Project
Jade Weser Port
A feasibility study

Status: Final

An assignment of:
Ballast Ham Dredging
Alkyon
Delft University of Technology

August 2002
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Preface

The final stages of becoming a civil engineer at the Technical University of Delft concludes with the final thesis. I have had to determine whether the proposed building of the Jade Weser Port will be nautically and economically feasible. For this I had to find, analyse new and existing data to simulate/calculate these with computer programmes.

I will also answer the following question of Ballast Ham Dredging: “Is an unprotected quay in the river Jade possible?” A complicating factor in this future development is that the port is not allowed to have any ‘downtime’.

To answer that question I spent some time at Ballast Ham Dredging and Alkyon. At Ballast Ham Dredging, I wrote the economical/financial topics of this research. Alkyon is a Consultancy and Research Company specialised in hydraulics. They have relevant contemporary data on the Jade area. They were able to provide me with assistance in my calculations/simulations with the computer programmes DELFT 3D, SWAN and SHIP NAVIGATOR.

The goal of this study is to determine the financial and nautical feasibility of the Jade Weser Port. The topic nautical feasibility resulted from the assignment of Ballast Nedam Dredging. The economical topic was chosen because a port study should comprise such a topic. Furthermore when the financial feasibility can not be proven, the nautical study does not make any sense. Of course personal interest into the economic topic was also a reason to include the financial feasibility as an important part of this study.

Many factors made this project a challenge for me. I would like to thank all the people who helped me finalise this project. First of all my supervisors, furthermore the people at Ballast Nedam Dredging, BNO and Alkyon, my house mates in Delft and in Zwolle, Topaz and other friends and last but not least Leo and my family.

This study has been done under supervision of:

Prof.ir. H. Ligteringen  
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Ir. I. Onassis

Rinske van der Meer
Zwolle, August 2002
Summary

Together with the amount of transported containers, the size of the container vessels increases. With the size of the ships their draught also becomes larger. At the moment Germany does not have a harbour, suitable to receive these large container vessels. The idea has risen to design and construct a new deep-water port.

The authorities took some time contemplating where this port has to be built. Wilhelmshaven versus Cuxhaven was the dilemma. Finally, in March 2001, a temporary decision was made: a new deepwater port is to be built near Wilhelmshaven. One of the strongest points of the area near Wilhelmshaven is the great possibilities for future expansion. The scope of this report is limited to the design of a deepwater port near the Wilhelmshaven: the Jade Weser Port.

The Jade estuary is very suitable as a harbour, having a natural deep-sea channel and being situated close to open sea. Besides that, a large area is available for the terminal and the infrastructure on land has good possibilities for expansion.

For a project, as great as the Jade Weser Port, several studies have to be done. The economic situation is one of the first studies that should be done. The Jade Weser Port studies into this subject are not widely available. This leads to the first question:

Is the Jade Weser Port economically/financial feasible?

Ballast Nedam has also done research into the future Jade Weser Port. Because of this research the design of the quay in the feasibility study gave reason to Ballast Nedam Dredging for some questions. The quay wall is not protected from waves and currents and there are no breakwaters to protect the berths. The quay lies parallel to the approach channel, just a couple of hundred meters away from it. This situation has led to the following question:

Does the unprotected quay lead to any nautical or operational difficulties? If so, is there not a better option for the layout of the quay?

The objective of this thesis study is to answer the questions that are outlined in the problem description above. This is done in the following studies:

1. Financial/economical study
2. Nautical/hydraulic study

This report is a feasibility study for the Jade Weser Port. This feasibility study consists of five parts. First a study on the location and environmental aspects of the Jade Weser Port has been done, secondly a financial study has been done and after that the preliminary design aspects of the port are described. At last the currents, waves and navigation in and around the port are analysed. The feasibility study is concluded with the conclusions and recommendations for the new port.

The results for the port can be presented by the following remarks:

The financial feasibility study of the port does not show very encouraging results, although a definitive negative advice can not be given.

The nautical feasibility study of the port does show promising results. The circumstances can be rough, but this will not result in much downtime.
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Part 1 Location and environment of the Jade Weser Port
1 Introduction

Ever since containers are used for transport, the volume of container traffic has been growing. Together with the amount of containers, the size of the ships has increased. Larger ships need deeper approach channels, so less and less harbours are suitable for the largest ships.

At the moment the Port of Rotterdam is the only European port that can keep up with the scaling up of the container ships. Ironically, the main growth of the container throughput is expected in Eastern Europe (a large share is destined for Eastern Germany), but Germany does not have a container port with a channel deep enough to receive these big ships.

Since transport on land is far more expensive than transport on water, the idea has risen to design and construct a deep-water port in Germany. Authorities have been contemplating about the location where this new port has to be built. Two possible options were Wilhelmshaven and Cuxhaven. In March 2001 it has been decided that the port has to be built, at Wilhelmshaven. The scope of this report is limited to the design of a deepwater port near the Wilhelmshaven: the Jade Weser Port.

Jade Weser Port has the potential to become a large-scale multi purpose seaport and a modern and large Container Terminal, capable of handling ships with a capacity of 8000 TEU and more. From a nautical and safety point of view the location in the Jade and Weser Estuary promises to be excellent (see also Figure 1-1). This report tries to confirm or disaffirm those excellent nautical conditions.

The main reasons for the authorities to choose this location are [ref. 10]:

- deep sea channel with a water depth of -18.0 m SKN (seekartennull = CD)
- the deep seaport can be reached at any time, no limitations
- close distance to the open sea
- availability of enormous space for storage of containers and settlement of related business (860 ha = 2125 acres)
- well developed traffic infrastructure
- possibilities and options for further extensions of berth capacities (container and bulk)

This report is a feasibility study for the Jade Weser Port. This feasibility study consists of five parts. First a study on the location and environmental aspects of the Jade Weser Port has been executed, secondly a financial study has been done and after that the preliminary design aspects of the port are described. At last the currents, waves and navigation in and around the port are analysed. The feasibility study is concluded with the conclusions and recommendations for the new port.
Part 1 Location and environment of the Jade Weser Port

Part one, Location and environment of the Jade Weser Port, is an introduction into the feasibility study. It gives information on the Jade area, the environmental conditions and is concluded with a problem analysis.

The financial study gives predictions into the cargo growth, and the future ships. The main goal of this part is to analyse the costs and revenues of the future port.

The study on the preliminary design of the Jade Weser Port gives a first impression on the necessary dimensions of the manoeuvring areas of the port. Those dimensions are obtained by thumb rules.

Waves and currents are modelled to further analyse the designed port. The main goal of the fourth part is to determine the navigational conditions.

The conclusions and recommendations that follow from the feasibility study will be given in part five.
2 The Jade area, and more specific Wilhelmshaven

2.1 History

In 1383, the city of Wilhelmshaven started as a citadel built by pirates. In the city part ‘Siebethsburg’ many streets are named after famous pirates and Friesian chiefs, still showing the city’s history of pirates.

In June 1869, King Wilhelm I performed the inauguration of the harbour and named the arisen settlement after himself. Wilhelmshaven was given city rights in 1873. By annexing several districts, Wilhelmshaven became a city of over 100,000 people in the year 1938.

During the Second World War, Wilhelmshaven has been a very important naval port of the ‘Wehrmacht’. The deepwater entrance combined with the sheltered location of the port were the reasons of its vigour. During the last period of the war, the port was heavily bombed.

After the Second World War, the responsible people wanted a new main function for Wilhelmshaven. They wanted the Jade city to develop into an independent city, freed from her one-sided militarist function. Industrial development was forced upon this city. In 1957 an oil port was build and this port became Germany’s main and only deepwater port. Private industrials came from mid and eastern Germany to establish themselves in Wilhelmshaven. [ref. 4].

2.2 Economics

Wilhelmshaven nowadays has about 90,000 inhabitants; it is the economic and cultural centre of the North Sea coast and has recreational possibilities. The port of Wilhelmshaven still is Germany’s only deepwater port. The oil port at the Jade bay is the most important tanker berth in Germany. Tankers with a draught of 20 m have no problem entering the Jade and berthing at the tranship jetty in the outer harbour (although they do experience a tidal window).

At the moment the area around Wilhelmshaven is unfavourable for companies with interregional connections and without interest in waterborne activities. Road and rail connections are in poor condition, but are undergoing improvements. The area is thus becoming more and more interesting for companies to settle. Unfortunately the distances to other major economic centres in Northern Germany remain great.

Since the mid eighties, the growth of the population in the area has been less than in the rest of the country. Nowadays, the area is experiencing a small decrease in population. The proportion of the population with the age between 18 and 45 is below average, which makes the proportion of the population outside this age group above average. Most of the inhabitants of the area live in the city Wilhelmshaven. Some live in one of the few settlements of the area.

The gross added value of the area is above the West German average, due to the chemical industry and the refinery. Unfortunately, these companies do not require many labourers. An important group of the working class is working in Bremen or Oldenburg. The unemployment rate in the area is above average and the income is below average. The area has a relative low amount of high level education and research centres. At the moment the area is undergoing some developments. The amount of people without qualifications is decreasing, the amount of people with middle high qualifications is growing, but the amount of people with universal qualifications is staying low.

The future perspectives of Wilhelmshaven mainly contain the port and other business aspects, the navy base, the development of progressive energy technologies and the further development as cultural and recreational centre situated at the North Sea. Wilhelmshaven is nowadays a well-known standing-place for sea-technical orientated and sea-economical companies. [ref. 11].
2.3 Wilhelmshaven versus Cuxhaven

For a long time the geographic situation of Wilhelmshaven with its near perfect deepwater entrance has triggered ideas and visions of a major deepwater port in Germany. Cuxhaven, a city situated at the entrance of the Elbe, was pinpointed as a possible location as well. The authorities took some time contemplating where this port had to be built; Wilhelmshaven versus Cuxhaven was the dilemma. Finally, at the end of March 2001, they reached a decision: The deepwater port is to be built near Wilhelmshaven.

In appendix I, both locations will be discussed. This discussion has been included in this report to give a complete picture of the political situation of the Jade Weser Port. Unfortunately it is hard to make a proper analysis, because some criteria are not openly discussed or published as some criteria might be influenced by political agenda’s, changing with the ruling politicians.

The main criterion to choose for Wilhelmshaven was the maximum quay length. The maximum capacity of Cuxhaven will be reached between 2022 and 2028. After 2028, Cuxhaven needs a new port area to cope with further growth in container transport. If then the only suitable new port area is near Wilhelmshaven, why not start the new port at Wilhelmshaven?

Another very important aspect is the financing of the port. Both ports have to find investors to get financial closure for the project. Public authorities will help for part of the necessary sum of money. The rest has to be paid by private investors. Unfortunately it is not clear if either one of the ports has enough investors to reach financial closure. The importance of criteria other than quay length or costs is hard to trace.

Current developments
In the winter of 2002 several studies have been done on the new port near Wilhelmshaven. These studies should be ready in the summer of 2002. These studies have to give positive results for Wilhelmshaven in order to continue the process of building the port. If those results are not positive, Cuxhaven becomes an option again.
3 Environment

In this chapter, some information will be given on the environment of the project area. This information is needed to assert the difficulties concerning the Jade Weser port in general. This chapter deals with the geography, the wind climate, waves, tide, currents, sedimentation and the soil conditions.

3.1 Geography

The Jade Weser Port will be constructed north of the German city Wilhelmshaven, and faces the Jade river. See: Figure 3-1 and figure 10.1 for the layout of the Jade area, and the location of the future Jade Weser Port.

The Jade is a part of the Jade-Weser estuary; the river Jade cuts deep into the mainland. The Jade has a great amount of discharge from the inland and lies in the first line of tidal influence. The Jade area can be divided into the following subdivisions: Outer Jade, Inner Jade and Jade Reservoir. The morphology of the Jade was created in the glacial age.

Part of the area for the port has already been reclaimed from the river Jade in the seventies. This is the Voslapper Groden area. The remaining area that is needed for the port still has to be reclaimed from the river.

Wilhelmshaven is Germanys only deepwater port and most important tanker discharging-berth. After Hamburg it is the second biggest harbour of Germany, measured by the mass of the throughput goods. Wilhelmshaven is connected with the international sea-traffic lines by a 18.50 m deep and 300 m broad fairway in the Jade – measurements with respect to Seekartennull (SKN = middle Spring tidal low water).

The distance to be sailed over the Jade is relatively short; about 27 nautical miles from the beginning of the Jade to the berths at Voslapper Groden and about 32 nautical miles from the beginning of the Jade to the entrance of the Wilhelmshaven inner harbour.

In the area river and harbour pilots are used and a radar guidance system is available. The river and harbour pilots change during the arrival and departure manoeuvre.
3.2 Wind climate

The wind conditions of the area are given in table 3-1, Wind conditions and figure 3-2, Wind conditions [ref. 10].

Table 3-1 Wind conditions

<table>
<thead>
<tr>
<th>Bft</th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
<th>all</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3-4</td>
<td></td>
<td>7.4 %</td>
<td></td>
<td></td>
<td></td>
<td>15.7 %</td>
<td>10.3 %</td>
<td>4.1 %</td>
<td>59.7 %</td>
</tr>
<tr>
<td>5-6</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>20.0 %</td>
</tr>
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<td>7-8</td>
<td>0.3 %</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.1 %</td>
<td>0.2 %</td>
<td>0.4 %</td>
<td>1.1 %</td>
</tr>
<tr>
<td>9.8 %</td>
<td>10.4 %</td>
<td>10.0 %</td>
<td>11.6 %</td>
<td>9.4 %</td>
<td>20.6 %</td>
<td>14.1 %</td>
<td>14.1 %</td>
<td>99.9 %</td>
<td></td>
</tr>
</tbody>
</table>
Part 1 Location and environment of the Jade Weser Port

Figure 3-2 Wind conditions

The table shows that the strongest winds come from the directions SW, W, NW and N. Figure 1-1 shows that the port is quite well protected from the SW to NW direction.

One remark has to be made concerning the strongest winds, this is the large effect of the wind on the biggest container ships. Winds from NW, N, NE and E may cause difficult situations, because of large wind waves. Figure 3-3 [ref. 10] shows how often these strong wind occur.

Figure 3-3 Frequency of maximum wind speeds of the weather station at Bremerhaven (CES, 1993)

3.3 Waves

For two different situations waves have been determined. This gives a first impression of the wave climate. In this report new calculations have to be done, because different assumptions have to be done in order to determine the dominant wave conditions in the manoeuvring areas (entrance channel and turning circle).
Part 1 Location and environment of the Jade Weser Port

- For the building stage a maximum wave height is set to check the stability of the site and the safety of the ships. This wave is set for the Inner Jade area during high water and has a maximum of 2,5 m and a period of 7-8 sec with wind of 30-40 knots from the NW to the north. Higher wind speeds have not been included because the limited depth doesn’t permit higher waves.

- The Franzius Institut has made some calculations with SWAN to judge the waves in the Jade area during storm surges. The goal of this research was to determine to amount of water which will wash onto the quay. The research area comprises the whole Jade-Weser estuary. The results of this research can be found at the website of the Franzius Institut [ref. 22] A short summary is given below.

Calculations have been made for all wind directions; several wind speeds from 8 m/s and 12 m/s up to 32 m/s; and several water levels from NN +0 m, NN +1 m, up to NN +7 m. The highest wave at the future quay has a significant wave height, Hs, of 2.2 m and a mean period, Tm, of 5.1 s. This wave is a result of a N/NNO wind of 24 m/s, a water level of NN +6,0 m. The wave direction is N/NNO.

3.4 Astronomical tide

This paragraph gives the tidal information for the Jade area. The information is available in two formats. In Table 3-2 the German way of presenting these values is given; Table 3-3 gives the values according to the Admiralty tide tables. The values in these two tables give a first impression of the tidal range. For the calculation of currents however, more detailed information on the tides is needed. This detailed information is given in part 4 of this report.

Table 3-2 German tidal information Jade Weser Port [ref. 10]

<table>
<thead>
<tr>
<th>German abbreviation</th>
<th>English explanation</th>
<th>Water level</th>
<th>Water level (with respect to CD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HHThw</td>
<td>highest measured high water</td>
<td>NN + 4,48 m</td>
<td>+ 6,58 m</td>
</tr>
<tr>
<td>MThw</td>
<td>average measured high water</td>
<td>NN + 1,60 m</td>
<td>+ 3,70 m</td>
</tr>
<tr>
<td>MTnw</td>
<td>average measured low water</td>
<td>NN – 1,82 m</td>
<td>+ 0,28 m</td>
</tr>
<tr>
<td>MSP Tnw = SKN = CD</td>
<td>Low Water Spring</td>
<td>NN – 2,10 m</td>
<td>0,00 m</td>
</tr>
<tr>
<td>NNTnw</td>
<td>lowest measured low water</td>
<td>NN – 3,87 m</td>
<td>– 1,77 m</td>
</tr>
</tbody>
</table>

Note: Chart Datum = Normal Null -2,10m (at the future Jade Weser Port location)

Table 3-3 Tidal information Wilhelmshaven [ref. 1]

<table>
<thead>
<tr>
<th>Tidal level</th>
<th>Explanation</th>
<th>Water level (with respect to CD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HAT</td>
<td>Highest Astronomical Tide</td>
<td>+ 4,5 m</td>
</tr>
<tr>
<td>MHWS</td>
<td>Mean High Water Spring</td>
<td>+ 4,3 m</td>
</tr>
<tr>
<td>MHWN</td>
<td>Mean High Water Neap</td>
<td>+ 3,8 m</td>
</tr>
<tr>
<td>MSL</td>
<td>Mean Sea Level</td>
<td>+ 2,3 m</td>
</tr>
<tr>
<td>MLWN</td>
<td>Mean Low Water Neap</td>
<td>+ 0,5 m</td>
</tr>
<tr>
<td>MLWS</td>
<td>Mean Low Water Spring</td>
<td>0,0 m</td>
</tr>
<tr>
<td>LAT</td>
<td>Lowest Astronomical Tide</td>
<td>- 0,4 m</td>
</tr>
</tbody>
</table>

The value to link Normal Null to Chart Datum varies along the coast, see also Table 3-4.
3.5 Currents

The tidal currents in the Jade are influenced by several factors.

- The Coriolis force. The Coriolis force causes the currents to deviate. The flood current is deviated to the western bank and the ebb current is deviated to the eastern bank.
- The waterworks. In the Jade several waterworks influence the tidal currents examples of these waterworks are the extension of the tidal channel to the Jade, the four throughput jetties, a guiding dam in the Jade Reservoir, the groynes at Minsener Oog and several dikes.
- Wind. The current is partial dominated by wind originated drift currents.

All these influences result in the fact that the tidal current is flowing in a week and meandering way in and out of the Jade. The flood and ebb currents in the Inner Jade and the Jade Reservoir follow different paths.

Another current is caused by an overflow, a volume of water, which flows during flood from the Jade to the Weser over the Hohe-Weg-Watt. This volume is only ca. 2% of the total volume of the Jade (about 1 milliard m3). This volume of water is free of particles, which have been deposited in the Inner Jade and are not resuspended for the transport out of the Jade.

Some current measurements were taken for the construction of a jetty just north of the future port for the WRG company. During site measurements a maximum current speed of 1,77 m/s has been measured near the island berth and near the jetty a maximum current speed of 1,49 m/s has been measured.

3.6 Soil conditions

This paragraph gives the soil conditions for the area where the new port is planned. From the bottom of the Jade in downward direction, the soil consist of the following layers [ref. 7]:

- First a mud layer
- Then a layer which differs in thickness all over the planned area. It consists of silty clay to fine/middle size sand (Wattsand). In this layer smaller mud layers may be present. The layer has a minor carrying capacity and can have properties of liquid soil types. This layer reaches in the planned area to depths up to NN-14 m to NN-19 m.
- The third layer consists of sandy clayish silt. The volume of silt, fine sand and clay particles are changing in this soil layer. These changing volumes result in changing consistency from soft and stiff to semi-firm. This layer does not have sufficient carrying capacity and gives great and continuing settlements, it has a thickness of 2 to 9 m and reaches depths of NN-14 m to NN-25 m.
- From depths between NN-14 m to NN-27 m, glacial pre-stressed soil kinds are present. In the upper reach, Lauenburger clay can be found, in deeper parts pre-stressed fine to middle sized sand and coarser sands can be found. Where the Lauenburger clay has a sufficient layer thickness, it can be used to carry pole loads. The glacial deposited fine/middle sized sand is suitable for foundations because of its high-density degree.

<table>
<thead>
<tr>
<th>Place along the coast</th>
<th>Difference between CD and NN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hooksiel</td>
<td>-1.98 m</td>
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<tr>
<td>Jade Weser Port</td>
<td>-2.10 m</td>
</tr>
<tr>
<td>Wilhelmshaven</td>
<td>-2.26 m</td>
</tr>
</tbody>
</table>
4 Problem analysis

4.1 The present situation

Together with the amount of transported containers, the size of the container vessels increases. With the size of the ships their draught also becomes larger. At the moment Germany does not have a harbour, suitable to receive these large container vessels. The idea has risen to design and construct a new deep water port in Wilhelmshaven at the Jade and Weser estuary: the Jade Weser Port.

The Jade and Weser estuary is very suitable as a harbour, having a natural deep sea channel and being situated close to open sea. Besides that, a large area is available for the terminal and the infrastructure on land has good possibilities for expansion.

4.2 Formulation of the problem

The idea to build a port in the Jade Weser area is not very new. One of the first articles about the Jade Weser Port was published in The ‘Wilhelmshavener Zeitung’ in 1971.

Authorities in Germany want a deepwater port, which can compete with the port of Rotterdam for the enormous container ships of the future. The container terminals of Hamburg and Bremerhaven can’t handle these ships because of a lack of space and/or because access channels cannot reach the depth that is required for these large vessels. Therefore a new location is needed to build a new deep water port and container terminal for the largest vessels.

The authorities took some time contemplating where this port has to be built. Wilhelmshaven versus Cuxhaven was the dilemma. Finally, in March 2001, a temporary decision was made: a new deepwater port is to be build near Wilhelmshaven. One of the strongest points of the area near Wilhemshaven is the great possibilities for future expansion.

For a project, as great as the Jade Weser Port, several studies have to be done. For the present, the most important study has been executed by a syndicate of German engineering agencies (IBP, ISL and PTC). They have made a feasibility study for the deepwater port.

The economic situation of the port is not clear yet. The studies into this subject are not widely available. This leads to the first question:

Is the Jade Weser Port economically/financial feasible?

Ballast Nedam has also done research into the future Jade Weser Port. Because of this research the design of the quay in the feasibility study gave reason to Ballast Nedam Dredging for some questions. The quay wall is not protected from waves and currents and there are no breakwaters to protect the berths. The quay lies parallel to the approach channel, just a couple of hundred meters away from it. This situation has led to the following question:

Does the unprotected quay lead to any nautical or operational difficulties? If so, is there not a better option for the layout of the quay?

4.3 Objective

The objective of this thesis study is to answer the questions that are outlined in the problem description above. This will be done in the following studies:

1. Financial/economical study
The economical study is a background study, it shows the financial feasibility of the port. The study will deal with the following topics:
- An analysis of the market situation and the port economics
- The expected ships and throughput capacity
- An analysis of the cost and revenues of the future port
The port is planned for ships with the enormous transport capacity of 8000 TEU and more. This might be a too prosperous prediction with respect to the growth in container transport. This study aims to give an advice for the necessity of this port.

2. *Nautical/hydraulic study*

This study will be the core of the thesis study. It will give an answer to the question whether the unprotected quay leads to any nautical or operational difficulties. This study consists of the following activities:
- Gathering of measurements of the hydraulic circumstances (wave statistics, horizontal and vertical tide, wind set up)
- Modelling the tidal currents in the Jade and Weser estuary
- Modelling the waves in the Jade and Weser estuary
- Simulating the circumstances at the berth itself (ship moored to the quay)
- Simulating the berthing, sailing in the approach channel and turning circle
To model the circumstances in the Jade and Weser estuary, information is needed about waves, currents and sedimentation. Because the time for this study is limited and sedimentation has a relatively low impact on the performance of the ships (the impact of currents and waves is much higher) it is decided not to look at the sedimentation process. When the environmental circumstances are modelled, the simulations can start. The goal of these simulations is to predict the downtime for ships in the Jade and Weser estuary and the berth itself.

4.4 * Preconditions*

For the design of the port several local and national authorities have set some preconditions, which limit the design. These preconditions are listed in this chapter, every precondition has been given a number, the list of requirements in paragraph 4.6 refers to these numbers. With every precondition, the party is stated that was responsible for those demands. Some demands have not yet officially been made, but they are mentioned anyway because in an official assignment they are very likely to be made.

**Natural preconditions**

- NP1: The effect of the maritime climate should been taken into account (*Port authority*)
- NP2: The soil condition should been taken into account (*Port authority*)
- NP3: Local flora and fauna should be spared as much as possible, or even compensated by ‘giving other areas up for nature’ (*Local government*)

**Legal preconditions**

- LP1: The designed terminal should comply with the local zone plan, as well as other laws and regulations, which apply for ports (*Government, Local authority*)
- LP2: The designed terminal should comply with the lows concerning flora and fauna (*Government, Local authority*)

**Logistics preconditions**

- LoP1: The terminal will be used for containerised cargo. (*Port authority*)
- LoP2: The port can be reached at any time, no limitations. (*Port authority*)
Part 1 Location and environment of the Jade Weser Port

- LoP3: The terminal should be operational for 24 hours/day. *(Port authority)*
- LoP4: The port should be capable of handling ships with a capacity of 8000 TEU and more *(Port authority)*
- LoP5: The necessary facilities for efficient cargo handling should be present, e.g. storage areas, service facilities, fuel facilities *(Shipping companies, Port authority, Terminal Operator)*
- LoP6: The terminals should be connected to the present infrastructure *(Port authority, Operator)*
- LoP7: The capacity of the terminal should be sufficient to comply with the growth for the next 20 years *(Port authority)*

Technical preconditions

- TP1: The terminal should be suitable for the representative ship-type. *(Shipping companies)*
- TP2: The water depth should be sufficient for the largest ship. *(Shipping companies)*
- TP3: The quay and other constructions should comply with the demands for stability and strength. *(Port authority)*
- TP4: The approach channel and the turning area should comply with the demands of the shipping traffic *(Shipping companies)*
- TP5: The necessary manoeuvring space should be available for ships. *(Shipping companies)*
- TP6: Tugs can not operate under (significant) wave conditions of more than 1,5 m. *(Tug companies)*

Execution preconditions

- EP1: The shipping traffic should not be tempered by construction activities. *(Shipping companies)*
- EP2: The construction site should be easily accessible for construction traffic and should offer sufficient space and facilities for construction traffic. *(Contractor)*
- EP3: The terminal shall be build in phases *(Port authority)*

Economical preconditions

- EcP1: The cost-quality ratio should be optimal. *(Port authority)*

Social preconditions

- SP1: Negative effects on environment and local population, due to construction and port activities should be minimised *(Government, Local authority)*

4.5 Assumptions

Because not all conditions are already clear, some assumptions about natural, legal and logistic conditions have been made.

Natural:

- The morphology effects of the port will roughly be estimated. They are regarded to obtain better current information.
- The tidal currents will be determined in a two dimensional calculation, the effect of waves on current will been taken into account.
- The chosen wind speeds are considered to be constant.
- The wind set-up caused by storms has been disregarded
- More assumptions are mentioned in the concerning chapters

Legal:
• Assumed is that all necessary permits have been granted or that they will cause no significant problems.

Logistics:
• Information from the feasibility study [ref. 10] will serve as preconditions stated by the port authority, some of this information will be checked in this report
• Most information comes from literature and prognoses from the year 2000. More recent developments have not been considered.
• The port will receive its first ships in 2006.
• The port layout as in appendix I is regarded
• The available for storage of containers and settlement of related business is large enough (860 ha = 2125 acres)
• In the future port is considered to have six berths for both feeders and deep-sea containerships (or four berths for the deep-sea ships), see also Figure 5-1. This is the first phase of the Jade Weser Port. In the future the port might be expanding and another eighteen berths might be realised.
• No larger ships than indicated as design ships will make use of the port.
• Downtime of 1% is acceptable for both the manoeuvring in the channel and the loading/unloading conditions
• Tugs have been compared with the tugs available in the area
• The ships are partly loaded
• More assumptions are mentioned in the concerning chapters.

This report does not comprise designs or studies into the following subjects:
• A complete economic study, which includes for example a throughput study for hinterland transport, a study into the effects of the port on flora and fauna, the effects on the employment of the population. Instead an extensive financial study is added, this comprises parts of an economic study
• The port constructions
• The detailed terminal layout
• Execution aspects
• A maintenance strategy

4.6 List of requirements

The following requirements have been deduced from the preconditions. Behind every requirement is stated the corresponding precondition number.

The starting information on tide, wave, wind and current information is as follows, more information will be presented further in the report, (NP1)

- Tidal information (CD = NN-2,10m):
  - HHThw (highest measured high water)  \( \text{NN} + 4.48 \text{ m} \)
  - MThw (average measured high water)  \( \text{NN} + 1.60 \text{ m} \)
  - MTnw (average measured low water)  \( \text{NN} - 1.82 \text{ m} \)
  - MSptnw = SKN = CD (Low Water Spring)  \( \text{NN} - 2.10 \text{ m} \)
  - NNTnw (lowest measured low water)  \( \text{NN} - 3.87 \text{ m} \)

- Wind strength and directions

<table>
<thead>
<tr>
<th>Bft</th>
<th>N</th>
<th>NO</th>
<th>O</th>
<th>SO</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
<th>all</th>
</tr>
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<td>0-2</td>
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<td>59.7 %</td>
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<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>2.5 %</td>
<td>20.0 %</td>
<td></td>
</tr>
</tbody>
</table>
Part 1 Location and environment of the Jade Weser Port

- Design wave height, wave directions height during the construction period:
  Max. wave height 2.5 m with a period of 7-8 sec.
  Max. wind of 30-40 knots from the NW to the North.
- Currents
  The flood current has a tendency for the western shore, the ebb has a tendency for the eastern shore. A current velocity of 1.77 m/s has been measured.

Ships and manoeuvring areas
- The design ships are presented in appendix VI (Lop4)
- The entrance channel has a water depth of -18.0 m SKN (seekartennull = CD)
- Close distance to the open sea, ± 27 nautical miles
- Berthing with the help of bow thrusters and tugs. Berthing has to be possible in all tidal phases.

Quay (Lop4)
- Designed lifecycle: 50 years (source: A fax to Ballast Nedam, Technische Informationen, Entwurfsnormen und Kriterien, 7/3/2000)
- The quay is to become 1.740 m long, containing 6 berth for container ships
  (source: Herr Reiche, Hafendienste Wilhelmshaven GmbH)
- Water depth in front of the quay wall is 16.0 m under CD = NN – 18.10 m. Quay wall needs to have a constructional reserve of 18.5 m under CD = NN – 20.60 m. [ref. 10]
- Quay = 7.10 m above NN (normal null) [ref. 10]
- Bottom protection, score protection: at the building depth of 18.5 m under SKN bottom protection is foreseen [ref. 10]

General Port requirements
- The terminal is operational for 24 hours/day (LoP2)
- Downtime of 1% is acceptable for both the manoeuvring in the channel and the loading/unloading conditions (LoP3)
- The capacity of the first phase of the terminal should be sufficient to comply with the growth for the next 20 years (LoP7)
- Tugs will not operate under (significant) wave conditions of more than 1.5 m. (TP6)
Part 2 Financial study

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5 Introduction to the financial study

This report is subdivided into several subsets: the main parts are the financial feasibility study and the nautical feasibility study. This part deals with the financial study.

In this financial subset of the thesis, several subject-like cargo growth, trends in the container fleet, the future port’s costs and revenues- will be dealt with in order to determine the financial feasibility of the future port.

The financial analysis is made to investigate the cashflow of the project through a determined period (here 20 years). The financial analysis is a tabulation of expenditures (capital costs, operation and maintenance costs) and revenues per year, throughout the period over which the project is evaluated.

The structure of this subset is as follows: Chapter six deals with the expected growth in container transport (both globally and locally). The modal split and range of the containerships will be shown in chapter seven. Finally, the costs versus the revenues of the container port will be analysed in chapter eight.

The points of attention for this subset are:

- In this subset the future port is considered to have six berths for both feeders and deep-sea containerships (or four berths for the deep-sea ships), see also Figure 5-1. This is the first phase of the Jade Weser Port. In the future the port might be expanding and another eighteen berths might be realised.

- Most information comes from literature and prognoses from the year 2000. More recent developments have not been considered.

- Examples of recent developments are [ref. 17]:
  - The setback in the world economy. This setback does not seem to change investment decisions of European Container Terminals. According to all research agencies, container throughput will continue to increase substantially in the coming decades. (This does not detract from the fact that at present the container sector is going through hard times world-wide. The slowing global economy on the one hand and the introduction of a lot of new shipping tonnage on the other hand have led to significant drops.)
  - Multi porting (more container terminals are visited directly); contrary of the hub and spoke concept. Reason for this development is the large scale of transactions that has arisen in world-wide container transport.
6 Expected cargo growth

6.1 Expected growth in container transport to and from Europe

This paragraph discusses the expected growth, world-wide and in northern Europe, in the container transport. The growth in northern Europe will be further analysed by mentioning port trends in northern Europe.

World-wide

The growth percentage of the container transport has been growing steadily for three years (1997-1999). The prognoses are that till 2012 a growth of 7-8% per year can be expected. This means the present volume (of 200 million TEU) will be doubled in 2010. (See Figure 6-1 Expected container transport - worldwide).

Reasons for this development are:
- Growth of the world economy.
- Increasing globalisation of the economy, resulting in more liberalism in trade.
- Continuous diminishing of the transport costs, for competition reasons.
- More cargo is being containerised; general cargo is converted into containerised cargo.

![Figure 6-1 Expected container transport - worldwide](image-url)
Northern Europe

The development in the container transport in northern Europe shows the mirror image of the world-wide development until now. This won’t continue in the future. The feasibility study Jade-Port predicts in the pessimistic estimation only 2.9 - 4.3% growth per year, till 2020. (See also Figure 6-2 Expected container transport – Northern Europe, the scenarios are elucidated in paragraph 6.2).

Reasons for lower growth in TEU in Northern Europe:
- In Europe, the transport of cargo is quite far containerised.
- The cost reductions, which have been achieved until know, can not continue in the same rate in the future (there is a limit in optimising transport chains and a lot of optimising has already been done).

Figure 6-2 Expected container transport – Northern Europe

Port trends in Northern Europe

Till 1999, the capacity for container transport was shifting to the west, to Antwerp and Rotterdam (see Figure 6-3). Although the container transport to and from Eastern Europe was growing. Extra throughput capacity at the German North Sea coast became necessary.

Results of these trends:
- The route of the Jumbo Containerships will shorten, the feeder routes will be lengthened.
- The extension of European long distance road and rail connections in west eastern direction is inevitable.
- The hinterland transport distance will grow, and the transport will be more concentrated. Large transport capacities will be necessary. This will have an effect on infrastructure and surroundings.

Other trends:
- The degree of automation on terminals is increasing. This will result in better planning, more

---

1 In 2001 some of the throughput moved to Germany. The company Maersk Sealand demanded their own terminal in Rotterdam, when it turned out to nothing they shifted to Bremen. Furthermore, several ports in the east are expanding in order to cope with the growth in Eastern Europe.
efficient transport and fewer employees.

- The Baltic is growing in importance; this will result in an out of proportion growing of feeders. These feeders will sail from deepwater ports to the Baltic.
- Optimising the transport chains: Combining the Multi-Port-Concept and the Hub-and-Spoke-Concept to attain the fastest, cheapest and most transparent option.
- All ports in Northern Europe have extensions planned in their neighbourhoods (independent of the demand).

![Figure 6-3 The comparison of German ports versus West European ports](image)

### 6.2 Expected containers for the Jade Weser Port

Like the prognoses for the port of Rotterdam, several global developments, scenarios, have been distinguished. These scenarios have been used, because most literature on the Jade Weser Port refers to these scenarios. [Ref. 15]

Global Competition: Liberated trade, world trade growth, economic integration and stability in Eastern Europe

European Co-ordination: Integration within Europe, formulising of trade barriers against international competition, less economic growth

Divided Europe: World-wide protectionism, low trade volumes

The scenarios used in Figure 6-2 and Figure 6-4 relate to these scenarios as follows: Scenario I relates to Global Competition, scenario II relates to European Co-ordination and scenario III relates to Divided Europe.

These scenarios suppose that next to the economic development a development in the container fleet will take place. With Global Competition, ships with a capacity of 8,000 TEU and more will arise sooner than with the other scenarios.
At the predicted throughput growth of the joint range (Hamburg and Bremerhaven), both ports would reach their capacity limit within the coming 10 years and Jade Weser Port as German port in this range will profit from the growth. The growth of the throughput in Jade Weser Port is based on the assumption that Hamburg and Bremerhaven\(^2\) can not realise any substantial extensions. In assumption, that the 8,000 TEU (and more) ships won’t visit the ports Hamburg and Bremerhaven, their market share is attached to the Jade Weser Port.

Of special meaning for the development of Jade Weser Port are the Scandinavian traffic and the traffic from and to the Far East, because on this route in particular the bigger ships are expected. The following throughput quantities have been predicted, see Table 6-1 and Figure 6-4.

Table 6-1 Prognoses of the container throughput in Jade Weser Port till 2015 (in million TEU, source ref. 12)

<table>
<thead>
<tr>
<th>Year</th>
<th>Global Competition</th>
<th>European Co-ordination</th>
<th>Divided Europe</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006</td>
<td>0,2</td>
<td>0,1</td>
<td>0,1</td>
</tr>
<tr>
<td>2010</td>
<td>1,2</td>
<td>1,1</td>
<td>1,0</td>
</tr>
<tr>
<td>2015</td>
<td>2,3</td>
<td>2,1</td>
<td>1,8</td>
</tr>
</tbody>
</table>

Till the year 2020 the throughput in the most optimistic scenario will grow to 4,1 million TEU per year. Approximately a third of this throughput will be expected as feeder transport; of this feeder transport more than 50 % comes from the deep sea. See also Figure 6-5. Chapter 7 will go into more detail concerning the expected ships.

\(^2\) after the realisation of the extensions Altenwerder and CT IV.
Figure 6-5 Modal Split of the Jade Weser Port in 2013, source ref. 11
7 Expected range in ships

7.1 World-wide trends in container vessels

This paragraph shows trends in the container fleet. These trends concern size and capacity of the vessels. The container fleet is developing, vessels become bigger. First some information will be given on the fleet as it was from 1991 - 2000, see Figure 7-1 (do not be fooled by the yellow bar, this series is twice as large as the other series). Table 7-1 shows the developments in the near future.

![Figure 7-1 World-wide container fleet development 1991-2000, source ref. 12](image)

![Table 7-1 World-wide tenders for containerships in July 2000, source ref.12](image)

<table>
<thead>
<tr>
<th>Class in TEU capacity</th>
<th>World fleet at 1.7.00</th>
<th>Tender file Number</th>
<th>1,000 TEU</th>
<th>Completion (estimated) Number</th>
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<th>Number</th>
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<td>24</td>
<td>13</td>
<td>30</td>
<td>8</td>
<td>19</td>
<td>28,2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2500-2999</td>
<td>171</td>
<td>35</td>
<td>92</td>
<td>5</td>
<td>13</td>
<td>27</td>
<td>70</td>
<td>3</td>
<td>8</td>
<td>20,5%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3000-3499</td>
<td>132</td>
<td>15</td>
<td>49</td>
<td>5</td>
<td>17</td>
<td>7</td>
<td>23</td>
<td>3</td>
<td>9</td>
<td>11,4%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3500-3899</td>
<td>68</td>
<td>6</td>
<td>22</td>
<td>6</td>
<td>22</td>
<td>8,8%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3900-4299</td>
<td>91</td>
<td>27</td>
<td>110</td>
<td>5</td>
<td>20</td>
<td>5</td>
<td>20</td>
<td>15</td>
<td>61</td>
<td>2</td>
<td>8</td>
<td>29,7%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4300-4999</td>
<td>89</td>
<td>18</td>
<td>84</td>
<td>7</td>
<td>34</td>
<td>1</td>
<td>4</td>
<td>10</td>
<td>46</td>
<td>2</td>
<td>0,2%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5000-5999</td>
<td>50</td>
<td>56</td>
<td>310</td>
<td>18</td>
<td>100</td>
<td>24</td>
<td>132</td>
<td>11</td>
<td>62</td>
<td>3</td>
<td>17</td>
<td>112%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6000-6999</td>
<td>29</td>
<td>35</td>
<td>225</td>
<td>6</td>
<td>38</td>
<td>18</td>
<td>116</td>
<td>11</td>
<td>71</td>
<td>120%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt; 7000</td>
<td>4</td>
<td>29</td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>7</td>
<td>2</td>
<td>14</td>
<td>1</td>
<td>7</td>
<td>13%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>2502</td>
<td>325</td>
<td>1104</td>
<td>102</td>
<td>287</td>
<td>146</td>
<td>483</td>
<td>71</td>
<td>303</td>
<td>6</td>
<td>32</td>
<td>13%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Part 2 Financial study

The above figures show an enormous growth in size and number of vessels. The following enumeration shows more details of design trends for the near future.

Present design trends for Jumbos, the largest ships:
- Capacity till 11,000 TEU
- Length/breadth/draught proportions (approximately): 350m/55m/15m
- Suez channel is the limiting factor in the development

From this paragraph can be concluded that enormous container vessels can be expected in the future. Future deepwater ports have to be designed for these ships.

7.2 Container vessels expected for the Jade Weser Port

The expectations are that, in 2020, ships with a capacity of 10,000 TEU will visit Jade Weser Port. These ships will mainly sail on the routes: Transpacific (via ports at the US West Coast), Far East – Europe and North America – South East Asia. The main use is expected on the route Far East – Europe.

Of course the super – Jumbos will not be the only type of vessels in the Jade Weser Port. This paragraph gives data about the vessels, the berths and the throughput in the Jade Weser Port. This data has been calculated with simple theories. This serves well enough for a feasibility study. For a more detailed study, this data has to be recalculated with a more sophisticated theory.

Arrivals

The number of TEU determines the number of vessels needed to transport the containers. The expected TEU of the Jade Weser Port is shown in Figure 6-4. The optimistic approach gives the following rate of arrivals for 2013, see Table 7-2. This table has been derived from the feasibility study on the Jade Weser Port and the values are assumed to be accurate. In this paragraph a check is done in order to get a first impression for the number of ships and the corresponding quay length. The waiting times are not allowed to be more than 10% of the service time.

Table 7-2 Arrivals, source ref. 10

<table>
<thead>
<tr>
<th></th>
<th>Σ TEU/year</th>
<th>Throughput/call</th>
<th>Arrivals/year</th>
<th>Arrivals/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeder</td>
<td>756,000 TEU</td>
<td>720 TEU</td>
<td>1,050</td>
<td>20,2</td>
</tr>
<tr>
<td>Midi</td>
<td>577,920 TEU</td>
<td>1,488 TEU</td>
<td>388</td>
<td>7,5</td>
</tr>
<tr>
<td>Jumbo</td>
<td>466,080 TEU</td>
<td>4,800 TEU</td>
<td>97</td>
<td>1,9</td>
</tr>
<tr>
<td>Total</td>
<td>1,800,000 TEU</td>
<td>average 1.173 TEU</td>
<td>1,535</td>
<td>30</td>
</tr>
</tbody>
</table>

Berths

Appendix VI shows more details of the design ships.

The ‘Queuing theory’ serves well for a first estimation of the number of berths needed for the Jade Weser Port, see also appendix VII. The following table, Table 7-3, shows the calculated quay length. The distance between the ships is the same as the values used in the feasibility study of the Jade Weser Port.
Table 7-3 Quay length

<table>
<thead>
<tr>
<th></th>
<th>Feeder berths</th>
<th>Midi berths</th>
<th>Jumbo berths</th>
<th>Distance between ships</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>According to ref. 10</td>
<td>2 * 160 m</td>
<td>2 * 200 m</td>
<td>2 * 360 m</td>
<td>7 * 40 m</td>
<td>1.720 m</td>
</tr>
<tr>
<td>1st calculation</td>
<td>3 * 160 m</td>
<td>2 * 200 m</td>
<td>1 * 360 m</td>
<td>7 * 40 m</td>
<td>1.520 m</td>
</tr>
<tr>
<td>2nd calculation</td>
<td>4 * 183 m</td>
<td>5 * 40 m</td>
<td></td>
<td></td>
<td>932 m</td>
</tr>
</tbody>
</table>

The value according to the first calculation is too high; it considers three independent quays. In reality, more efficient use of the quay can be realised; there will be one quay that can cope with all design ships. An efficient case would be the second calculation. The reality is a little bit less efficient, and therefore a first estimation would be six berths with a quay length of 1.300 m.

Alternative approach: The benchmark for quay productivity of two recent (or future) container terminals has been compared with the quay productivity of the Jade Weser Port. Euromax (The Netherlands) is designed for 1000 TEU/m\(^1\) quay per year and CT9 (Hong Kong), Pasir Panjang (Singapore) are designed at 1400 TEU/m\(^1\). In general: West-European ports are designed for ±1000 TEU/m\(^1\) quay per year and Asiatic ports are designed for ±1400 TEU/m\(^1\). The high productivity is only possible with highly productive (and more expensive) terminal equipment, which are required due to lack of or expensive terminal space. Equivalent productivity would result in a quay length of 1.200 to 1.800 m for the Jade Weser Port (source Ir. D.C. Roukema).

The result from the feasibility study [ref. 10] is six berths, two for each design ship with a total length of 1.725 m. This quay length lies above the calculated values of the queuing theory. The designed quay seems to be over estimated; therefore a strategic choice for high/low productivity is advised. This report continues with the quay as designed in the feasibility study [ref. 10], because the goal of this report is to evaluate their design.

According to ref. 10, there are six berths planned on a distance of 1.725 m. Two berths for each of the following vessel types. (A different approach gives four berths, each designed for the largest design ships, this equals the six berths. See also Figure 5-1 for the layout of the quay with its berths.)
- Feeder type A length 160 m
- Feeder type B (Midi) length 200 m
- Super- Jumbo length 360 m

The largest expected design ship can carry 6.000-11.000 TEU

**Throughput**

The following percentages indicate what has been mentioned before in this study. There is no inland shipping and the feeders are very important (even more important than the transport over land).

The throughput (see also Figure 6-5):
- 35% transhipment (transported by feeders)
- 7% short sea (transported by feeders)
- 58% deep sea
- 30% will be transported over land
8 Costs and revenues of the container terminal

In this chapter an answer is given on the financial feasibility of the terminal. First the costs of the terminal will be specified, in the following paragraph the revenues of the terminal will be mentioned. This will be followed by the cost/revenue analysis. The chapter ends with the conclusions of the financial feasibility.

The costs of the terminal have been based on the presentation of Roland Berger & Partner GmbH – International Management Consultants at the BAW convention in Hanover (2000), see also ref.19. The costs have been kept the same, only the terminology has been altered in some cases for consistency reasons.

The revenues have been based on charges of the Port of Rotterdam. These charges are relatively high in comparison to other European ports. The charges should relate to the service and accessibility of the port. For the Jade Weser Port, both service and accessibility are expected to be above average, therefore the charges can be relatively high.

For the financial analysis only the costs and revenues of the infrastructure are considered, running costs like wages and consumables are not included in this analysis. In appendix IX the costs and revenues of the operator have been calculated, running costs are included in this calculation.

8.1 Costs of the terminal

The costs can be subdivided as follows:

*Infrastructure:*  
- Quay wall  
- Land reclamtion  
- Shore protection  
- Other preparations (dredging works, foundations for road and rail works at the terminal)  
- Compensation and mitigation measurements for environmental impact  
- Remaining costs (engineering, permits, contract management)  
- Infrastructure on the terminal, buildings, roads, etc.

*Topworks:*

The terminal will be built with 4 berths for the largest container vessels. The planned capacity limit is 1.8 million TEU, meaning 1.2 million containers annually. The terminal will reach this maximum capacity somewhere between 2013-2015 (this estimation dates from 1999). One of the qualities of the Jade Weser Port is that extensions of the terminal are possible.

For the present analysis it is assumed that eight berths (3.4 km quay) have double the capacity of four berths (in reality the capacity will more than double, more than 3.6 million TEU). Figure 6-4 shows that the port has the potency to cope with more than 4 million TEU in the year 2020. Therefore eight berths will be sufficient until 2020. Ten or twenty-four berths (4.4 respective 10.4 km quay) give an enormous capacity, the year in which these limits will be reached have not been predicted yet.

Table 8-1 shows the infrastructure costs for four berths and the extra money needed for respectively eight, ten and twenty-four berths. The costs for equipment and topworks will be discussed in the next paragraph.
Table 8-1 Cost of terminal infrastructure, source ref. 19

<table>
<thead>
<tr>
<th>Costs (million €)</th>
<th>Quay: 1.7 km (4 berths)</th>
<th>Cost of the expansion 1.7 to 3.4 km quay</th>
<th>Cost of the expansion 3.4 to 4.4 km quay</th>
<th>Cost of the expansion 4.4 to 10.4 km quay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quay wall</td>
<td>104.8</td>
<td>104.8</td>
<td>60.8</td>
<td>310.5</td>
</tr>
<tr>
<td>Land reclamation</td>
<td>81.0</td>
<td>30.9</td>
<td>15.4</td>
<td>143.0</td>
</tr>
<tr>
<td>Shore protection</td>
<td>64.7</td>
<td>19.5</td>
<td>14.6</td>
<td>93.1</td>
</tr>
<tr>
<td>Other preparations</td>
<td>103.2</td>
<td>8.7</td>
<td>4.3</td>
<td>129.0</td>
</tr>
<tr>
<td>Compensation + mitigation</td>
<td>15.3</td>
<td>4.1</td>
<td>2.1</td>
<td>24.0</td>
</tr>
<tr>
<td>Remaining costs</td>
<td>9.7</td>
<td>4.9</td>
<td>2.4</td>
<td>17.0</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>378.8</strong></td>
<td><strong>172.9</strong></td>
<td><strong>99.7</strong></td>
<td><strong>716.5</strong></td>
</tr>
<tr>
<td><strong>Cumulative costs:</strong></td>
<td><strong>378.8</strong></td>
<td><strong>551.7</strong></td>
<td><strong>651.4</strong></td>
<td><strong>1.367.9</strong></td>
</tr>
</tbody>
</table>

These costs will be used for the cost and revenue analysis, see appendix IX. There is one exception, the costs for the ‘other preparations’. In this table they are included, because the literature on the feasibility of the Jade Weser Port also includes these costs. Most economic analyses include only the building costs of the terminal itself; therefore in this analysis only the dredging works are included (these are estimated at 2/3 of the other preparation costs, about 23,6 million m³ has to be removed). The road and rail works at the terminal will be included in the costs for topworks.

For the first phase the costs of the terminal infrastructure are $378.8 - 1/3 * 103.2 = € 344.4$ million.

**Topworks**

The feasibility study of the Jade Port reserves € 330,6 million for equipment and topworks. From appendix VIII can be seen that the costs for terminal equipment add up to roughly € 205 million. This means that € 125,6 million will be spend on topworks. This includes the offices, the roadwork, the stacking area, the fencing, etc.

The costs for the topworks will be completely covered by the operator, also known as operator’s contribution.

For the first phase the costs of the topworks are $125.6 + 1/3 * 103.2 = € 160$ million.

**Maintenance**

Maintenance will result in some additional costs, costs for maintenance dredging and costs for maintenance of topworks (e.g. maintenance of the roadwork). The following assumptions have been made:

- The maintenance dredging will be 15% of the dredged volume (which is dredged to deepen the access of the new port).
- The estimated maintenance dredging cost is € 1,8 per m³.
- The maintenance of topworks will be 2-3% of the investment costs (2.5% of € 160 million), these costs will be paid by the operator and are not included in this analyses.

For the first phase the costs of maintenance are € 6,4 million per year.

See appendix IX for the cost and revenue analysis. The division of costs over the building phase has been derived from the time/work schedule of the feasibility study of the Jade Weser Port.
Conclusion:
The terminal costs € 504 million; this can be subdivided in € 344 million for infrastructure and € 160 million for topworks.

8.2 Revenues of the terminal

The revenues of the port can be divided in container charges, port charges, terminal lease and the government contribution. Container charges are the charges for the containers that are moved onto or of the terminal area, these are taxes that have to be paid to the authorities. Port charges comprise several costs: the pilots, tugs, mooring charges, port charges etc. Terminal lease is the amount that operators pay to the port authority to rent the terminal. These amounts, the container charges, the port charges and the terminal lease, can be used to pay off the investment costs of the terminal. In most port projects a governmental contribution is necessary to reach financial closure.

Container charges

The expected throughput is 1.800.000 TEU in 2013, after seven previous years of terminal handling. Figure 6-4 shows the expected throughput per year. The middle scenario has been used in the calculations.

Some assumptions have been made in order to determine the container charges:
- The proportion 20 and 40 feet containers is assumed as 1:1; so 1.800.000 TEU = 1.200.000 containers
- Percentage full / empty containers = 85% / 15%
- Percentage import / export containers = 50% / 50%
- The throughput: 35% transhipment (at Bremerhaven this is 28%, for Hamburg 30%)
  7% short sea (both transhipment and short see are transported by feeders)
  58% deep sea
  30% transported over land

In the following table, Table 8-2 the throughput is subdivided into the amount of import, export or transhipment TEU. In Table 8-3 the container charges are calculated.

<table>
<thead>
<tr>
<th></th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total throughput</td>
<td>500</td>
<td>600</td>
<td>750</td>
<td>1000</td>
<td>1200</td>
<td>1300</td>
<td>1500</td>
<td>1800</td>
</tr>
<tr>
<td>35% transhipment</td>
<td>175</td>
<td>210</td>
<td>262.5</td>
<td>350</td>
<td>420</td>
<td>455</td>
<td>525</td>
<td>630</td>
</tr>
<tr>
<td>Import</td>
<td>162.5</td>
<td>195</td>
<td>243.75</td>
<td>325</td>
<td>390</td>
<td>422.5</td>
<td>487.5</td>
<td>585</td>
</tr>
<tr>
<td>Export (same as import)</td>
<td>162.5</td>
<td>195</td>
<td>243.75</td>
<td>325</td>
<td>390</td>
<td>422.5</td>
<td>487.5</td>
<td>585</td>
</tr>
</tbody>
</table>

The following calculation has to be done in order to know the container charges:
The number of containers = the number of TEU*2/3
Import and export moves = the number of transhipment containers*2
Transhipment moves = number of transhipment containers*2

The handling charge is € 11,8 (the tranship containers are moved twice, therefore they are charged double).
Part 2 Financial study

Table 8-3 Container charges

<table>
<thead>
<tr>
<th>Unit</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transhipment</td>
<td>1000 moves</td>
<td>234</td>
<td>280</td>
<td>350</td>
<td>466</td>
<td>560</td>
<td>606</td>
<td>700</td>
</tr>
<tr>
<td>Import + export</td>
<td>1000 moves</td>
<td>216</td>
<td>260</td>
<td>325</td>
<td>434</td>
<td>520</td>
<td>564</td>
<td>650</td>
</tr>
<tr>
<td>Total moves</td>
<td>1000 moves</td>
<td>450</td>
<td>540</td>
<td>675</td>
<td>900</td>
<td>1080</td>
<td>1170</td>
<td>1350</td>
</tr>
<tr>
<td>Container charges</td>
<td>million €</td>
<td>5,3</td>
<td>6,4</td>
<td>8,0</td>
<td>10,6</td>
<td>12,7</td>
<td>13,8</td>
<td>15,9</td>
</tr>
</tbody>
</table>

Port charges

The port charges consist of several specified costs, like harbour dues, quay dues, buoy dues, towage, pilotage dues, etc. The harbour dues are the most dominant costs and are directly related to the terminal infrastructure, and therefore only these costs are considered. The charges from the Port of Rotterdam have been used for the calculation (see Table 8-4), because the future harbour dues for the Jade Weser Port have not yet been determined.

Table 8-4 Harbour dues of the Port of Rotterdam, source ref. 18

<table>
<thead>
<tr>
<th>Type of vessel</th>
<th>Harbour dues</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeders/shortsea</td>
<td>€ 0,356 per GT</td>
<td>Quantity of cargo amounts to 50% or more of GT of the vessel</td>
</tr>
<tr>
<td></td>
<td>€ 0,156 per GT + € 0,401 per metric ton of discharged/loaded cargo</td>
<td>Quantity of cargo amounts to less than 50% of GT</td>
</tr>
<tr>
<td>Container vessels</td>
<td>€ 0,417 per GT</td>
<td>Quantity of cargo amounts to 51,3% or more of the GT of the vessel</td>
</tr>
<tr>
<td></td>
<td>€ 0,207 per GT + € 0,408 per metric ton of discharged/loaded cargo</td>
<td>Quantity of cargo amounts to less than 51,3% of GT</td>
</tr>
</tbody>
</table>

The following assumptions have been made in order to calculate the harbour dues:
- Quantity of cargo amounts to at least 52% of the GT of the vessel
- The design ship parameters as in appendix VI have been used

Table 8-5 Harbour dues for each design ship in 2013

<table>
<thead>
<tr>
<th>Length</th>
<th>GT</th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>160 m</td>
<td>10.000</td>
<td>1.050 ships/year * € 0,356/GT * 10.000 GT/ship = € 3.738.000/year</td>
</tr>
<tr>
<td>200 m</td>
<td>28.000</td>
<td>388 ships/year * € 0,356/GT * 28.000 GT/ship = € 3.867.584/year</td>
</tr>
<tr>
<td>360 m</td>
<td>93.000</td>
<td>97 ships/year * € 0,417/GT * 93.000 GT/ship = € 3.761.757/year</td>
</tr>
</tbody>
</table>

Table 8-5 shows the calculation of the harbour dues in 2013 for each design ship. The total harbour dues in 2013 = € 11.367.341 or € 11,4 million.

The harbour dues before 2013 are lower, because the lower throughput will result in less ships/year. The influence each of the different ships (feeder/midi/jumbo) is almost the same, therefore for the years 2006-2012 the harbour dues will be proportionally lower according to the throughput, see Table 8-6.

Table 8-6 Port charges

<table>
<thead>
<tr>
<th>Throughput</th>
<th>1000 TEU</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
<tbody>
<tr>
<td>Harbour dues</td>
<td>million €</td>
<td>3,2</td>
<td>3,8</td>
<td>4,8</td>
<td>6,3</td>
<td>7,6</td>
<td>8,2</td>
<td>9,5</td>
<td>11,4</td>
</tr>
</tbody>
</table>

Terminal lease
The terminal lease consists of charges for the rent of the quay length and charges for the rent of the terminal area. The charges of the quay can be subdivided in charges for the quay with quay wall and charges for the quay without quay wall. For the revenues of the terminal lease, see Table 8-7.

Table 8-7 Terminal lease

<table>
<thead>
<tr>
<th>Description</th>
<th>Formula</th>
<th>Revenue (€)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quay wall</td>
<td>1725 m * 1134 €/m =</td>
<td>€ 1,956,150</td>
</tr>
<tr>
<td>Terminal area</td>
<td>4,08 €/m² * (1725 m * 1001 m + 0,5 * 1001 m * 700,9 m) =</td>
<td>€ 8,476,304</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>€ 10,432,454</td>
</tr>
</tbody>
</table>

The terminal area consists partly of the container terminal area and partly of a distribution park, the price that has been used is the average of both values.

The revenues of this paragraph are the basis for the cost/revenue analysis, see also appendix IX.

8.3 Cost revenue analysis

There are several ways of determining the financial feasibility of a port, but the financial feasibility can best be determined by a discounted cash flow calculation. This is an accurate method to determine the return on the investments.

This paragraph gives some explanation on the discounted cash flow calculation as used in appendix IX. The costs and the revenues come from the former paragraphs of this chapter and do not require any clarification. The column ‘Cash Flow’ will be the main topic of this paragraph.

Cash flow = Revenues - Costs.

The costs and revenues of the project are determined over a period of 20 years. The cash flow values differ throughout the years and should be corrected for time (discounting). For all the cash flows a discounted value is calculated using a constant discount percentage $\gamma$.

\[ D.C.F_n = \frac{C.F_n}{(1 + \gamma)^{n-1}} \]

In which:
- $D.C.F_n$ = discounted cash flow value of year $n$
- $C.F_n$ = cash flow of year $n$
- $n$ = year from the start (in the first year $n-1 = 0$)
- $\gamma$ = discount percentage = discount rate + risk - inflation

This formula shows that early revenues and cost are most important for the feasibility of the project, future costs and revenues are of less importance. In the calculation $\gamma = 9\%$. The sum of all discounted cash flows yields the net present value (N.P.V.).

\[ N.P.V_{20} = \sum_{n=1}^{20} D.C.F_n \]

The Internal Rate of Return (I.R.R.) is the most important standard for the return of costs and is defined as the discounting percentage for which the net present value becomes zero.

\[ I.R.R. = \gamma \therefore N.P.V_{20} = 0 \]

The discounted cash flow calculation gives an internal return rate of $10\%$. The used value of $\gamma (9\%)$ is an often-used percentage, and it symbolises a minimum for a financial feasible port project (the true minimum is determined by the stakeholders of the project). An internal rate of return of $10\%$ is not
sufficient for a financial feasible project and is not even near general accepted rates for large port projects, as stated by the Worldbank and Drewry Shipping Consultants (± 18% before tax).

As has been mentioned before most port projects need a governmental contribution to reach financial closure. This contribution has been included in the discounted cash flow calculation. This gives a more optimistic answer to the calculation, without this contribution the internal return rate would be 3%.

This contribution can be justified for being a compensation for the value the ports adds to its surroundings (the spinn off), e.g. increasing employment rates, coming up of new businesses, the increase of tax income for the area. Also the government contribution can be seen as a subsidy to stimulate areas that lay behind in their economic development.

The minimum for the internal return rate (I.R.R.) depends on the investors. Commercial projects, with private investors require an I.R.R. varying between 15-20%. For governmental projects the I.R.R. can be lower. The Jade Weser Port will be a combination of the two, it will be partly financed by the government and partly by private investors. Still the conclusion stays the same, this project is with these costs and revenues not feasible.

The cost revenue analysis has been made for the first phase (1725 m quay). In the future the port might expand and extensions might be build. These extensions can do with lower investments, but the revenues will be at the same level, this will result in a more positive financial analysis.

8.4 Jade Weser Ports financial feasibility

The cost revenue analysis shows the low financial feasibility of the Jade Weser Port. This paragraph will elucidate this result.

There can be several reasons for a low financial feasibility:
- costs might be too high
- revenues might be too low
- most costs are made in the first few years
- most revenues are made in the last few years.

In most projects the last two facts can hardly be influenced. The first two aspects are responsible for the low feasibility of this project. This can be indicated by the sum of the cash flows; the answer to that sum is negative. This proves that the costs are too high in comparison with the revenues.

The revenues have been calculated with values from the Port of Rotterdam; it is possible that the charges of the Jade Weser Port will be higher. This would not be a very wise decision though. With high charges, the port would attract less cargo, which would make the port less attractive.

The costs are high in comparison with the revenues. Some research should be done to examine these costs. One solution could be to build a smaller and more efficient port, which would use less area, so less land has to be reclaimed.

Another financial feasibility study can also been done for the operator of the terminal. This feasibility study should be positive, the operator is a private entrepreneur and should make enough profit.
Part 3 Preliminary design

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Part 3 Preliminary design
9 Introduction

Designing is an iterative process, it starts with concept designs and it goes on, after another iterative step, into detailed design. In feasibility studies, the designs are still in a preliminary stage. The necessary detail of the study depends on the kind of questions asked.

This report tries (among other things) to determine the nautical feasibility of the port. This feasibility is determined in two steps, a conceptual step and a more detailed step. Part 3, deals with the concept design of the nautical areas of the Jade Weser Port.

This part gives an introduction into the nautical values for the future Jade Weser Port. The first chapter starts with an introduction into the area. In the other chapters the nautical areas of the port will be tested by thumb rules. Those chapters give only rough design values for the future port; the calculations and simulations in the following subset (part 4) will go into much more detail.
10 Characterising the area

The Jade is Germany’s largest navigable estuary, see figure 10.1 for an overview of the Jade. Some values of the Jade are given.

- The distance, between the beginning of the Jade and the old outer harbour of Wilhelmshaven, is 32 nautical miles or ± 59 kilometres.
- The navigable water has an entrance channel with a width of 300 m and a maximum depth of 20 m below SKN (seekartennull = CD).
- The tidal difference near the future Jade Weser Port has an average of 3,40 m.

The Jade can be subdivided into three districts: The Outer Jade, the area till Schillighörn, the Inner Jade, from Schillighörn till Wilhelmshaven, and the Jade Reservoir.

The Jade is a relative young estuary, the Jade was built by the drain of the melting water of the glacial age. The Inner Jade is even younger, it has been formed in the last hundred years by the impact of heavy storm surges.

The present shape of the Jade Reservoir has been jointly originated by land reclamation (reclaimed areas: Rüstersieler and Voslapper Groden) and by the impact of the tide and waves. Many authors have presented theories of the morphologic development of this area. In general, the estuary is morphologically very interesting.

Outline over the history of the Jade

The Jade estuary together with the Weser estuary makes a large estuary in the German Bight. A short description is given on the developments of the Jade from 1957 and onwards.

The economic developments in the ‘Bundesrepublik’ of Germany necessitated the extension of the Jade to navigable water for ships with large draughts with corresponding loading equipment for deep water. The Jade navigable water has been deepened in several stages, starting with 12 m, till 18,5 m below SKN. This leads finally to a shipping channel of ± 59 km in length.

- The deepening took place between 1957 and 1975. The reaction on the deepening to 18,5 m was noticeable for at least 10 years after the release of the channel.
- Between 1971 and 1974, the reclamation of the area Voslapper Grodens was started.
- The last large change happened between 1985 and 1990. In this era, the channel of the Jade near Hooksiel was relocated to the east.

Tide and morphology

Observations show that the tidalcurve (present shape) has stabilised itself from the interventions, and now it approximates a sinus shape. The land reclamation caused the tidal curve to flatten. In consequence, the maximum current speed there became less. The tidal volume decreased with ca. 20 million m³ (this is very little in comparison to the tidal volumes of the entire Jade with a content of 1 billion m³).

Inspections in the German Bight show, that a landward pointed undertow over the sea floor exists, which continuously takes care of the supply of fine sediments towards the coast. The coast parallel current guides this sediment into the Jade. A further transport into the Jade is also guaranteed. At every tide 2 - 3% of the flood volume flows out over the Hohe Weg, and is not available anymore for seaward’s transport. The flood volume lost over the Hohen Weg is wind dependent. [ref. 2]
11 Design values of the approach channel

The approach channel can be defined as the waterway linking the turning circle with deepwater. The Jade Weser Port does not have a clear divined turning circle, instead there is a manoeuvring area in front of the port. The German Bight can be defined as deep water. The distance between Jade-activation and Jade Weser Port is ± 27 nm. = 50 km.

There are three design parameters for the approach channel: The alignment, the channel width and the channel depth.

The design ship for this report (different from the design ships in the financial study) has the following dimensions, see Table 11-1.

Table 11-1 Design container ship

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>11,000 TEU</td>
</tr>
<tr>
<td>Length over all</td>
<td>355.0 m</td>
</tr>
<tr>
<td>Length between perpendiculars</td>
<td>337.0 m</td>
</tr>
<tr>
<td>Beam</td>
<td>52.9 m</td>
</tr>
<tr>
<td>Draught</td>
<td>14.5 m</td>
</tr>
<tr>
<td>Dead-weight</td>
<td>130,000 ton</td>
</tr>
</tbody>
</table>

11.1 Alignment

The ideal approach channel should be the best combination of solutions to the following requirements:
- the channel should have the shortest possible length, taking into account wave, wind and current conditions
- minimise cross-currents and/or cross-winds
- the channel should have a small angle with the dominant wave direction
- minimise the number of bends and avoid bends close to the port entrance

The channel can be seen in figure 10.1. One part of the channel is the original channel, which is already in use for ships visiting Wilhelmshaven or one of the four jetties in the Jade. Another part is new, this is a channel which is dredged as an access linking the former channel to the future port. The design from the feasibility study has been used [ref. 10].

In actual cases the geometry and bottom conditions play an important role. High dredging costs resulting from a badly chosen channel layout can result in uneconomic or costly entrance channels.

Comments on the alignment

The channel does have a relatively short length. A shorter length would not follow the geometry of the bottom, and is therefore not chosen.

The channel does not experience cross currents, because the natural geometry is followed. Cross-wind on the other hand will influence the ships. Fortunately the dominant wind direction is the south-west direction, and with this direction the wind comes from land. The windforce will be reduced by the friction it undergoes from the land.

The dominant wave direction would be the south-west to north-west directions (see also chapter 17). Fortunately the channel is also sheltered by land for these directions. Furthermore the channel does also have a small angle (20°) with the north-west waves.
Part 3 Preliminary design

A thumb rule for bends in channels is a turning radius of $5 \times L_{pp}$, for ships without assistance using a rudder angle of $20^\circ$ at a water depth/draught ratio of 1.3-1.4. For a 11.000 TEU ship this would be $5 \times 337 = 1685$ m. This requirement is achieved in the channel for the Jade Weser Port (The first curve makes a turn of $18^\circ$, second curve turns $20^\circ$) [ref.20]

From this paragraph it can be concluded, that the alignment of the channel is well designed.

11.2 Width of the approach channel

Table 7-2 shows that the largest design ship has 97 arrivals per year or 1.9 arrivals per week, therefor a one-way channel should have enough capacity to avoid waiting times. The other vessels arrive more often but they need far less space, they can use the channel as a two-way channel.

The actual sailed track of a vessel is determined by [ref. 20]:
- cross-current and cross-current gradient
- cross wind
- speed of the vessel
- waves
- rudder response
- bottom topography
- position information
- human response

The current channel width is 300 m, this dimension will be checked in this paragraph for the design ships of the future Jade Weser Port. PIANC recommends the following formula for channel width ($W$) of straight sections of one-way channels: $W = W_{BM} + \sum W_i + 2W_B$

Basic width ($W_{BM}$): The basic width at a relative deep channel can be $1.6B$
$B = \text{beam of the ship}$

Additional width ($W_i$): For prevailing long currents an additional width of $0.1B$ is advised
For seabed characteristics, here a soft channel bottom, an extra width of $0.2B$ is advised

Bank clearance ($W_B$): The banks of the channel have an sloping edge, therefor an extra width of $0.5B$ is advised

The above assumptions result in a channel width of $2.9B = 2.9 \times 52.9 = 154$ m. This is relatively small but the (normal) circumstances are ideal, a channel which can follow the tidal gully and a channel that is protected by land in the prevailing wind and wave directions.

The same calculations can be done for extreme conditions, this results in a channel width of $4.1B = 4.1 \times 52.9 = 217$ m.

Channels subjected to a large tidal range are often given a width $> \text{the length of the largest design vessel}$. This is because if a ship runs aground on one channel bank, it may turn on the tide and (in a narrow channel) also run aground with its stern on the opposite bank. Since the channel transit will normally take place around HW, the ship might break in two at the falling tide. This could block the channel for an extended period.

Here the channel is not supposed to have a tidal window, therefor only at low tides the banks are a threat and the risk for the ship to break in two is not as great. This results in fact that the channel is not as wide as the length of the ship.

The channel width is 300 m, this is sufficient for a one-way channel for the largest design ship, and also for a two-way channel for other (smaller) ships.
11.3 Depth of the approach channel

There are two ways to determine the depth of the channel. The first one gives the minimum depth needed for manoeuvring reasons. The second one gives the minimum depth for which the ship will not hit the channel bottom.

1. As a rough estimation the design ship should have a keel clearance of 15% (or a clearance of 10%, combined with the average squat), this results in an advised channel depth of 1,15*14,5 = 16,7 m. This represents the minimum required water depth, at the lowest tidal moment, in which the ship is still allowed to enter.

The guaranteed channel depth is SKN -18,5 m (SKN = CD), this is 2,10 m below NN (or mean sea level). At the lowest measured spring tide the water level is NN -3,87 m, which means the available nautical depth is 18,5 + 2,10 - 3,87 = 16,7 m. According to this rough estimation, the channel depth is sufficient. See also Table 11-2.

2. The following formula gives the necessary depth for the ship for which the ship stays clear from the channel bottom [ref. 20]:

\[ d = D - T + s_{\text{max}} + r + m \]

- \( d \) = guaranteed depth (with respect to the reference level)
- \( D \) = draught of the design ship
- \( T \) = tidal elevation above reference level, below which no entrance is allowed
- \( s_{\text{max}} \) = maximum sinkage (for or aft) due to squat and trim
- \( r \) = vertical motion due to wave response
- \( m \) = remaining safety margin or net underkeel clearance

Values are:
- \( D = 14,5 \) m
- \( T = \text{NN} - 3,87 \) m (lowest measured low water)
- \( s_{\text{max}} = 0,21 \) m (calculated as the maximum of Huuska and Barrass II)
- \( r = H_s/2 = 2,1/2 = 1,1 \) m at the offshore side of the channel
- \( m = 0,3 \) m (for soft mud soils)

Resulting depth

\[ d = 14,5 + 3,87 + 0,21 + 1,1 + 0,3 = 20,0 \] m (below NN), the depth of the channel is 20,6 m (with respect to NN, or 18,5 with respect to SKN) so the channel is deep enough! See also Table 11-2.

Note: there are different ways to determine this depth, an alternative approach does not divide \( H_s \) by two, which would result in a depth below the guaranteed depth. Further research might show that in extreme conditions (a few hours per year) the deepest ship would experience a tidal window.

Table 11-2 Overview depth results

<table>
<thead>
<tr>
<th></th>
<th>With respect to SKN</th>
<th>With respect to NN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Guaranteed depth</td>
<td>- 18,50 m</td>
<td>- 20,60 m</td>
</tr>
<tr>
<td>1. Depth necessary for manoeuvring</td>
<td>- 18,47 m</td>
<td>- 20,57 m</td>
</tr>
<tr>
<td>2. Depth necessary for not touching the channel bottom</td>
<td>- 17,90 m</td>
<td>- 20,00 m</td>
</tr>
</tbody>
</table>
12 Manoeuvring areas in or near the port

This chapter deals with manoeuvring areas in or near the port. Furthermore some information on tugs is given.

In the channel layout as chosen, the quay is unprotected by breakwaters. This results in maintaining the channel in the port area like an offshore channel. Also calculations on port basins are not necessary. The area should be checked on the availability of an area large enough to turn, a turning circle.

The diameter of the turning circle should be \( > 2 \times \text{length of the design ship} = 710 \text{ m} \). The designed manoeuvring area is 1,400 m wide, and even more meters long, therefore even the largest ships should be able to turn here. Unfortunately the current in front of the quay is quite strong and in storms large wave heights can be generated, therefore a further check on this area is done by a simulation, see chapter 19.

The speed of ship that are not assisted by tugs has to be over 3-4 kn. This is a minimum speed through the water needed to maintain sufficient rudder control. The simulation in chapter 19 will show wetter the small design vessel (170m) is able to arrive or departure with or without tugs under extreme conditions.

Some more information on tugs:
- The time, for the tugboats to make fast, lies in the range of 10-20 minutes.
- The limiting speed of the vessel in order to fasten the tugs is 5-6 kn.
- The limiting significant wave height is 1,5 m, in order to fasten the tugs (very well trained crew can cope with even higher waves)
- Large ships will give astern power the moment tugboats can control the course and, subsequently stop in about 1,5L from an initial speed of 4kn. [ref. 20]

Example:
The distance it takes to attach the tugs and to fully stop the ship, with the ship starting at a speed of 6kn. is about 3,5 km.

The tugs, which are already in use, have their berth at Hooksiel and they tie up to the vessels just east of Hooksiel. This is at a distance of over 6 km to the first or north berth of the Jade Weser Port, this gives enough distance and time to tie up the tugs to the container ships.
13 Conclusions

The conclusions, which can be derived from the first estimations of this subset, are:

- The alignment of the approach channel is well designed
- The channel width is 300 m, this is sufficient for a one-way channel for the largest design ship, and also for a two-way channel for other (smaller) ships.
- The depth of the channel is sufficient for the largest design vessel
- The manoeuvring area is large enough to serve as a turning circle
- Tugs start to tie up east of Hooksiel, this is at a distance of over 6 km to the first or north berth of the Jade Weser Port, this gives enough distance and time to tie up the tugs to the container ships.

These conclusions give a first impression of the nautical feasibility of the port. This first impression is positive, but more detailed information is necessary in order to give a more solid judgement for the nautical feasibility of the Jade Weser Port.
# Part 4 Detailed hydraulic and nautical analysis

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14 Introduction

This report is subdivided into several subsets: the main parts are the financial feasibility study and the nautical feasibility study. This part deals with the nautical study.

In the previous part some values for the port area have been calculated by thumb rules. From those results the conclusion can be drawn that the port is nautically well designed. On the other hand one of the assumptions was that the port should have no down time. This is a strong demand and more research should be done in order to make sure that this demand is satisfied.

The goal in this part is to answer the following question: Does the design of the Jade Weser Port comply with the precondition port without downtime?

This question can be easily answered, a port “without downtime” is not possible. Still for the Jade Weser Port this precondition is very important, therefore this precondition will be changed in a version which offers calculation possibilities. The port will satisfy the condition port without downtime, if the probability for downtime is less than 1%.

The next question arises, what is downtime and what can cause this downtime. Downtime is the interval in which a functional unit (here the ship) can not carry out the function it was supposed to do. Here the nautical downtime is examined, meaning the ship’s downtime cause by maritime factors like wind, waves and currents. This downtime will be checked at the following locations: The approach channel, the manoeuvring area near the port and the berth.

The structure of this subset is as follows:

In order to investigate this downtime first the relevant maritime conditions need to be known. First a short discussion on the morphology is given, which was required as input in order to obtain better current simulations. Furthermore the tidal currents will be simulated and the waves during rough conditions will be determined.

When the maritime conditions are known, a manoeuvring simulation is carried out with the design ships in the approach channel and the manoeuvring area near the port. For the situation of the moored ship at the berth a complete study can be done, here only a rough estimation will be done.

The points of attention for this subset are:

- In this subset the future port is considered to have six berths for both feeders and deep-sea containerships (or four berths for the deep-sea ships). This is the first phase of the Jade Weser Port. In the future the port might be expanding and another eighteen berths might be realised.

- The design ships here are different from the design ships from the financial subset. The design ships here are two available ships in the program Ship Navigator which are most similar to the design ships of the financial subset. See Table 19-1 for the characteristics of the ships.
15 Morphology

15.1 Introduction

This chapter gives a rough first impression on some of the morphology changes, caused by the reclamation of the new land area for the future Jade Weser Port. Goal for this chapter is to get a first impression of the morphology changes in order to improve the current calculations, which are the topic of the following chapter.

15.2 Method

The method, which has been used to calculate the future bathymetry, is based on equilibrium depths. The future bathymetry is the stage during which the Jade Weser Port is operational and the erosion and accretion will reach an equilibrium stage.

The results of the tidal flow calculation immediately after the reclamation of the Jade Weser Port (see also chapter 16) showed very high and very low velocities at certain locations in the Jade. The goal for the flow calculations was to create input for a navigation simulation and especially those high velocities near the quay of the port would give unrealistic results in such a simulation. Therefore the equilibrium depths have been calculated in order to get more realistic velocities.

Equidep is the program that was used to calculate the equilibrium depths, this program is made by Alkyon. This program uses velocity differences to calculate a new equilibrium bottom. This is a program which gives a first impression of the new equilibrium depths.

Input for the program were the results of two flow calculations and their bathymetry values. One calculation represents the present situation, no land reclamation and the present equilibrium stage. The second calculation represents the situation immediately after the completion of the land reclamation of the new port. In the second calculation no erosion or accretion was added (or subtracted) to the bathymetry.

15.3 Results

Output of the program is the level of erosion/accretion caused by the reclamation of the port area, see also figure 15.1. Furthermore a new bathymetry file is created for the new equilibrium stage, this file will be used for flow calculations in the following chapter.
16 Tidal currents

16.1 Introduction

The nautical study tries to answer the question whether or not the design vessels (a feeder of 170 meters in length and a container vessel of 355 meters in length) can safely manoeuvre in the Jade and near the future Jade Weser Port without having to much downtime.

The objective for this chapter is to show the approach of the determination of the current conditions. These velocity conditions will be calculated in order to find the limiting nautically conditions for vessels heading for the Jade Weser Port.

The motivation for the used programs is given in appendix X. Appendices XVI gives even more information on the used programs. Furthermore appendix XI shows the assumptions and the used parameters, which were the input for the several calculation programs.

16.2 Method

16.2.1 Determination of the maximum tidal range during 2000

The tidal range changes in time; there are daily variations and two-weekly variations (the spring tide differs throughout the year). In order to find the extreme velocity conditions, the maximum tidal range during one year will be determined.

The tidal range variation over the years is not very large. Here, the year 2000 was chosen because, it’s recent but not too recent so that measured data can be obtained in order to verify the calculated values (this check has not been done in this research).

At Alkyon 50 tidal components are available as input for the tidal prediction program. The results of the tidal prediction model have been presented in graphs (see figures 16.1-16.3). The tide of April the 18th seems to have the largest tidal range during 2000.

16.2.2 Calculations with Delft3D-FLOW

The calculations were done to determine the tidal currents at 18 April 2000. The moment of high water is not equal for the entire region, therefor part (the last 40 minutes) of 17 April has also been included into the calculations.

At Alkyon a flow model of the Jade estuary has been made for a former project [ref. 2]. This model was detailed enough (see figures 16.4 –16.7) to determine the flow conditions near the future Jade Weser Port. Detailed enough because there are enough (more than 8) cells in the areas where eddies could develop.

With the Alkyon model three different calculations were done, see Table 16-1.

<table>
<thead>
<tr>
<th>Calculation</th>
<th>Situation</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Without port</td>
<td>Original, depth of Alkyon model</td>
</tr>
<tr>
<td>2</td>
<td>Immediately after implementation of port</td>
<td>Depth according to list of demands</td>
</tr>
<tr>
<td>3</td>
<td>The operational port</td>
<td>Equilibrium depth</td>
</tr>
</tbody>
</table>
1. This calculation was done in the original state (without the new port). This calculation was done in order to compare the new situation (calculation 2) with the old situation (calculation 1). Furthermore, this calculation was also done in order to determine the equilibrium depths in the Jade after the implementation of the new port. The new equilibrium depth will be based on the velocity differences between the old and the new situation.

2. This calculation was done with the new port, including the new required depth in front of the terminal area and the new entrance channel. Modifications were done on the layout and depth of the entrance channel; also the area between the old and new channel was deepened (because erosion is expected there).

3. This calculation was done with the new port, at the new equilibrium depth. The equilibrium depth was calculated, by using the velocity differences of the two already mentioned calculations. The equilibrium depth is the bathymetry input for all future calculations. Assume that the equilibrium state is reached during the building phase of the terminal. This will not be completely true. This assumption has been done, because the largest erosion and accretion will appear immediately after the implementation of the new port. (At the navigation areas not the equilibrium depth but the guaranteed depth has been used).

16.3 Results

Validation

For the validation of the original model see reference 2, ‘Zufahrt Hooksiel’. The adaptations made to the model are minor, therefor the model does not have to be recalibrate.

Results

Only the results of the third calculation will be discussed, because these will be used in Ship Navigator.

Figures 16.12 and 16.13 show respectively the currents and the water level just in front of the quay of the Jade Weser Port, from these figures the extreme velocity conditions (extreme high or extreme low velocities) at the Jade Weser Port can be determined.

The most extreme moments are: High water at 17 April 23.40, maximum velocity at 18 April 02.40, low water at 18 April 05.50 and maximum velocity at 18 April 08.40 (see also figures 16.8-16.11). Those four extreme moments will be used in Ship Navigator as current input.

The results in more detail

The detailed figures of velocity contours (figures 16.14 and 16.15) show that eddies will not develop. Eddies could give difficult situations for ships to manoeuvre, therefor this is a positive result for the future port.

Those detailed figures also show that the velocity conditions (especially during maximum velocity conditions during ebb and flood) vary along the quay. This may result in different manoeuvring conditions in the simulation program, therefor the north berth and the south berth will be simulated.

Furthermore it can be concluded that the current follows the navigational channel, therefor the ships do not have to deal with crosstcurrents (except when manoeuvring in front of the quay).

Last but not least it can be concluded that currents with a velocity up to 1.4 m/s can occur. The simulation will show if ships experience manoeuvring problems caused by these high velocities.
17 Waves

17.1 Introduction

The objective is to determine the extreme wave conditions in order to find the limiting nautical conditions for vessels heading for the Jade Weser Port.

The motivation for the used programs is given in appendix X. Appendices XVI gives even more information on the used programs. Furthermore appendix XI shows the assumptions and the used parameters, which were the input for the several calculation programs.

17.2 Method

17.2.1 Statistical analysis

Data of the Ship database of Alkyon gives the input for the statistical analysis. This data has been derived from quality controlled observations made from ships. The used data comprises wind, significant wave height, mean period, directions and probability values at the offshore location 53°90’N 8°10’E (North-Sea above Germany).

With Hydrobase the probability of exceedance tables and the combined wind/wave and wave/period tables have been made. (See tables 17.3-17.5, in appendix IV) These tables give the wind speeds and mean wave periods, which will be used in the wave field calculations.

17.2.2 Creating input for the wave field calculations

- Grids

Three grids will be used, one overall grid, grid 1, and two detail grids, grid 2 and 3. Two detail grids are necessary because the wave field in front of the quay has to have a resolution of 20m (the entrance channel should be at least ten cells wide) in order to create input for Ship Navigator.

Grid 3 has a resolution of 20m. The detail grid 2 is necessary because a grid with a resolution of 20 meter gives too much calculation time when it would cover the whole entrance channel. Grid 2 has a resolution of 40m. Figure 17.2 shows the used grids.

- Bathymetry

The bathymetry data of the German Bight flow model will be used, see also figure 17.1. The German Bight model is an Alkyon model.

- Offshore wave field

From wave height information on internet (results of Swan calculations done by the Franzius institut, see reference 22) a first estimate can be made for the reduction of offshore waves to waves in the Jade Weser Port area. This area includes the port area and the channel up to five kilometres north of the terminal. That is where the tugs are fastened to the vessels. The limit for safely attaching these tugs to the container ships is a wave height of 1.5 m.

The port is to be designed as a port without limitations/downtime. Since no downtime gives no value for the calculation, a 1.5 m wave with an exceedance of 1% or less (in the port area) is acceptable. This value is combined with the most difficult moment in the tide and the most difficult tidal curve of the year 2000. Together this gives a downtime value, which is practically zero.
A significant wave height of 3.25m has been chosen, because this height has an exceedance of 1% or less (see table 17.3). From internet information (Swan calculations Franzius institut, ref. 22) the conclusion can be drawn that the 3.25m wave will reduce to less than 1.5m.

The following offshore wave height (with an exceedance of 1% or less) and directions etc. will be used for the Swan calculation, see Table 17-1 here below.

Table 17-1 Swan input

<table>
<thead>
<tr>
<th>Direction (º)</th>
<th>Direction (º)</th>
<th>Significant wave height (m)</th>
<th>Peak period (s)</th>
<th>Wind speed (m/s)</th>
<th>Prob. of exceedance (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>nautical</td>
<td>Cartesian</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>60</td>
<td>210</td>
<td>3.25</td>
<td>6.73</td>
<td>13.9</td>
<td>0.03</td>
</tr>
<tr>
<td>30</td>
<td>240</td>
<td>3.25</td>
<td>6.96</td>
<td>13.8</td>
<td>0.03</td>
</tr>
<tr>
<td>0</td>
<td>270</td>
<td>3.25</td>
<td>7.67</td>
<td>13.6</td>
<td>0.09</td>
</tr>
<tr>
<td>330</td>
<td>300</td>
<td>3.25</td>
<td>7.45</td>
<td>14.0</td>
<td>0.71</td>
</tr>
<tr>
<td>300</td>
<td>330</td>
<td>3.25</td>
<td>7.80</td>
<td>14.1</td>
<td>1.09</td>
</tr>
</tbody>
</table>

The mean wave periods and the wind speeds have been interpolated from tables 17.4 and 17.5. The peak period has been calculated from the mean periods, the following formula has been used:

\[ T_p = 1.2 \times T_m \]

The nautical directions 0º, 300º and 330º will be calculated because the normative waves are expected to be from one of those directions. The expectations are that waves from west to north will give the highest waves in the port area. The other directions have been calculated because they could cause difficult berthing manoeuvring. Another reason for those other directions is that a study of the Franzius institut in Hannover showed that the northern to eastern waves are dominant. This study was done in order to determine the amount of water, which will wash onto the quay. Unfortunately the internet site is nowadays restricted but some results can be seen at reference 22.

- **Water level**

Four water levels have been calculated: High tide, low tide and the moments of maximum velocity (during ebb and flood). Because high water/low water appear not at every location at the same time, the tidal phases at Jade Weser Port are used. The simulated water levels are high tide at 17 April 2000 at 23.40, maximum velocity at 18 April 2000 at 02.40, low tide at 18 April 2000 at 05.50 and maximum velocity at 18 April 08.40.

The water level is with respect to mean sea level. This is not constant throughout the grid. Therefore a file was made with roughly the water levels at the above mentioned times. These water levels have been interpolated from the Delft 3D calculations. The values do not cover the whole Swan grid, therefore the values have been extrapolated throughout the grid.

- **Other assumptions for the Swan calculation**

The other assumptions are shown in appendix XI

**17.2.3 Calculations**

See Table 17-2 (here below) for what kind of Swan calculations will be done, these calculations will be done for every grid.
Table 17-2 Calculations

<table>
<thead>
<tr>
<th>Direction (nautical)</th>
<th>Water level</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60 Low tide</td>
</tr>
<tr>
<td>2</td>
<td>60 High tide</td>
</tr>
<tr>
<td>3</td>
<td>60 Max. current during ebb</td>
</tr>
<tr>
<td>4</td>
<td>60 Max. current during flood</td>
</tr>
<tr>
<td>5</td>
<td>30 Low tide</td>
</tr>
<tr>
<td>6</td>
<td>30 High tide</td>
</tr>
<tr>
<td>7</td>
<td>30 Max. current during ebb</td>
</tr>
<tr>
<td>8</td>
<td>30 Max. current during flood</td>
</tr>
<tr>
<td>9</td>
<td>0 Low tide</td>
</tr>
<tr>
<td>10</td>
<td>0 High tide</td>
</tr>
<tr>
<td>11</td>
<td>0 Max. current during ebb</td>
</tr>
<tr>
<td>12</td>
<td>0 Max. current during flood</td>
</tr>
<tr>
<td>13</td>
<td>330 Low tide</td>
</tr>
<tr>
<td>14</td>
<td>330 High tide</td>
</tr>
<tr>
<td>15</td>
<td>330 Max. current during ebb</td>
</tr>
<tr>
<td>16</td>
<td>330 Max. current during flood</td>
</tr>
<tr>
<td>17</td>
<td>300 Low tide</td>
</tr>
<tr>
<td>18</td>
<td>300 High tide</td>
</tr>
<tr>
<td>19</td>
<td>300 Max. current during ebb</td>
</tr>
<tr>
<td>20</td>
<td>300 Max. current during flood</td>
</tr>
</tbody>
</table>

17.3 Results

From the results can been seen that with an exceedance of 1% the wave height result in maximum about 1.30 m waves in the berthing area. The results have been presented in the following figures 17.3-17.12. High Water results in the highest waves, therefor all directions for this tidal moment have been included in this report. From the other tidal moments only the directions which will serve as input for ship navigator are presented. The waves during ebb and flood are about similar therefor, those waves have been presented as combined figures.

The Swan results show that in front of the quay the local waves are dominant peak period of 2.5 – 4.5 second can be noticed.

The situations high water, low water and maximum velocity will all be simulated in Ship for the direction 0° (nautical), because waves from this direction give the highest waves in the berthing area. Also the situation waves from 60° will be simulated because this give waves which could cause difficult berthing situations. Last situation to be simulated is without waves but with wind from 240°, this could also cause difficult berthing situations. There are hardly any waves from that direction because there is no fetch; the wind comes from land.
18 Downtime at the berth

18.1 Introduction

The downtime at the berth can be specified in two conditions, the operational downtime and the survival downtime.

The operational downtime is the interval during which the ship cannot be loaded/unloaded. The waves might be too high or the wind might be too strong, which cause the ship to move. These motions are critical because of the high precision needed for loading/unloading of containers. When the motions become too large the containers get stuck in the cell guides and this causes delays. Strong wind also causes downtime for cranes the movements, the movements are less controlled and therefore the loading/unloading is stopped, this results in downtime for the ship as well.

The survival conditions or limit state, this is the condition where the ship has to leave the berth for safety reasons. Actually the ship will leave the berth before this condition is reached, because otherwise the departure itself could cause dangerous situations. These conditions can be simulated with a computer program, Ship Mooring for example.

Here only the operational downtime is determined, more precisely the operational downtime caused by waves. Only the 11.000 TEU ship is regarded, because for this ship downtime results in huge losses.

The operational downtime of the smaller ship will be larger than the 11.000 TEU ship, because the smaller ship responds to a larger range of wave periods. This makes it also harder to determine a first impression of the downtime. The losses per time unit on the other hand are less for this ship. In a more detailed study to the operational downtime the smaller ship should also be observed.

18.2 Operational downtime

This paragraph gives a rough first impression on operational downtime, caused by waves. This downtime at the berth should also be less than 1% in order to comply to the demand “Port without downtime”.

For a first impression the following criterion can be used for container ships:

The limiting significant wave height should be less than 0.5 m for waves impacting at the head or stern of the ship [ref. 20]. This criterion is crude, because the wave periods and the effect of the mooring system are not taken into account.

The waves which influence the motions of the large design vessel (Table 19-1) at the berth are swell waves. Especially waves lengths in the order of two times the ship’s length are causing unacceptable motions of the ship. Assumed is that waves with a peak period of less than 8 seconds, do not have a considerable impact on the large design ship (see also figure 18.3 for a first impression of the movements).

A calculation was started to determine the wave height in front of the quay, caused by offshore waves with:
- a significant wave height of 3.25 m
- a peak period of 8.0 s
- from the most dominant wave direction
- during the tidal moment which would result in the largest waves (high water)

The result of the calculation contained waves with a maximum significant height of 0.25 m in front of the quay.
Waves with a peak period of 8 s have a probability of exceedance of about 1% (only the directions from which swell waves can be expected were taken into account).

The above two remarks combined give a positive answer to a downtime of less than 1%. With the following limitations:
- the response and downtime cause by waves of different angles have not been considered
- the response to waves with lower periods have not been considered, a comment has to be made that the local generated wave can become relatively high

### 18.3 Operational downtime, a more detailed approach

**The moored ship**

A moored vessel is subject to several external actions. The geometric and physical characteristics of the ship’s mooring-fender system play a major role in how the ship responds to these external actions. The aim should be that the moored ship could resist the total forces, without responding with too large movements. See 18.1 for the possible ship movements.

Containers are handled by shore-based cranes and ship motions should be kept to a minimum to provide uninterrupted container handling conditions. Positioning and picking-up of containers for example are hampered and containers can become stuck in their guides in the case of strong roll motions. Maximum container handling rates are an essential requirement for these ships sailing on tight time schedules.

Therefore, it is important to know the ensemble of external actions on the moored vessel, as well as their magnitude and relative importance. The following factors are relevant: Wind, current, waves, resonance because of long wave phenomena, astronomical tide, passing ships, loading and unloading operations.

Container vessels are generally moored with steel spring lines, to reduce surge motions, and polypropylene mooring lines. All lines are connected to bollards positioned at the front side of the quay wall. Rails for container cranes extend along the whole quay and prevent the use of breasting lines under operating conditions.

Spring lines are used to reduce the surge motions of a moored ship in order to keep the ship in a fixed position along the quay or berth. These lines should be as parallel as possible to the ship (maximum 10 degrees) and should have sufficient length.

Breast lines are used to reduce sway and yaw motions. These lines should be perpendicular to the ship axis to be efficient and should be connected to ship’s bollards positioned at the bow and stern.

Head and stern lines are used in addition to spring and breast lines and function to reduce ship motions. (see figure 18.2 for a moored ship with it’s mooring lines) [ref. 14]

**Approach**

In this study the detailed berthing conditions are not determined. In order to give a brief impression of the possible response of those large design ships a reference can be made to another graduation project of a student of the faculty of Civil Engineering and Geosciences the Technical University of Delft [ref. 8]. That thesis deals with the downtime analyses of the Westerschelde Container Terminal (WCT).

That terminal is similar to this terminal, because it also contains a quay without protection of breakwaters, furthermore a similar design vessel is represented. The current wind and wave conditions are not similar though.
Part 4 Detailed hydraulic and nautical analysis

For the WCT simulations have been done of a moored ship under several conditions. The criteria here are not the waves, but the movements of the ship. These movements should not exceed the values of Table 18-1, or at least they should have a probability of exceedance of less than 1%.

Two levels of safe working are established by a Working group for this special category of ships. One level is representing an uninterrupted container handling at an efficiency rate of 90 to 100%, whereas the second level reflects a 50% handling efficiency rate (see Table 18-1). It should be noted that besides ship motions the skill of the container crane drivers plays an important role for the overall efficiency of handling containers in a port.

The current PIANC norm for the movements is presented in Table 18-1. A future norm might be stricter, because the present practical experience at the quay shows a lower tolerance than the PIANC norm advises.

Table 18-1 Norm for moored ship movements

<table>
<thead>
<tr>
<th>Norm</th>
<th>Cargo Handling Equipment</th>
<th>Surge (m)</th>
<th>Sway (m)</th>
<th>Heave (m)</th>
<th>Yaw (°)</th>
<th>Pitch (°)</th>
<th>Roll (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PIANC 100% efficiency</td>
<td></td>
<td>1,0</td>
<td>0,6</td>
<td>0,8</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>PIANC 50% efficiency</td>
<td></td>
<td>2,0</td>
<td>1,2</td>
<td>1,2</td>
<td>1,5</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

The results of WTC have been extrapolated, and are presented into a graph of the average response (in meters or degrees relative to the significant wave height) of the ship for several wave periods, see also figure 18.3. Peak periods of 8 seconds will be discussed. Waves with higher periods, have a probability of exceedance of less than 1%, and are therefore not regarded.

Note: For WTC a different approach has been used in determining the downtime. The graph corresponds with a downtime of a few hours per year.

The movements of the ship are scored for the norm (see Table 18-2), this gives a first impression for the responses of the ship. Actually the norm presented as in Table 18-1 shows the maximum allowed movement and figure 18.3 shows the average movements. In order to compare the values the average movements are multiplied by three in order to obtain the ‘maximum’ movements. The value three was obtained from the Rayleigh distribution, because the movements can be presented by this distribution.

Table 18-2 Maximum movements of the moored design ship at peak period of 8 seconds

<table>
<thead>
<tr>
<th>Value</th>
<th>Surge (m)</th>
<th>Sway (m)</th>
<th>Heave (m)</th>
<th>Yaw (°)</th>
<th>Pitch (°)</th>
<th>Roll (°)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y-axes of graph</td>
<td>0,40</td>
<td>0,35</td>
<td>0,06</td>
<td>0,32</td>
<td>0,03</td>
<td>0,35</td>
</tr>
<tr>
<td>Y-axes of graph * X</td>
<td>0,10</td>
<td>0,09</td>
<td>0,02</td>
<td>0,08</td>
<td>0,01</td>
<td>0,09</td>
</tr>
<tr>
<td>Y-axes of graph * X * 3</td>
<td>0,30</td>
<td>0,26</td>
<td>0,05</td>
<td>0,24</td>
<td>0,02</td>
<td>0,26</td>
</tr>
</tbody>
</table>

What can be seen is that the values of the graph are far lower than the norm.

Conclusion

The first approach in paragraph 18.2 shows a positive result for the downtime estimation.
- Waves with a peak period of 8 seconds have a probability of exceedance of about 1% (only the directions from which swell waves can be expected were taken into account).
- The significant wave height of the 8 second waves in front of the quay is 0,25 m, this is less than the allowed 0,5 m.

Paragraph 18.3 shows also positive results, response of the design ship to 8 second waves is below the norm. Unfortunately these results can not be totally transferred to the Jade area. Advised is that further research should be done for both moored design ships in the Jade.
19 Downtime in the entrance channel

19.1 Introduction

The goal in this part was to answer the following question: Does the design of the Jade Weser Port comply with the precondition port without downtime? The assumption is that the port will satisfy the condition port without downtime, if the probability for downtime is exceeded by less than 1%.

Goal for this chapter is to verify the sizes and shapes of the manoeuvring areas in extreme conditions, in order to determine if the chosen extreme conditions result in downtime. These chosen extreme conditions have a probability of exceedance of less than 1%.

The structure of this chapter is that first the method is explained and then the results are being discussed. The paragraph method is divided into the approach, the used data and the nautical consideration. The results have been split into results from a simulation program and a discussion with a pilot.

19.2 Method

19.2.1 Approach

In order to determine the nautical feasibility for a port without downtime, the sailing of the design vessels in the channel and the manoeuvring areas should be simulated. The chosen extreme conditions as determined in previous chapters (13, 14 and 15) should serve as input for this simulation.

Nautical simulations have been done with two ships, a general cargo ship of 30,000 DWT and a container ship of 11,000 TEU. The general cargo ship should represent the design feeder ship (of 160 m, see also appendix VI).

The runs were prepared for several conditions, see also appendix XII. On forehand it is difficult to determine the dominant condition, therefor all the plausible dominant conditions will be simulated. The idea is to test the manoeuvrability of the vessels under those conditions, and further more to discuss the results with a pilot in order to test the theory to practical experience.

The simulations have been done with the real-time simulation program Ship Navigator, see appendix XVI for a description of the program.

19.2.2 Used data

The input for the navigation simulation program will be shortly described here. The simulated runs are presented in appendix XII.

- Lay-out

The newest layout\(^3\) for the Jade Weser Port was used, this layout was also used to obtain current and wave data. Two layout versions were created one for the container ship and one for the ‘feeder’ ship. Both ships have to arrive or departure at a fully occupied quay. Two berths were used for the simulation, the most north one and the most south one. This has been done because the circumstances are different at those berths. Ships which arrive or departure at/from those

\(^3\) This layout was obtained from the JadeWeserPort Entwicklungsgesellschaft mbH
berths could experience the peaks of the current conditions, the north one during ebb and the south one during flood. See also figure 19.1

- **Bathymetry**

Four tidal moments will be tested, each one has it’s own bathymetry file with a correction with respect to the mean sea level which relates to the water level at the respectively tidal moment. The bottom geometry is the same as the input for the waves and currents.

- **Wind and waves**

The wave grids have an angle with respect to the axes in their (Cartesian) co-ordinate system, this angle is not allowed for input grids in Ship Navigator. The wave results haven been transformed into a grid without angle in order to obtain input for Ship.

The wave and wind direction 0° (nautical) is simulated in Ship, because waves from this direction give the highest waves in the berthing area. Also the situation waves and wind from 60° will be simulated because this gives a wave and wind situation which could cause difficult berthing situations. Last situation to be simulated is without waves but with wind from 240°, this could also cause difficult berthing situations. There are hardly any waves from that direction because there is no fetch; the wind comes from land.

The waves and wind are regarded to be constant in time. The wind speed corresponds with the values used for the wave simulation see also Table 17-1. The wind speeds are ± 14 m/s.

- **Current**

Four different current (or tidal) situations will be simulated, high water, maximum current velocities during ebb, low water and maximum current velocities during flood. The currents change during the navigation, therefor a changing current field has been simulated.

- **Type of ships**

Two different ships have been used for the simulation (see also Table 19-1):
- 30.000 DWT general cargo ship
- 11.000 TEU container ship

<table>
<thead>
<tr>
<th>Table 19-1 Design ships</th>
<th>Container ship</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeder</td>
<td></td>
</tr>
<tr>
<td>Length Loa</td>
<td>170,0 m</td>
</tr>
<tr>
<td>Length Lpp</td>
<td>162,0 m</td>
</tr>
<tr>
<td>Beam</td>
<td>27,0 m</td>
</tr>
<tr>
<td>Draught</td>
<td>9,9 m</td>
</tr>
<tr>
<td>Dead-weight</td>
<td>30.000 ton</td>
</tr>
<tr>
<td>Capacity</td>
<td>± 1.500 TEU</td>
</tr>
<tr>
<td>Engine</td>
<td>7.300 kW</td>
</tr>
<tr>
<td>Container ship</td>
<td>355,0 m</td>
</tr>
<tr>
<td>Length Loa</td>
<td>355,0 m</td>
</tr>
<tr>
<td>Length Lpp</td>
<td>337,0 m</td>
</tr>
<tr>
<td>Beam</td>
<td>52,9 m</td>
</tr>
<tr>
<td>Draught</td>
<td>14,5 m</td>
</tr>
<tr>
<td>Dead-weight</td>
<td>130.000 ton</td>
</tr>
<tr>
<td>Capacity</td>
<td>11.000 TEU</td>
</tr>
<tr>
<td>Engine</td>
<td>85.000 kW</td>
</tr>
</tbody>
</table>

The ships with the most similar manoeuvring abilities to the design ships mentioned in the financial study were chosen for the nautical simulation. The small container ships, which were available in Ship Navigator, would not give a correct representation of the manoeuvring abilities of the feeder ships, a general cargo ship was chosen in stead. The manoeuvring abilities of the general cargo ship are a little different from the abilities of the feeder. The general cargo ship is usually broader and more unwieldy than the feeder, and is therefor less course stable but has better
Part 4 Detailed hydraulic and nautical analysis

turning abilities. Further more this general cargo ship does not have a bow thruster, some -but not all- feeders do have bow thrusters, so here the most unfavourable circumstance has been simulated.

The simulated ships are loaded to their design depths.

- Tugs

Three different tugs have been used. For the feeder ship 30 t bollard pull tugs will be used. The container ship may use 60 t bollard pull tugs. The idea is to check the arrival and departure procedure with minimum use of tugs in order to investigate the roughness of the circumstances.

See also appendix XV for a first impression of the necessary tug power. When the necessary tug power is calculated, it can be seen that two tugs of 55 and 65t bollard pull should be able to fully control the ship. This is less than what will be used during the simulation, because the current and wave condition are harsh as well.

19.2.3 Nautical consideration

Three different manoeuvres will be simulates during several conditions: Sailing in the channel, an arrival and a departure procedure. The sailing in the channel will be simulated in order to determine the navigational characteristics of the entrance channel in the Inner Jade area. Furthermore the arrival and departure are simulated in order to determine navigational characteristics in the manoeuvring area of the Jade Weser Port.

In this paragraph the criteria are determined, for which the runs will be tested.

General

Some aspects have already been discussed for the port, waves, currents, the channel layout etc. Here some more (nautical) aspects will be mentioned, these remarks should be kept in mind whilst sailing/manoeuvring in the area.

- In the Inner Jade, the entrance channel comprises two curves, these curves could give difficult circumstances because the ships velocity will be relatively low (6 kn.) whilst sailing through them.
- Furthermore the low cruising speed, could cause difficult sailing conditions in the entrance channel, during cross wind/waves.
- Near the Jade Weser Port, four jetties are present in the channel. One of them is linked through submarine pipelines to an island berth near the entrance channel and cautious should be taken whilst crossing this oil berth.
- Close to the south of the quay of the Jade Weser Port a jetty for bulk cargo (coal) is present. The arrival and departure times of should not interfere with each other.

This results in the importance of good manoeuvring characteristics of the ship and well-trained pilots and personnel of the container ship and tugs. All this is tested in the simulation.

Arrival/departure

The following criteria should be satisfied during arrival or departure simulations

- The ship’s velocity in the channel should be less than 6 kn., in the berthing area the velocity should be limited to 4 kn.
- A safe crossing distance to the oil and bulk berths should be kept. At sailing next to the island (oil) berth the entrance channel should be followed in order to safely pass that berth.
- The distance kept to ships at their berth should be at least one ships beam wide.
- There are no time limitations concerning the arrival/departure procedure.
• During the ships manoeuvring the turning speed should be lower than 20 degrees/minute (physically it is possible to turn faster, but for navigation safety this is kept as a maximum).
• During the berthing procedure the lateral speed should be lower than 0.3 kn. (fenders are dimensioned on a maximum operational speed of about 0.15 m/s (= about 0.3 kn.).

**Tugs**

The following criteria should be satisfied during arrival or departure simulations, whilst using tugs

• For attaching the tugs to the vessel, the ship’s velocity should be smaller than 6 kn. and the significant wave height should be lower than 1.5 m
• Tugs are able to pull at a significant wave height of 1.5 m
• Tugs are able to push at a significant wave height of 1 m
• The attachment procedure will take between 5-15 minutes, the average of 10 minutes is simulated
• The tugs are more effective at decreasing speed and decreasing wave heights. The effectiveness is the product of the effectiveness of the tugs as a result of the speed and wave height.

**The available manoeuvring areas**

• The entrance channel is 300 m wide and 20.6 m deep with respect to NN.
• The quay is 1.7 km long
• The manoeuvring area is between 0.7 and 1.4 km wide (east-west) and between 1.9 and 4.6 km long (north-south). The area available for manoeuvring is actually somewhat smaller, because, ships might be moored to the quay and at least a ships beam distance should be kept.

**Sailing in the channel, arriving and departing**

The departure procedure starts at the north or south berth with a ship’s velocity of 0 kn. (with respect to the bottom). The start position of the ship, is the position at which the bow points in the most difficult direction, this is in the same direction as the currents (or in absence of the currents, if possible, the bow pointing in the same direction as the wind/waves). The condition with minimum use of tugs is simulated. In some runs, spring lines have been used in order to obtain an angle between the ship and the quay. The simulation stops if the ship is sailing in the channel on its own power.

The sailing in the channel has been simulated by two simulations, one for each design vessel. The condition with cross-waves and winds (direction 60º) combined with the maximum currents (in the ship’s sailing direction) seems to be the most severe condition and therefor this has been simulated. The main question is, is a velocity of 6 kn. enough for the ship to stay within the channel boundaries.

The arrival procedure starts just after the second bent in the channel (the bends are already simulated in the channel run). The ship starts with a velocity of 6 kn. The ship has to slow down but remain in control in order to give the tugs time to tie up. Assumed is that in the channel the tugs had already five minutes to tie up, so they need just five more minutes. When the tugs are in position they bring the ship to its berth, with the bow of the ship in opposite direction of the current (in absence of currents, the direction opposite to the wave/wind direction will be chosen, if possible).

**Criteria**

The above mentioned criteria should be satisfied. Some of them have already been satisfied, e.g. the waves in the area are where the tugs tie up to the ships have a significant wave height of less than 1.5 m. Other criteria will be met during the run, e.g. the 10 minutes tie up time for the tugs.

Altogether the above mentioned remarks result in the following criteria for which the runs will be tested:

- Is the ship able to stay within the manoeuvring area?
- Is a velocity of 6 kn. enough to fully control the ship?
- Is sailing with a maximum of half of the engine’s power enough to fully control the ship?
- Are the available tugs powerful enough to keep the ship in control? The ship’s bow thrusters will also be used, but the use of the ship’s engine should be limited.
- Is the turning velocity kept within controllable limits (above 35 degrees per minute is certainly regarded as uncontrolled)?

19.3 Results

The runs are shown in appendix XII. The results can been seen in appendix XIII and are summarised in appendix XIV. All runs have been tested on the criteria mentioned in the previous paragraph and have been given a score. The final score resembles the lowest score of the run.

+ Resembles that the criteria has been satisfied

/+/- Resembles that the criteria has not been satisfied, but with another try or a bit more tug power the criteria will be satisfied

– resembles that the criteria has not been met. It is difficult to judge these runs. Possible the criteria can be satisfied with more tug power and a more experienced pilot and tug operators

Runs

Here a short discussion is given on the runs, the numbers refer to the numbers of appendices XII and XIII.

Departure

1. This run has been done with three 60 t bollard pull tugs. The wind blows the ship away from the quay, and the ship turns by using the tugs and the ship’s main engine combined with it’s bow thruster. This run passed all the criteria. Probably it is even possible to use two tugs insted of three.
2. This run uses four 60 t bollard pull tugs. This run passed all the criteria.
3. This run uses four 60 t bollard pull tugs. This manoeuvre is well controlled provided some further demands are met.
   - The tug capacity is insufficient, because there are no margins. Tugs of 80 t are required.
   - There should be sufficient space between the berthing line and the quay. The ship needs this space to make an angle with the current and use the current during the departure. (If this space can not be provided, this run is still feasible provide larger tugs are used.
   - The area to the south is minimal. Some additional space is required. This problem can be solved by, turning in the northern area of the port. A different solution would be to make the distance between the berths a little smaller. At the moment a distance of 100 m has been used, this is twice the norm.
4. (and 5) These run have been using four 60 t bollard pull tugs. All criteria have been met, although the tugs should not be reduced.
6. This run uses four 60 t bollard pull tugs, an passed all the criteria.
7. This run has been done without tugs. The wind blows the ship away from the quay, and the ship turns by using its main engine (this ship does not have a bow thruster). This run scored average on the turning speed and the engine propulsion (al lot of power is needed).
8. This run has been done with one 30t bollard pull tug, and it passed all the criteria.
9. This run has been done with two 30t bollard pull tugs and scored average on the turning speed.
10. This run has been done by using spring lines. This run failed on turning speed and scored average on engine propulsion (al lot of power is needed).
11. This run has been done with two 30t bollard pull tugs. This run failed on the area needed for turning and scored average on the turning speed.

Channel

12. This run was a little bit difficult, the ship is not course stable, but by using the bow thrusters the ship is able to stay within the channel boundaries at a speed of less than 6 kn.
Part 4 Detailed hydraulic and nautical analysis

13. This run was done with the small ship. It scored average, it was difficult to sail within the channel at a speed of less than 6 kn.

Arrival
14. This run uses four 60 t bollard pull tugs, and passed all the criteria. It was very difficult to manoeuvre, because the tugs are insufficient. Tugs of 80 t are advised or the fenders should be designed for high impact velocities.
15. This run uses four 60 t bollard pull tugs, and passed all the criteria. It was very difficult to manoeuvre, because area in the south is very small. Tugs of 80 t are advised and the turning of the ship should be done in the north of the manoeuvring area.
16. This run uses four 60 t bollard pull tugs. This run scored average on the area. It was very difficult to manoeuvre, because area in the south is very small. Tugs of 80 t are advised, because if the ship turns too much and is caught by the current, the control is lost.
17. This run uses four 60 t bollard pull tugs and passed all criteria. 80 t tugs are advised.
18. This run uses four 60 t bollard pull tugs and passed all criteria. Although this run passed all criteria there are no margins. 80 t tugs are advised
19. This run uses four 60 t bollard pull tugs and passed all criteria.
20. This run has been done with two tugs of 30 t bollard pull each. The run failed on the turning speed, and scored average on average on maintaining a low velocity (below 6 kn.) and on engine propulsion
21. This run has been done with two tugs of 30 t bollard pull each. This run scored average on all criteria except on tugs. The criteria staying within the area failed because the ship came too close to other ship.
22. This run has been done with three tugs of 30 t bollard pull each. This run scored average on all criteria except on tugs and maintaining within the area.
23. (and 24) These runs have been done with two tugs of 30 t bollard pull each, the runs have passed all criteria

Summarising: 3 runs failed, 8 runs scored average and 13 runs passed.
Of the failed runs, two were departure runs. These problems during the run might be solved by turning in the north of the manoeuvring area, with the use of more tugs or more tug power. The other one was an arrival run with land wind, during this run risk were taken in order to turn as close to the berth as possible. A minimum of tugs would be needed to push the ships to the quay, this failed but could be solved by using more and/or more powerful tugs.

Pilot comments

An experts opinion was asked in order to discuss the results of the simulation.

The pilot is mister W. Verbaan, he works for Port of Rotterdam. He has experience as an pilot but also experience with real full fast time simulations of a 12.500 TEU container ship sailing in the future Maasvlakte 2.

His remarks:
- First estimation: The simulated circumstances are difficult but they shall not result in enormous downtime
- Two conditions may result in difficult arrival/departure circumstances: The arrival procedure during flood with 60º wind and waves (nautical) and the departure procedure under the same conditions.
- The tugs for the largest design ship might be a little under powered.

When these remarks are compared to the findings of the simulation, some problems are confirmed. These are the dominant departure conditions and the insufficient tug power. The arrival procedure during flood with 60º wind and waves resulted also in difficult manoeuvring circumstances but the direction 330º-0º resulted in even more severe circumstances.


Conclusions and recommendations

The conclusions, which can be derived from this chapter, are:

- A person without practical experience as a pilot cannot completely answer the question of the nautical feasibility of a port without downtime. The answer is partly positive and remains partly open. Although more simulation time could positively influence the results.
- The wind and current were the most difficult factors during the manoeuvring, although in the north of the channel the force of the waves is also high.
- The most difficult arrival run was flood, combined with 330° wind and waves.
- The most difficult departure condition was flood, combined with 60° wind and waves.
- The entrance channel should be sailed during these rough conditions at a speed of at least 6 kn.
- The manoeuvring space in the south of the manoeuvring area is small.
- The tugs used for both ships were insufficient.

The recommendations, which can be derived from this chapter, are:

- The advice is to turn the departing ships in the north of the manoeuvring area.
- The advice is to provide in some space between the quay and the ship.
- The advice is to use more and/or more powerful tugs for the arriving and departing ships.
- An official pilot should test the departure procedure during the condition flood with 60° wind and waves (nautical) and the arrival during flood and 330°.
Part 5 Conclusions and recommendations

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20 Conclusions

Financial study

- The cost revenue analysis shows a low financial feasibility of the Jade Weser Port. The discounted cash flow calculation gives an internal return rate of 10%.
- The low financial feasibility is caused by the fact that the costs are being high in comparison with the revenues.
- The feasibility is not low enough to abort the idea Jade Weser Port, because the minimum internal rate of return of 9% is exceeded.
- The low feasibility pinpoints a possible problem in finding private investors. Commercial projects, with private investors require an I.R.R. varying between 15-20%.
- Several ports in Europe are aiming for the future growth in containerised cargo. A lot of ports have extensions planned. If all these extensions are being built an over-capacity in quay length will be present in Europe. This could mean less cargo for the Jade Weser Port, but also pressures on the harbour dues. This would make the situation for the operator not any easier.

Nautical study

- The alignment of the approach channel is well designed
- The channel width is 300 m, this is sufficient for a one-way channel for the largest design ship, and also for a two-way channel for other (smaller) ships. During extreme conditions the channel should also be a one-way channel for the smaller ships.
- The depth of the channel is sufficient for the largest design vessel
- The manoeuvring area is large enough to serve as a turning circle
- Tugs start to tie up east of Hooksiel, this is at a distance of over 6 km to the first or north berth of the Jade Weser Port, this gives enough distance and time to tie up the tugs to the container ships.
- Currents of 1.4 m/s may be present in the manoeuvring area during ebb
- Currents of 1.1 m/s may be present in the manoeuvring area during flood
- No eddies (caused by tidal currents) will develop in front of the quay
- In extreme conditions waves of 1.3 m (Hs) will reach the quay
- The wave directions between 330º and 0º are dominant
- No eddies will develop in front of the quay
- Swell waves will not reach the quay
- The rough estimation of the operational downtime caused by swell waves, for moored 11.000 TEU ships results in acceptable movements
- The operational downtime for moored smaller (than 11.000 TEU) ships will result in more movements due to their response to a larger range of wave periods
- The feeder ship needs tug assistance during rough wetter conditions
- The manoeuvring area is sufficient as long as the ships heading for the southern berths turn in the north part of the manoeuvring area.
- A person without practical experience as a pilot can not completely answer the question of the nautical feasibility of a port without downtime. The answer is partly positive and remains partly open. Although more simulation time could positively influence the results.
- The wind and current were the most difficult factors during the manoeuvring, although in the north of the channel the force of the waves is also high.
- The most difficult arrival run was flood, combined with 330º wind and waves.
- The most difficult departure condition was flood, combined with 60º wind and waves.
- The entrance channel should be sailed during these rough conditions at a speed of at least 6 kn.
- The manoeuvring space in the south of the manoeuvring area is small
- The tugs used for both ships (60 t for the deep-see ship and 30 t for the feeder) were insufficient. The arrival/departure procedures can be done, but there are no safety margins left
Part 5 Conclusions & recommendations

Summarising:

The financial feasibility study of the port does not show very encouraging results, although a definitive negative advice can not be given.

The nautical feasibility study of the port does show promising results. The circumstances can be rough, but this will not result in much downtime.

One problem arises, the advised 80 t tugs do not exist yet and with the current technology they can not even be built. Fortunately the 11.000 TEU ships are still on the drawing board, this gives time for the 80 t tugs to be developed.
21 Recommendations

Financial study

- A financial feasibility study should been done for the operator of the terminal. This feasibility study should be positive, the operator is a private entrepreneur and should make enough profit. This study combined with the feasibility of the terminal should give a definitive answer to the financial feasibility.
- Simulations should be done to determine the optimal terminal layout. One solution could be to build a smaller and more efficient port, which would use less area and highly productive (and more expensive) terminal equipment, so less land has to be reclaimed.

Nautical Study

- Advised is that further research should be done for both moored ships in the Jade (especially with peak periods between 6 and 8 seconds).
- The advice is to turn the departing ships in the north of the manoeuvring area.
- The advice is to provide in some space between the quay and the ship.
- The advice is to use more and/or more powerful tugs for the arriving and departing ships.
- An official pilot should test the departure procedure during the condition flood with 60º wind and waves (nautical) and the arrival during flood and 330º.

General, the following follow-up studies are recommended (if the financial feasibility of the operator shows a positive result)

- A complete economic study, which includes for example a throughput study for hinterland transport, a study into the effects of the port on flora and fauna, the effects on the employment of the population. (a more profound governmental contribution can then be calculated)
- The port constructions
- The detailed terminal layout. For the operator’s feasibility study more details into the layout of the terminal are required.
- Execution aspects (the shipping traffic should not be tempered by construction activities and the phasing of the project should be looked into)
- A maintenance strategy. Currently ships with draughts over 13,5 m experience a tidal window, this reports shows that ships of 14,5 m can enter without a tidal window, this mean that the current safety margin is larger than the margin according to the calculations from this report. The ‘Hafenamt’ of Wilhelmshaven confirmed that SKN -18,5 m is the guaranteed water depth.
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Newest design layout of the Jade Weser Port
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Scour
Equilibrium state during Jade Weser Port

Jade Weser Port

Figure 15.1
Figure 16.1: Tide Wilhelmshaven 2000

Waterlevel w.r.t. mean sea level (m)

Time (months)

Waterlevel
Maximum tidal range
Figure 16.2: Tide Wilhelmshaven April 2000

![Graph of Tide Wilhelmshaven April 2000](image)
Figure 16.3: Tide Wilhelmshaven April the 18th
Figure 16.4

Grid
Jade Modell

Jade Weser Port

Alte Mellum
Wangerooge
Hooksiel
Wilhelmshaven
Butjadingen
Grid resolution (detail)

Jade Modell

Jade Weser Port
Currents
High Water at 17 April 2000, time: 23.40

Jade Weser Port
Currents
Ebb at 18 April 2000, time: 02.40

Jade Weser Port
Low Water at 18 April 2000, time: 05.50

Currents

Velocity scale: \( = 2.5 \text{ m/s} \)
Jade Weser Port

Currents
Flood at 18 April 2000, time: 08.40

Figure 16.11

Velocity scale: 2.5 m/s

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<td>1.20 - 1.30</td>
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<td>1.00 - 1.10</td>
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Velocity (m/s)

5915 5920 5925 5930 5935 5940 5945 5950 5955 5960 5965

3420 3425 3430 3435 3440 3445 3450 3455 3460

X Gauss-Krüger (km)

Y Gauss-Krüger (km)
Figure 16.4

Grid
Jade Modell

Jade Weser Port
Wake study
Flood
18 April 2000, time: 08.40

Velocity scale:  \( \approx 2.5 \text{ m/s} \)
Swan Grids
German Bight Modell
Grid 1: pink, grid 2: brown, grid 3: green

Jade Weser Port

Figure 17.2
Waves
Tidal moment: High_Water
Wave direction: 60 degrees (nautical)

Jade Weser Port

Figure 17.3
Waves
Tidal moment: High_Water
Wave direction: 30 degrees (nautical)
Waves
Tidal moment: High_Water
Wave direction: 0 degrees (nautical)

Jade Weser Port

Figure 17.5
Waves
Tidal moment: High_Water
Wave direction: 330 degrees (nautical)

Jade Weser Port
Waves
Tidal moment: High_Water
Wave direction: 300 degrees (nautical)

Jade Weser Port
Waves

Tidal moment: Low_Water
Wave direction: 60 degrees (nautical)
Waves
Tidal moment: Low_Water
Wave direction: 330 degrees (nautical)

Jade Weser Port
Waves
Tidal moment: Ebb/Flood
Wave direction: 60 degrees (nautical)

Jade Weser Port
Waves
Tidal moment: Ebb/Flood
Wave direction: 330 degrees (nautical)

Jade Weser Port
Direction of rotational and lateral motions of a ship
Typical mooring arrangements for tankers

JADE WESER PORT

Fig. 18.2
Movements panamax ship wave direction 45°

- surge
- roll
- sway
- Heave
- pitch
- yaw

Movements of the design ship
Westerschelde Container Terminal

JADE WESER PORT
Fig. 19.1

Layout Jade Weser Port for Ship Navigator

JADE WESER PORT
Appendix IV Tables of part 4 Estimation and models

Table 17.3  Probability of exceedance (%) of combined sea & swell
Table 17.4  Mean value of mean zero crossing period, Tm01 (s)
Table 17.5  Mean value of wind speeds (m/s) at a height of 10 m
<table>
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<th>Hs (m)</th>
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Table 17.3 Probability of exceedance (%) of Combined sea & swell
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Season: All Year
Period: 1960 to 1993
Location: Offshore North-Sea
Source: Ship observations
No. of obs.: 7059
Type of data: Combined sea & swell
Record: Mean wave period (Tm01) for each Hs and direction, Location offshore North-Sea Season: All Year

Table 17.4 Mean value of mean zero crossing period Tm01 (s)
### Table 17.5 Mean value of wind speed (m/s) at a height of 10 m

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<th>Hs (m)</th>
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**Season:** All Year  
**Period:** 1960 to 1993  
**Location:** Offshore North-Sea  
**Source:** Ship observations  
**No. of obs.:** 29409  
**Type of data:** Wind  
**Record:** Wind speed for each Hs and direction, Location offshore North-Sea
Appendix V Wilhelmshaven versus Cuxhaven

For a long time the geographic situation of Wilhelmshaven with its near perfect deepwater entrance has triggered ideas and visions of a major deepwater port in Germany. For other reasons Cuxhaven, a city situated at the entrance of the Elbe, was pinpointed as a possible location as well. The authorities took some time contemplating where this port had to be built; Wilhelmshaven versus Cuxhaven was the dilemma. Finally, at the end of March 2001, they reached a decision: The deepwater port is to be built near Wilhelmshaven.

Both locations will be discussed. First the criteria are given to test both locations. Then a discussion follows on the scores of the locations on the criteria. Unfortunately it is hard to make a proper analysis, because some criteria are not openly discussed or publicised (some criteria might be influenced by political agenda’s, changing with the ruling politicians).

The two locations will be tested on the following criteria:
- Maximum quay length
- Maximum number of berths
- Efficiency of area planning
- Availability
- Hinterland connections
- Hinterland investments
- Project realisation time
- Reaching capacity limit
- Effects on unemployment
- Costs
- Environment

Table 1 shows the properties of the locations in reference to the mentioned criteria.

Table 1 Criteria to compare the port locations [ref. 19]

<table>
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<tr>
<th>Port location</th>
<th>Wilhelmshaven</th>
<th>Cuxhaven</th>
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<tr>
<td>Maximum quay length</td>
<td>10.5 km</td>
<td>4.4 km</td>
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<td>Maximum number of berths</td>
<td>24 berths</td>
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<tr>
<td>Efficiency</td>
<td>Lower</td>
<td>High</td>
</tr>
<tr>
<td>Availability</td>
<td>Fine</td>
<td>Some difficulties arise</td>
</tr>
<tr>
<td>Hinterland connections</td>
<td>Feeders, rail and road</td>
<td>Feeders, rail, road and inland transport</td>
</tr>
<tr>
<td>Hinterland investments</td>
<td>Lower investment costs</td>
<td>Higher investment costs, later on cheaper transport costs</td>
</tr>
<tr>
<td>Project realisation time</td>
<td>First stage 2006, final stage .. far into the future</td>
<td>Final stage 2012</td>
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<tr>
<td>Reaching capacity limit</td>
<td>Is not predicted yet; far beyond 2020</td>
<td>Between 2022-2028</td>
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<td>Effects on unemployment (in final stage)</td>
<td>4,200 new jobs (Wilhelmshaven has currently a higher unemployment rate than Cuxhaven)</td>
<td>1,750 new jobs</td>
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<tr>
<td>Costs (terminal &amp; equipment, 4 berths)</td>
<td>€ 710 million</td>
<td>€ 646 million</td>
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<tr>
<td>Environment</td>
<td>Compensations have to be made</td>
<td>Compensations have to be made</td>
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Maximum quay length, maximum number of berths (reaching capacity limit)
The terminals are built in stages; the first stage of the terminal near Wilhelmshaven is four berths and
the first stage of the terminal in Cuxhaven is also four berths. The final stage for Wilhelmshaven is 24
berths and for Cuxhaven 10 berths. This means that Cuxhaven will reach its capacity limit sooner than
Wilhelmshaven, this will be somewhere between 2022 and 2028.

Efficiency
Cuxhaven has less area available for the port, and because the limited space this terminal uses the area
as efficient as possible (29% higher productivity ~TEUs per meter quay per year). The Cuxhaven will
have more sophisticated equipment in order to make the best use of the quay with a high number of
moves per hour. Wilhelmshaven has an enormous area, but still does not have an efficient area
planning, this results in a lower productivity per year: 1.345 TEU/meter quay in Cuxhaven versus
1.043 TEU/meter quay in Wilhelmshaven. For four berths, the productivity of Cuxhaven is 2.32
million TEU/year and the productivity of Wilhelmshaven is 1.9 million TEU/year.

Availability
Cuxhaven has negative influence on the port of Hamburg, meaning longer waiting periods for the
ships. These waiting periods occur because of the extra turning circle of the new port and lower sailing
speeds because of swell and wake caused by ships passing the Cuxhaven. The largest containerships
can block the channel for about 30 minutes by using the turning circle, this causes waiting periods for
other vessels. The lower sailing speeds might be necessary due to the short distance (300 m) between
the channel and the quay. The number of ship movements will rise considerably in the Elbe; so more
attention has to be paid on safety. The nautical safety has to be guarded in the busy Elbe.

Hinterland connections and investments
Hinterland connections: The main difference in hinterland connections is that Wilhelmshaven will not
have any inland shipping connections. In the financial feasibility study (part 2) more details will be
given on the modal split of the port near Wilhelmshaven. Cuxhaven will have inland shipping. This
will consist (among other things) of a shuttle from Cuxhaven to Hamburg.
Investments: Cuxhaven has higher building costs for the necessary traffic infrastructure (rail and road,
B73), about € 77 million more than Wilhelmshaven (just rail). Later on, the transport costs will be
cheaper for Cuxhaven. The transport costs by road will be € 5 cheaper/TEU and by rail € 10
cheaper/TEU. This will be due to efficiency benefits, because there will be more infrastructure
available in the Cuxhaven surroundings.

Project realisation time
Cuxhaven can be realized a lot faster than Wilhelmshaven, because the plans are in a more detailed
stage. Only the traffic situation in the Elbe, the road traffic and the effect of noises to the surroundings
can cause delays for permits. The final building stage of Cuxhaven can be reached in 2012.

Effects on unemployment
The economic need is higher in the Wilhelmshaven surroundings, because of higher unemployment
rates (Wilhelmshaven 14.2% in September 2000 and Cuxhaven 9.3% in September 2000). 
Wilhelmshaven citizens have an average lower income of € 3.070/year in comparison to Cuxhaven
citizens. The 10 berths of Cuxhaven give 1.750 new jobs and the 24 berths of Wilhelmshaven give
4.200 new jobs.

Costs [ref. 19]

<table>
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<tr>
<th>Costs in million €</th>
<th>Cuxhaven 4 berths</th>
<th>Cuxhaven 10 berths</th>
<th>Wilhelmshaven 4 berths</th>
<th>Wilhelmshaven 10 berths</th>
<th>Wilhelmshaven 24 berths</th>
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<td>Infrastructure</td>
<td>192.4</td>
<td>407</td>
<td>378.9</td>
<td>650</td>
<td>1.450</td>
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<td>Total</td>
<td>646</td>
<td>710</td>
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The terminal infrastructure of Cuxhaven is much cheaper, but the equipment is more expensive (less area available, higher productivity must be reached, more expensive equipment). In total, for the first 4 berths, the Cuxhaven is €64 million cheaper. The infrastructure of Wilhelmshaven is more expensive, because an enormous land area has to be reclaimed. This land is necessary because all the infrastructure concerning containers, distribution centres and port related activities etc., has to be built. The calculation for Wilhelmshaven has only been based on the costs for the container terminal area.

Environment
Both terminals have to compensate for the lost nature area, but this will not be an impregnable obstacle. The area needed for the Wilhelmshaven is large. This means a negative influence on the current vegetation and animal life. The ports are planned outside the national parks. In Cuxhaven, a protected biotope will be affected. For Wilhelmshaven this still has to be investigated. If there is protected biotope present, then legal permission is obligatory. Other effects on the environment are as follows. In Wilhelmshaven a recreational beach of the local population will be lost and in Cuxhaven noise protection is demanded.

Conclusion
Government chiefs from the states of Bremen, Hamburg and Lower Saxony chose the location for the port. They chose Wilhelmshaven. The most important criterion for this decision was the maximum quay length. When the maximum capacity is reached in Cuxhaven, new port area is necessary. If then the only suitable area is near Wilhelmshaven, why not start the new port at Wilhelmshaven?

Another very important aspect is the financing of the port. Both ports have to find investors to get financial closure for the project. Public authorities will help for part of the necessary sum of money. The rest has to be paid by private investors. Unfortunately it is not clear if either one of the ports has enough investors to reach financial closure. Those costs might be the conclusive factor in the decision Wilhelmshaven versus Cuxhaven. The importance of criteria other than quay length or costs is hard to trace.
Appendix VI Design Ships

There are three kinds of design ships [ref. 10], two kinds of feeders and a deep-sea containership:

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<th>Feeder</th>
<th>Feeder</th>
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<td>25 m</td>
<td>32.2 m</td>
<td>53 m</td>
</tr>
<tr>
<td>Draught</td>
<td>9.5 m</td>
<td>12 m</td>
<td>(&gt; 14.5 m)</td>
</tr>
<tr>
<td>GT</td>
<td>10.000 ton</td>
<td>28.000 ton</td>
<td>93.000 ton</td>
</tr>
<tr>
<td>Dead-weight</td>
<td>16.000 ton</td>
<td>38.000 ton</td>
<td>(&gt; 100.000 ton)</td>
</tr>
<tr>
<td>Capacity</td>
<td>800 TEU</td>
<td>2.400 TEU</td>
<td>&gt; 8.000 TEU</td>
</tr>
</tbody>
</table>

The GT is calculated from the following formula: \( GT = 11,528 \times \text{TEU} + 545.6 \) (source Mr. H. Rugebregt)

The symbol (> ) is given, because in the feasibility study [ref. 10] these values were presented in this way. In the nautical subset (part 3 and 4) more details on the containership are given.
### Appendix VII Queuing theory

#### Table 1 Arrivals

<table>
<thead>
<tr>
<th></th>
<th>Σ TEU/year</th>
<th>Throughput/call</th>
<th>Arrivals/year = λ</th>
<th>Arrivals/week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Feeder</td>
<td>756.000 TEU</td>
<td>720 TEU</td>
<td>1.050</td>
<td>20.2</td>
</tr>
<tr>
<td>Midi</td>
<td>577.920 TEU</td>
<td>1.488 TEU</td>
<td>388</td>
<td>7.5</td>
</tr>
<tr>
<td>Jumbo</td>
<td>466.080 TEU</td>
<td>4.800 TEU</td>
<td>97</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>1.800.000 TEU</strong></td>
<td><strong>average 1.173 TEU</strong></td>
<td><strong>1.535</strong></td>
<td><strong>30</strong></td>
</tr>
</tbody>
</table>

The ‘Queuing theory’ serves well for a first estimation of the number of berths needed for the Jade Weser Port. The average rate of arrival (λ) is indicated in Table 1. The average service time (μ⁻¹) and the utilisation (ψ) still have to be determined. Some assumptions concerning the cranes features have to be made:

- proportion 20 and 40 feet containers is 1:1
- 40 moves/hour = 60 TEU/hour
- Crane interference 20 %
- 3 hours needed for berthing and for customs paperwork

Assumptions for the port:

- Workable hours: 50 * 24 = 8.400 hours/year
- An E2/E2/n distribution is used. The first letter stands for the arrival time distribution; the second letter stands for the service time distribution and n stands for the number of berths. E2 stands for an Erlang 2 distribution. This is a more general distribution than a random distribution like a negative exponential distribution (M). For this container port the arrival and service time distribution are quite well known, this justifies the use of the Erlang 2 distribution.
- Accepted waiting time is 10% of the service time.

The queuing theory can not be used to simulate the several ships with interchangeable berths; therefore two other calculations will be done. The first calculation determines the number of berths with the limitation that the feeders, midi and jumbo ships each have their own berths. In this calculation the quay length is determined without interchangeable berths. The second calculation has been done with the average ship and with interchangeable berths.

#### First calculation

Quay length for the several ships will be determined separately, see Table 2, Table 3 and Table 4.

**Table 2 Feeder**

<table>
<thead>
<tr>
<th>λ</th>
<th>= 1.050 ships/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 cranes/ship</td>
<td>= (1 – 20 % crane interference) * 2 cranes * 60 TEU/hour = 96 TEU/hour</td>
</tr>
<tr>
<td>μ⁻¹</td>
<td>= 3 hours berthing and customs + (720 TEU/ship) / (96 TEU/hour) = 10,5 hours</td>
</tr>
<tr>
<td></td>
<td>= λ / (μ*n) = (1.050 * 10,5) / (8.400 * n)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n</th>
<th>ψ</th>
<th>W = …. % of the service time</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.656</td>
<td>33 %</td>
</tr>
<tr>
<td>3</td>
<td>0.438</td>
<td>3.2 %</td>
</tr>
</tbody>
</table>
Table 3 Midi

<table>
<thead>
<tr>
<th>λ</th>
<th>= 388 ships/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 cranes/ship</td>
<td>= (1 – 20 % crane interference) * 3 cranes * 60 TEU/hour = 144 TEU/hour</td>
</tr>
<tr>
<td>μ⁻¹</td>
<td>= 3 hours berthing and customs + (1.488 TEU/ship) / (144 TEU/hour) = 13,3 hours</td>
</tr>
<tr>
<td>ψ</td>
<td>= λ / (μ⁻¹) n = (388 * 13,3) / (8.400 * n)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n</th>
<th>ψ</th>
<th>W = … % of the service time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,614</td>
<td>69 %</td>
</tr>
<tr>
<td>2</td>
<td>0,307</td>
<td>2,6 %</td>
</tr>
</tbody>
</table>

Table 4 Jumbo

<table>
<thead>
<tr>
<th>λ</th>
<th>= 97 ships/year</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 cranes/ship</td>
<td>= (1 – 20 % crane interference) * 6 cranes * 60 TEU/hour = 288 TEU/hour</td>
</tr>
<tr>
<td>μ⁻¹</td>
<td>= 3 hours berthing and customs + (4.800 TEU/ship) / (288 TEU/hour) = 19,7 hours</td>
</tr>
<tr>
<td>ψ</td>
<td>= λ / (μ⁻¹) n = (97 * 19,7) / (8.400 * n)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>n</th>
<th>ψ</th>
<th>W = … % of the service time</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0,227</td>
<td>7,9 %</td>
</tr>
<tr>
<td>2</td>
<td>0,114</td>
<td>0,14 %</td>
</tr>
</tbody>
</table>

**Second calculation**

Quay length will be calculated for the average ship, see Table 5.

Table 5 Average ship

| Average ship | = (1.050 ships * 160 m + 388 ships * 200 m + 97 ships * 360 m) / 1.535 ships = 183 m |
| λ       | = 1.535 ships/year |
| 3 cranes/ship | = (1 – 20 % crane interference) * 3 cranes * 60 TEU/hour = 144 moves/hour |
| μ⁻¹     | = 3 hours berthing and customs + (1.173 TEU/ship) / (144 TEU/hour) = 11,1 hours |
| ψ       | = λ / (μ⁻¹) n = (1.535 * 11,1) / (8.400 * n) |

<table>
<thead>
<tr>
<th>n</th>
<th>ψ</th>
<th>W = … % of the service time</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0,676</td>
<td>20 %</td>
</tr>
<tr>
<td>4</td>
<td>0,507</td>
<td>5,4 %</td>
</tr>
</tbody>
</table>

The following table, Table 6, shows the calculated quay length. The distance between the ships is the same as the values used in the feasibility study of the Jade Weser Port.

Table 6 Quay length

<table>
<thead>
<tr>
<th></th>
<th>Feeder berths</th>
<th>Midi berths</th>
<th>Jumbo berths</th>
<th>Distance between ships</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1&lt;sup&gt;st&lt;/sup&gt; calculation</td>
<td>3 * 160 m</td>
<td>2 * 200 m</td>
<td>1 * 360 m</td>
<td>7 * 40 m</td>
<td>1.520 m</td>
</tr>
<tr>
<td>2&lt;sup&gt;nd&lt;/sup&gt; calculation</td>
<td>4 * 183 m</td>
<td></td>
<td>5 * 40 m</td>
<td></td>
<td>932 m</td>
</tr>
</tbody>
</table>

The first value is too high; it considers three independent quays. In reality, more efficient use of the quay can be realised; there will be one quay that can cope with all design ships. An efficient case would be the second calculation. The reality is a little bit less efficient, and therefore a first estimation would be six berths with a quay length of 1.300 m.
Appendix VIII Costs Equipment

In this appendix, the terminal equipment will be dealt with in more detail. The feasibility study of the Jade Port shows that for a quay of 1700m, 5 doublehoist cranes and 9 singlehoist cranes are needed, a total of 14 quay cranes. For the equipment to transport the containers from the quay cranes over the terminal to and from the stacks several alternatives are possible.

These alternatives consist of: Van Carriers, a combination of Automatic Guided Vehicles with Rail Mounted Gantry or a combination of Linear Motor-based Transfer technology with Rail Mounted Gantry. Table 2 shows the alternatives of terminal equipment. E.g. alternative one has 14 quay cranes and 74 straddle carriers, the terminal area needed is 166 ha and the number of personnel needed is 1.145.

Table 3 shows the prices of the equipment.

Table 2 Alternatives for the terminal equipment, source ref. 11

<table>
<thead>
<tr>
<th>Necessary equipment at terminal of 1.8 million TEU pro year</th>
<th>Dimension</th>
<th>Throughput system</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Alternative 1: Van Carrier</td>
</tr>
<tr>
<td>Quay Crane (QC)</td>
<td>Unit</td>
<td>14</td>
</tr>
<tr>
<td>Straddle Carrier (SC)</td>
<td>Unit</td>
<td>74</td>
</tr>
<tr>
<td>Rail Mounted Gantry (RMG)</td>
<td>Unit</td>
<td>-</td>
</tr>
<tr>
<td>Automated Guided Vehicle (AGV)</td>
<td>Unit</td>
<td>-</td>
</tr>
<tr>
<td>Linear Motor-based Transfer Technology (LMTT)</td>
<td>Unit</td>
<td>-</td>
</tr>
<tr>
<td>Terminal area</td>
<td>Ha</td>
<td>166</td>
</tr>
<tr>
<td>Employees</td>
<td>Number</td>
<td>1.145</td>
</tr>
</tbody>
</table>

E.g. alternative one has 14 quay cranes and 74 straddle carriers, the terminal area needed is 166 ha and the number of personnel needed is 1.145.

Table 3 Prices for terminal equipment (costs in millions), source ref. 20

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Estimated cost per unit</th>
<th>Alternative 1: Van Carrier</th>
<th>Alternative 2: RMG/AGV</th>
<th>Alternative 3: RMG/LMT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portainer or quay crane</td>
<td>$ 3.5-7</td>
<td>€ 77,7</td>
<td>€ 77,7</td>
<td>€ 77,7</td>
</tr>
<tr>
<td>Straddle carrier</td>
<td>$ 0.5-1</td>
<td>€ 61,4</td>
<td>€ 14,3</td>
<td>€ 14,3</td>
</tr>
<tr>
<td>RMG</td>
<td>$ 1.5-2.5</td>
<td>€ 0</td>
<td>€ 82,3</td>
<td>€ 82,3</td>
</tr>
<tr>
<td>AGV (rough estimation)</td>
<td>$ 0.3-0.5</td>
<td>€ 0</td>
<td>€ 26,6</td>
<td>€ 0</td>
</tr>
<tr>
<td>LMTT (price for FLT)</td>
<td>$ 0.3-0.6</td>
<td>€ 0</td>
<td>€ 0</td>
<td>€ 33,2</td>
</tr>
<tr>
<td>Total per alternative</td>
<td></td>
<td>€ 139,1</td>
<td>€ 200,9</td>
<td>€ 207,5</td>
</tr>
</tbody>
</table>

This adds up to roughly € 205 million for terminal equipment (including various other mobile equipment).

Alternative approach

There is no rule of thumb for equipment. In a different feasibility study (Port Said, Egypt) with a throughput of 700,000 TEU the equipment was estimated at € 65 million.
Conclusions

As a first estimation, the terminal equipment seems a little too high. A more detailed research to the terminal layout, combined with the estimation of costs of the equipment will give more accurate amounts.
<table>
<thead>
<tr>
<th></th>
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<td>16.0</td>
<td>16.0</td>
<td>-57.3</td>
<td>-57.3</td>
<td>-57.3</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>39.0</td>
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<td>20.0</td>
<td>25.0</td>
<td>7.7</td>
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<td></td>
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<td>206.0</td>
<td>0.0</td>
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<td>16.0</td>
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<td></td>
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<td>603.3</td>
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<td>433.7</td>
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<td></td>
<td></td>
<td>N.P.V.= 14.2</td>
<td>IRR= 10%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Appendix X Programs

1. Programs used for tidal currents

- Delft3D-FLOW
  
  At Alkyon a 2 dimensional flow model of the Jade estuary has been made for a former project (ref. 2). This modal has been made in Delft3D, therefor in this report the tidal currents will be calculated by using their Delft3D-FLOW model. In this case the Alkyon model has been used to determine the flow conditions near the future Jade Weser Port.

- Getijsys
  
  The tidal range changes in time; there are daily variations and two-weekly variations (the spring tide differs throughout the year). In order to find the extreme velocity conditions, the maximum tidal range during one year will be determined. Getijsys is a tidal analysis and prediction program, therefor this program has been used to determine the largest tidal range during the chosen year (2000).

- Quickin
  
  Quickin is an additional program of Delft3D, it’s purpose is to create, manipulate and visualize model bathymetries for Delft3D-FLOW. Several calculations will be done with Delft3D-FLOW, the main difference between them is the bathymetry. These bathymetry adaptations have been done by using Quickin.

- Tekagx
  
  Tekagx is a program which can be used to present results of calculation programs. Plots of flow calculations have been made with this program.

2. Programs used for waves

- Hydrobase
  
  A program, which can be used for analysis and presentation of hydraulic design conditions. Hydrobase is developed by Alkyon, this program transfers ship observations of wave data to statistical data.

- Swan
  
  A program, which can be used for the simulation of wave generation, propagation and dissipation in coastal areas. The choice for wave simulation was a choice between Hydrobase and Swan. Swan was chosen because the reflection of the waves at the Jade Weser Port could not be neglected.
Appendix XI Input parameters

1. Assumptions and used parameters for tidal currents
   - Grid parameters:
     A curvilinear grid has been used, see figures 16.4-16.7. The maximum number of cells in M direction is 126 and 348 in the N direction. Both the grid file and the grid enclosure file have been used (without alterations) of the Alkyon Jade model.
     
     Grid: file jade06.grd
     Grid Enclosure: file jade.enc
     Grid Dimensions: Mmax 126, Nmax 348, Kmax 1
     Latitude origin: 53.50
   - Bathymetry:
     Three different bathymetry files have been used. First the original file of the Alkyon Jade model. Second the bathymetry for the situation immediately after the implementation of the Jade Weser port. Third the bathymetry for the situation when the new equilibrium depth has been reached at the Jade Weser port.
     
     Bathymetry: file jade06.dep
   - Dry Points:
     The Alkyon model does not have any specified dry points. The Jade Weser port has been modeled in the program by dry points.
     None / future port area
   - Thin Dams
     The file of thin dams of the Alkyon model has been used without adaptations.
     Thin dams: file j06.thd
     A few dams are present in the estuary
   - Time Frame
     Three days will be simulated, two days for adaptation and one simulated day. The timestep has to be chosen within certain limits. Not to large in order to get a stable calculation and not to small otherwise the calculation time will become very large.
     Reference date 01 04 2000 day month year
     Simulation Start Time 16 04 2000 00 00 00 day month year hour minute second
     Simulation Stop Time 19 04 2000 00 00 00 day month year hour minute second
     Time step 0.400 min
   - Processes
     No processes have been simulated
   - Initial Conditions
     The approximate water level at the 16th of April 2000 will be given, so the program will not have to adapt to the water level.
     Uniform water level 1.500 m
   - Boundaries
     The boundaries of the Alkyon model have been used without adaptations.

<table>
<thead>
<tr>
<th>Type of open boundary</th>
<th>Forcing type of the Boundary condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>O 1</td>
<td>Water Elevation</td>
</tr>
<tr>
<td>O 2</td>
<td>Water Elevation</td>
</tr>
<tr>
<td>NO 1</td>
<td>Water Elevation</td>
</tr>
<tr>
<td>NO 2</td>
<td>Water Elevation</td>
</tr>
<tr>
<td>N 1</td>
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</tr>
<tr>
<td>NW 1</td>
<td>Water Elevation</td>
</tr>
<tr>
<td></td>
<td>Astronomical Tide</td>
</tr>
<tr>
<td></td>
<td>Astronomical Tide</td>
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<tr>
<td></td>
<td>Astronomical Tide</td>
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<td>Astronomical Tide</td>
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<tr>
<td></td>
<td>Astronomical Tide</td>
</tr>
<tr>
<td></td>
<td>Astronomical Tide</td>
</tr>
</tbody>
</table>
Per section several tidal components with each an amplitude and a phase

- **Physical Parameters**
  The physical parameters are standard parameters; chosen so they will not interfere with developments of eddies. The roughness can be used to calibrate the program. The following physical parameters have been used:

<table>
<thead>
<tr>
<th>Constants</th>
<th>Gravity</th>
<th>9.8130 m/s^2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Water Density</td>
<td>1023.000 kg/m^3</td>
</tr>
<tr>
<td></td>
<td>Temperature</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Salinity</td>
<td>0</td>
</tr>
<tr>
<td>Roughness</td>
<td>Manning</td>
<td>Uniform</td>
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<tr>
<td></td>
<td>Horizontal viscosity/Diffusivity</td>
<td>Uniform</td>
</tr>
<tr>
<td></td>
<td>u = 0.0260</td>
<td>v = 0.0260</td>
</tr>
<tr>
<td>Viscosity</td>
<td>Horizontal Eddy Viscosity = 1 m^2/s</td>
<td></td>
</tr>
</tbody>
</table>

- **Numerical Parameters**
  For drying and flooding the parameter max has been chosen, this means that the maximum depth in the surrounding velocity points is used in combination with the water depth in the water level point to determine if a cell is being dried or flooded. The parameter max is a default value and it gives in most cases the best results.
  The threshold depth is a depth above which a cell is considered to be wet. This parameter is necessary, because a depth of zero could give problems in the calculation. A threshold depth of 0.1 m is commonly used.
  A marginal depth of ~999 m shows that this parameter has not been used, this parameter will be used in areas with a lot of sandbanks and with shallow gullies. For the interest area near the future Jade Weser Port (the west side of the Jade) this is not the case.
  Smoothing time is a parameter, which will be used at the start of the simulation for a smooth transition between initial and boundary conditions (when there is a large difference in water level over the model area at the start of the calculation). This is the case for the Jade model and 120 min smoothing time will be enough to overcome this difference.
  The following numerical parameters have been used:

  | Extra Drying/Flooding | max |
  | Threshold depth       | 0.100 m |
  | Marginal depth        | -999.000 m |
  | Smoothing Time        | 120.000 min |

- **Discharge**
  None

- **Monitoring**
  Observation: Several observation points in the entrance channel and in front of the quay have been added. The observation points of the Alkyon report were also used
  Drogue: None
  Cross Section: None

- **Additions**
  Additional Parameters: None

- **Output**
  Both map and history intervals were produced at every 10 minutes. The short map intervals make detailed input for Ship Navigator. Furthermore it gives good results in animations.
2. **Assumptions for the Swan calculation**

**Wind**
- The input resembles a constant wind (at a height of 10 m above the still water level)
- The speed (in m/s) is the speed which belongs to a significant wave height of 3.25 m (it resembles a speed of 6-7 Bft, see also new table 2.1)
- The directions are the same as the wave directions

**Initial wave conditions:**
- The Jonswap spectrum will be used with an enhancement factor 3.3
- The peak period of the waves will be used
- The directional distribution has a power of 6
- The area has been divided several area’s
  - **South:** First part consists of land, significant wave height 0.1 m, peak period 99 s
    - Second part consists of water, the waves from the south should not have a greater effect than the other directions, because this will not be the dominant wave direction. The wave height and period will be a little lower, than the design wave.
      - significant wave height 1.0 m
      - peak period 3 s
    - Third part consists of land
      - significant wave height 0.1 m
      - peak period 99 s
  - **East:** First part consists of land, significant wave height 0.1 m, peak period 99 s
    - Second part consists of shallow water, therefor the wave height will be a bit lower.
      - significant wave height 2.0 m
      - peak period design value (see new table 2.1)
    - Third part consists of water
      - significant wave height design value
      - peak period design value
  - **North:** Whole part consists of water, significant wave height design value
    - peak period design value
  - **West:** First part consists of water, significant wave height design value
    - peak period design value
    - Second part consists of shallow water, therefor the wave height will be a bit lower.
      - significant wave height 2.0 m
      - peak period design value
    - Third part consists of land
      - significant wave height 0.1 m
      - peak period 99 s

**Reflection:**
- The reflection occurs at the port at two different locations, first at the quay, second at the bank of the reclaimed terminal area
- Both locations completely block the wave transmission
- The reflection at the quay is almost 100%, and gets a value of 0.95
- The reflection at the bank is a lot less and is assumed to be 0.40

Most other input parameters have default values.

**Physics:**
- the third generation mode was used
- the stationary mode was used
- parameter Komen for wave growth was used
- for depth-induced wave breaking the value for the rate of dissipations is 1.0 and the ratio of maximum individual wave height over depths is 0.73
- for bottom friction Jonswap was used, with a value of 0.0380 which is default for swell. Swell is dominant, because the shallow water (and sand banks) to the east of the port area hinder the sea waves to enter the port area.

Numerics:
- maximum number of iterations 15
- the iteration stops when the change in local wave height and period is less than 0.02
- the iteration stops when the change in average significant wave height is less than 0.02 and the change in average mean wave period is less than 0.2
- the iteration stops if the two above mentioned conditions are valid for 98% of all the wet grid points
### Appendix XII Runs simulated in Ship Navigator

#### Table 1 Runs

<table>
<thead>
<tr>
<th>Maneuver</th>
<th>Ship</th>
<th>Tidal moment</th>
<th>Wind and/or wave direction</th>
<th>Average Hs in front of quay</th>
<th>Berth location</th>
<th>Bow direction</th>
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</thead>
<tbody>
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<td>cartesian</td>
<td>nautical</td>
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<td>60º</td>
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<td>South</td>
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<td>High water</td>
<td>210º</td>
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<td>South</td>
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<td>210º</td>
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</table>
### Appendix XIV Summarised results of Ship Navigator

Table 1 Scores of the runs

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<tr>
<th>Score</th>
<th>Area</th>
<th>Tugs</th>
<th>Speed</th>
<th>Rate of turn</th>
<th>Engine</th>
<th>Final Score</th>
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</tbody>
</table>
Appendix XV Wind versus tugs

Here the tug power related to the wind force will be calculated. The formula for wind force is as follows:

\[ F = C_d * 0,5 * \rho_a * u^2 * A \]

- \( F \) = wind force (N)
- \( C_d \) = drag coefficient
- \( \rho_a \) = specific mass of air (= 1,28 kg/m³)
- \( u \) = wind velocity (= 14 m/s)
- \( A \) = the area which is subjected to the wind (m²)

The area

<table>
<thead>
<tr>
<th></th>
<th>Wind area for x-force (m²)</th>
<th>Wind area for y-force (m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Large ship</td>
<td>1834</td>
<td>9097,997</td>
</tr>
<tr>
<td>Small ship</td>
<td>460</td>
<td>2070</td>
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</tbody>
</table>

The drag coefficient is different for each wind direction with respect of the ship. The drag coefficient can be split into a longitudinal and a transversal direction combined with a yawing moment.

The dominant wind direction for the largest ship is a wind of 120º with respect to the ships (cartesian) axes – x pointing to the bow and y pointing to the side of the ship. The dominant direction for the smallest ship is a wind of 90º.

The dominant wind force can be determined and split into a force for a tug at the bow and a second tug at the stern.

- For the largest ship this results in 642 kN respectively 663 kN. This means this ship needs a 65 t bollard pull tug and a 70 t bollard pull tug in order to cope with a wind of 14 m/s. Possibly, the tug at the bow can be a 60 t bollard pull tug, because the bow thruster can also assist the ship.

- For the smaller ship this results in 110 kN respectively 119 kN. This means this ship needs two 15 t bollard pull tugs in order to cope with a wind of 14 m/s. More power full tugs have been used, because the wave conditions are rough.
Appendix XVI Delft3D FLOW, Swan and Ship Navigator
DELFT3D: another dimension

Increasingly, the designing of complex engineering projects and the management of water systems demands an integrated, multi-disciplinary approach. Figuratively speaking, one needs to be able to spin the problems around and examine them from many angles, not only from a spatial perspective, but also in terms of time. In response to this challenge, DELFT HYDRAULICS has developed a unique, fully-integrated, three-dimensional computer program: DELFT3D. This power package system, which is designed for coastal, river and estuarine areas, simulates flows, sediment transport, waves, water quality, morphological developments (bottom changes), and ecology. It is intended to be used by experts and non-experts alike, often at the same time, decision makers such as managers, regulators and governmental authorities, as well as consultants, contractors and engineers.

A few key features should be highlighted:

- linked, integrated programs
- cutting edge process knowledge built in
- user-friendly graphical interface.

Morphodynamics Waddensee, the Netherlands: strait between Texel-Vlieland. Initial situation.
Spatially speaking, nature is three dimensional (3D). It extends in two planes horizontally - longitudinally and laterally - and on the vertical axis too. Natural processes are, of course, also three dimensional and inter-related. Hydrodynamics, for example, affects sediment transport, sediment transport influences morphology, and that in turn affects hydrodynamics. And so on, and so on. DELFT HYDRAULICS has always appreciated nature's complexity and approached its work accordingly. This understanding has now been translated into reliable, commercially available 3D software.

DELFTED simulates six phenomena and their inter-relatedness: flows, sediment transport, water quality, waves, morphology and ecology. While suitable for a wide variety of situations, it will be used mostly for coastal, river and estuarine areas. DELFTED consists of a number of tried, tested, and well-known modules, which are linked and integrated with each other. These modules, which we use ourselves at DELFT HYDRAULICS, include:

**hydrodynamics module (TRISULA)**
Simulates flows in relatively shallow water. Includes effects of tides, wind, density currents, waves, spiral motion and turbulence up to $k = e$. With integrated heat and mass transport solver. DELFT HYDRAULICS' front-running knowledge of stratified hydrodynamics is built into this package.

**water quality module (DELWAQ/DLDPAR)**
Models far- and mid-field water quality problems. Includes several advection-diffusion solvers and advanced process modules. DELFT HYDRAULICS is on the cutting edge in the understanding of water quality.

**sediment transport module**
Models equilibrium- and suspended-transport of sediment (sand or silty) using a variety of formulae. For rivers, the effects of spiral flow at bends are included. For coastal areas, the effects of wave motion on transport magnitude and direction are included. DELFT HYDRAULICS is on the cutting edge in knowledge of sedimentation and silt transport processes (which are increasingly important, because silt carries contaminants).

**wave module (HISWA)**
Computes the propagation of short-crested waves over an uneven bathymetry (bottom), utilizing varying water levels and velocity fields.

**morphological module**
Computes bottom changes due to transport gradients and various types of boundary conditions. Keeps the user updated about the shape of things below. DELFT HYDRAULICS is in the forefront in this field.

**ecological module**
We have a variety of ecological modules that fit into the DELFT3D system. For example, modules describing the governing processes of biotic and abiotic ecosystems, and the interactions between them.
DELT3D is an integrated software package. That means it is more than the sum of its parts. In your water-system, for example, you can explore currents, morphology and water quality in sequence and be confident that the models are cross-referenced and inter-related, just as it is in nature. But, while too little information might be costly and dangerous, too much can be confusing. The graphical user interface is designed to tackle this headache.

The user interface facilitates an easy and structured application of the models, including data-entry and management, visualization of model data and control of the computations. The interface assists you in the management of projects and scenarios, archiving of results, and logging of activities. It also provides error trails, import and export functions for data, model results, and graphical displays.

These programs, which can be bought separately or as an exceptionally nimble power package, allow you to visualize your results two- or three-dimensionally on your computer screen. Thus you can look at your system - an estuary, say - and examine the tides flowing in and out, gradually, fast forward or fast backwards. You can gather a wide, overhead perspective of your entire system. Or, on the contrary, zoom in on a particularly relevant and troublesome spot.

It is said that one picture is worth a thousand words (or formulae). This may be true. But it should be remembered that DELT3D is not a virtual reality toy that pumps out colourful - but perhaps inaccurate - pictures. It is a scientific tool based on our long-time research efforts, that is designed for managers, engineers, and others, who need to look into real events - often murky and turbulent - and present and defend their findings in a clear and convincing manner.

other features and options

features

User-friendly graphical interface. Designed to facilitate a logical and structured application of the wide variety of models at your command. Features include data-entry and management, visualization of model data and control of the computations. Another notable feature of the interface is the "Advanced Project Scenario Manager", which helps you keep track of where you started and what changes you have made: a kind of bookmark in your program. New scenarios can be created from zero, but they can also be derived from existing ones. Derivative scenarios are displayed as "descendent".
Curvilinear grid generator: A curvilinear grid simulates the boundaries of a natural system more accurately than the rectilinear grids normally found in computer software. This means a snugger fit between model and reality and the possibility of enlarging with high resolution and a great amount of detail complex and important areas of your system. This cuts computational costs and time.

Programs can be time-dependent or independent.

options

DELTED may be purchased as an entire package or as individual programs.

If you wish, we can calibrate the programs for you, advise on the appropriate programs, and help you to use them to maximum advantage.

validation

The validation of a compound modelling system such as DELTID requires continuous attention. Even though the individual components of the system have been thoroughly tested, the system as a whole must be tested and validated too. While it is impossible to test all possible combinations - due to the huge variety of them built into the system - we are carrying out tests of the most likely combinations. The results of these tests are given in the Validation Documents that are supplied with the system.

technical talk

Hardware: DELTID works on HP 9000/700 and IBM RS/6000 Series work stations. Additional hardware requirements are:
- Memory: While the system can function on 32 Mb, 48 Mb is highly recommended. Depending on the models used, even more memory may be necessary.
- Hard Disk: Minimum 1 Gb
- Screen: either a console with a 19’ colour monitor with 1280x1024 resolution, or an X-terminal with 10 Mb memory.

Software: Appropriate ANSI C and Fortran compiler must be available during installation of DELTID. During operations it uses the following software:
- X Window System and OSF/Motif libraries
- Uniras agX library and Unigraph+2000
- Oracle RDBMS

Graphical user interface is based on the OSF/Motif standard.

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SWAN
Simulation of wave generation, propagation and dissipation in coastal areas

Applications

Data on wave conditions is often available offshore but not nearshore. Accurate on site wave data is crucial in studies into coastal development, harbour design or breakwater design. SWAN is a wave generation and propagation model which can be applied to derive the wave conditions in the nearshore area. SWAN is also suitable for use as a wave hindcast model in water of intermediate and shallow depth for situations where the wind field may be considered constant. Typical areas for the application of SWAN range between 10 X 5 km2 and 30 X 100 km2 (e.g. along a coastal strip).

Processes

The processes modelled by SWAN are shown in the box right. SWAN explicitly includes the effects of non-linear four wave interactions (quadruplets) and three wave interactions (triads). The discrete representation of the frequency spectrum means that SWAN is more suitable than previous models for application in areas where strong growth due to wind action may occur where swell or the remains of old sea states is also present (e.g. behind island barriers or bank systems)

Representation

SWAN represents the wave field on a two dimensional horizontal rectangular grid covering the computational area. At each grid point, SWAN represents the complete 2D action density spectrum discretely as a function of frequency and direction. (Action is equivalent to energy when there are no currents). SWAN represents wave propagation in all directions. It explicitly includes the effect of non-linear four wave interactions (quadruplets) and three wave interactions (triads). The solution technique marches forward row by row over the grid beginning at the incident wave boundary, where the incident wave characteristics can be defined. The results in each direction sector at each grid point are computed from the results for the grid points in the previous row. The propagation of energy is modelled using an energy balance equation adapted to include terms for wave growth by wind action or dissipation due to bottom friction or wave breaking.

SWAN was developed by the Technical University of Delft and has been verified using results from both field measurements and from physical model tests.

Further reading

The construction of new or extended harbours and terminals involve large and expensive infrastructural works such as dredged channels, breakwaters, trestles and fixed or floating mooring systems. The size and location of these infrastructures and sometimes the layout of the entire terminal are a function of the nautical requirements (manoeuvring width, navigational aids, tug support) of the ships calling at the port or terminal.

Optimisation of the design from a nautical point of view requires a thorough knowledge and experience in ship handling and harbour design and efficient design tools for ship manoeuvring.

ALKYON’s experts have much experience in the design and testing of harbours. They carried out many harbour studies, with more than 50 nautical projects since 1990.

For the nautical assessment and optimisation of designs ALKYON has available the computer program SHIP-NAVIGATOR. This is a tool capable of simulating ship manoeuvres in real-time as well as faster than real-time. Also it is possible to exercise the controls manually as well as through a track-following autopilot. With these possibilities the model allows for both a fast analysis of a large number of design alternatives as well as for a detailed analysis of berthing and de-berthing procedures.
 Nowadays the construction of terminals is realised at locations of increasingly difficult environmental conditions. Therefore, **SHIP-NAVIGATOR** has been designed such that it allows for accurate close-quarter manoeuvring characteristics and possibilities. Better than most other fast-time simulators it allows for the following features:

- it models the actual characteristics of rudder and propeller with detailed modelling of the interaction between rudder, propeller and hull. Thus realistic ship manoeuvring is possible in all modes of operation (manoeuvring ahead, astern, sideways, accelerating, stopping, being towed or pushed).
- with double rudder/propeller-ships it is possible to individually control propellers and rudders.
- it has a detailed tug modelling with towing and pushing possibility; control of their towing-line length, towing position and towing angle; tug effectiveness is restricted depending on the speed and relative direction of the tow, of the tugs own speed and of the waves at the tug location. Wave shielding at the lee-side of the ship is taken into account.
- ship and tugs may be handled both manually (interactive) by the user as by a track-following autopilot.
- close quarter manoeuvring is facilitated for the user with a user-friendly control panel for ship (Figure 2), winch (Figure 4) and tug control (Figure 3) and with real-time birds-eye-view colour-visualisation of the ship, the tugs and the surroundings (coast, channel, manoeuvring aids, harbour, berths). Also the time-scale is adjustable.
- for debriefing purposes it is possible to replay an earlier executed run.

**Figure 3 Tugs control panel**

**Figure 4 Winches control panel**
SHIP-NAVIGATOR is part of the nautical SHIP suite of programs developed by ALKYON. The programs may be used either integrated or in a stand-alone fashion. SHIP models:

- the simulation of the manoeuvring of a sailing vessel
- the horizontal and vertical motions of a vessel sailing in waves
- motions and mooring forces of a vessel moored to a jetty, quay, SPM or spread mooring system

In these simulations the effects of in time and space varying wind, waves, currents and water depths can be considered. Also the influence of rudder(s), propeller(s), bow and stern thrusters, tugs, mooring lines and fenders are included.

**Model properties**

- Modular set-up with special emphasis for hull-propeller-rudder interaction and manoeuvring properties for slow speeds and astern manoeuvres.
- Propeller forces (full four-quadrant modelling).
- Rudder forces (incl. effects of screw race / flow attack for all manoeuvring conditions).
- Bow and stern-thruster forces (with speed-correction).
- Full model of engine-propeller with correct revolutions build-up and reduction.
- Shallow water-effects.
- Wind forces.
- Current; effect of variable current over the length of the ship.
- Multiple wave fields (e.g. sea and swell); effect of diminishing wave forces over the length of the ship when entering a protected area.
- Wave reduction caused by the ship herself (used for operation of tugs on the lee-side of the ship).
- Realistic tugboat usage depending on sailing direction, speed, waveheight at tug location and time required to change tow-direction; tug (schematically) and towline presented on screen
- Clear presentation with birds-eye-view in colour of manoeuvring area, infrastructure, ship and navigational aids.
- Manual or automatic steering.
- Checking of manoeuvring characteristics with standard manoeuvring tests.
- Possibility of modelling of fenders and mooring lines (at jetties etc.)

**Input**

- Input and checking of ship-coefficients, environmental data, track and autopilot-setting is possible through interactive input-screens or through input-files
- Input of contours and colouring of birds-eye view using an ASCII-file
- Various checking possibilities for environmental conditions (current, wind, waves, depth) by visualisation prior to the simulation and partly also during the simulation
SHIP-NAVIGATOR Alkyon’s ship manoeuvring simulator
for cost-effective designing and optimising harbours and marine terminals

Options

- On-line choice of simulation-speed and control-method (track-following autopilot or manual control)
- Possibility to replay earlier executed runs with all instruments active during the replay; replay-speed adjustable
- Variable orientation of birds-eye-view with respect to North
- Variable number of tugs (maximum four)
- Option to show swept path during simulation or during replay
- Choice for normal simulation or automatic execution of standard manoeuvring tests (turning circles, zig-zag tests)

Controls and instruments

- Manual control with mouse of “buttons” and “handles”:
  - telegraph;
  - ruddercontrol;
  - (de)coupling of propellers and rudders in case of twin propulsion;
  - bow-thruster;
  - stern-thruster;
  - tugs (pull; push; push/pull; direction; connection point; line length);
  - winches (pulling, paying out, slipping).
- Instruments and position-indication:
  - time;
  - doppler-log (u,v);
  - sallog;
  - rate-of-turn;
  - water depth;
  - heading;
  - wave heights (sea en swell);
  - wind speed and direction (relative);
  - distance indication rings and heading-line
  - repeaters for RPM, rudder (both double if required), bow and stern thruster
Output

- Interactive output control screen with various possibilities to compile output with 1 to 3 plots per page.
- Track-plots of runs.
- Plot possibilities for e.g. speeds, rudder, propeller, tug usage and site conditions.
- Possibility to plot against time or distance along the track.
- Output files (ASCII) with all parameters and also with all force-contributions exerted on the ship.

The results are presented in the form of track-plots (see figure 7) and plots of parameters such as speed, rate-of-turn, engine settings, tug usage and any other parameters relevant to the particular study (see figures 5 and 6).

The results are used to evaluate accurately, cost-effectively and in a short period of time the downtime and safe manoeuvring conditions for many design alternatives and thus facilitate an optimal design choice.
Development

Given the high level of demands on a specialised consultant, we view the development of our software-tools in general and of **SHIP** in particular as a continuous process. Where possible, we directly implement experience and specific know-how gained during our many projects.

**SHIP-NAVIGATOR** has been developed by a team of engineers in the field of ship hydrodynamics, flow and wave hydrodynamics, applied mathematics and system developers. This team has in-depth expertise and experience both in the nautical field as well as in the design of complex software systems. The team has previous working experience at Delft Hydraulics (including the three former section heads of Harbours, Ship Hydrodynamics and Waves and Currents), the Maritime Research Institute Netherlands (MARIN), The Netherlands Organisation of Applied Scientific Research (TNO) and The National Aerospace Laboratory (NLR). As a team and as individuals they have developed several simulation models, including new or further developments of ship-simulation software for TNO, the Netherlands Royal Navy, Delft Hydraulics and IHC.

**SHIP-NAVIGATOR** has been programmed by a group of programmers under the supervision of an experienced software system developer. The latter has previously also been responsible for the software design and implementation of complex refraction-diffraction models, of a 3-D finite-element model for the computation of hydrodynamic forces on floating bodies and of a Navier-Stokes model for simulating breaking waves on coastal defences. He also participated in the EU projects ESPRIT and REDO.