1 is a more neutral solution. Looking at the problems, the water depth due to the sandbank and the lock stand out. Furthermore, there are not many plus points for this location, but also not many minus points.

In short, it can be said that locations 1 and 2 (and especially location 2B) are preferred for the placement of MMTs. This will save the most time in the system and qualitatively it has the least negative points.

4. Conclusion

Looking back on the research, it can be stated that for the first research question, it was possible to draw up criteria which the locations should meet for the placement of MMTs. The criteria relating to available surface, depth of water, distance to (main) waterway and environmental factors formed the basis for the qualitative research. The results provided first insights into locations that would be preferred for the placement of MMTs.
For the second research question, the model was used with some modifications, to estimate the time saved by using MMTs. This quantitative research generated results that allowed to classify the potential locations based on the time savings they would provide in the port.
By combining the results of both the qualitative and quantitative research, a balanced compromise can be reached between the practical issues involved on the one hand and the time savings on the other. With this, a conclusion can be formulated to the third research question. For the port of Rotterdam, the conclusion is that location 1 is the most suitable. For the port of Antwerp, it can be concluded that locations 1 and 2A are both the most suitable locations.

5. Recommendations

Taking the whole investigation into consideration, there are a number of points that can be improved and which can serve as a basis for a follow-up investigation.
For the investigation itself the choice has been made to take the locations that consist of multiple parts, such as location 2A and 2B in Antwerp, together as 1 location where the number of placeable MMTs from both locations is added up. This means that there are 4 MMTs to place at location 2 in Antwerp. In the investigation, no distinction is made in the model that only 1 MMT fits on location 2A and 3 MMTs on location 2B. Also, the average of the MT_sail times to both locations is used. This can cause an inaccuracy in the results because the terminals are not equally distributed over the two locations.
The assumption is made that the system works with pairs and that the import and export MMT is at the same location, so IX_sail can be taken as a constant value. However, for location 2 in Antwerp, it is not possible to comply with this. Therefore it is not likely that the assumption of a constant IX_sail applies here. In the future, it is better to keep this kind of locations split up so that the results give a more realistic picture.

The research was also only carried out for a static case. However, it is more likely that container handling is a dynamic process in which the number of ships or containers to be handled is constantly changing. This is one of the reasons why it is important for a follow-up study to pay more attention to the dynamic component.

With regard to the model, it is recommended to develop a location-dependent model, where the selection of locations is also part of the optimisation process. In that way, the model could indicate which locations and how many MMTs are used per location to reach an optimal solution. An addition to this model might be that per location all MT_sail times to the connected deep sea container terminals are included. Currently, it was always assumed that one deep sea container terminal was connected and the model was used with that. This was done separately for each deep sea container terminal and then the average was taken of all time savings. It is better to make a model in which the different MT_sail times per location are used. In the model, it would be possible to use several locations at the same time. By applying an optimisation here, the model can then also indicate which locations are connected to which deep sea container terminals.

It is also necessary to look for a solution to manually change the values of MT_sail and the number of MMTs per location. This prevents errors in the results.

Instead of looking at which regions are linked in the model, one can look at which ships can be linked to which MMTs. By getting an idea of which ships will use which MMTs, it can be determined which locations need MMTs and how many. It can also be determined which MMT is the best for the ship to save the most time. It is important that the model clearly indicates which MMTs are connected to which deep sea container terminals, otherwise it is more difficult to determine which ships should go to which MMT.

Currently, pre-designated locations are used. Another approach could be to work with coordinates. For this purpose it can be determined which coordinates are dropped because there are no MMTs possible due to, for example, areas with an anchor ban or other port activities. This can also be used to indicate, for example, how many meters from the (main) waterway MMTs have little or no nuisance from passing ships and which coordinates are therefore dropped. Of the remaining coordinates, it can be determined whether they meet the other established criteria. Eventually, the system can then provide insight into which locations in the ports would be suitable for the placement of MMTs. Instead of using pre-designated locations. In case of changes in, for example, the density of the shipping routes or other port activities, this can be processed relatively easily in the model and then new locations are determined by the model.

Finally, for a follow-up study, it is important to also look at the economic aspect. What are the economic benefits of saving time in the port? For which players in the chain does it yield economic benefits? Are there also players who are disadvantaged?
It will also be possible to look at the costs of both the acquisition and maintenance of the MMT. A couple of questions that should be asked are: Who is responsible for the MMT? How are the costs divided over the IWVs that use the MMTs and the connected deep sea container terminals?
Furthermore, the return on investment of the MMT can be looked at. How profitable is it to use an extra MMT if the extra time saved is minimal? For this, the costs of the MMT and the economic benefits of the extra time savings will have to be set off against each other.

Literature

[1] Rozendaal, J. (2021, February 10). *Wachttijden Antwerpse terminals lopen op door toestroom containers*. NT. Retrieved 9 June 2022, from https://www.nt.nl/havens/2021/02/10/wachttijden-antwerpse-terminals-lopen-op-door-toestroom-containers/
[2] Freight Forwarder - Expediteur - Trans Ocean Pacific. *Lange wachttijden in Rotterdamse haven*. (2020, June 26). Retrieved 12 May 2022, from https://www.top.nl/en/2018/03/27/lange-wachttijden-in-rotterdamse-haven/
[3] CONTARGO. *CONTARGO - UPDATE: Congestion in Antwerp en Rotterdam*. (2022, June 8). Retrieved 9 June 2022, from https://www.contargo.net/nl/news/2022-06-08_congestion_update/
[4] Business Insider Nederland. *Containers Rotterdamse haven vaker over de weg door lange wachttijden*. (n.d.). Retrieved 9 June 2022, from https://www.businessinsider.nl/containers-uit-rotterdam-vaker-de-weg-door-lange-wachttijden/
[5] PZC. *Rederij Maersk meldt vertragingen tussen twee en vier dagen aan Antwerpse terminals*. (2022, January 12). Retrieved 9 June 2022, from https://www.pzc.nl/antwerpen/rederij-maersk-meldt-vertragingen-tussen-twee-en-vier-dagen-aan-antwerpse-terminals~aba506aa/
[6] Krsteski, D. (2022, March 21). *Top 49 grootste en drukste containerhavens in 2022*. MoverDB.com. Retrieved 29 April 2022, from https://moverdb.com/nl/top-49-container-poorten/
[7] Rijkswaterstaat. *Maatgevende schepen ten behoeve van richtlijnen vaarwegen CEMT-klasse I t/m IV - Rijkswaterstaat Rapportendatabank*. (1980, July). Retrieved 21 May 2022, from https://puc.overheid.nl/rijkswaterstaat/doc/PUC_134790_31/
[8] Port of Rotterdam. *Optimalisatie containerbinnenvaartketen*. (n.d.). Retrieved 1 May 2022, from https://www.portofrotterdam.com/nl/logistiek/verbindingen/intermodaal-transport/binnenvaart/optimalisatie-container
[9] Port of Antwerp Bruges. *Binnenvaart | Port of Antwerp-Bruges*. (2021, August 25). Retrieved 1 May 2022, from https://www.portofantwerpbruges.com/business/transport/binnenvaart
[10] NOVIMOVE. *What we do – NOVIMOVE*. (n.d.). Retrieved 28 April 2022, from https://novimove.eu/concept/
[11] NOVIMOVE. *NOVIMOVE - Smart & sustainable waterways* . (n.d.). Retrieved 28 April 2022, from https://novimove.eu/
[12] Friedhoff, B., Martens, S. E., Ley, J., Thill, C., Ramne, B., & Pot, H. (2021, September 30). *Concepts and selection of innovative NOVIMOVE concepts.: Deliverable D4.2* [NOVIMOVE - Novel inland waterway transport for moving freight effectively].
[13] van Hassel, E., Alias, C., Gründer, D., zum Felde, J., Pedersen, J.T., Samuel, L., Boukani, L., Atasoy, B., & Nicolet, A. (2021, November 30). *Development of the NOVIMOVE logistics innovations; Deliverable D2.4* [NOVIMOVE - Novel inland waterway transport for moving freight effectively].
[14] Shobayo, P., Nicolet, A., van Hassel, E., Atasoy, B. Vanelslander, T., & Negenborn, R. (2022). *Assessing the Role of Mobile Terminals to Reduce Container Barge Inefficiency in Seaports*. Submitted to a conference.
[15] Port of Rotterdam. *Locaties en informatie boeien en palen*. (n.d.). Retrieved 21 March 2022, from https://www.portofrotterdam.com/nl/zeevaart/boeien-en-palen/locaties-en-informatie-boeien-en-palen
[16] Blauwe Golf. *Blauwe Golf, Verbindend*. (n.d.). Retrieved 20 March 2022, from https://blauwegolfverbindend.nl/kaart/13/51.91503/4.21309;jsessionid=node01qbidk90uj88x1rf2ysc88c9d55014.node0?0
[17] Port of Rotterdam *ArcGIS Web Application*. (n.d.). Ligplaatsen Binnenvaart. Retrieved 22 March 2022, from https://portofrotterdam.maps.arcgis.com/apps/webappviewer/index.html?id=2b0a8d71f471495c9d48002b7bb9c100
[18] Ministerie van Infrastructuur en Waterstaat. (2020, December 21). *River Information Services*. Rijkswaterstaat. Retrieved 21 March 2022, from https://www.rijkswaterstaat.nl/zakelijk/verkeersmanagement/scheepvaart/scheepvaartverkeersbegeleiding/river-information-services
[19] Binnenvaart Kennis. *Betonning en markeringen – Binnenvaart Kennis*. (2021, October 16). Retrieved 22 March 2022, from https://www.binnenvaartkennis.nl/2021/10/betonning-en-markeringen/
[20] Friedhoff, B., Martens, S. E., Ley, J., Thill, C., Ramne, B., & Pot, H. (2021, September 30). *Concepts and selection of innovative NOVIMOVE concepts.: Deliverable D4.2* [NOVIMOVE - Novel inland waterway transport for moving freight effectively]. Chapter 3.2.
[21] Brolsma, J. U., Rijkswaterstaat Dienst Verkeer en Scheepvaart. Afdeling Netwerken Ontwerp en Inrichting. (2011). *Richtlijnen vaarwegen 2011*. Rijkswaterstaat.
[22] Bendegom, V. L. (1969). *Inleiding verkeerswaterbouwkunde: Deel A, B, C | TU Delft Repositories* [Slides]. Repository TU Delft. https://repository.tudelft.nl/islandora/object/uuid:55c7ca45-e780-4a1d-9695-9d5679076607?collection=research
[23] NOS. (2022, February 2). *Rotterdam meest vervuilende Europese haven, becijfert milieuorganisatie*. Retrieved 18 March 2022, from https://nos.nl/artikel/2415372-rotterdam-meest-vervuilende-europese-haven-becijfert-milieuorganisatie
[24] Milieudefensie.*Waar is de lucht ongezond?* (n.d.). Retrieved 19 March 2022, from https://milieudefensie.nl/recht-op-gezonde-lucht/waar-is-de-lucht-ongezond?gclid=CjwKCAjwxOCRBhA8EiwA0X8hi-JKa1YKpWRFtawAqUVW9R1q_Dj4IJeX0BmQH9CK71Ygp1DJxM71rxoCClYQAvD_BwE
[25] Natuur en Milieufederatie Zuid-Holland. *Luchtvervuiling en geluidsoverlast teruggedrongen*. (2020, October 30). Retrieved 20 March 2022, from https://milieufederatie.nl/blog/eindelijk-grootschalige-uitrol-walstroom-rotterdam/
[26] Port of Rotterdam. *Proef met extra walstroom uit batterij voor binnenvaart*. (2022, March 4). Retrieved 21 March 2022, from https://www.portofrotterdam.com/nl/nieuws-en-persberichten/proef-met-extra-walstroom-uit-batterij-voor-binnenvaart

[27] Port of Antwerp. *Extra containercapaciteit*. (n.d.). Retrieved 23 March 2022, from https://www.portofantwerp.com/nl/extra-containercapaciteit-haven-van-antwerpen
[28] BügelHajema. (2020, February). *Notitie reikwijdte en detailniveau facetbestemmingsplan geluid havengebied Rotterdam*. Figure 1, page 7.
[29] Port of Rotterdam. *Ligplaatsen*. (n.d.). Retrieved 24 March 2022, from https://www.portofrotterdam.com/nl/binnenvaart/ligplaatsen
[30] Leeuwestein Scheepsinstallaties b.v. *Spudpalen - Leeuwestein Scheepsinstallaties | Spudpaalsystemen*. (2017, March 28). Retrieved 25 March 2022, from https://www.leeuwestein-scheepsinstallaties.nl/spudpalen/
[31] Mackor, R. (2020, February 10). *Stilstand en wereldrecord op Maasvlakte door storm Ciara*. NT. Retrieved 25 March 2022, from https://www.nt.nl/havens/2020/02/10/stilstand-en-wereldrecord-op-maasvlakte-door-storm-ciara/
[32] Rotterdam's Tide Times. *Get Rotterdam's tide times*. (n.d.). Retrieved 23 March 2022, from https://www.tideschart.com/Netherlands/South-Holland/Gemeente-Rotterdam/Rotterdam/
[33] Port of Rotterdam (2022, February). *Port information guide*. port-information-guide.pdf (portofrotterdam.com)
[34] Antwerp Tide Times. *Get Antwerp (prosperpolder) Schelde River's tide times*. (n.d.). Retrieved 25 March 2022, from https://www.tideschart.com/Belgium/Flanders/Provincie-Antwerpen/Antwerp-(prosperpolder)-Schelde-River/
[35] Reddingsbrigade. Getijden (eb en vloed). (n.d.). Retrieved 20 May from: https://www.reddingsbrigade.nl/wij/wat-wij-doen/voorlichting/getijden/
[36] Varen doe je samen. *Voorkom hinderlijke golfslag*. (2018, July 27). Retrieved 22 March 2022, from https://varendoejesamen.nl/kenniscentrum/artikel/voorkom-hinderlijke-golfslag
[37] Port of Rotterdam. *Container terminals port of Rotterdam*. (n.d.). Retrieved 6 April 2022, from https://www.portofrotterdam.com/sites/default/files/2021-06/container-terminals-and-depots-in-the-rotterdam-port-area.pdf
[38] Port of Antwerp Bruges. (2022, April 26). *Containers | Port of Antwerp-Bruges*. Retrieved 2 May 2022, from https://www.portofantwerpbruges.com/business/cargo/containers
[39] Waterkaart. *Waterkaart*. (n.d.). Retrieved 26 April 2022, from https://waterkaart.net/

Appendix 1 – Original mathematical model

Parameters

The potential time savings achieved through the use of MMTs are evaluated using a dynamic optimization model, whose goal is to determine which regions should be linked to the MMTs so as to minimize the total time of all barges in the system. The parameters used in the model are presented in Table 8. Note that, due to the dynamicity, some parameters are time-dependent. We thus introduce the index $t \in [1,12]$ to represent the monthly variations.

Table 8: Model parameters

Param.	Unit	Description
$\lvert I \rvert$	-	Number of deep-sea terminals
t_i^{hand}	hr/TEU	Handling time at deep-sea terminal i per container
t_S^{sail}	hr	Average sailing time between two deep-sea terminals (incl. manoeuvrings)
t_{it}^{wait}	hr	Waiting time at deep-sea terminal i for an inland vessel for month t
F_{rt}	-	Number of services sailing between seaport and region r
D_{irt}	TEUs	Total transport demand between deep-sea terminal i and region r for month t
D_{rit}	TEUs	Total transport demand between region r and deep-sea terminal i for month t
t_{Sr}	hr	Sailing time between seaport area and hinterland region r
t_{rS}	hr	Sailing time between hinterland region r and seaport area
K	TEUs	Capacity of a module of MMT
t_M^{wait}	hr	Waiting time at MMT for an inland vessel
t_M^{hand}	hr/TEU	Handling time at MMT per container
t_{MS}^{sail}	hr	Sailing time between MMT and seaport area (incl. manoeuvrings)
t_{MM}^{sail}	hr	Sailing time between import MMT and export MMT (incl. manoeuvrings)
A	m^2	Surface for an entire MMT (1 crane module + 4 floating modules)
A^{max}	m^2	Maximal available surface for MMTs at seaport area

Some of these parameters, namely the transport demand (D_{irt} and D_{rit}), the sailing time(t_{Sr} and t_{rS}) and the number of services (F_{rt}) are based on some data. For other parameters, we further describe the assumptions hereafter.

The vessels are estimated to visit an average of four terminals per port visit, hence $|I|$=4. We assume that the demand for each pair is evenly split among the deep-sea terminals. The analysis further estimates an average waiting time of four hours at each terminal before the inland vessel can be served and a service time of three minutes to load or unload each container. We thus set for all i: t_{it}^{wait}=4 (for all t) and t_i^{hand}=1/20. We finally estimate the sailing time from one terminal to another, including the (un)mooring manoeuvrings, to 1 hour (t_S^{sail}=1).
Regarding the modular terminals, it is assumed that each inland container vessel will spend an hour waiting before it can be served (t_M^{wait}=1). This is so because the mobile terminals are dedicated to the inland container vessels; hence they do not need to wait long hours before being served. The one-hour waiting time is used to moor and prepare the vessel for handling. The service time is kept to three minutes per container (t_M^{hand}=1/20).

As stated earlier, the capacity of an MMT module K is equal to 138 TEUs; then, the total mobile terminal capacity is 676 TEUs (138 x 4 base modules, 124 x 1 crane module). Furthermore, we assume that the sailing time (including the manoeuvrings) between the MMTs and the port and between the import and export MMTs are respectively 1 hour and 20 minutes: t_{MS}^{sail}=1 and t_{MM}^{sail}=2/5. Finally, the surface of a MMT (with safety margins and mooring spaces for IWVs) A is estimated to 10'000 m^2 and the maximal available surface A_{max} to 300'000 m^2 for both ports.

Objective function and decision variables

The objective of the model is to minimize the total time spent by all barges during a year in the system depicted in Figure 1. It is expressed as a sum of several components over twelve months. The first one is the sailing time of IWV between the hinterland and the seaport area T_t^R. The three next components are related to the seaport: the service time at terminals $T_t^{S,serve}$, the time spent waiting to be served at deep-sea terminals for IWV and shuttle barges $T_t^{S,wait}$ and the time spent by IWV sailing between deep-sea terminals $T_t^{S,sail}$. Four additional terms relate to time spent with MMT: the time for inland vessels being served by MMT $T_t^{M,serve}$, the waiting time at MMT for inland vessels $T_t^{M,wait}$, the sailing time between MMT and seaport area $T_t^{M,sail}$ and the sailing time between import MMT and export MMT T_t^{MM}. The generic objective function is thus:

$$\min \Phi = \sum_{t=1}^{12} T_t^R + T_t^{S,serve} + T_t^{S,wait} + T_t^{S,sail} + T_t^{M,serve} + T_t^{M,wait} + T_t^{M,sail} + T_t^{MM}$$

The decision variables, as well as the development of the terms of the objective function, are presented in Table 9.

Table 9: Decision variables

DECISION VARIABLES	
$\boldsymbol{x_t^{in}} \in \mathbb{N}$	Number of import MMTs operated during month *t*
$\boldsymbol{x_t^{ex}} \in \mathbb{N}$	Number of export MMTs operated during month *t*
$\boldsymbol{y_{rt}} \in \{\mathbf{0},\mathbf{1}\}$	Whether region *r* is linked to MMTs for month *t*
$\boldsymbol{z_{it}} \in \mathbb{N}$	Total number of shuttles between MMTs and terminal *i* for month *t*
OBJECTIVE FUNCTION COMPONENTS	
	$T_t^R = \sum_{r\in R} F_{rt}(t_{rS} + t_{Sr})$
	$T_t^{S,serve} = \sum_{r\in R}\sum_{i\in I} t_i^{hand}(D_{rit} + D_{irt})$
	$T_t^{S,wait} = \sum_{i\in I} t_{it}^{hand} \sum_{r\in R}(1 - y_{rt})F_{rt}$
	$T_t^{S,sail} = \sum_{r\in R} F_{rt} t_S^{sail}(1 - y_{rt})\lvert I\rvert$
	$T_t^{M,serve} = t_M^{hand} \sum_{r\in R}\sum_{i\in I} y_{rt}(D_{rit} + D_{irt})$
	$T_t^{M,wait} = 2t_M^{wait} \sum_{r\in R} y_{rt}F_{rt}$
	$T_t^{M,sail} = 2t_{MS}^{sail} \sum_{i\in I} z_{it}$
	$T_t^{MM} = t_{MM}^{sail}\left[\sum_{r\in R} y_{rt}F_{rt} + \sum_{i\in I} z_{it}\right]$

Constraints

We now present the constraints of the optimization model. The first ones limit the number of hours that each import, respectively export MMT can operate to 480 hours per month (i.e. 120 hours per week):

$$\sum_{i\in I}\sum_{r\in R} y_{rt} D_{irt} t_M^{hand} \leq 480 x_t^{in} \qquad \forall t \in [1,12]$$

$$\sum_{i\in I}\sum_{r\in R} y_{rt} D_{rit} t_M^{hand} \leq 480 x_t^{ex} \qquad \forall t \in [1,12]$$

The second constraints impose the required frequency of shuttle barges to a terminal i given import and export demand respectively and the capacity of a module. The shuttles' frequency will then be set on the direction with the most demand:

$$\sum_{r \in R} y_{rt} D_{irt} \leq z_{it} K \qquad \forall i \in I, \ \ \forall t \in [1,12]$$

$$\sum_{r \in R} y_{rt} D_{rit} \leq z_{it} K \qquad \forall i \in I, \ \ \forall t \in [1,12]$$

The fourth constraints define the number of import, resp. export MMTs based on the total number of shuttles traveling to the deep-sea terminals. It is assumed that, within one day, 2 modules per MMT can be shuttled to the seaport; whereas the other two modules remain at the MMT to hold the cargo coming from (or going to) the hinterland. Because 2 shuttles per MMT are allowed per day, the constraints are expressed as:

$$\frac{\sum_{i \in I} z_{it}}{30} /2 \leq x_t^{in} \qquad \forall t \in [1,12]$$

$$\frac{\sum_{i \in I} z_{it}}{30} /2 \ + 1 \geq x_t^{in} \qquad \forall t \in [1,12]$$

$$\frac{\sum_{i \in I} z_{it}}{30} /2 \leq x_t^{ex} \qquad \forall t \in [1,12]$$

$$\frac{\sum_{i \in I} z_{it}}{30} /2 \ + 1 \geq x_t^{ex} \qquad \forall t \in [1,12]$$

The final constraints prevent that the total surface occupied by the MMTs exceeds the maximal available surface:

$$A\left(x_t^{in} + x_t^{ex}\right) \leq A^{max} \qquad \forall t \in [1,12]$$

Appendix 2 – (Adjusted) Python code

This example is for the port of Rotterdam, which can be seen by "NL33", with the configuration that all locations participate. So there are four different MT_sail times and a maximum of fourteen MMTs which can be placed. Eight on location 1, two on location 2, two on location 3 and two on location 4. Furthermore, the MT_sail times are taken to deep sea container terminal 1.

```
# -*- coding: utf-8 -*-

#!/usr/bin/env python3.7

import math
#import sys
import gurobipy as gp
from gurobipy import GRB,quicksum
import pandas as pd

#Features of the model
port='NL33' #volumes of year 2021 + times of new cost-time model
dynamic = 0

#Factors for sensitivity analyses
demand_factor=1
services_factor=1
serveTime_factor=1
sailTime_factor=1
waitTime_variation=0
calls_variation=0

IX_sail = 0.25 #sail time between import and export MMT
MT_sail = 2.8 #sail time between MMT and deep-sea port (incl. mooring/unmooring at port
and MMT)
MT_sail_01 = 1.15 #sail time between MMT and deep-sea port from potential location 1
(incl. mooring/unmooring at port and MMT)
MT_sail_02 = 2.35 #sail time between MMT and deep-sea port from potential location 2
(incl. mooring/unmooring at port and MMT)
MT_sail_03 = 6.95 #sail time between MMT and deep-sea port from potential location 3
(incl. mooring/unmooring at port and MMT)
MT_sail_04 = 7.95 #sail time between MMT and deep-sea port from potential location 4
(incl. mooring/unmooring at port and MMT)
MT_wait = 1 #waiting time for IWV at MMT
MT_serve = 0.05 #handling time per TEU at MMT
term_wait_shuttle = 0 #SHOULD STAY 0 : waiting time of MMT shuttles at deep-sea terminals

MT_crane_cap = 124 #crane module capacity (TEUs)
MT_barge_cap = 138 #other module capacity (TEUs)
#MT_cap = 3*MT_barge_cap

#MT_surf = 10000 #rough surface of a whole MMT

month_factor18=[0.0855,0.0941,0.1052,0.0927,0.0960,0.0985,0.0924,0.0818,0.0773,0.0659,0.05
02,0.0604]
```

```
month_factor =
[0.0783,0.0806,0.0881,0.0831,0.0863,0.0858,0.0909,0.0856,0.0837,0.0832,0.0778,0.0766]
#fraction of yearly demand per month

if(port == 'NL33'):
    regions =
['BE22','BE23','BE25','CH03','DE11','DE12','DE13','DE71','DEA1','DEA2','DEB1','DEB3','FRF1
','NL22','NL31','NL32','NL34','NL41','NL42']
    export_volume =
[4104,32802,5519,16798,4648,3021,2136,28348,183850,22469,9367,48850,20464,26145,57630,1312
31,40181,144269,38364]
    import_volume =
[48662,288188,87598,177029,0,13192,2088,22307,402797,37054,9795,172465,17910,54805,35208,8
4436,33494,115328,43977]
    export_time = [19,14,15,18,23,69,54,69,43,21,27,35,47,74,12,8,12,14,9,21]
    import_time = [19,14,15,18,23,69,54,69,43,21,27,35,47,74,12,8,12,14,9,21]
    freq = [189,800,270,400,16,163,75,160,1563,240,58,562,146,654,312,993,400,3189,1000]
    #max_SURF = 300000 #assumption of max. available surface for MMTs
    MAX_MMT = 14 #Maximum available MMTs
    N_term = 4 + calls_variation #number of visited terminals by IWV in seaport
    term_wait = 4 + waitTime_variation #waiting time at each deep-sea terminal for IWV
    term_serve = 0.05 * serveTime_factor #handling time per TEU at deep-sea terminal
    term_sail = 1 * sailTime_factor #sailing time between each deep-sea terminals

if(port == 'BE21'):
    regions =
['BE22','BE23','BE24','BE25','BE33','CH03','DE11','DE12','DE13','DE71','DEA1','DEA2','DEB1
','DEB2','DEB3','FRF1','NL22','NL31','NL32','NL41','NL42']
    export_volume =
[18638,24353,14448,102007,46247,25808,7390,34258,7483,7743,163721,30901,44069,9639,97953,7
9406,12398,232,205043,121367,77476]
    import_volume =
[6850,12385,3401,163011,12685,27875,4345,15654,1491,6038,56223,12103,9689,657,69422,22994,
9579,27573,278516,83951,32576]
    export_time = [7,7,3,10,11,71,61,56,71,45,23,29,37,45,49,76,14,15,18,5,10]
    import_time = [7,7,3,10,11,71,61,56,71,45,23,29,37,45,49,76,14,15,18,5,10]
    freq =
[275,400,300,600,250,180,175,141,101,203,870,241,184,150,618,252,400,98,993,444,450]
    #max_SURF = 300000 #assumption of max. available surface for MMTs
    MAX_MMT = 14 #Maximum available MMTs
    N_term = 4 + calls_variation #number of visited terminals by IWV in seaport
    term_wait = 4 + waitTime_variation #waiting time at each deep-sea terminal for IWV
    term_serve = 0.05 * serveTime_factor #handling time per TEU at deep-sea terminal
    term_sail = 1 * sailTime_factor #sailing time between each deep-sea terminals

I = range(N_term)
R = range(len(regions))

M=999999 #Big number for cosntraint consistency

export_volume_year = [demand_factor*element for element in export_volume]
```

```
import_volume_year = [demand_factor*element for element in import_volume]
freq_year = [round(services_factor*element) for element in freq]


export_volume_year_i=[[round(element/N_term) for element in export_volume_year]]*N_term
import_volume_year_i=[[round(element/N_term) for element in import_volume_year]]*N_term
term_wait_i=[term_wait]*N_term
term_serve_i=[term_serve]*N_term

nMonths = len(month_factor)
T=range(nMonths)

freq_month = [[round(element/nMonths) for element in freq_year]]*nMonths
freq_year = [sum([row[i] for row in freq_month]) for i in range(0,len(freq_month[0]))]

export_volume_month_i = [[[] for i in I] for t in T]
import_volume_month_i = [[[] for i in I] for t in T]
for t in T:
    for i in I:
            export_volume_month_i[t][i]=[round(month_factor[t]*element) for element in 
export_volume_year_i[i]]
            import_volume_month_i[t][i]=[round(month_factor[t]*element) for element in 
import_volume_year_i[i]]

term_wait_month_i=[term_wait_i]*nMonths
term_serve_month_i=[term_serve_i]*nMonths


t_rt_hinter = lambda r,t : freq_month[t][r]*(export_time[r]+import_time[r])
t_rt_sail = lambda r,t : freq_month[t][r]*term_sail*N_term
t_rt_wait = lambda r,t : freq_month[t][r]*sum(term_wait_month_i[t][i] for i in I)
t_rt_serve = lambda r,t : 
sum(term_serve_month_i[t][i]*(export_volume_month_i[t][i][r]+import_volume_month_i[t][i][r
]) for i in I)

sequence = ["sail","wait","serv"]

T_hinterl = sum(t_rt_hinter(r,t) for r in R for t in T)
T_port = [sum(t_rt_sail(r,t) for r in R for t in T), sum(t_rt_wait(r,t) for r in R for t 
in T), sum(t_rt_serve(r,t) for r in R for t in T)]

barges_port = sum(math.ceil(freq_year[r]) for r in R)

print("")
print("PARAMETERS")
print("Yearly import demand for regions ", end=' ')
print(regions, end=" : ")
print([round(el) for el in import_volume_year])
print("Yearly export demand for regions ", end=' ')
print(regions, end=" : ")
print([round(el) for el in export_volume_year])
```

```
print("Nr. services per year for regions ", end=' ')
print(regions, end=" : ")
print(freq_year)
print("---------------------------------------")
print("BASE CASE")
print("Time in hinterland: %d" % T_hinterl)
for k in range(len(T_port)):
    print("Time " + sequence[k] + "ing in port: %d" % T_port[k])
print("Total time: %d" % (T_hinterl+sum(T_port)))
print("")
print("Barges in port per year: %d" % barges_port)
print("---------------------------------------")

BENCHMARK = T_hinterl+sum(T_port)

n = gp.Model("MT_model")

x_import = []
x_export = []
for t in T:
    x_import.append(n.addVar(lb = 0, vtype = GRB.INTEGER, name = 'x_import('+str(t)+')'))
    x_export.append(n.addVar(lb = 0, vtype = GRB.INTEGER, name = 'x_export('+str(t)+')'))
y = []
z = []
for t in T:
    y.append([])
    z.append([])
    for r in R:
        y[t].append(n.addVar(vtype = GRB.BINARY, name = 'y['+str(t)+']['+str(r)+']'))
    for i in I:
        z[t].append(n.addVar(lb = 0, vtype = GRB.INTEGER, name =
'z['+str(t)+']['+str(i)+']'))

T_hinter = []
T_port_sail = []
T_portH_wait = []
T_portM_wait = []
T_port_serve = []
T_MT_sail = []
T_MT_wait = []
T_MT_serve = []

for t in T:
    T_hinter.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name =
'T_hinter('+str(t)+')'))
    T_port_sail.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name =
'T_port_sail('+str(t)+')'))
    T_portH_wait.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name =
'T_portH_wait('+str(t)+')'))
    T_portM_wait.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name =
'T_portM_wait('+str(t)+')'))
```

```
    T_port_serve.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name = 'T_port_serve('+str(t)+')'))
    T_MT_sail.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name = 'T_MT_sail('+str(t)+')'))
    T_MT_wait.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name = 'T_MT_wait('+str(t)+')'))
    T_MT_serve.append(n.addVar(lb = 0, vtype = GRB.CONTINUOUS, name = 'T_MT_serve('+str(t)+')'))
n.update()

for t in T:
    n.addConstr(T_hinter[t] == quicksum(t_rt_hinter(r,t) for r in R))
    n.addConstr(T_port_sail[t] == quicksum(N_term*term_sail*freq_month[t][r]*(1-y[t][r]) for r in R))
    n.addConstr(T_portH_wait[t] == quicksum(term_wait_month_i[t][i]*quicksum(freq_month[t][r]*(1-y[t][r]) for r in R) for i in I))
    n.addConstr(T_portM_wait[t] == quicksum(term_wait_shuttle*z[t][i] for i in I))
    n.addConstr(T_port_serve[t] == quicksum(t_rt_serve(r,t) for r in R))
    n.addConstr(T_MT_sail[t] == (2*MT_sail+IX_sail)*quicksum(z[t][i] for i in I) + quicksum(freq_month[t][r]*(y[t][r]*IX_sail) for r in R))

    n.addConstr(T_MT_sail[t] == ((8*MT_sail_01+ 2*MT_sail_02 + 2*MT_sail_03 + 2*MT_sail_04)+IX_sail)*quicksum(z[t][i]/7 for i in I) + quicksum(freq_month[t][r]*(y[t][r]*IX_sail) for r in R))
    n.addConstr(T_MT_wait[t] == quicksum(2*MT_wait*y[t][r]*freq_month[t][r] for r in R))
    n.addConstr(T_MT_serve[t] == quicksum(MT_serve*y[t][r]*(export_volume_month_i[t][i][r]+import_volume_month_i[t][i][r]) for i in I for r in R))

n.setObjective(quicksum((T_hinter[t] + T_port_sail[t] + T_portH_wait[t] + T_portM_wait[t] + T_port_serve[t] + T_MT_sail[t] + T_MT_wait[t] + T_MT_serve[t]) for t in T))
n.modelSense = GRB.MINIMIZE
n.update()

for t in T:
    n.addConstr(quicksum(y[t][r]*import_volume_month_i[t][i][r] for r in R for i in I)*MT_serve<=480*x_import[t])
    n.addConstr(quicksum(y[t][r]*export_volume_month_i[t][i][r] for r in R for i in I)*MT_serve<=480*x_export[t])

for t in T:
    n.addConstr(quicksum(z[t][i] for i in I)/30/2 <= x_import[t])
    n.addConstr(quicksum(z[t][i] for i in I)/30/2 + 1 >= x_import[t])
    n.addConstr(quicksum(z[t][i] for i in I)/30/2 <= x_export[t])
    n.addConstr(quicksum(z[t][i] for i in I)/30/2 + 1 >= x_export[t])
    #n.addConstr(MT_surf * (x_import[t]+x_export[t]) <= max_SURF)
    n.addConstr((x_import[t]+x_export[t]) <= MAX_MMT)
    for i in I:
        n.addConstr(z[t][i]<=quicksum(y[t][r] for r in R)*M)
```

```
        n.addConstr(quicksum(y[t][r]*import_volume_month_i[t][i][r] for r in R) <=
z[t][i]*MT_barge_cap)
        n.addConstr(quicksum(y[t][r]*export_volume_month_i[t][i][r] for r in R) <=
z[t][i]*MT_barge_cap)

    if not dynamic:
        for d in T:
            n.addConstr(x_import[t]==x_import[d])
            n.addConstr(x_export[t]==x_export[d])
            for i in I:
                n.addConstr(z[t][i]==z[d][i])
            for r in R:
                n.addConstr(y[t][r]==y[d][r])

n.update()

n.write('MMTCase.lp')
n.setParam('OutputFlag', False)
n.optimize()

barges_port = math.ceil((sum((1-y[t][r].x)*freq_month[t][r] for r in R for t in
T)+sum(z[t][i].x for i in I for t in T))/50)

importMT_time = []
exportMT_time = []

for t in T:
    if x_import[t].x>0:
        importMT_time.append(sum(y[t][r].x*import_volume_month_i[t][i][r] for r in R for i
in I)*MT_serve/x_import[t].x)
    if x_export[t].x>0:
        exportMT_time.append(sum(y[t][r].x*export_volume_month_i[t][i][r] for r in R for i
in I)*MT_serve/x_export[t].x)

print("OD BUNDLING STRATEGY (DYNAMIC)")
print("Time in hinterland: %d" % sum(T_hinter[t].x for t in T))
print("Time sailing in port: %d" % sum(T_port_sail[t].x for t in T))
print("Time waiting in port: %d" % sum((T_portH_wait[t].x+T_portM_wait[t].x) for t in T))
print("Time serving in port: %d" % sum(T_port_serve[t].x for t in T))
print("Time sailing between MMTs and port: %d" % (sum(T_MT_sail[t].x for t in T) -
IX_sail*sum(sum(z[t][i].x for i in I)+sum(freq_month[t][r]*y[t][r].x for r in R) for t in
T)))
print("Time sailing between importMT and exportMT: %d" % sum(T_MT_sail[t].x-
2*MT_sail*sum(z[t][i].x for i in I) for t in T))
print("Time sailing between importMT and exportMT: %d" % sum(T_MT_sail[t].x-(8*MT_sail_01+
2*MT_sail_02 + 2*MT_sail_03 + 2*MT_sail_04)*sum((1/7)*z[t][i].x for i in I) for t in T))
print("Time waiting at MT: %d" % sum(T_MT_wait[t].x for t in T))
print("Time serving at MT: %d" % sum(T_MT_serve[t].x for t in T))
print("Total time: %d" % n.objVal)
print("")
print("SOLUTION:")
```

```
print("Max. number of import crane modules: %d" % max(x_import[t].x for t in T))
print("Max. number of export crane modules: %d" % max(x_export[t].x for t in T))
print("Min. number of import crane modules: %d" % min(x_import[t].x for t in T))
print("Min. number of export crane modules: %d" % min(x_export[t].x for t in T))
#    for r in R:
#        print("Region %s linked to MT: %d" % (regions[r],y[r].x))
for t in T:
    if(sum(y[t][r].x for r in R) > 0):
        print("")
        for i in I:
            print("   -> Month %s frequency to terminal %s of MT shuttle: %d" %
(t+1,i,z[t][i].x))
print("")
print("Max. handling time per month per import crane module [h]: " +
str(round(max(importMT_time),2)))
print("Max. handling time per month per export crane module [h]: " +
str(round(max(exportMT_time),2)))
print("Min. handling time per month per import crane module [h]: " +
str(round(min(importMT_time),2)))
print("Min. handling time per month per export crane module [h]: " +
str(round(min(exportMT_time),2)))
print("")
print("KPIs per month:")
for t in T:
    print("   -> Month %s Time savings per IVW linked with MMT [h]: %.3f" %
(t+1,((sum(t_rt_hinter(r,t)+t_rt_sail(r,t)+t_rt_wait(r,t)+t_rt_serve(r,t) for r in R)-
(T_hinter[t].x+T_port_sail[t].x+T_portH_wait[t].x+T_portM_wait[t].x+T_port_serve[t].x+T_MT
_sail[t].x+T_MT_wait[t].x+T_MT_serve[t].x))/sum(y[t][r].x*freq_month[t][r] for r in R))))
    print("   -> Month %s Barges in port: %d" % (t+1,(sum((1-y[t][r].x)*freq_month[t][r]
for r in R)+sum(z[t][i].x for i in I))))
    print("   -> Month %s Occupancy of import shuttle modules: %.3f" %
(t+1,(sum(y[t][r].x*(import_volume_month_i[t][i][r]) for r in R for i in
I)/sum(z[t][i].x*MT_barge_cap for i in I))))
    print("   -> Month %s Occupancy of export shuttle modules: %.3f" %
(t+1,(sum(y[t][r].x*(export_volume_month_i[t][i][r]) for r in R for i in
I)/sum(z[t][i].x*MT_barge_cap for i in I))))
    print("")
print("")
print("KPIs per year:")
print("Time savings per IVW linked with MMT [h]: %.3f" % ((BENCHMARK-
n.objVal)/sum(y[t][r].x*freq_month[t][r] for r in R for t in T)))
print("Time savings per IVW linked with MMT (incl. shuttles) [h]: %.3f" % ((BENCHMARK-
n.objVal)/(sum(y[t][r].x*freq_month[t][r] for r in R for t in T)+sum(z[t][i].x for i in I
for t in T))))
print("Barges in port: %d" % (sum((1-y[t][r].x)*freq_month[t][r] for r in R for t in
T)+sum(z[t][i].x for i in I for t in T)))
print("Occupancy of import shuttle modules: %.3f" %
(sum(y[t][r].x*(import_volume_month_i[t][i][r]) for t in T for r in R for i in
I)/sum(z[t][i].x*MT_barge_cap for i in I for t in T)))
```

```
print("Occupancy of export shuttle modules: %.3f" %
(sum(y[t][r].x*(export_volume_month_i[t][i][r]) for t in T for r in R for i in
I)/sum(z[t][i].x*MT_barge_cap for i in I for t in T)))
```

Appendix 3 – Code changes explanation

In the original model, one MT_sail time is used. In the new model, this has been changed to MT_sail_01 till MT_sail_04 in order to include all the different locations. If only location 1 and 2 are used, location 3 and 4 have to be deactivated.

Original code:
MT_sail = 2.8 #sail time between MMT and deep-sea port (incl. mooring/unmooring at port and MMT)

Will be changed in:
MT_sail_01 = 0.55 #sail time between MMT and deep-sea port from potential location 1 (incl. mooring/unmooring at port and MMT)
MT_sail_02 = 1.05 #sail time between MMT and deep-sea port from potential location 2 (incl. mooring/unmooring at port and MMT)
MT_sail_03 = 1.65 #sail time between MMT and deep-sea port from potential location 3 (incl. mooring/unmooring at port and MMT)
MT_sail_04 = 6.75 #sail time between MMT and deep-sea port from potential location 4 (incl. mooring/unmooring at port and MMT)

This has the consequence that " n.addConstr(T_MT_sail[t] == (2*MT_sail+IX_sail)*quicksum(z[t][i] for i in I) + quicksum(freq_month[t][r]*(y[t][r]*IX_sail) for r in R)" from the original model must be adjusted.
MT_sail must be divided into MT_sail_01 till MT_sail_04, depending on which locations are involved. Furthermore, a factor must be added that depends on the number of MMT terminals that can be placed on that specific location. Suppose that for the port of Rotterdam, locations 1,2 and 3 are used and respectively eight, two and two MMTs can be placed then this looks like this in the adjusted code (see the purple part):
n.addConstr(T_MT_sail[t] == ((8*MT_sail_01+ 2*MT_sail_02 + 2*MT_sail_03)+IX_sail)*quicksum(z[t][i]/6 for i in I) + quicksum(freq_month[t][r]*(y[t][r]*IX_sail) for r in R))

The six highlighted in orange is the result of assuming that pairs are formed with each pair having one import and one export MMT at the same location. The six is therefore the number of potential pairs that can be used. In the course of the study, these numbers must therefore be adjusted due to the dependency on the locations and the number of MMTs (and thus also the number of pairs).

Furthermore, "MT_surf = 10000 #rough surface of a whole MMT" is replaced by a constraint per port that indicates how many MMTs can be placed. This number has to be adjusted during the research because it depends on how many and which locations participate. In the adjusted code this line can be found:
MAX_MMT = 12 #Maximum available MMTs depending on how many locations are involved

Removing the maximum area of the MMT has the consequence that
"n.addConstr(MT_surf * (x_import[t]+x_export[t]) <= max_SURF)"
is no longer necessary and can be replaced by:
"n.addConstr((x_import[t]+x_export[t]) <= MAX_MMT)"

Appendix 4 – Rotterdam location 1

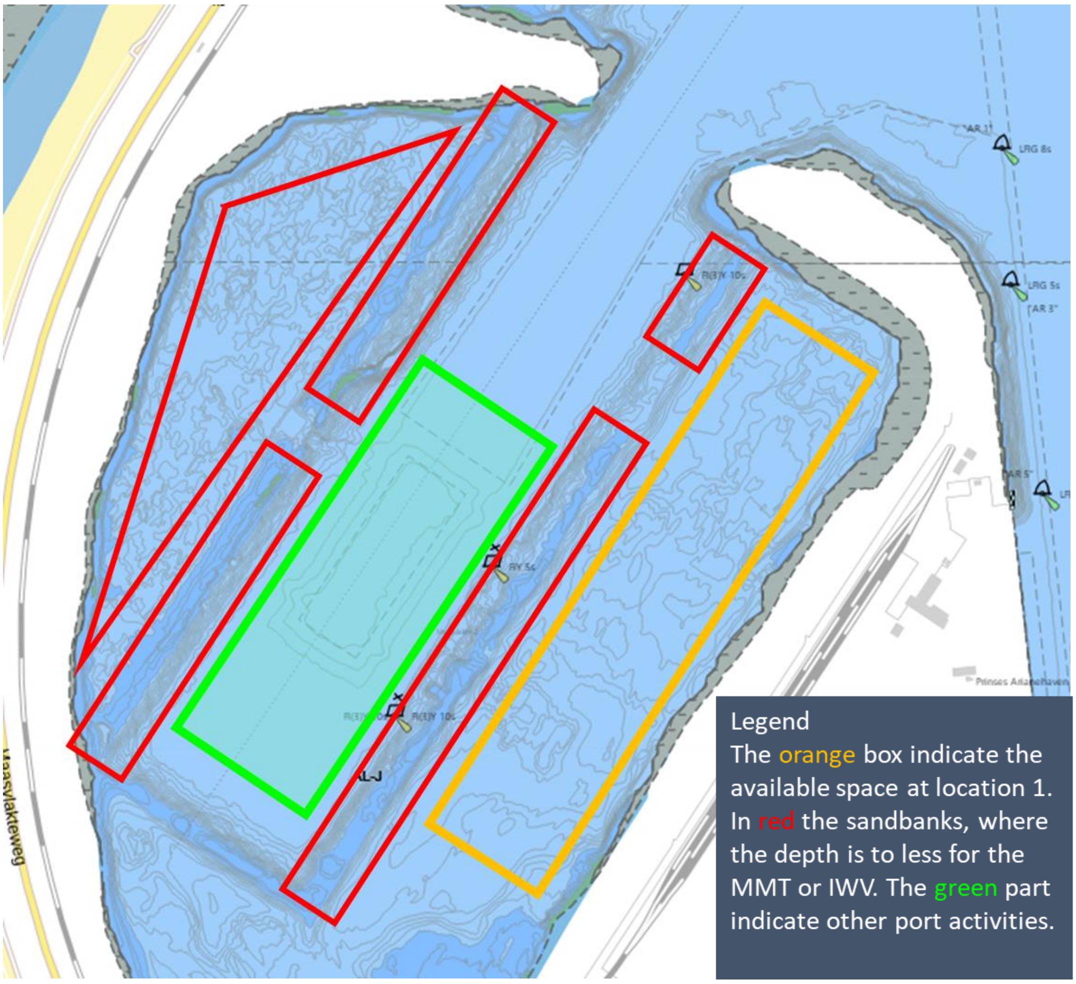

Figure 14: Available space at location 1 Port of Rotterdam [39]

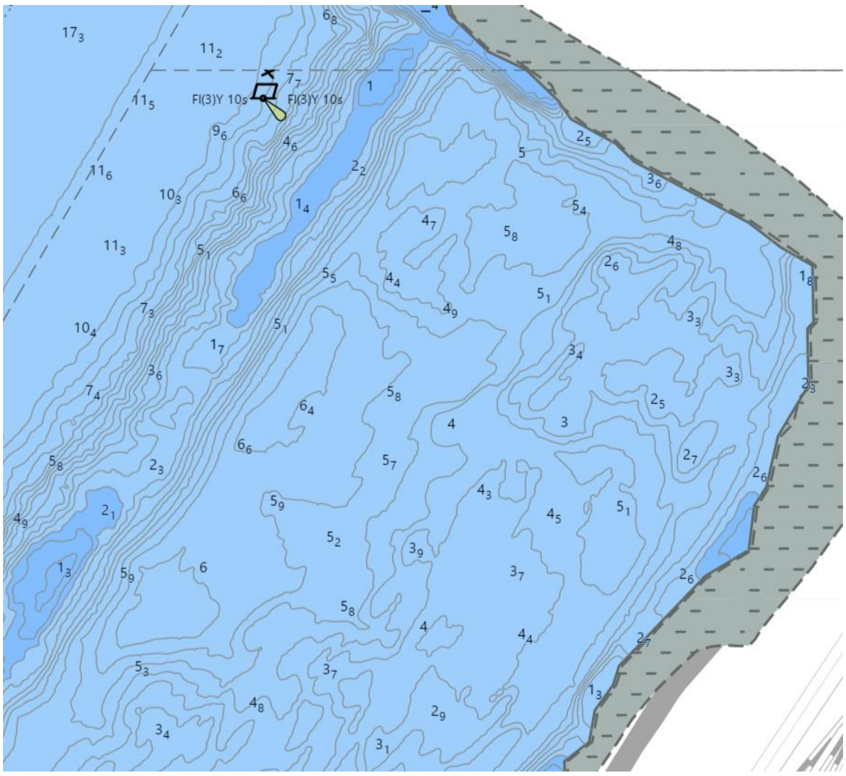

Figure 15: Depth in meters Rotterdam location 1 part 1 [39]

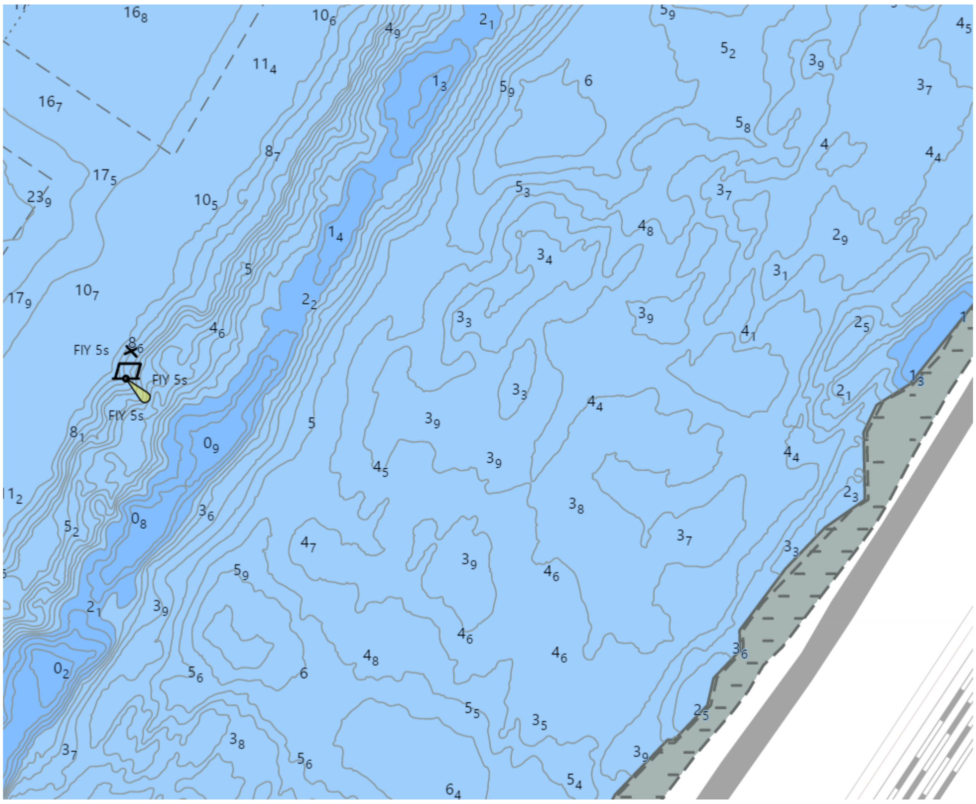

Figure 16: Depth in meters Rotterdam location 1 part 2 [39]

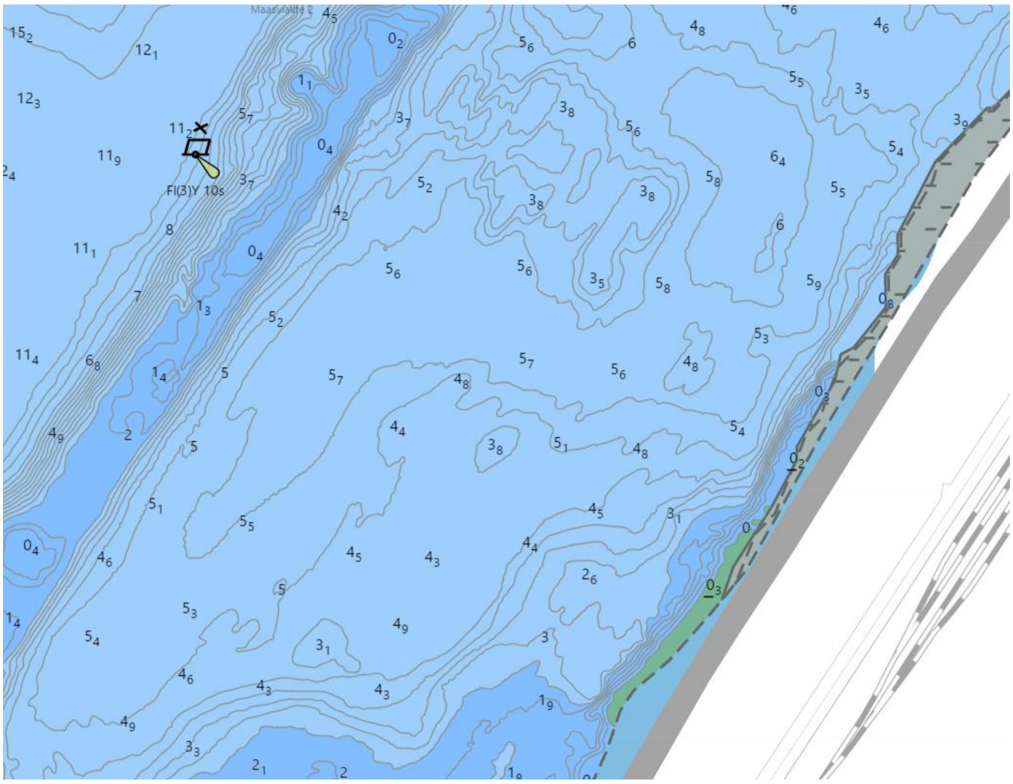

Figure 17: Depth in meters Rotterdam location 1 part 3 [39]

Appendix 5 – Rotterdam location 2

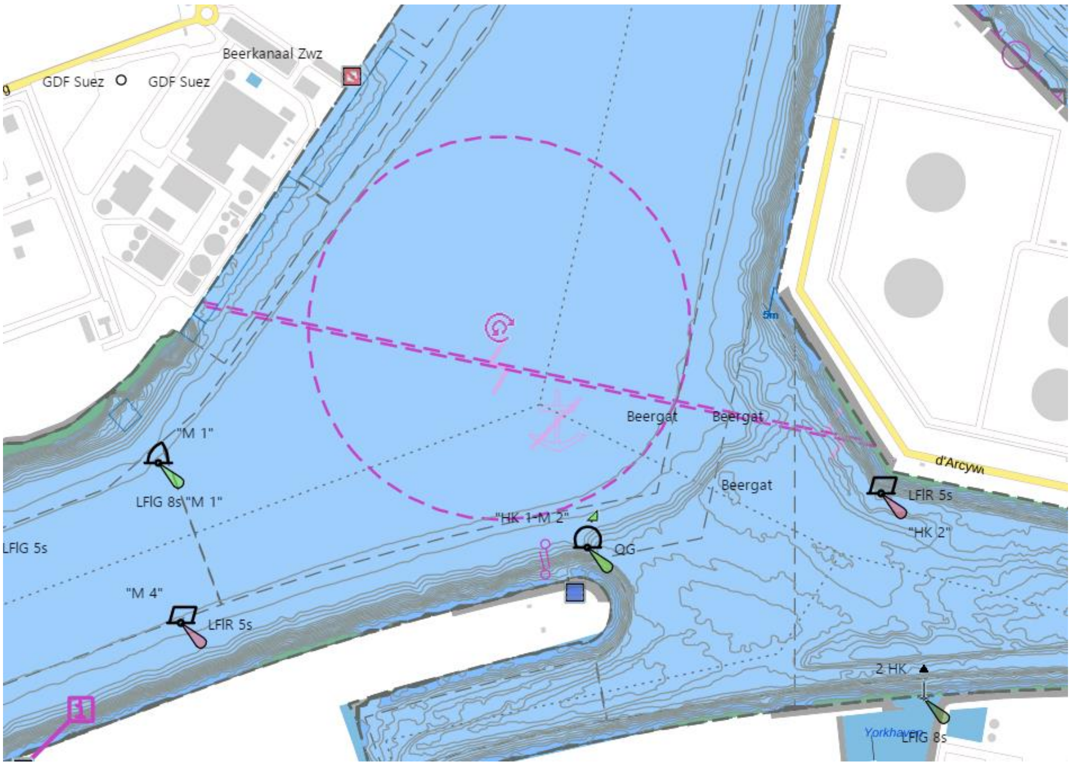

Figure 18: Anchor restrictions Rotterdam location 2 [39]

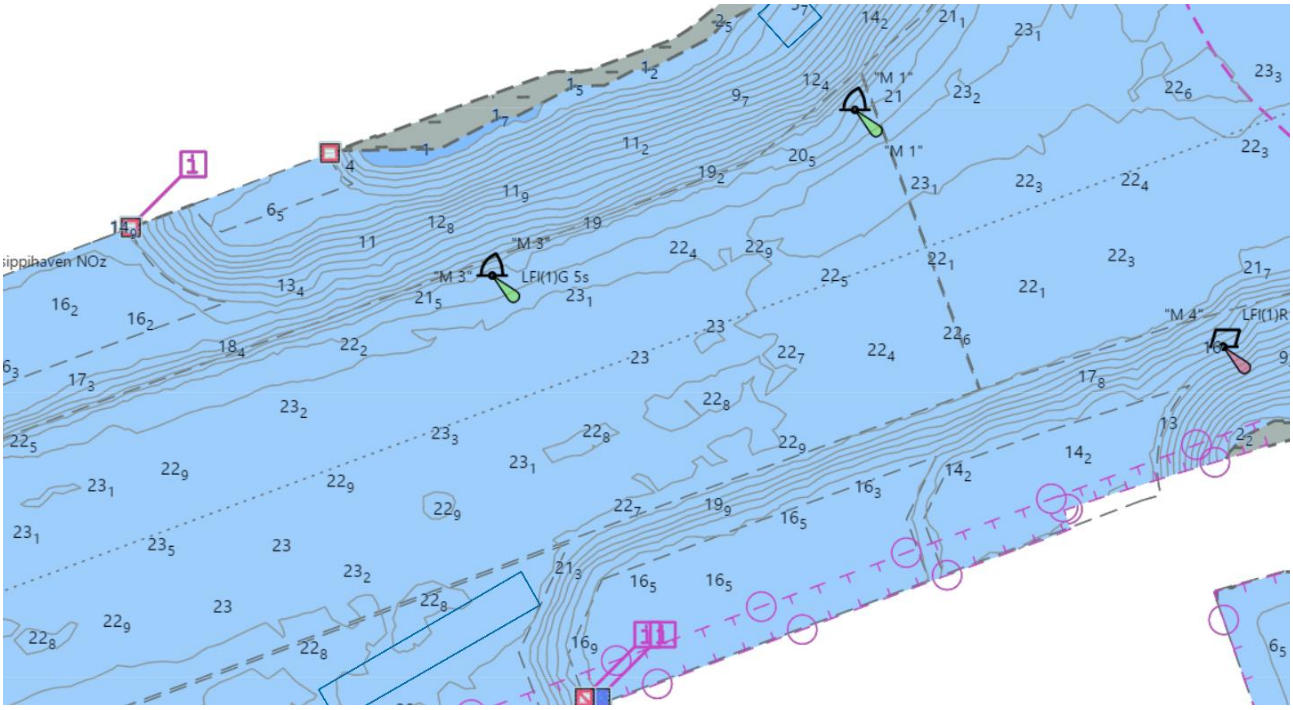

Figure 19: Depth in meters Rotterdam location 2 [39]

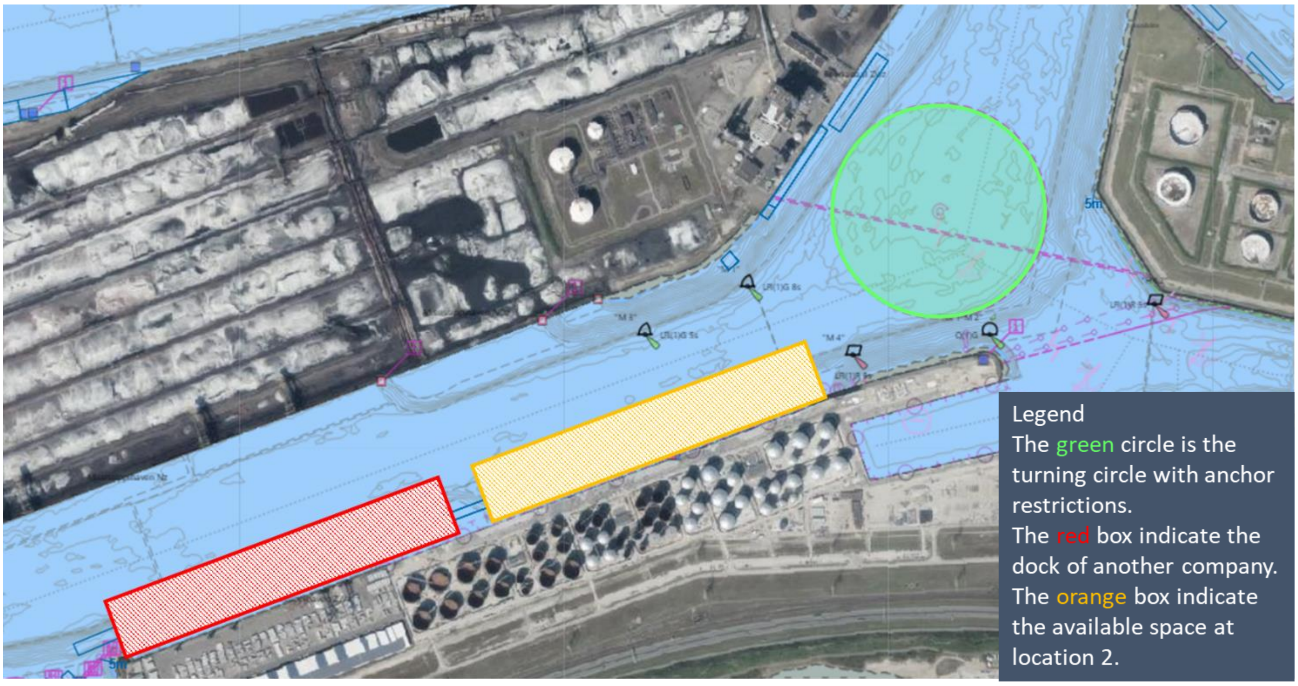

Figure 20: Overview Rotterdam location 2 [39]

Appendix 6 – Rotterdam location 3

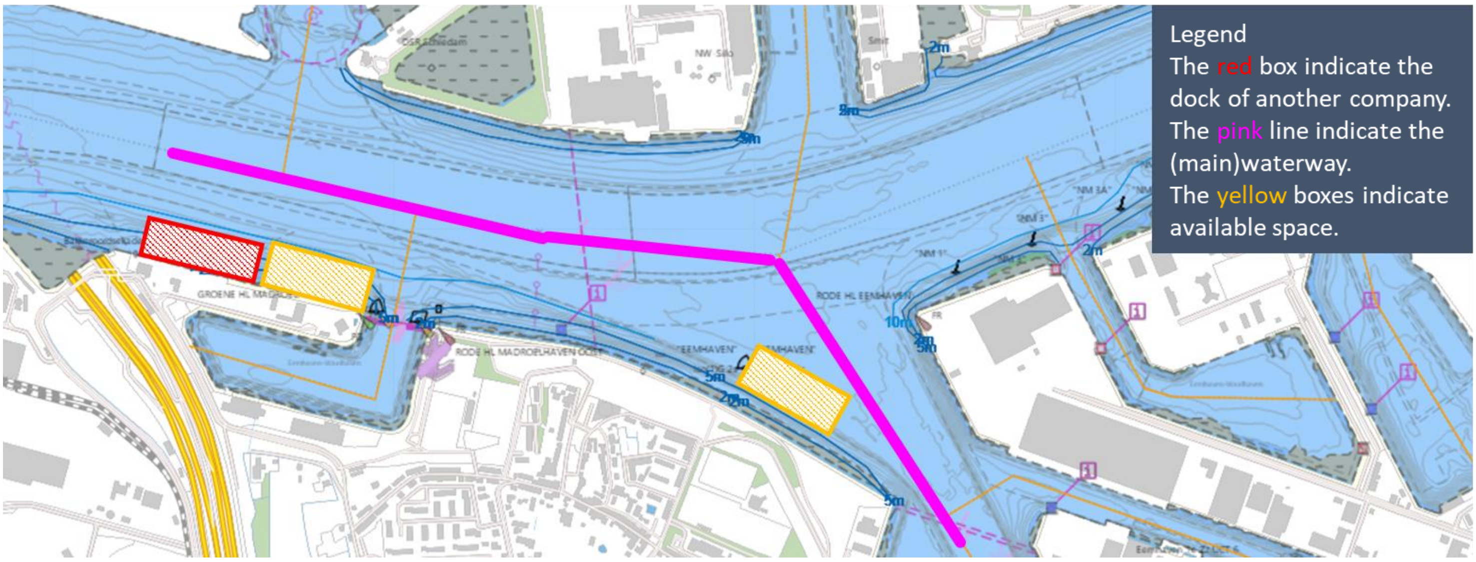

Figure 21: Overview Rotterdam location 3 [39]

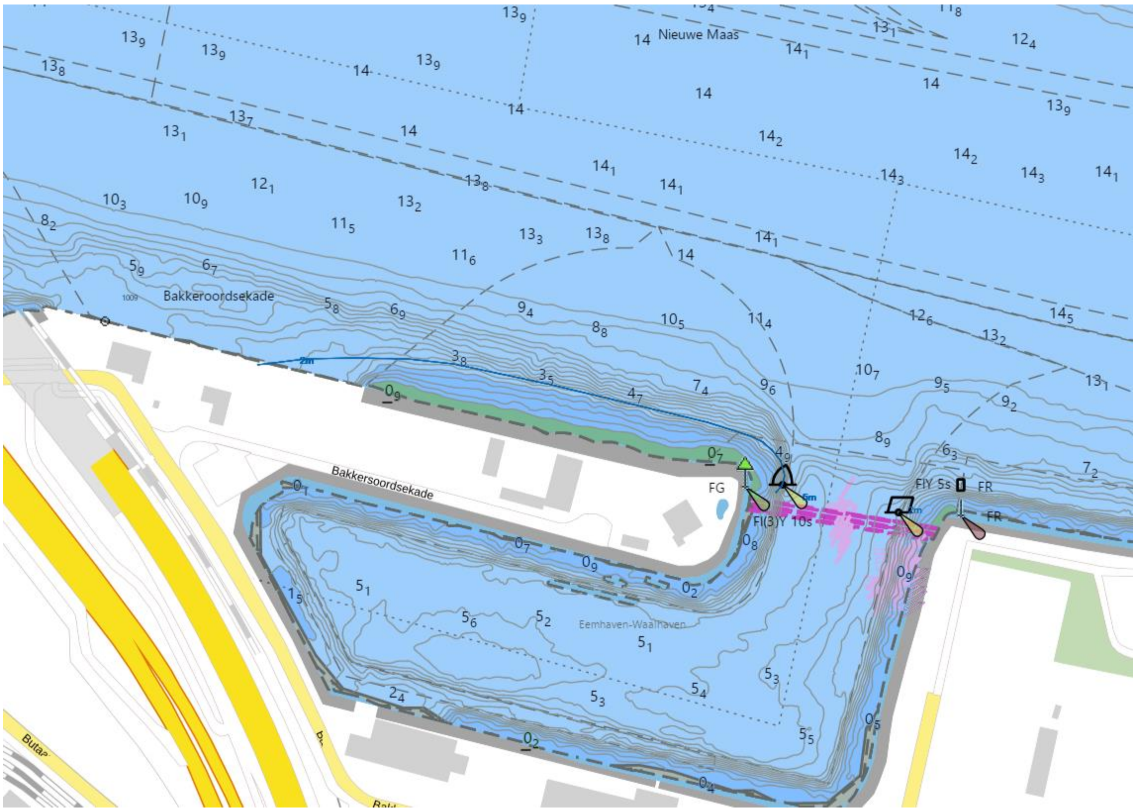

Figure 22: Depth in meters Rotterdam location 3A [39]

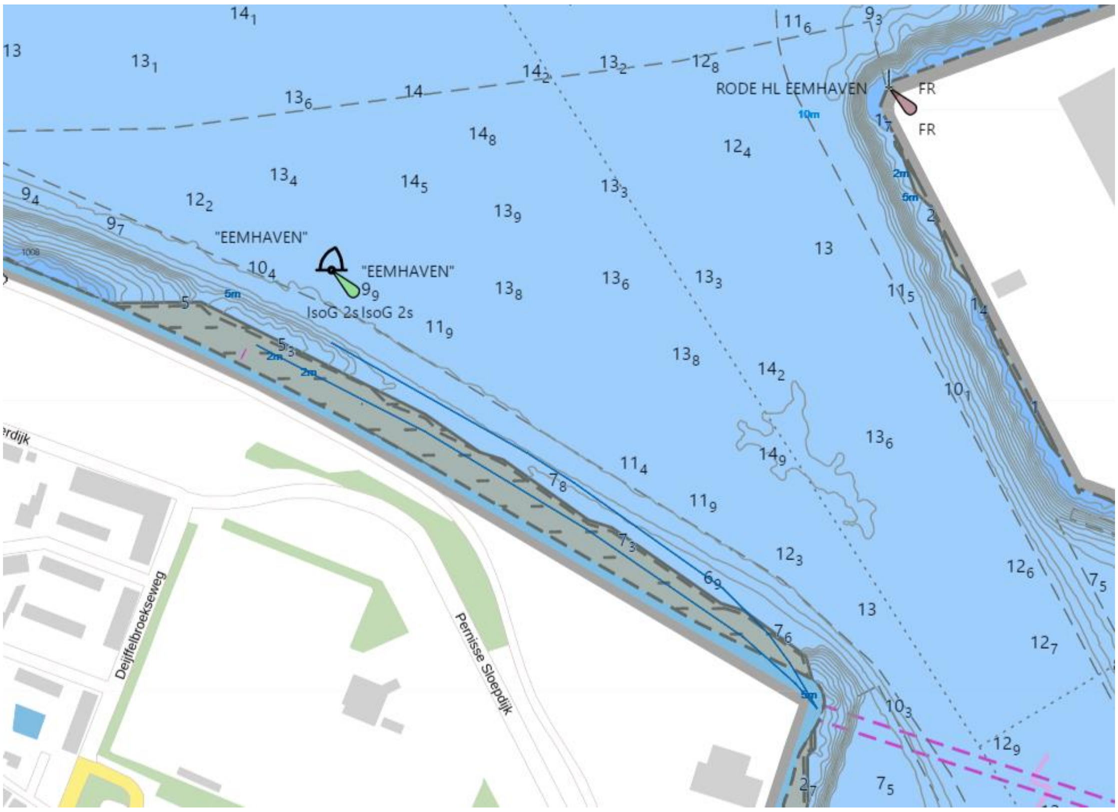

Figure 23: Depth in meters Rotterdam location 3B [39]

Appendix 7 – Rotterdam location 4

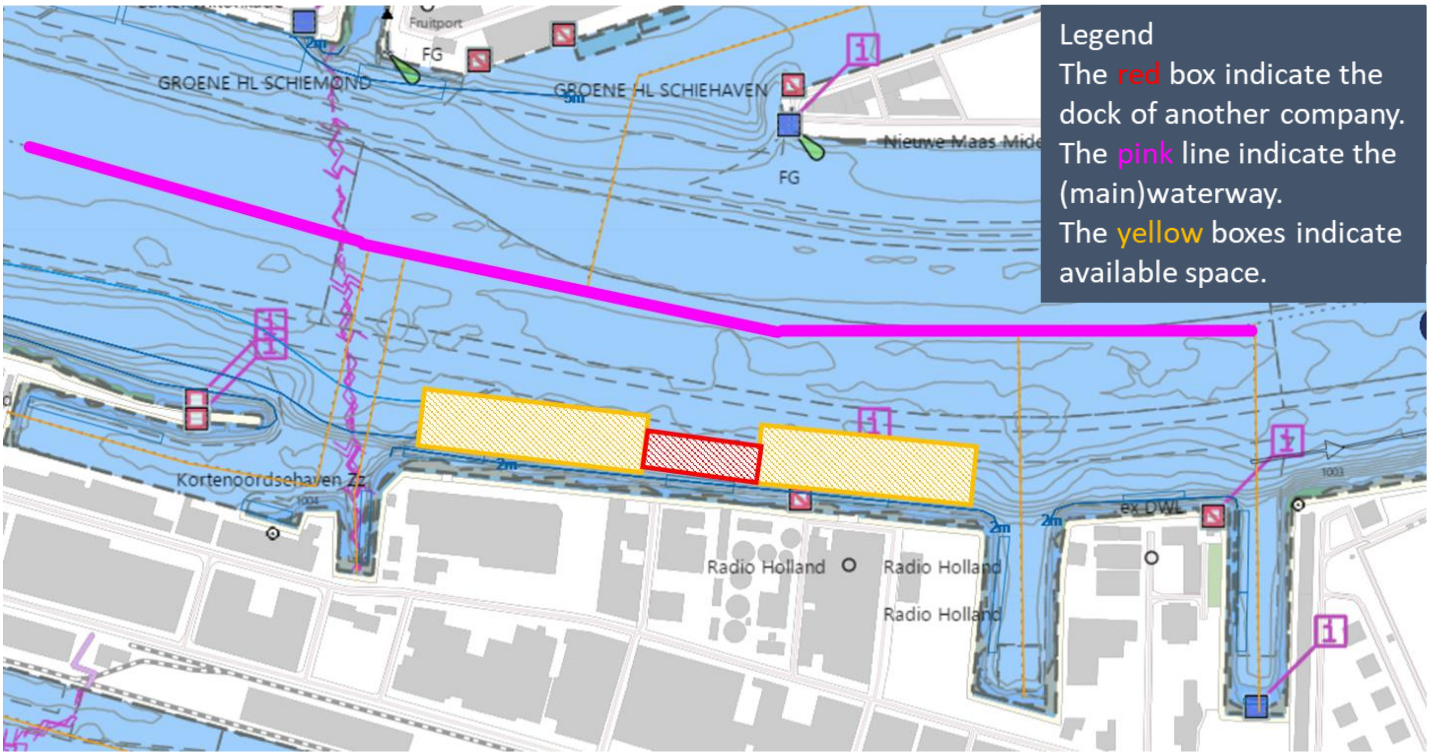

Figure 24: Overview Rotterdam location 4 [39]

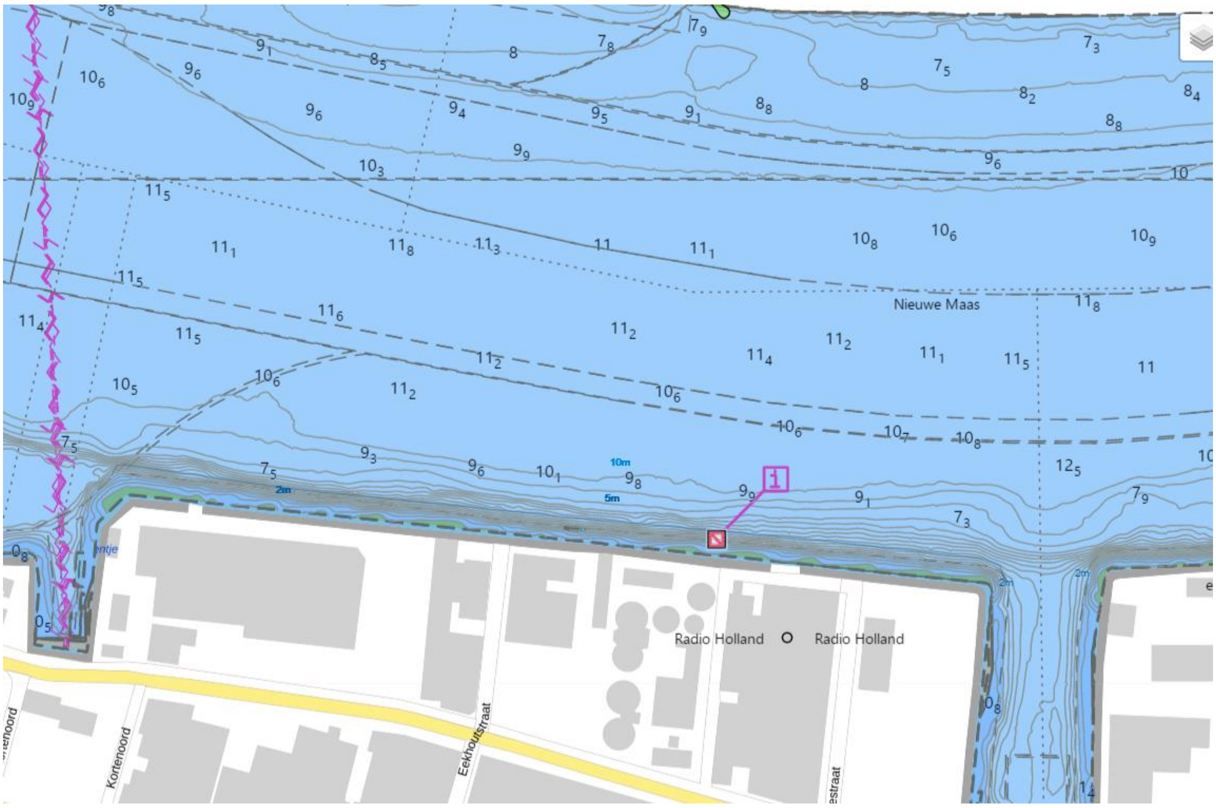

Figure 25: Depth in meters Rotterdam location 4 [39]

Appendix 8 – Antwerp location 1

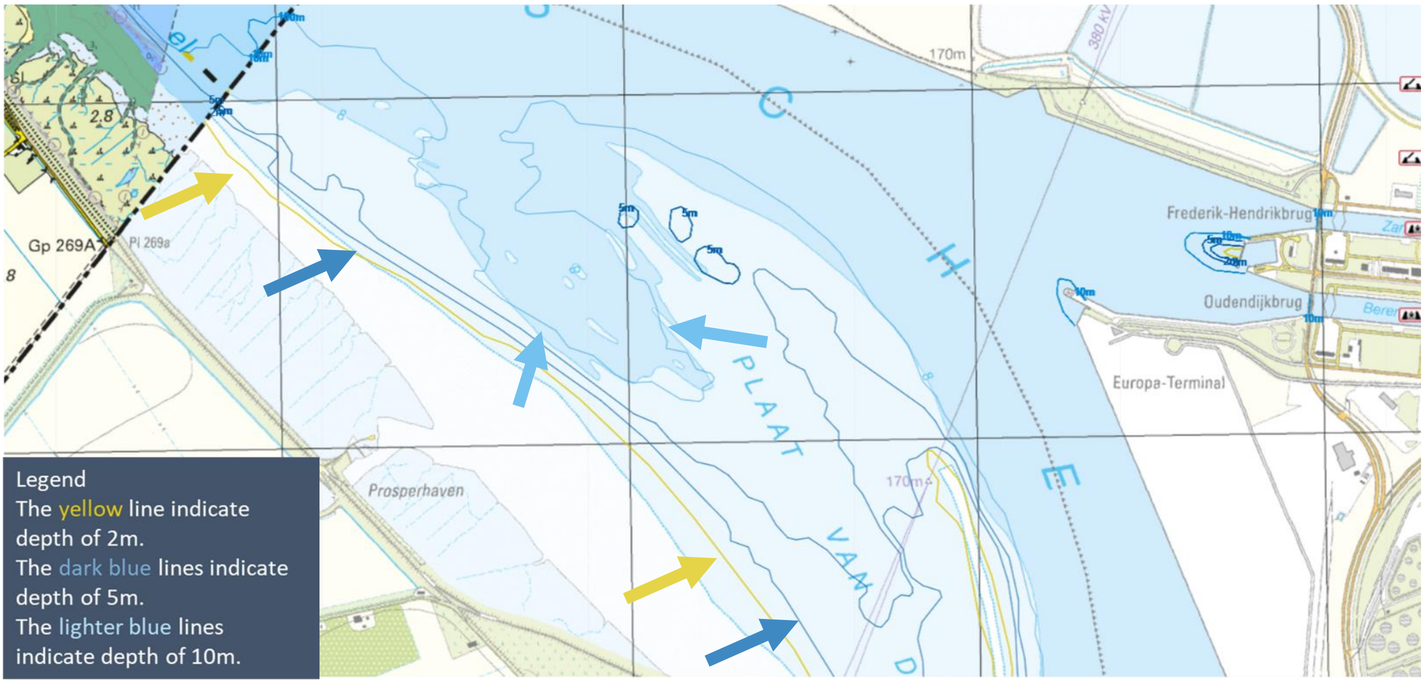

Figure 26: Depth in meters Antwerp location 1 [39]

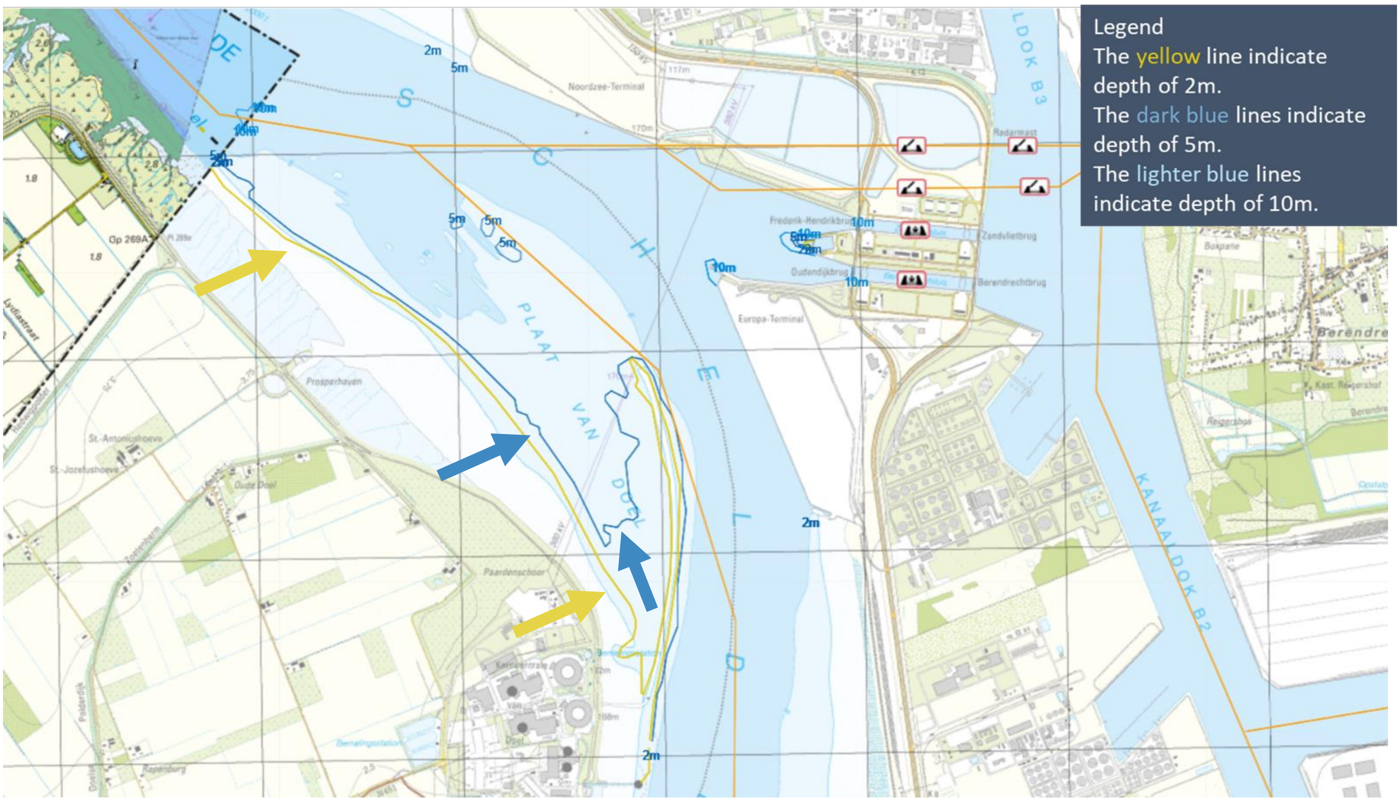

Figure 27: Depth in meters Antwerp location 1 [39]

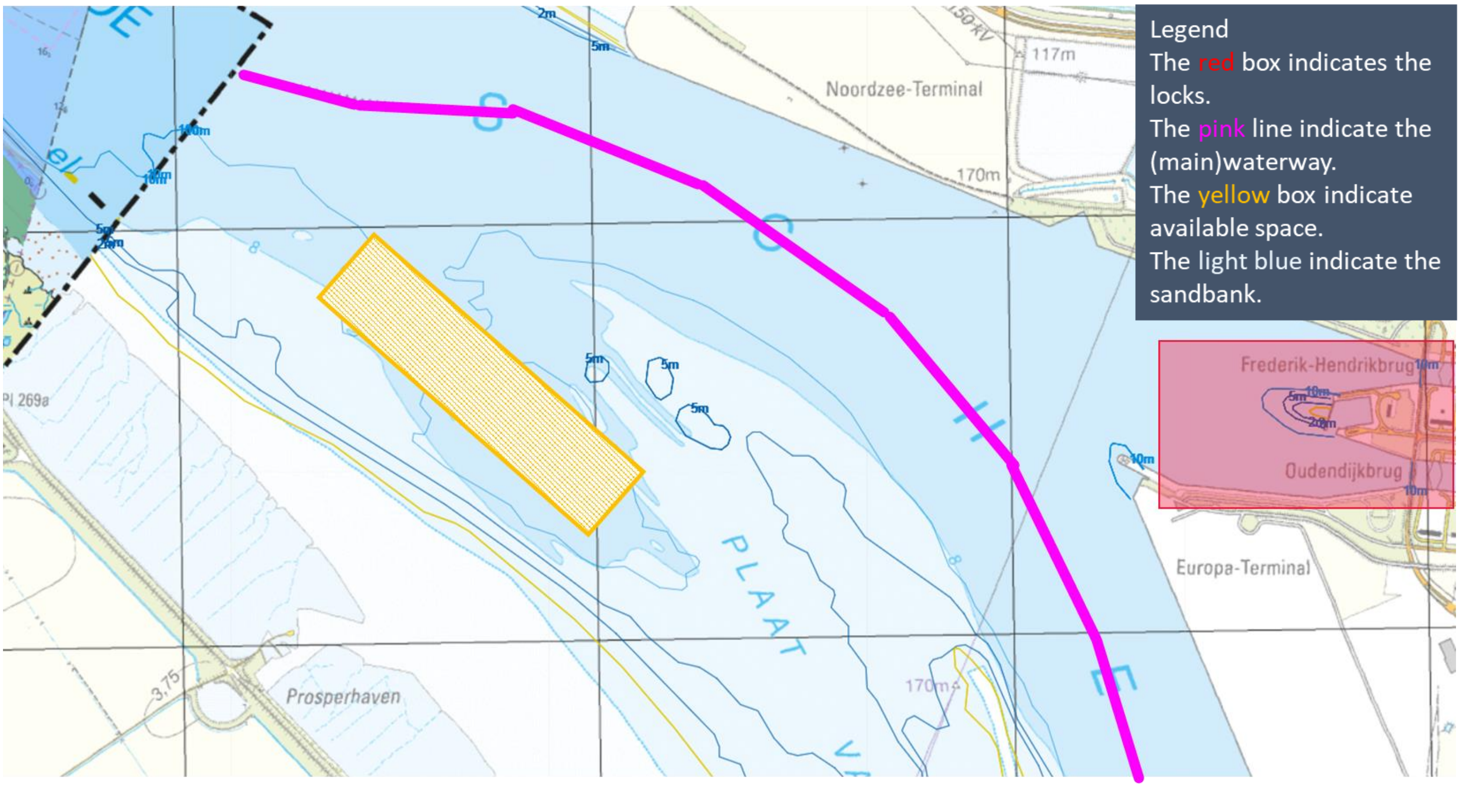

Figure 28: Overview Antwerp location 1 [39]

Appendix 9 – Antwerp location 2

Figure 29: Overview Antwerp location 2 [39]

Figure 30: Depth in meters Antwerp location 2 [39]

Appendix 10 – Antwerp location 3

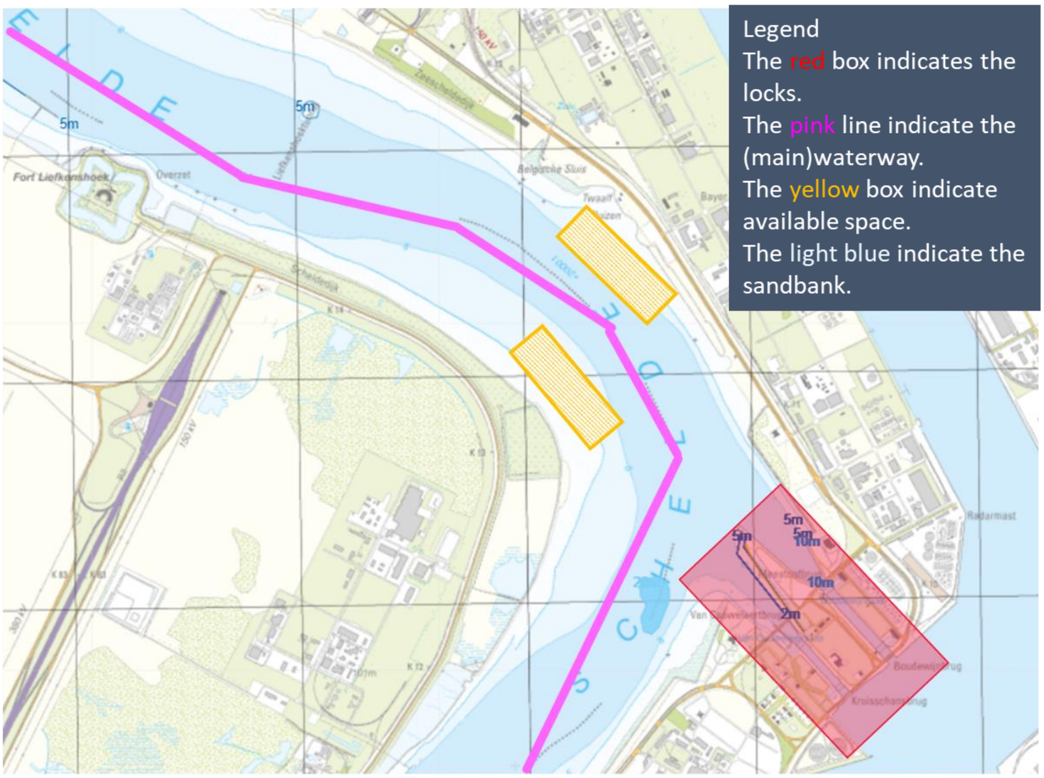

Figure 31: Overview Antwerp location 3 [39]

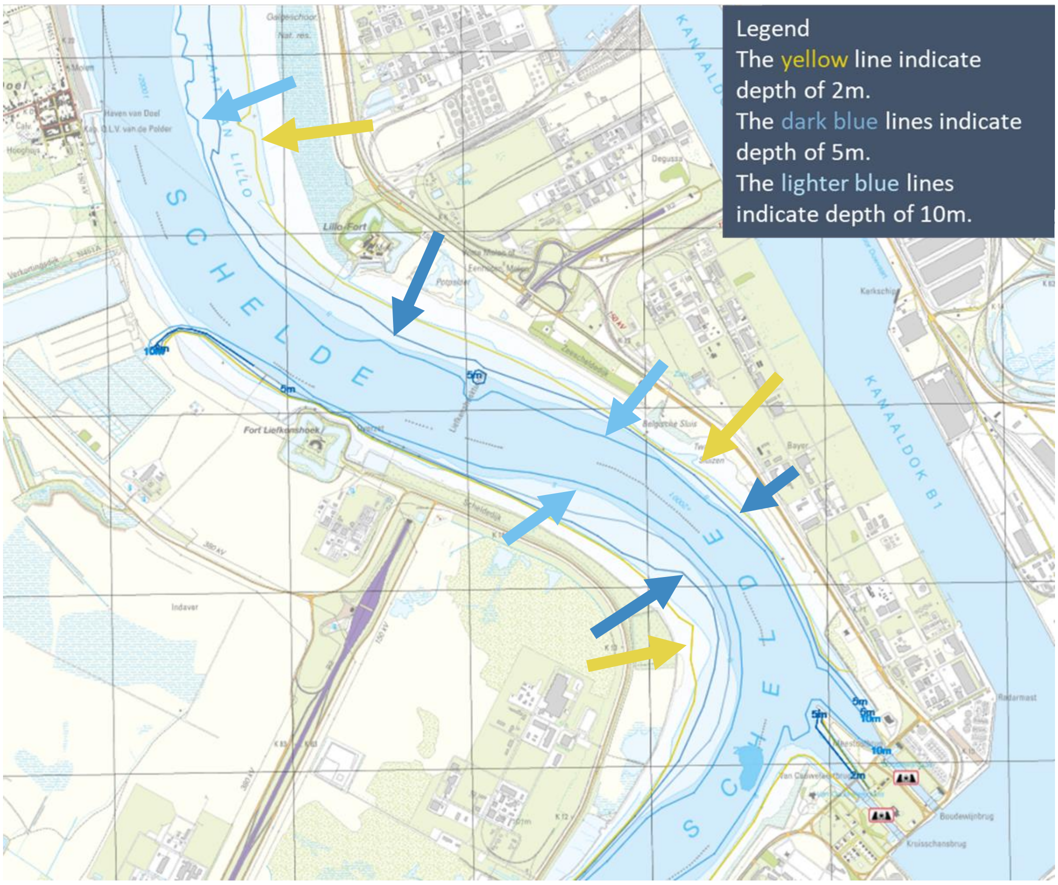

Figure 32: Depth in meters Antwerp location 3 [39]

Appendix 11 – Results Port of Rotterdam

Table 10: Results Location 1 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	19632	19632	19632	19632	20400		
Time waiting in port:	78528	78528	78528	78528	81600		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	6084	6084	6660	11268	13987		8816,6
Time sailing between importMT and exportMT:	1746	1746	1746	1746	1689		
Time waiting at MT:	12528	12528	12528	12528	12144		
Time serving at MT:	35589	35589	35589	35589	32950		
Total time:	819631	819631	820207	824815	828268		822510,4
Total time without time in hinterland	277975	277975	278551	283159	286612		280854,4
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	68793	68793	68217	63609	60156		65913,6
Percentage time saved	19,84%	19,84%	19,67%	18,34%	17,35%		19,01%
Max. number of import crane modules:	4	4	4	4	4		
Max. number of export crane modules:	4	4	4	4	4		
Min. number of import crane modules:	4	4	4	4	4		
Min. number of export crane modules:	4	4	4	4	4		
Month 1 frequency to terminal 0 of MT shuttle:	60	60	60	60	57		
Max. handling time per month per import crane module [h]:	411.85	411.85	411.85	411.85	356.55		
Max. handling time per month per export crane module [h]:	396.85	396.85	396.85	396.85	392.2		
Min. handling time per month per import crane module [h]:	347.1	347.1	347.1	347.1	300.5		
Min. handling time per month per export crane module [h]:	334.5	334.5	334.5	334.5	330.55		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	10.982	10.982	10.890	10.155	9.907		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	7.523	7.523	7.460	6.956	6.830		
Barges in port:	7788	7788	7788	7788	7836		
Occupancy of import shuttle modules:	0.912	0.912	0.912	0.912	0.831		
Occupancy of export shuttle modules:	0.879	0.879	0.879	0.879	0.914		

Table 11: Results Location 2 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
2 MMTs at location 2	Total time: 888424		Total time:	346768			
	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	38448	38448	38448	38448	38448		
Time waiting in port:	153792	153792	153792	153792	153792		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	3384	3384	2088	1800	1224		2376
Time sailing between importMT and exportMT:	570	570	570	570	570		
Time waiting at MT:	3120	3120	3120	3120	3120		
Time serving at MT:	8612	8612	8612	8612	8612		
Total time:	872910	872910	871614	871326	870750		871902
Total time without time in hinterland	331254	331254	329958	329670	329094		330246
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	15514	15514	16810	17098	17674		16522
Percentage time saved	4,47%	4,47%	4,85%	4,93%	5,10%		4,76%
Max. number of import crane modules:	1	1	1	1	1		
Max. number of export crane modules:	1	1	1	1	1		
Min. number of import crane modules:	1	1	1	1	1		
Min. number of export crane modules:	1	1	1	1	1		
Month 1 frequency to terminal 0 of MT shuttle:	15	15	15	15	15		
Max. handling time per month per import crane module [h]:	412.0	412.0	412.0	412.0	412.0		
Max. handling time per month per export crane module [h]:	370.8	370.8	370.8	370.8	370.8		
Min. handling time per month per import crane module [h]:	347.2	347.2	347.2	347.2	347.2		
Min. handling time per month per export crane module [h]:	312.4	312.4	312.4	312.4	312.4		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	9.944	9.944	10.775	10.960	11.329		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.804	6.804	7.373	7.499	7.751		
Barges in port:	10332	10332	10332	10332	10332		
Occupancy of import shuttle modules:	0.913	0.913	0.913	0.913	0.913		
Occupancy of export shuttle modules:	0.821	0.821	0.821	0.821	0.821		

Table 12: Results Location 3 Rotterdam

Port of Rotterdam	BASE CASE		BASE CASE without hinterland time				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
2 MMTs at location 3	Total time: 888424		Total time:	346768			
	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	39744	39744	39744	39744	39744		
Time waiting in port:	158976	158976	158976	158976	158976		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	6672	5712	6672	5520	5520		6019,2
Time sailing between importMT and exportMT:	429	429	429	429	429		
Time waiting at MT:	2472	2472	2472	2472	2472		
Time serving at MT:	5139	5139	5139	5139	5139		
Total time:	878417	877457	878417	877265	877265		877764,2
Total time without time in hinterland	336761	335801	336761	335609	335609		336108,2
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	10007	10967	10007	11159	11159		10659,8
Percentage time saved	2,89%	3,16%	2,89%	3,22%	3,22%		3,07%
Max. number of import crane modules:	1	1	1	1	1		
Max. number of export crane modules:	1	1	1	1	1		
Min. number of import crane modules:	1	1	1	1	1		
Min. number of export crane modules:	1	1	1	1	1		
Month 1 frequency to terminal 0 of MT shuttle:	10	10	10	10	10		
Max. handling time per month per import crane module [h]:	269.2	269.2	269.2	269.2	269.2		
Max. handling time per month per export crane module [h]:	198.0	198.0	198.0	198.0	198.0		
Min. handling time per month per import crane module [h]:	227.0	227.0	227.0	227.0	227.0		
Min. handling time per month per export crane module [h]:	166.8	166.8	166.8	166.8	166.8		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	8.096	8.873	8.096	9.028	9.028		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	5.832	6.391	5.832	6.503	6.503		
Barges in port:	10416	10416	10416	10416	10416		
Occupancy of import shuttle modules:	0.895	0.895	0.895	0.895	0.895		
Occupancy of export shuttle modules:	0.657	0.657	0.657	0.657	0.657		

Table 13: Results Location 4 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
2 MMTs at location 4	Total time: 888424		Total time:	346768			
	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	39744	39744	39744	39744	39744		
Time waiting in port:	158976	158976	158976	158976	158976		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	7632	6672	7632	6480	6480		6979,2
Time sailing between importMT and exportMT:	429	429	429	429	429		
Time waiting at MT:	2472	2472	2472	2472	2472		
Time serving at MT:	5139	5139	5139	5139	5139		
Total time:	879377	878417	879377	878225	878225		878724,2
Total time without time in hinterland	337721	336761	337721	336569	336569		337068,2
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	9047	10007	9047	10199	10199		9699,8
Percentage time saved	2,61%	2,89%	2,61%	2,94%	2,94%		2,80%
Max. number of import crane modules:	1	1	1	1	1		
Max. number of export crane modules:	1	1	1	1	1		
Min. number of import crane modules:	1	1	1	1	1		
Min. number of export crane modules:	1	1	1	1	1		
Month 1 frequency to terminal 0 of MT shuttle:	10	10	10	10	10		
Max. handling time per month per import crane module [h]:	269.2	269.2	269.2	269.2	269.2		
Max. handling time per month per export crane module [h]:	198.0	198.0	198.0	198.0	198.0		
Min. handling time per month per import crane module [h]:	227.0	227.0	227.0	227.0	227.0		
Min. handling time per month per export crane module [h]:	166.8	166.8	166.8	166.8	166.8		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	7.320	8.096	7.320	8.252	9.028		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	5.272	5.832	5.272	5.944	6.503		
Barges in port:	10416	10416	10416	10416	10416		
Occupancy of import shuttle modules:	0.895	0.895	0.895	0.895	0.895		
Occupancy of export shuttle modules:	0.657	0.657	0.657	0.657	0.657		

Table 14: Results Locations 1&2 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
2 MMTs at location 2							
Total 10 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	16512	16512	16512	16512	17856		
Time waiting in port:	66048	66048	66048	66048	71424		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	9288	9288	8568	12888	14296		10865,6
Time sailing between importMT and exportMT:	1941	1941	1941	1941	1840		
Time waiting at MT:	14088	14088	14088	14088	13416		
Time serving at MT:	44168	44168	44168	44168	39611		
Total time:	817750	817750	817030	821350	824080		819592
Total time without time in hinterland	276094	276094	275374	279694	282424		277936
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	70674	70674	71394	67074	64344		68832
Percentage time saved	20,38%	20,38%	20,59%	19,34%	18,56%		19,85%
Max. number of import crane modules:	5	5	5	5	5		
Max. number of export crane modules:	5	5	5	5	5		
Min. number of import crane modules:	5	5	5	5	5		
Min. number of export crane modules:	5	5	5	5	5		
Month 1 frequency to terminal 0 of MT shuttle:	75	75	75	75	68		
Max. handling time per month per import crane module [h]:	409.88	409.88	409.88	409.88	349.36		
Max. handling time per month per export crane module [h]:	393.04	393.04	393.04	393.04	370.72		
Min. handling time per month per import crane module [h]:	345.44	345.44	345.44	345.44	294.44		
Min. handling time per month per export crane module [h]:	331.24	331.24	331.24	331.24	312.4		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	10.033	10.033	10.135	9.522	9.592		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.640	6.640	6.707	6.302	6.452		
Barges in port:	7728	7728	7728	7728	7728		
Occupancy of import shuttle modules:	0.908	0.908	0.908	0.908	0.853		
Occupancy of export shuttle modules:	0.870	0.870	0.870	0.870	0.905		

Table 15: Results Locations 1&3 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
2 MMTs at location 3							
Total 10 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	17856	17280	17856	18048	18048		
Time waiting in port:	71424	69120	71424	72192	72192		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	14426	13700	14949	17043	20085		16040,6
Time sailing between importMT and exportMT:	1840	1883	1840	1823	1823		
Time waiting at MT:	13416	13704	13416	13320	13320		
Time serving at MT:	39611	41530	39611	39273	39273		
Total time:	824211	822883	824733	827318	830359		825900,8
Total time without time in hinterland	282555	281227	283077	285662	288703		284244,8
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	64213	65541	63691	61106	58065		62523,2
Percentage time saved	18,52%	18,90%	18,37%	17,62%	16,74%		18,03%
Max. number of import crane modules:	5	5	5	5	5		
Max. number of export crane modules:	5	5	5	5	5		
Min. number of import crane modules:	5	5	5	5	5		
Min. number of export crane modules:	5	5	5	5	5		
Month 1 frequency to terminal 0 of MT shuttle:	68	71	68	66	66		
Max. handling time per month per import crane module [h]:	349.36	365.64	349.36	359.92	359.92		
Max. handling time per month per export crane module [h]:	370.72	389.32	370.72	354.0	354.0		
Min. handling time per month per import crane module [h]:	294.44	308.16	294.44	303.32	303.32		
Min. handling time per month per export crane module [h]:	312.4	328.08	312.4	298.36	298.36		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	9.573	9.565	9.495	9.175	8.718		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.439	6.388	6.387	6.218	5.908		
Barges in port:	7728	7728	7728	7680	7680		
Occupancy of import shuttle modules:	0.853	0.855	0.853	0.906	0.906		
Occupancy of export shuttle modules:	0.905	0.911	0.905	0.891	0.891		

Table 16: Results Locations 2&3 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
2 MMTs at location 2	Total time: 888424		Total time:	346768			
2 MMTs at location 3							
Total 4 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	29040	29040	29040	29040	29040		
Time waiting in port:	116160	116160	116160	116160	116160		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	12771	11379	11518	9570	9013		10850,2
Time sailing between importMT and exportMT:	1152	1152	1152	1152	1152		
Time waiting at MT:	7824	7824	7824	7824	7824		
Time serving at MT:	17239	17239	17239	17239	17239		
Total time:	849345	847953	848092	846143	845586		847423,8
Total time without time in hinterland	307689	306297	306436	304487	303930		305767,8
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	39079	40471	40332	42281	42838		41000,2
Percentage time saved	11,27%	11,67%	11,63%	12,19%	12,35%		11,82%
Max. number of import crane modules:	2	2	2	2	2		
Max. number of export crane modules:	2	2	2	2	2		
Min. number of import crane modules:	2	2	2	2	2		
Min. number of export crane modules:	2	2	2	2	2		
Month 1 frequency to terminal 0 of MT shuttle:	29	29	29	29	29		
Max. handling time per month per import crane module [h]:	391.3	391.3	391.3	391.3	391.3		
Max. handling time per month per export crane module [h]:	392.1	392.1	392.1	392.1	392.1		
Min. handling time per month per import crane module [h]:	329.8	329.8	329.8	329.8	329.8		
Min. handling time per month per export crane module [h]:	330.5	330.5	330.5	330.5	330.5		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	9.990	10.345	10.310	10.808	10.950		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	7.368	7.630	7.604	7.971	8.076		
Barges in port:	8652	8652	8652	8652	8652		
Occupancy of import shuttle modules:	0.897	0.897	0.897	0.897	0.897		
Occupancy of export shuttle modules:	0.898	0.898	0.898	0.898	0.898		

Table 17: Results Locations 1&4 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
2 MMTs at location 4							
Total 10 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	17856	17856	17856	18048	18048		
Time waiting in port:	71424	71424	71424	72192	72192		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	15732	14426	16254	18311	21352		17215
Time sailing between importMT and exportMT:	1840	1840	1840	1823	1823		
Time waiting at MT:	13416	13416	13416	13320	13320		
Time serving at MT:	39611	39611	39611	39273	39273		
Total time:	825516	824211	826039	828585	831626		827195,4
Total time without time in hinterland	283860	282555	284383	286929	289970		285539,4
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	62908	64213	62385	59839	56798		61228,6
Percentage time saved	18,14%	18,52%	17,99%	17,26%	16,38%		17,66%
Max. number of import crane modules:	5	5	5	5	5		
Max. number of export crane modules:	5	5	5	5	5		
Min. number of import crane modules:	5	5	5	5	5		
Min. number of export crane modules:	5	5	5	5	5		
Month 1 frequency to terminal 0 of MT shuttle:	68	68	68	66	66		
Max. handling time per month per import crane module [h]:	349.36	349.36	349.36	359.92	359.92		
Max. handling time per month per export crane module [h]:	370.72	370.72	370.72	354.0	354.0		
Min. handling time per month per import crane module [h]:	294.44	294.44	294.44	303.32	303.32		
Min. handling time per month per export crane module [h]:	312.4	312.4	312.4	298.36	298.36		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	9.378	9.573	9.300	9.985	8.528		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.308	6.439	6.256	6.089	5.779		
Barges in port:	7728	7728	7728	7680	7680		
Occupancy of import shuttle modules:	0.853	0.853	0.853	0.906	0.906		
Occupancy of export shuttle modules:	0.905	0.905	0.905	0.891	0.891		

Table 18: Results Locations 2&4 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
2 MMTs at location 2	Total time: 888424		Total time:	346768			
2 MMTs at location 4							
Total 4 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	29040	29040	29040	29040	29040		
Time waiting in port:	116160	116160	116160	116160	116160		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	14163	12771	12910	10962	10405		12242,2
Time sailing between importMT and exportMT:	1152	1152	1152	1152	1152		
Time waiting at MT:	7824	7824	7824	7824	7824		
Time serving at MT:	17239	17239	17239	17239	17239		
Total time:	850737	849345	849484	847535	846978		848815,8
Total time without time in hinterland	309081	307689	307828	305879	305322		307159,8
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	37687	39079	38940	40889	41446		39608,2
Percentage time saved	10,87%	11,27%	11,23%	11,79%	11,95%		11,42%
Max. number of import crane modules:	2	2	2	2	2		
Max. number of export crane modules:	2	2	2	2	2		
Min. number of import crane modules:	2	2	2	2	2		
Min. number of export crane modules:	2	2	2	2	2		
Month 1 frequency to terminal 0 of MT shuttle:	29	29	29	29	29		
Max. handling time per month per import crane module [h]:	391.3	391.3	391.3	391.3	391.3		
Max. handling time per month per export crane module [h]:	392.1	392.1	392.1	392.1	392.1		
Min. handling time per month per import crane module [h]:	329.8	329.8	329.8	329.8	329.8		
Min. handling time per month per export crane module [h]:	330.5	330.5	330.5	330.5	330.5		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	9.634	9.990	9.954	10.452	10.594		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	7.105	7.368	7.342	7.709	7.814		
Barges in port:	8652	8652	8652	8652	8652		
Occupancy of import shuttle modules:	0.897	0.897	0.897	0.897	0.897		
Occupancy of export shuttle modules:	0.898	0.898	0.898	0.898	0.898		

Table 19: Results Locations 3&4 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
2 MMTs at location 3	Total time: 888424		Total time:	346768			
2 MMTs at location 4							
Total 4 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	29040	29040	29040	29040	29040		
Time waiting in port:	116160	116160	116160	116160	116160		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	20566	17782	20566	17226	17226		18673,2
Time sailing between importMT and exportMT:	1152	1152	1152	1152	1152		
Time waiting at MT:	7824	7824	7824	7824	7824		
Time serving at MT:	17239	17239	17239	17239	17239		
Total time:	857140	854356	857140	853799	853799		855246,8
Total time without time in hinterland	315484	312700	315484	312143	312143		313590,8
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	31284	34068	31284	34625	34625		33177,2
Percentage time saved	9,02%	9,82%	9,02%	9,99%	9,99%		9,57%
Max. number of import crane modules:	2	2	2	2	2		
Max. number of export crane modules:	2	2	2	2	2		
Min. number of import crane modules:	2	2	2	2	2		
Min. number of export crane modules:	2	2	2	2	2		
Month 1 frequency to terminal 0 of MT shuttle:	29	29	29	29	29		
Max. handling time per month per import crane module [h]:	391.3	391.3	391.3	391.3	391.3		
Max. handling time per month per export crane module [h]:	392.1	392.1	392.1	392.1	392.1		
Min. handling time per month per import crane module [h]:	329.8	329.8	329.8	329.8	329.8		
Min. handling time per month per export crane module [h]:	330.5	330.5	330.5	330.5	330.5		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	7.997	8.709	7.997	8.851	8.851		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	5.898	6.423	5.898	6.528	6.528		
Barges in port:	8652	8652	8652	8652	8652		
Occupancy of import shuttle modules:	0.897	0.897	0.897	0.897	0.897		
Occupancy of export shuttle modules:	0.898	0.898	0.898	0.898	0.898		

Table 20: Results Locations 1,2&3 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
2 MMTs at location 2							
2 MMTs at location 3							
Total 12 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	17856	17280	17856	17856	18048		
Time waiting in port:	71424	69120	71424	71424	72192		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	14443	13944	13899	15857	17503		15129,2
Time sailing between importMT and exportMT:	1812	1854	1812	1812	1797		
Time waiting at MT:	13416	13704	13416	13416	13320		
Time serving at MT:	39611	41530	39611	39611	39273		
Total time:	824227	823127	823683	825642	827777		824891,2
Total time without time in hinterland	282571	281471	282027	283986	286121		283235,2
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	64197	65297	64741	62782	60647		63532,8
Percentage time saved	18,51%	18,83%	18,67%	18,10%	17,49%		18,32%
Max. number of import crane modules:	5	5	5	5	5		
Max. number of export crane modules:	5	5	5	5	5		
Min. number of import crane modules:	5	5	5	5	5		
Min. number of export crane modules:	5	5	5	5	5		
Month 1 frequency to terminal 0 of MT shuttle:	68	71	68	68	66		
Max. handling time per month per import crane module [h]:	349.36	365.64	349.36	349.36	359.92		
Max. handling time per month per export crane module [h]:	370.72	389.32	370.72	370.72	354.0		
Min. handling time per month per import crane module [h]:	294.44	308.16	294.44	294.44	303.32		
Min. handling time per month per export crane module [h]:	312.4	328.08	312.4	312.4	298.36		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	9.570	9.530	9.651	9.359	9.106		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.438	6.364	6.492	6.296	6.171		
Barges in port:	7728	7728	7728	7728	7680		
Occupancy of import shuttle modules:	0.853	0.855	0.853	0.853	0.906		
Occupancy of export shuttle modules:	0.905	0.911	0.905	0.905	0.891		

Table 21: Results Locations 2,3&4 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
2 MMTs at location 2	Total time: 888424		Total time:	346768			
2 MMTs at location 3							
2 MMTs at location 4							
Total 6 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	22800	22800	22800	22800	22800		
Time waiting in port:	91200	91200	91200	91200	91200		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	23936	21120	22668	19008	18444		21035,2
Time sailing between importMT and exportMT:	1543	1544	1543	1544	1544		
Time waiting at MT:	10944	10944	10944	10944	10944		
Time serving at MT:	25851	25851	25851	25851	25851		
Total time:	841612	838796	840344	836684	836120		838711,2
Total time without time in hinterland	299956	297140	298688	295028	294464		297055,2
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	46812	49628	48080	51740	52304		49712,8
Percentage time saved	13,50%	14,31%	13,87%	14,92%	15,08%		14,34%
Max. number of import crane modules:	3	3	3	3	3		
Max. number of export crane modules:	3	3	3	3	3		
Min. number of import crane modules:	3	3	3	3	3		
Min. number of export crane modules:	3	3	3	3	3		
Month 1 frequency to terminal 0 of MT shuttle:	44	44	44	44	44		
Max. handling time per month per import crane module [h]:	398.2	398.2	398.2	398.2	398.2		
Max. handling time per month per export crane module [h]:	385.0	385.0	385.0	385.0	385.0		
Min. handling time per month per import crane module [h]:	335.6	335.6	335.6	335.6	335.6		
Min. handling time per month per export crane module [h]:	324.47	324.47	324.47	324.47	324.47		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	8.555	9.069	8.786	9.455	9.558		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.172	6.544	6.340	6.822	6.897		
Barges in port:	7812	7812	7812	7812	7812		
Occupancy of import shuttle modules:	0.902	0.902	0.902	0.902	0.902		
Occupancy of export shuttle modules:	0.872	0.872	0.872	0.872	0.872		

Table 22: Results Locations 1,2&4 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
2 MMTs at location 2							
2 MMTs at location 4							
Total 12 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	17856	17856	17856	18048	18048		
Time waiting in port:	71424	71424	71424	72192	72192		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	15531	14443	14987	16447	18559		15993,4
Time sailing between importMT and exportMT:	1812	1812	1812	1797	1797		
Time waiting at MT:	13416	13416	13416	13320	13320		
Time serving at MT:	39611	39611	39611	39273	39273		
Total time:	825315	824227	824771	826721	828833		825973,4
Total time without time in hinterland	283659	282571	283115	285065	287177		284317,4
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	63109	64197	63653	61703	59591		62450,6
Percentage time saved	18,20%	18,51%	18,36%	17,79%	17,18%		18,01%
Max. number of import crane modules:	5	5	5	5	5		
Max. number of export crane modules:	5	5	5	5	5		
Min. number of import crane modules:	5	5	5	5	5		
Min. number of export crane modules:	5	5	5	5	5		
Month 1 frequency to terminal 0 of MT shuttle:	68	68	68	66	66		
Max. handling time per month per import crane module [h]:	349.36	349.36	349.36	359.92	359.92		
Max. handling time per month per export crane module [h]:	370.72	370.72	370.72	354.0	354.0		
Min. handling time per month per import crane module [h]:	294.44	294.44	294.44	303.32	303.32		
Min. handling time per month per export crane module [h]:	312.4	312.4	312.4	298.36	298.36		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	9.408	9.570	9.489	9.265	8.948		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.329	6.438	6.383	6.278	6.063		
Barges in port:	7728	7728	7728	7680	7680		
Occupancy of import shuttle modules:	0.853	0.853	0.853	0.906	0.906		
Occupancy of export shuttle modules:	0.905	0.905	0.905	0.891	0.891		

Table 23: Results Locations 1,3&4 Rotterdam

Port of Rotterdam	**BASE CASE**		**BASE CASE without hinterland time**				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
2 MMTs at location 3							
2 MMTs at location 4							
Total 12 MMTs	Barges in port per year: 11172						
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	18048	18048	18048	18048	22800		
Time waiting in port:	72192	72192	72192	72192	91200		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	19932	17820	20354	21199	15822		19025,4
Time sailing between importMT and exportMT:	1797	1797	1797	1797	1455		
Time waiting at MT:	13320	13320	13320	13320	10944		
Time serving at MT:	39273	39273	39273	39273	25851		
Total time:	830206	828094	830629	831473	833498		830780
Total time without time in hinterland	288550	286438	288973	289817	291842		289124
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	58218	60330	57795	56951	54926		57644
Percentage time saved	16,79%	17,40%	16,67%	16,42%	15,84%		16,62%
Max. number of import crane modules:	5	5	5	5	3		
Max. number of export crane modules:	5	5	5	5	3		
Min. number of import crane modules:	5	5	5	5	3		
Min. number of export crane modules:	5	5	5	5	3		
Month 1 frequency to terminal 0 of MT shuttle:	66	66	66	66	44		
Max. handling time per month per import crane module [h]:	359.92	359.92	359.92	359.92	398.2		
Max. handling time per month per export crane module [h]:	354.0	354.0	354.0	354.0	385.0		
Min. handling time per month per import crane module [h]:	303.32	303.32	303.32	303.32	335.6		
Min. handling time per month per export crane module [h]:	298.36	298.36	298.36	298.36	324.47		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	8.741	9.058	8.678	8.551	10.038		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	5.924	6.139	5.881	5.795	7.242		
Barges in port:	7680	7680	7680	7680	7812		
Occupancy of import shuttle modules:	0.906	0.906	0.906	0.906	0.902		
Occupancy of export shuttle modules:	0.891	0.891	0.891	0.891	0.872		

Table 24: Results Locations 1,2,3&4 Rotterdam

Port of Rotterdam	BASE CASE		BASE CASE without hinterland time				
	Time in hinterland: 541656						
Static case	Time sailing in port: 44688						
IX_sail [hr] = 0.25	Time waiting in port: 178752						
	Time serving in port: 123328						
8 MMTs at location 1	Total time: 888424		Total time:	346768			
2 MMTs at location 2							
2 MMTs at location 3	Barges in port per year: 11172						
2 MMTs at location 4							
Total 14 MMTs							
							Average
	1. Rotterdam World Gateway container terminal	2. APM Terminals Maasvlakte II	3. Hutchison Ports ECT Euromax	4. APM Terminals Rotterdam	5. Hutchison Ports ECT Delta		
MT_sail_01 [hr]	1,15	1,15	1,25	2,05	2,65		
MT_sail_02 [hr]	2,35	2,35	1,45	1,25	0,85		
MT_sail_03 [hr]	6,95	5,95	6,95	5,75	5,75		
MT_sail_04 [hr]	7,95	6,95	7,95	6,75	6,75		
Time in hinterland:	541656	541656	541656	541656	541656		
Time sailing in port:	18048	18048	18048	18048	18048		
Time waiting in port:	72192	72192	72192	72192	72192		
Time serving in port:	123328	123328	123328	123328	123328		
Time sailing between MMTs and port:	19098	17288	18645	19189	20999		19043,8
Time sailing between importMT and exportMT:	1778	1778	1778	1778	1778		
Time waiting at MT:	13320	13320	13320	13320	13320		
Time serving at MT:	39273	39273	39273	39273	39273		
Total time:	829373	827562	828920	829463	831273		829318,2
Total time without time in hinterland	287717	285906	287264	287807	289617		287662,2
Total time base case without time in hinterland:	346768	346768	346768	346768	346768		346768
Total time saved without time in hinterland:	59051	60862	59504	58961	57151		59105,8
Percentage time saved	17,03%	17,55%	17,16%	17,00%	16,48%		17,04%
Max. number of import crane modules:	5	5	5	5	5		
Max. number of export crane modules:	5	5	5	5	5		
Min. number of import crane modules:	5	5	5	5	5		
Min. number of export crane modules:	5	5	5	5	5		
Month 1 frequency to terminal 0 of MT shuttle:	66	66	66	66	66		
Max. handling time per month per import crane module [h]:	359.92	359.92	359.92	359.92	359.92		
Max. handling time per month per export crane module [h]:	354.0	354.0	354.0	354.0	354.0		
Min. handling time per month per import crane module [h]:	303.32	303.32	303.32	303.32	303.32		
Min. handling time per month per export crane module [h]:	298.36	298.36	298.36	298.36	298.36		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	8.867	9.138	8.934	8.853	8.581		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.008	6.193	6.055	5.999	5.815		
Barges in port:	7680	7680	7680	7680	7680		
Occupancy of import shuttle modules:	0.906	0.906	0.906	0.906	0.906		
Occupancy of export shuttle modules:	0.891	0.891	0.891	0.891	0.891		

Appendix 12 – Results Port of Antwerp

Table 25: Results Location 1 Antwerp

Port of Antwerp	**BASE CASE**			**BASE CASE without hinterland**			
	Time in hinterland: 367176						
Static case	Time sailing in port: 29280						
IX_sail [hr] = 0.25	Time waiting in port: 117120						
	Time serving in port: 99383						
4 MMTs at location 1	Total time: 612959			Total time	245783		
	Barges in port per year: 7320						
							Average
	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869		
MT_sail_01 [hr]	1,55	1,75	1,55	0,55	0,55		
Time in hinterland:	367176	367176	367176	367176	367176		
Time sailing in port:	18960	18960	18960	18960	18960		
Time waiting in port:	75840	75840	75840	75840	75840		
Time serving in port:	99383	99383	99383	99383	99383		
Time sailing between MMTs and port:	4284	4860	4284	1404	1404		3247,2
Time sailing between importMT and exportMT:	825	825	825	825	825		
Time waiting at MT:	5160	5160	5160	5160	5160		
Time serving at MT:	13831	13831	13831	13831	13831		
Total time:	585639	586215	585639	582759	582759		584602,2
Total time without time in hinterland	218463	219039	218463	215583	215583		217426,2
Total time base case without time in hinterland:	245783	245783	245783	245783	245783		245783
Total time saved without time in hinterland:	27320	26744	27320	30200	30200		28356,8
Percentage time saved	11,12%	10,88%	11,12%	12,29%	12,29%		11,54%
Max. number of import crane modules:	2	2	2	2	2		
Max. number of export crane modules:	2	2	2	2	2		
Min. number of import crane modules:	2	2	2	2	2		
Min. number of export crane modules:	2	2	2	2	2		
Month 1 frequency to terminal 0 of MT shuttle:	30	30	30	30	30		
Max. handling time per month per import crane module [h]:	220.7	220.7	220.7	220.7	220.7		
Max. handling time per month per export crane module [h]:	407.8	407.8	407.8	407.8	407.8		
Min. handling time per month per import crane module [h]:	186.0	186.0	186.0	186.0	186.0		
Min. handling time per month per export crane module [h]:	343.7	343.7	343.7	343.7	343.7		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	10.589	10.366	10.589	11.705	11.705		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	6.796	6.653	6.796	7.512	7.512		
Barges in port:	6180	6180	6180	6180	6180		
Occupancy of import shuttle modules:	0.489	0.489	0.489	0.489	0.489		
Occupancy of export shuttle modules:	0.903	0.903	0.903	0.903	0.903		

Table 26: Results Location 2 Antwerp

Port of Antwerp	**BASE CASE**			**BASE CASE without hinterland**								
	Time in hinterland: 367176											
Static case	Time sailing in port: 29280											
IX_sail [hr] = 0.25	Time waiting in port: 117120											
	Time serving in port: 99383											
4 MMTs at location 2	Total time: 612959			Total time	245783							
	Barges in port per year: 7320											
												Average
	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869		
MT_sail_02 [hr]	0,65	0,85	0,65	1,45	1,15	0,75	0,95	0,75	1,25	0,95		
Time in hinterland:	367176	367176	367176	367176	367176	367176	367176	367176	367176	367176		
Time sailing in port:	18960	18960	18960	18960	18960	18960	18960	18960	18960	18960		
Time waiting in port:	75840	75840	75840	75840	75840	75840	75840	75840	75840	75840		
Time serving in port:	99383	99383	99383	99383	99383	99383	99383	99383	99383	99383		
Time sailing between MMTs and port:	1692	2268	1692	3996	3132	1980	2556	1980	3420	2556		2527,2
Time sailing between importMT and exportMT:	825	825	825	825	825	825	825	825	825	825		
Time waiting at MT:	5160	5160	5160	5160	5160	5160	5160	5160	5160	5160		
Time serving at MT:	13831	13831	13831	13831	13831	13831	13831	13831	13831	13831		
Total time:	583047	583623	583047	585351	584487	583335	583911	583335	584775	583911		583882,2
Total time without time in hinterland	215871	216447	215871	218175	217311	216159	216735	216159	217599	216735		216706,2
Total time base case without time in hinterland:	245783	245783	245783	245783	245783	245783	245783	245783	245783	245783		245783
Total time saved without time in hinterland:	29912	29336	29912	27608	28472	29624	29048	29624	28184	29048		29076,8
Percentage time saved	12,17%	11,94%	12,17%	11,23%	11,58%	12,05%	11,82%	12,05%	11,47%	11,82%		11,83%
Max. number of import crane modules:	2	2	2	2	2	2	2	2	2	2		
Max. number of export crane modules:	2	2	2	2	2	2	2	2	2	2		
Min. number of import crane modules:	2	2	2	2	2	2	2	2	2	2		
Min. number of export crane modules:	2	2	2	2	2	2	2	2	2	2		
Month 1 frequency to terminal 0 of MT shuttle:	30	30	30	30	30	30	30	30	30	30		
Max. handling time per month per import crane module [h]:	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7	220.7		
Max. handling time per month per export crane module [h]:	407.8	407.8	407.8	407.8	407.8	407.8	407.8	407.8	407.8	407.8		
Min. handling time per month per import crane module [h]:	186.0	186.0	186.0	186.0	186.0	186.0	186.0	186.0	186.0	186.0		
Min. handling time per month per export crane module [h]:	343.7	343.7	343.7	343.7	343.7	343.7	343.7	343.7	343.7	343.7		
KPIs per year:												
Time savings per IVW linked with MMT [h]:	11.594	11.370	11.594	10.701	11.036	11.482	11.259	11.482	10.924	11.259		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	7.441	7.297	7.441	6.868	7.083	7.369	7.226	7.369	7.011	7.226		
Barges in port:	6180	6180	6180	6180	6180	6180	6180	6180	6180	6180		
Occupancy of import shuttle modules:	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489	0.489		
Occupancy of export shuttle modules:	0.903	0.903	0.903	0.903	0.903	0.903	0.903	0.903	0.903	0.903		

Table 27: Results Location 3 Antwerp

Port of Antwerp	**BASE CASE**			**BASE CASE without hinterland**								
	Time in hinterland: 367176											
Static case	Time sailing in port: 29280											
IX_sail [hr] = 0.25	Time waiting in port: 117120											
	Time serving in port: 99383											
6 MMTs at location 3	Total time: 612959			Total time	245783							
	Barges in port per year: 7320											
												Average
	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869		
MT_sail_03 [hr]	1,25	1,45	1,25	1,95	1,65	1,35	1,55	1,35	1,85	1,65		
Time in hinterland:	367176	367176	367176	367176	367176	367176	367176	367176	367176	367176		
Time sailing in port:	17136	17136	17136	18144	17136	17136	17136	17136	17136	17136		
Time waiting in port:	68544	68544	68544	72576	68544	68544	68544	68544	68544	68544		
Time serving in port:	99383	99383	99383	99383	99383	99383	99383	99383	99383	99383		
Time sailing between MMTs and port:	4815	5641	4815	6272	6467	5228	6054	5228	7292	6467		5827,9
Time sailing between importMT and exportMT:	930	930	930	836	930	930	930	930	931	930		
Time waiting at MT:	6072	6072	6072	5568	6072	6072	6072	6072	6072	6072		
Time serving at MT:	19334	19334	19334	16387	19334	19334	19334	19334	19334	19334		
Total time:	583736	584562	583736	586622	585387	584149	584975	584149	586213	585387		584891,6
Total time without time in hinterland	216560	217386	216560	219446	218211	216973	217799	216973	219037	218211		217715,6
Total time base case without time in hinterland:	245783	245783	245783	245783	245783	245783	245783	245783	245783	245783		245783
Total time saved without time in hinterland:	29223	28397	29223	26337	27572	28810	27984	28810	26746	27572		28067,4
Percentage time saved	11,89%	11,55%	11,89%	10,72%	11,22%	11,72%	11,39%	11,72%	10,88%	11,22%		11,42%
Max. number of import crane modules:	3	3	3	3	3	3	3	3	3	3		
Max. number of export crane modules:	3	3	3	3	3	3	3	3	3	3		
Min. number of import crane modules:	3	3	3	3	3	3	3	3	3	3		
Min. number of export crane modules:	3	3	3	3	3	3	3	3	3	3		
Month 1 frequency to terminal 0 of MT shuttle:	43	43	43	35	43	43	43	43	43	43		
Max. handling time per month per import crane module [h]:	196.47	196.47	196.47	177.27	196.47	196.47	196.47	196.47	196.47	196.47		
Max. handling time per month per export crane module [h]:	389.27	389.27	389.27	319.2	389.27	389.27	389.27	389.27	389.27	389.27		
Min. handling time per month per import crane module [h]:	165.6	165.6	165.6	149.4	165.6	165.6	165.6	165.6	165.6	165.6		
Min. handling time per month per export crane module [h]:	328.07	328.07	328.07	269.0	328.07	328.07	328.07	328.07	328.07	328.07		
KPIs per year:												
Time savings per IVW linked with MMT [h]:	9.625	9.353	9.625	9.460	9.081	9.489	9.217	9.489	8.810	9.081		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	5.730	5.568	5.730	5.900	5.406	5.649	5.487	5.649	5.244	5.406		
Barges in port:	6348	6348	6348	6216	6348	6348	6348	6348	6348	6348		
Occupancy of import shuttle modules:	0.455	0.455	0.455	0.505	0.455	0.455	0.455	0.455	0.455	0.455		
Occupancy of export shuttle modules:	0.902	0.902	0.902	0.909	0.902	0.902	0.902	0.902	0.902	0.902		

Table 28: Results Locations 1&2 Antwerp

Port of Antwerp	**BASE CASE**			**BASE CASE without hinterland**			
	Time in hinterland: 367176						
Static case	Time sailing in port: 29280						
IX_sail [hr] = 0.25	Time waiting in port: 117120						
	Time serving in port: 99383						
4 MMTs at location 1	Total time: 612959			Total time	245783		
4 MMTs at location 2							
Total 8 MMTs	Barges in port per year: 7320						
							Average
	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869		
MT_sail_01 [hr]	1,55	1,75	1,55	0,55	0,55		
MT_sail_02 [hr]	0,7	0,9	0,7	1,35	1,05		
Time in hinterland:	367176	367176	367176	367176	367176		
Time sailing in port:	14640	14640	14640	14640	14640		
Time waiting in port:	58560	58560	58560	58560	58560		
Time serving in port:	99383	99383	99383	99383	99383		
Time sailing between MMTs and port:	5841	6973	5841	4849	4000		5500,8
Time sailing between importMT and exportMT:	1092	1092	1092	1092	1092		
Time waiting at MT:	7320	7320	7320	7320	7320		
Time serving at MT:	27703	27703	27703	27703	27703		
Total time:	582246	586215	582246	581255	580405		582473,4
Total time without time in hinterland	215070	219039	215070	214079	213229		215297,4
Total time base case without time in hinterland:	245783	245783	245783	245783	245783		245783
Total time saved without time in hinterland:	30713	26744	30713	31704	32554		30485,6
Percentage time saved	12,50%	10,88%	12,50%	12,90%	13,25%		12,40%
Max. number of import crane modules:	4	4	4	4	4		
Max. number of export crane modules:	4	4	4	4	4		
Min. number of import crane modules:	4	4	4	4	4		
Min. number of export crane modules:	4	4	4	4	4		
Month 1 frequency to terminal 0 of MT shuttle:	59	59	59	59	59		
Max. handling time per month per import crane module [h]:	226.25	226.25	226.25	226.25	226.25		
Max. handling time per month per export crane module [h]:	403.25	403.25	403.25	403.25	403.25		
Min. handling time per month per import crane module [h]:	190.65	190.65	190.65	190.65	190.65		
Min. handling time per month per export crane module [h]:	339.85	339.85	339.85	339.85	339.85		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	8.392	8.082	8.392	8.662	8.894		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	4.731	4.556	4.731	4.884	5.014		
Barges in port:	6492	6492	6492	6492	6492		
Occupancy of import shuttle modules:	0.509	0.509	0.509	0.509	0.509		
Occupancy of export shuttle modules:	0.908	0.908	0.908	0.908	0.908		

Table 29: Results Locations 1&3 Antwerp

Port of Antwerp	**BASE CASE**			**BASE CASE without hinterland**			
	Time in hinterland: 367176						
Static case	Time sailing in port: 29280						
IX_sail [hr] = 0.25	Time waiting in port: 117120						
	Time serving in port: 99383						
4 MMTs at location 1	Total time: 612959			Total time	245783		
6 MMTs at location 3							
Total 10 MMTs	Barges in port per year: 7320						
							Average
	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869		
MT_sail_01 [hr]	1,55	1,75	1,55	0,55	0,55		
MT_sail_03 [hr]	1,3	1,5	1,3	1,9	1,65		
Time in hinterland:	367176	367176	367176	367176	367176		
Time sailing in port:	13680	14640	13680	13680	12960		
Time waiting in port:	54720	58560	54720	54720	51840		
Time serving in port:	99383	99383	99383	99383	99383		
Time sailing between MMTs and port:	8736	8496	8736	8467	7885		8464
Time sailing between importMT and exportMT:	1143	1056	1143	1143	1197		
Time waiting at MT:	7800	7320	7800	7800	8160		
Time serving at MT:	30331	27703	30331	30331	33015		
Total time:	583641	584901	583641	583373	582328		583576,8
Total time without time in hinterland	216465	217725	216465	216197	215152		216400,8
Total time base case without time in hinterland:	245783	245783	245783	245783	245783		245783
Total time saved without time in hinterland:	29318	28058	29318	29586	30631		29382,2
Percentage time saved	11,93%	11,42%	11,93%	12,04%	12,46%		11,95%
Max. number of import crane modules:	5	4	5	5	5		
Max. number of export crane modules:	5	4	5	5	5		
Min. number of import crane modules:	5	4	5	5	5		
Min. number of export crane modules:	5	4	5	5	5		
Month 1 frequency to terminal 0 of MT shuttle:	70	59	70	70	74		
Max. handling time per month per import crane module [h]:	169.0	226.25	169.0	169.0	194.32		
Max. handling time per month per export crane module [h]:	382.4	403.25	382.4	382.4	405.84		
Min. handling time per month per import crane module [h]:	142.44	190.65	142.44	142.44	163.8		
Min. handling time per month per export crane module [h]:	322.24	339.85	322.24	322.24	342.0		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	7.517	7.666	7.517	7.586	7.508		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	4.038	4.322	4.038	4.075	4.013		
Barges in port:	6780	6492	6780	6780	6792		
Occupancy of import shuttle modules:	0.401	0.509	0.401	0.401	0.436		
Occupancy of export shuttle modules:	0.907	0.908	0.907	0.907	0.911		

Table 30: Results Locations 2&3 Antwerp

Port of Antwerp	**BASE CASE**			**BASE CASE without hinterland**			
	Time in hinterland: 367176						
Static case	Time sailing in port: 29280						
IX_sail [hr] = 0.25	Time waiting in port: 117120						
	Time serving in port: 99383						
4 MMTs at location 2	Total time: 612959			Total time	245783		
6 MMTs at location 3							
Total 10 MMTs	Barges in port per year: 7320						
							Average
	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869		
MT_sail_02 [hr]	0,7	0,9	0,7	1,35	1,05		
MT_sail_03 [hr]	1,3	1,5	1,3	1,9	1,65		
Time in hinterland:	367176	367176	367176	367176	367176		
Time sailing in port:	12960	12960	12960	14640	13680		
Time waiting in port:	51840	51840	51840	58560	54720		
Time serving in port:	99383	99383	99383	99383	99383		
Time sailing between MMTs and port:	6819	8240	6819	8949	8803		7926
Time sailing between importMT and exportMT:	1197	1197	1197	1056	1143		
Time waiting at MT:	8160	8160	8160	7320	7800		
Time serving at MT:	33015	33015	33015	27703	30331		
Total time:	581262	582683	581262	585354	583709		582854
Total time without time in hinterland	214086	215507	214086	218178	216533		215678
Total time base case without time in hinterland:	245783	245783	245783	245783	245783		245783
Total time saved without time in hinterland:	31697	30276	31697	27605	29250		30105
Percentage time saved	12,90%	12,32%	12,90%	11,23%	11,90%		12,25%
Max. number of import crane modules:	5	5	5	4	5		
Max. number of export crane modules:	5	5	5	4	5		
Min. number of import crane modules:	5	5	5	4	5		
Min. number of export crane modules:	5	5	5	4	5		
Month 1 frequency to terminal 0 of MT shuttle:	74	74	74	59	70		
Max. handling time per month per import crane module [h]:	194.32	194.32	194.32	226.25	169.0		
Max. handling time per month per export crane module [h]:	405.84	405.84	405.84	403.25	382.4		
Min. handling time per month per import crane module [h]:	163.8	163.8	163.8	190.65	142.44		
Min. handling time per month per export crane module [h]:	342.0	342.0	342.0	339.85	322.24		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	7.769	7.421	7.769	7.542	7.500		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	4.153	3.967	4.153	4.252	4.029		
Barges in port:	6792	6792	6792	6492	6780		
Occupancy of import shuttle modules:	0.436	0.436	0.436	0.509	0.401		
Occupancy of export shuttle modules:	0.911	0.911	0.911	0.908	0.907		

Table 31: Results Locations 1,2&3 Antwerp

Port of Antwerp	**BASE CASE**			**BASE CASE without hinterland**			
	Time in hinterland: 367176						
Static case	Time sailing in port: 29280						
IX_sail [hr] = 0.25	Time waiting in port: 117120						
	Time serving in port: 99383						
4 MMTs at location 1	Total time: 612959			Total time	245783		
4 MMTs at location 2							
6 MMTs at location 3							
Total 14 MMTs	Barges in port per year: 7320						
							Average
	1. MPET K1742	2. MPET K1718	3. AG K1700	4. PSAA K913	5. PSAA K869		
MT_sail_01 [hr]	1,55	1,75	1,55	0,55	0,55		
MT_sail_02 [hr]	0,7	0,9	0,7	1,35	1,05		
MT_sail_03 [hr]	1,3	1,5	1,3	1,9	1,65		
Time in hinterland:	367176	367176	367176	367176	367176		
Time sailing in port:	10464	11184	10464	11184	10464		
Time waiting in port:	41856	44736	41856	44736	41856		
Time serving in port:	99383	99383	99383	99383	99383		
Time sailing between MMTs and port:	9442	10673	9442	10320	9133		9802
Time sailing between importMT and exportMT:	1330	1278	1330	1278	1330		
Time waiting at MT:	9408	9048	9408	9048	9408		
Time serving at MT:	41384	38700	41384	38700	41384		
Total time:	581369	583064	581369	582710	581061		581914,6
Total time without time in hinterland	214193	215888	214193	215534	213885		214738,6
Total time base case without time in hinterland:	245783	245783	245783	245783	245783		245783
Total time saved without time in hinterland:	31590	29895	31590	30249	31898		31044,4
Percentage time saved	12,85%	12,16%	12,85%	12,31%	12,98%		12,63%
Max. number of import crane modules:	6	6	6	6	6		
Max. number of export crane modules:	6	6	6	6	6		
Min. number of import crane modules:	6	6	6	6	6		
Min. number of export crane modules:	6	6	6	6	6		
Month 1 frequency to terminal 0 of MT shuttle:	90	86	90	86	90		
Max. handling time per month per import crane module [h]:	214.53	193.43	214.53	193.43	214.53		
Max. handling time per month per export crane module [h]:	412.4	392.87	412.4	392.87	412.4		
Min. handling time per month per import crane module [h]:	180.8	163.0	180.8	163.0	180.8		
Min. handling time per month per export crane module [h]:	347.53	331.07	347.53	331.07	347.53		
KPIs per year:							
Time savings per IVW linked with MMT [h]:	6.715	6.608	6.715	6.686	6.781		
Time savings per IVW linked with MMT (incl. shuttles) [h]:	3.501	3.455	3.501	3.496	3.535		
Barges in port:	6936	6924	6936	6924	6936		
Occupancy of import shuttle modules:	0.475	0.448	0.475	0.448	0.475		
Occupancy of export shuttle modules:	0.913	0.910	0.913	0.910	0.913		