Container terminal
development
Port of Shanghai

C. Riemslag
August 2001

Graduation committee:

Prof ir. H. Ligteringen (TU Delft)
Ir. R. Groenveld (TU Delft)
Ir. T.H.W. Horstmeier (TU Delft)
Ir. M. Pluijm (Boskalis)
Summary

At the time of writing this report the Chinese economy is one of the largest in the world. Although China is registered as a developing country, this will probably change fast while it is highly likely that China will be entering the World Trade Organisation (WTO) soon.

Shanghai as “the dragon head” of the Yangtze River forms the connection of China with the rest of the world. With the growth of China, Shanghai as a container port will also grow. Plans of the Chinese government are even to turn Shanghai into the main container hub of Southeast Asia. While the throughput of Shanghai during the past few years was quite small compared to the major ports like Hong Kong and Singapore, it showed an annual growth of 28 % from the year 1992.

To sustain this growth Shanghai will probably have to expand its capacity while current throughput figures are already above the design capacity (6 million TEU). Although Shanghai has far-developed plans to build new container terminals, these can probably not manage the future throughput. To be able to handle the expected throughput a new container port should be constructed. The location of this new port is sought outside the Yangtze River while the depth of this river is not sufficient to receive the largest vessels.

To be able to get an indication of the future demanded requirements regarding container handling capacity, a masterplan has been made within this report.

To be able to determine these future requirements, first a prognosis has been made in which the expected container handling volumes have been determined up till the year 2025. Due to the fact that a prognosis is subject to various non predictable events, two scenarios have been made. Within the low scenario a throughput of 30 million TEU (mTEU) will be reached by the year 2025. Within the high scenario a throughput of almost 40 mTEU will be reached by that year.

Within this report a scenario has further been used that holds the average of both mentioned scenarios. In the following table the values can be found with which further calculations have been made.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>mTEU</td>
<td>5.0</td>
<td>7.7</td>
<td>11.8</td>
<td>17.3</td>
<td>24.6</td>
<td>34.9</td>
</tr>
</tbody>
</table>

Based on this growth scenario the expected number of vessels has been determined. In the future a capacity increase is expected of the individual vessels. Especially the ocean vessels will increase their capacity. By the year 2010 a maximum capacity of 12,500 TEU is even expected.

Now the expected number of vessels and their probable dimensions have been determined, the requirements regarding the terminal facilities can be determined. With these requirements eventually a location can be sought that meets these requirements.

While the extra required capacity of 28 mTEU will be too large for only one terminal, the decision has been made to construct 6 terminals each able to handle a throughput of 5 mTEU per year. While these terminals are all equal to each other the requirements of only one of these terminals has been calculated.

With the queue theory a total number of berths of 13 per terminal had been found. The terminal furthermore required a total area of 216 hectare. With 6 terminals the total required area will be almost 1300 ha.
With this space requirement a suitable location has been sought. Of 3 possible locations eventually the location near Nanhu Zui has been chosen. This area lies only 80 kilometre south east of Shanghai outside the mouth of the Yangtze River. A location outside the Yangtze River was required due to the increasing number of vessels calling at Shanghai having large draughts.

The disadvantage of this location is that due to its location near the mouth of the Yangtze River it faces high annual returning maintenance dredging works. The advantages of this location however led to this choice.

While not sufficient natural depth is available along the coast of Nanhu Zui an approach channel has been dimensioned within this report. During the calculation of this approach channel it turned out that a total volume of 200 million m$^3$ of capital dredging should be executed. In combination with the expected maintenance dredging works, the costs would probably be very high. Within this report therefore another solutions has been investigated.

This solution contains a main port on the islands of Yangshan, 35 kilometres off shore, in combination with satellite terminals along the coast. The Yangshan islands had been evaluated before during the search for a location. This location had not been chosen at that time due to the fact that it should have a connection with main land. A bridge connection was at that time considered as too expensive.

The main port at Yangshan will handle all vessels that normally call at Shanghai. While many containers with a domestic destination are transported to and from Shanghai by truck and train, a connection with mainland is necessary. This connection is formed by so called shuttle barges that sail to and from Yangshan. The home terminals of these shuttles are so called satellite terminals situated at Nanhu Zui and the current container terminals of Shanghai.

Again, for these terminals the requirements should be calculated in order to make a design. With the complex situation by the year 2025 due to the numerous vessel movements the choice has been made to make a simulation model for these movements to determine the future requirements regarding the number of berths and storage area. This model has been written in the Prosim modelling language.

The results of the simulation eventually lead to the calculation of the terminal requirements that are presented in the following table,

<table>
<thead>
<tr>
<th>Terminal</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Apron area (ha)</td>
<td>26.8</td>
<td>26.8</td>
<td>30.9</td>
<td>26.8</td>
<td>26.8</td>
<td>26.8</td>
<td>164.8</td>
</tr>
<tr>
<td>Storage area (ha)</td>
<td>162.5</td>
<td>161.4</td>
<td>176.8</td>
<td>165.1</td>
<td>162.7</td>
<td>158.9</td>
<td>987.4</td>
</tr>
<tr>
<td>Additional area (ha)</td>
<td>81.2</td>
<td>80.7</td>
<td>88.4</td>
<td>82.6</td>
<td>81.4</td>
<td>79.4</td>
<td>493.7</td>
</tr>
<tr>
<td>Total (ha)</td>
<td>270.5</td>
<td>268.9</td>
<td>296.1</td>
<td>274.5</td>
<td>270.9</td>
<td>265.1</td>
<td>1646.0</td>
</tr>
<tr>
<td>Throughput (TEU)</td>
<td>5.8E+06</td>
<td>5.7E+06</td>
<td>6.3E+06</td>
<td>5.9E+06</td>
<td>5.8E+06</td>
<td>5.6E+06</td>
<td>3.5E+07</td>
</tr>
<tr>
<td>Throughput/area ratio (TEU/ha)</td>
<td>21,443</td>
<td>21,195</td>
<td>21,275</td>
<td>21,493</td>
<td>21,411</td>
<td>21,123</td>
<td>21,263</td>
</tr>
</tbody>
</table>

With these results 4 design proposals have been made for the Yangshan islands. The Nanhu Zui satellite terminals require a separate design study. The design proposals of the Yangshan terminals are presented in the figure below.
Of these 4 designs eventually design number 3 has been chosen. Within this design all vessels make use of the same basins leading to a reduction of breakwater length. With this advantage some other advantages are mentioned within the report.

The costs of this design have been estimated to give a general indication of the investments to be made. While there is no detailed information available concerning the local conditions around the islands only a rough estimation has been made. In total the costs will be $14.3 billion converted to the year 2001. While these costs form an important factor within the feasibility of this design the recommendation has been made to first collect detailed information of the local conditions around the islands.

The construction of this project will be executed in phases. In general the following phases will be made. Along with these phases the investments have been projected. These investments have been converted to the year of investment using an inflation of 5% annually.

<table>
<thead>
<tr>
<th>Start Year</th>
<th>Yangshan terminals</th>
<th>Delivery Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>Terminal 1</td>
<td>2005</td>
</tr>
<tr>
<td>2004</td>
<td>2nd half</td>
<td>2006</td>
</tr>
<tr>
<td>2005</td>
<td>Terminal 2</td>
<td>2007</td>
</tr>
<tr>
<td>2007</td>
<td>2nd half</td>
<td>2009</td>
</tr>
<tr>
<td>2008</td>
<td>Terminal 3</td>
<td>2010</td>
</tr>
<tr>
<td>2011</td>
<td>2nd half</td>
<td>2013</td>
</tr>
<tr>
<td>2014</td>
<td>Terminal 4</td>
<td>2016</td>
</tr>
<tr>
<td>2016</td>
<td>2nd half</td>
<td>2018</td>
</tr>
<tr>
<td>2018</td>
<td>Terminal 5</td>
<td>2020</td>
</tr>
<tr>
<td>2020</td>
<td>2nd half</td>
<td>2022</td>
</tr>
<tr>
<td>2021</td>
<td>Terminal 6</td>
<td>2023</td>
</tr>
<tr>
<td>2022</td>
<td>2nd half</td>
<td>2024</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Start Year</th>
<th>Nanhui Zui satellite</th>
<th>Delivery Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Terminal 1</td>
<td>2010</td>
</tr>
<tr>
<td>2013</td>
<td>2nd half</td>
<td>2015</td>
</tr>
<tr>
<td>2018</td>
<td>Terminal 2</td>
<td>2020</td>
</tr>
<tr>
<td>2021</td>
<td>2nd half</td>
<td>2023</td>
</tr>
</tbody>
</table>
Table of contents

1 Introduction ......................................................................................................................... 1
  1.1 History of the port of Shanghai ....................................................................................... 1
  1.2 Current situation ............................................................................................................. 2
  1.3 Problem analysis and general aim of this study .............................................................. 2

2 Current situation of Shanghai ............................................................................................ 5
  2.1 Available terminals .......................................................................................................... 5
  2.2 Expansion plans at Shanghai’s immediate surroundings .................................................. 7
  2.3 Container movements to and from Shanghai ................................................................. 7

3 Future situation of Shanghai ............................................................................................... 13
  3.1 Comparison with port of Hong Kong .............................................................................. 13
  3.2 General economic situation ............................................................................................ 16
  3.3 Expected throughput development ................................................................................ 17
     3.3.1 Forecasting method .................................................................................................. 18
     3.3.2 Low growth scenario ............................................................................................. 19
     3.3.3 High growth scenario ............................................................................................ 19
     3.3.4 Average growth scenario ....................................................................................... 20
  3.4 Expected number of vessels ............................................................................................ 21
     3.4.1 Development of world container shipping ............................................................... 21
     3.4.2 Modal split .............................................................................................................. 23
     3.4.3 Average TEU capacity per service group ................................................................. 25
     3.4.4 Parcel size per service group .................................................................................. 26
     3.4.5 Total expected number of vessels for Shanghai ....................................................... 27
     3.4.6 Expected vessels on the new terminal .................................................................... 28
  3.5 Expected dimensions of vessels ..................................................................................... 29
     3.5.1 Ocean services group ............................................................................................. 29
     3.5.2 Short sea services group ....................................................................................... 29
     3.5.3 Domestic services group ....................................................................................... 30
     3.5.4 Depth requirements ............................................................................................... 30

4 Project requirements for design .......................................................................................... 33
  4.1 Starting points ................................................................................................................ 33
  4.2 Assumptions .................................................................................................................. 33
  4.3 Boundary conditions ...................................................................................................... 34

5 Needed facilities & Global dimensioning ............................................................................ 35
  5.1 Container handling system ............................................................................................ 36
     5.1.1 Quay handling .......................................................................................................... 36
     5.1.2 Quay to yard transfer (and vice versa) ................................................................. 37
     5.1.3 Yard handling .......................................................................................................... 37
     5.1.4 Yard to transfer modality (and vice versa) ............................................................. 38
  5.2 Quay length .................................................................................................................. 38
     5.2.1 Berths .................................................................................................................. 39
  5.3 Apron area .................................................................................................................... 40
  5.4 Storage area .................................................................................................................. 41
     5.4.1 Share per container type ....................................................................................... 41
     5.4.2 Required storage area ............................................................................................ 42
  5.5 Total terminal requirements .......................................................................................... 43
     5.5.1 Terminal area .......................................................................................................... 43
     5.5.2 Total required terminals ....................................................................................... 43

6 Possible locations ................................................................................................................. 45
  6.1 General ........................................................................................................................ 45
  6.2 Ningbo ........................................................................................................................ 46
  6.3 Nanhui Zui .................................................................................................................... 49
  6.4 Yangshan island ......................................................................................................... 51

7 Location selection ............................................................................................................... 53
  7.1 Description of criteria ................................................................................................... 53
  7.2 Choice of location ......................................................................................................... 55
8 Terminal design ................................................................. 57
  8.1 Description of the natural condition of the area .................. 57
  8.1.1 Geographical ....................................................... 57
  8.1.2 Hydraulic .......................................................... 58
  8.1.3 Meteorological .................................................... 59
  8.2 Approach channel .................................................... 60
  8.2.1 Alignment .......................................................... 60
  8.2.2 Number of lanes .................................................. 61
  8.2.3 Shape of the channel ............................................. 62
  8.2.4 Channel bend calculation for southern variant ................ 67
  8.2.5 Volume of capital dredging .................................... 68
  8.3 Design of the proposed terminals on the Yangshan islands .... 69
    8.3.1 Transport movements .......................................... 69
    8.3.2 Properties of the shuttlebarge ............................... 71
    8.3.3 Determination of number of calls at the terminals .......... 72
  8.4 Configuration within the terminals ................................ 74
  8.5 Determination of the properties of all terminals ................ 76
    8.5.1 Simulation ...................................................... 76
    8.5.2 PROSIM ........................................................ 77
    8.5.3 Determination of the validity of the program ............... 85
    8.5.4 Simulation methodology and results ........................ 92
    8.5.5 Number of berths per terminal ................................ 98
    8.5.6 Apron area ..................................................... 99
    8.5.7 Storage area .................................................. 99
    8.5.8 Total terminal area ........................................... 102
  8.6 Terminal lay-out ..................................................... 102
    8.6.1 Design concepts for the Yangshan terminals ............... 103
    8.6.2 Description of the proposed designs ....................... 103
    8.6.3 Choice for a design ......................................... 109
  8.7 Details of the chosen design ...................................... 111
    8.7.1 Anchorage ...................................................... 111
    8.7.2 Approach to the terminals basins ............................ 111
    8.7.3 Port entrance .................................................. 112
    8.7.4 Basins .......................................................... 112
    8.7.5 Quay constructions .......................................... 114
    8.7.6 Stack areas .................................................... 116
    8.7.7 Building and services per terminal .......................... 116
    8.7.8 General services .............................................. 116
  8.8 Phasing of execution ................................................. 118
  9 Required investments .................................................. 121
    9.1 Determination of the costs ...................................... 121
      9.1.1 Approach channel ............................................ 121
      9.1.2 Breakwaters .................................................. 122
      9.1.3 Reclamation of the terminals' areas ....................... 123
      9.1.4 Quay structure .............................................. 126
      9.1.5 Yard pavement and infrastructure .......................... 127
      9.1.6 Buildings and services ..................................... 127
      9.1.7 Equipment .................................................... 127
      9.1.8 Shuttle barges .............................................. 129
      9.1.9 Nanhui Zui satellite terminal ............................. 129
    9.2 Scheduling of investments ...................................... 131
  10 Conclusions .............................................................. 133
  11 Recommendations ....................................................... 135
  12 References .............................................................. 137
    12.1 Literature ....................................................... 137
    12.2 Magazines ....................................................... 138
Table of figures

Figure 1-1: Container throughput development of Shanghai 1980-1999 ............................ 1
Figure 1-2: Possible locations for port extension ................................................................... 3
Figure 2-1: Picture of terminal positions Huang Pu as well as Waigaoqiao ............................ 6
Figure 2-2: Modal split for container throughput of 1997 ..................................................... 8
Figure 3-1: Container throughput development Hong Kong 1978-1999 ............................ 13
Figure 3-2: Location of Hong Kong and Shanghai ................................................................. 14
Figure 3-3: Prognosis for world container shipping until 2012 ............................................. 16
Figure 3-4: Loading degree vs. available depth per container vessel generation ............... 17
Figure 3-5: Three growth scenarios of Shanghai ................................................................. 20
Figure 3-6: Modal Split for the year 2025 ............................................................................. 24
Figure 3-7: Resulting needed extra capacity ........................................................................ 28
Figure 5-1: General layout of a container terminal ............................................................ 35
Figure 5-2: Transport of new portainer cranes ................................................................. 37
Figure 5-3: RTG system (6 wide 4 high) ............................................................................ 38
Figure 6-1: Map of Ningbo’s surroundings ....................................................................... 46
Figure 6-2: Infrastructural connections with Daxie Dao ..................................................... 47
Figure 6-3: Location of Nanhui Zui .................................................................................... 49
Figure 8-1: Annual sedimentation rate and sediment characteristics .............................. 57
Figure 8-2: Possible approaches to Nanhui Zui ................................................................. 60
Figure 8-3: Elements of the channel width ........................................................................ 64
Figure 8-4: Difference in embankments ............................................................................. 66
Figure 8-5: Graphs for determination of bend radius and width ........................................ 67
Figure 8-6: Transport volumes per modality in the year 2025 ........................................... 71
Figure 8-7: Pablo Metz ...................................................................................................... 72
Figure 8-8: Monthly number of calls per transport modality in the year 2025 ................. 73
Figure 8-9: Schematisation of a Yangshan terminal ......................................................... 74
Figure 8-10: Schematisation of the inter relations between terminals and vessels ............ 75
Figure 8-11: General set up of the simulation ................................................................... 77
Figure 8-12: Processes within the ocean vessel component .............................................. 80
Figure 8-13: Processes within the shuttle components ..................................................... 82
Figure 8-14: Processes of the trucks and trains ................................................................. 83
Figure 8-15: Process of an ocean vessel ............................................................................. 88
Figure 8-16: Distribution of total handling time over the ocean vessels ......................... 93
Figure 8-17: Distribution of total handling time over the shortsea vessels ...................... 94
Figure 8-18: Results of two simulations for the river barges at Yangshan ..................... 95
Figure 8-19: Distribution of total handling time over the river barges ............................ 96
Figure 8-20: Stack size development during 4 years at Shanghai .................................... 97
Figure 8-21: General overview of design proposals ......................................................... 103
Figure 8-22: Lay out of design number 1 ....................................................................... 104
Figure 8-23: Lay out of design number 2 ....................................................................... 106
Figure 8-24: Lay out of design number 3 ....................................................................... 107
Figure 8-25: Lay out of design number 4 ....................................................................... 108
Figure 8-26: Approach to the terminals basins ............................................................... 111
Figure 8-27: Principal directions of wave attack .............................................................. 112
Figure 8-28: Placement of the berths per terminal .......................................................... 113
Figure 8-29: Design proposal for the quays [27] ............................................................... 115
Figure 8-30: Throughput development of the various terminals .................................... 118
Figure 8-31: Schedule of delivery of Yangshan terminals .............................................. 119
Figure 9-1: Rough cross section of the breakwater for estimation purposes ................. 122
Figure 9-2: Rough cross section of the shore protection along the terminals ............... 123
Figure 10-1: Overview of the Yangshan terminals .......................................................... 133
Figure 13-1: Cost minimisation for berth construction [14] ............................................ 14
Figure 13-2: Waiting time vs. utilisation rate for E2/E2/n system per number of berths 16
Figure 13-3: Waiting time vs. utilisation rate for E2/E2/n system per number of berths 17
Figure 13-4: Waiting time vs. utilisation rate for M/E2/n system per number of berths 17

vii
Table of tables

Table 2-1: Properties of SCT.................................................................5
Table 2-2: Target areas for port expansion [2]........................................7
Table 2-3: Monthly calls of the ocean services group [2]...........................9
Table 2-4: Division of containers over ocean and shortsea services groups....9
Table 2-5: Monthly calls of the Short sea services group [5].........................10
Table 2-6: Division of modalities for domestic services............................10
Table 3-1: Container lift cost comparison (in US$) [35]............................14
Table 3-2: Container throughput development for low growth scenario........19
Table 3-3: Container throughput development for low growth scenario........19
Table 3-4: Container throughput development for average growth scenario....20
Table 3-5: Overview of vessel generations............................................22
Table 3-6: Share of transport modes within the domestic services group........24
Table 3-7: Transport volumes in mTEU of the several transport modalities for 2025...24
Table 3-8: Overview of currently sailing vessels and vessels on order [9].......25
Table 3-9: Average estimated ocean vessel capacity for the next 25 years......25
Table 3-10: Average estimated Short sea vessel capacity for the next 25 years...26
Table 3-11: Average estimated domestic vessel capacity for the next 25 years...26
Table 3-12: Parcel size development per service group............................27
Table 3-13: Expected monthly calls per service group for Shanghai............27
Table 3-14: Expected monthly calls per service group for the new terminal area...28
Table 3-15: Future standard vessels for ocean services group....................29
Table 3-16: Future standard vessels for Short sea services group...............29
Table 3-17: Future standard vessels for domestic services group................30
Table 5-1: Total needed quay length per service group per year................39
Table 5-2: Throughput/quay length ratio for several terminals in Asia [12]...39
Table 5-3: World container output per type in thousands of TEUs [9]..............41
Table 5-4: Import/Export division of total throughput [3]..........................41
Table 5-5: Required area per type of container stack (ha)..........................43
Table 5-6: Total required terminal area................................................43
Table 7-1: Results of the MCA............................................................55
Table 8-1: Horizontal tide values..........................................................58
Table 8-2: Seasonal wave data observed by a pilot vessel........................59
Table 8-3: Significant wave heights per season........................................59
Table 8-4: Traffic intensity of the approach channel...................................62
Table 8-5: Factor for basic manoeuvring lane width..................................64
Table 8-6: Total needed channel width..................................................67
Table 8-7: Amount of capital dredging per channel variant per section..........68
Table 8-8: Number of containers transported per transport modality..............69
Table 8-9: Container handling volumes of the various terminals by the year 2025...70
Table 8-10: Properties of the shuttlebarge.............................................72
Table 8-11: Number of monthly calls per terminal of the various transport modes...73
Table 8-12: Division of destinations over the Yangshan terminals................74
Table 8-13: Average values of the properties of the various vessel modalities...84
Table 8-14: Average values resulting from the simulation after 4 simulation years...86
Table 8-15: Differences between model’s averages and calculated averages........87
Table 8-16: Rectification of the difference made by trucks at Nanhui Zui terminal 1........88
Table 8-17: Explanation of the cause of the difference made within the model........89
Table 8-18: Check of the balance of the containers handled in Shanghai....................90
Table 8-19: Check of the balance of the containers handled in Nanhu Zui...................90
Table 8-20: Check of the balance of the containers handled at Yangshan......................91
Table 8-21: Resulting waiting times as percentage of service time..........................93
Table 8-22: Resulting waiting times for the river barges......................................96
Table 8-23: Needed number of shuttles per satellite terminal..................................97
Table 8-24: Needed number of berths at the Nanhu Zui satellite terminals....................97
Table 8-25: Needed number of berths per terminal per vessel group..........................98
Table 8-26: Required quay length per terminal per vessel group..............................98
Table 8-27: Average dwell times per vessel type at Yangshan................................100
Table 8-28: Difference in average dwell times due vessel capacities........................100
Table 8-29: Resulting acceptable average dwell time for 2025.................................101
Table 8-30: Required storage area per stack type per terminal................................101
Table 8-31: Total required area per terminal.........................................................102
Table 8-32: Results of the MCA for the design proposals.........................................110
Table 8-33: Calculation of the needed number of tug boats......................................117
Table 8-34: Delivery schedule of Yangshan terminals.............................................119
Table 8-35: Delivery schedule of Nanhu Zui terminals...........................................120
Table 9-1: Calculated soil volumes per terminal.....................................................123
Table 9-2: Calculated dredging volumes within the terminals’ basins........................124
Table 9-3: Soil volumes to be displaced ...................................................................125
Table 9-4: Costs per reclamation element in million US$ (Price level of 1997).............126
Table 9-5: Costs of quay structures per terminal......................................................126
Table 9-6: Yard pavement and infrastructural costs per terminal...............................127
Table 9-7: Costs per terminal of buildings and services...........................................127
Table 9-8: Equipment costs per terminal.................................................................128
Table 9-9: Total investments throughout the years....................................................131

APPENDICES:
Table 13-1: Overview of currently sailing vessels and vessels on order......................5
Table 13-2: Calculation of expected vessel capacity..................................................5
Table 13-3: Modal split for the year 2008.................................................................6
Table 13-4: Container volumes in mTEU per transport modality for the year 2008......6
Table 13-5: Modal split for the year 2015.................................................................6
Table 13-6: Container volumes in mTEU per transport modality for the year 2015......6
Table 13-7: Modal split for the year 2025...............................................................7
Table 13-8: Container volumes in mTEU per transport modality for the year 2025......7
Table 13-9: Parameters queue theory for 5 mTEU terminal.......................................13
Table 13-10: Utilisation per service group per berth...............................................15
Table 13-11: Optimisation of queue theory results..................................................18
Table 13-12: Optimalisation per service group according to results of 5 mTEU terminal18
Table 13-13: Optimalisation according to the ocean services group..........................19
Table 13-14: Optimalisation according to the short sea services group.....................19
Table 13-15: Optimalisation according to the domestic services group......................19
Table 13-16: Results of maximisation of the waiting times per service group............20
Table 13-17: Quay length of optimalisation according to the ocean services group......21
Table 13-18: Quay length of optimalisation according to the short sea services group ..21
Table 13-19: Quay length of optimalisation according to the domestic services group ..21
Table 13-20: Soil conditions around Nanhui Zui.....................................................1
Table 13-21: Basis manoeuvring width....................................................................35
Table 13-22: Traffic density table..............................................................................35
Table 13-23: Cargo hazard .......................................................................................35
Table 13-24: Additional width for Passing distance in two-way traffic.........................35
Table 13-25: Additional width for bank clearance.....................................................35
Table 13-26: Additional widths for straight channel sections.....................................36
Table 13-27: Channel dimensions for the northern variant........................................37
Table 13-28: Total volume to be dredged for northern variant ........................37
Table 13-29: Channel dimensions for the southern variant ..........................38
Table 13-30: Total volume to be dredged for southern variant ..................38
Table 13-31: Difference in capital dredging volumes between variants.........38
Table 13-32: Valuations and results per design within the MCA....................46
Table 13-33: General elements investments..............................................49
Table 13-34: Yangshan terminals investments..........................................49
Table 13-35: Nanhui Zui terminals investments........................................49
Table 13-36: Investment in shuttles.........................................................50
Table 13-37: Total investments in the several elements throughout the years....50
1 Introduction

1.1 History of the port of Shanghai

Yangtze River is with 6300 km the largest river in China. The river runs through 9 Provinces that account for an estimated 40 % of China’s Gross Domestic Product (GDP) and 21 % of its trade [2]. Around 400 million people rely on the economic activities deployed via this river that can be seen as the largest economic east-west connection of China with the rest of the world.

Lying at the mouth of the river, Shanghai acts as the central trading place between economic activities in the Yangtze River Basin and the rest of the world. Shanghai isn’t therefore accidentally called “The dragon head” of the Yangtze River.

Since the port of Shanghai was officially opened to the public in 1263 the port only became an international trading centre halfway the 19th century. In the 1920’s and 1930’s Shanghai reached its climax of power but during the Second World War this climax came to an end.

After the adoption of the reform and opening up policy in 1978, the government of China finally put a great effort into stimulating the development and construction of new ports. This stimulation policy led to the construction of 363 deepwater berths able to accommodate ships of 10,000 dwt and over in the last 2 decades. The total number of berths able to handle ships of 10,000 dwt and over came to 496 in 1997, which was almost fourfold of the number of deepwater berths in 1978.

Along this development, China had focused on specialisation of berths, which also led to 30 ports operating container-handling businesses with a total annual handling capacity of 10 million TEUs. Up to 1997, 65 dedicated container berths had been constructed and 400 large gantry cranes had been installed following the yearly container traffic growth rate of over 25 % since 1978.

![Figure 1-1: Container throughput development of Shanghai 1980-1999](image-url)
At present moment the Yangtze River delta is the most developed region of China. The average annual increase in foreign development is 20%. From 1990 till 1999 the annual increase of container transport in the region was 27%. Shanghai port accounts for ¾ of the total annual container throughput in the region. Due to the limited water depth, the development of container transport along the Yangtze River is slow.

1.2 Current situation

At this moment the Chinese economy is one of the largest in the world and with its probable accession to the World Trade Organisation international shipping via Yangtze River will increase rapidly.

As "The dragon head" of Yangtze River, the government plans to turn Shanghai into an international finance, economic and trading centre processing a large share of the Asia region's cargo exchanges. The government even has plans to take over the leading positions of ports like Hong Kong, Singapore and Kaohsiung.

At present moment the port of Shanghai owns 3 terminal facilities: The first is a terminal along the bank of the Huangpu River that has 7 container berths with a total design capacity of 1.45 mTEU. The second is the Waigaoqiao terminal phase 1 that has 3 container berths with a design capacity of 0.6 mTEU. And the third is the Waigaoqiao terminal phase 2 that has the same properties as phase 1.

When Shanghai as a port entered in 1998 the top 10 of the port throughput league it wasn’t much of a threat to the leading ports. But when it turned out to be one of the fastest growing ports in the world the leading ports started to worry. From 1992 till 1999 the annual growth rate average was almost 28% leading to a throughput in 1999 of 4.2 mTEU. This figure is still a small one compared to the world’s leading ports like Hong Kong (16.2 mTEU) and Singapore (15.9 mTEU) but at this growth rate it will soon catch up with these ports.

1.3 Problem analysis and general aim of this study

To accommodate the aforementioned growth, Shanghai needs to expand its container handling facilities while the actual annual throughput already exceeds the design capacity of the terminals. Furthermore it is not only the capacity of the terminals that calls for expansion, it is also the increasing draught of the ships. The present terminals aren’t able to handle fully laden fourth generation ships while the trend in container shipping leads to ships able to carry up to 12,500 TEU (Post 5th generation ships).

To build new terminals, Shanghai faces a few problems like the lack of space in the immediate surroundings of the existing container terminals and high yearly returning dredging costs to maintain a deepwater approach channel in the Yangtze River. To cope with these problems Shanghai aims for a new container terminal at a location outside the Yangtze River delta area.

At the surroundings of Shanghai there are many locations that can be considered for expansion of the existing container terminals. This report deals with 3 locations at which Shanghai is currently aiming.
The first is an area along the coast of Nanhai Zui. Current plans are to construct a 4-berth container terminal able to handle 0.80 mTEU near Jinshan Zui. This terminal is projected for completion by the year 2004.

The second option is to construct a terminal on the islands Xiaoyangshan (Big Island) and Dayangshan (Little Island) lying 30 km offshore. These islands don’t face the siltation problems that Shanghai faces. The new container terminal could be connected with mainland via a 6-lane highway bridge.

The port at Ningbo is the third option due to the fact that it has favourable geographic conditions such as natural deep water areas close to shore. Ningbo lies in the Hangzhou bay area and is naturally protected by the Zhoushan islands.

In this report these 3 options will be examined on their economic suitability. After this process, a choice will be made to further develop one of the locations. Therefore a container terminal design will be made.

The general aim of this study will be:

'The design of a container terminal for expansion of the port of Shanghai on one of three potential locations'
2 Current situation of Shanghai

2.1 Available terminals

In 1999 the combined designed container handling capacity for ports in the Yangtze River delta was 4.3 million TEUs. The actual throughput however was almost 5.4 mTEU. At present there are 7 container ports in the Yangtze River delta area. Of these ports, Shanghai and Ningbo are the most important ones.

Shanghai as China’s largest port is registering one of the fastest growing rates in Asia. It is now firmly established as the region’s fifth largest and world’s seventh largest container port. Container operations at the port of Shanghai, which account for 78.3 % of the total container throughput of all container ports in the Yangtze River delta, are managed by Shanghai Container Terminals (SCT) and Shanghai Port Authority (SPA). SCT operates 3 container terminals at Huang Pu River and SPA operates a terminal at Waigaoqiao, which is situated along the Pudong coastline, between Shanghai and the East Chinese Sea.

Shanghai Container Terminals (SCT), established in 1993, is a joint venture of Shanghai Port Authority (SPA) and Hutchinson Port Holdings (HPH). SPA is involved for 60 % and HPH, part of Hutchison Whampoa Ltd (Hong Kong), is involved for 40 %. This joint venture has 10 terminals at Huang Pu River of which 3 are dedicated container terminals. See Figure 2-1 for their location. These 3 terminals have 11 container handling berths with a total length of 2280 metres. Further properties of these terminals are given in Table 2-1.

In October 1999, SCT handled its 10 millionth TEU since the establishment in 1993. This figure meant an average annual growth rate of 18 %. Currently SCT is handling 70 % of Shanghai’s annual throughput. The design capacity for container handling is 2.03 mTEU per year. In 1999 however the container throughput was 2.6 mTEU. SCT could reach this high figure because containers have been handled more efficiently. It isn’t however likely that SCT will sustain this increase while all terminals lie at Huang Pu River. This river is not able to cope with the trend of increasing ship dimensions. Already some vessels docking at the Huang Pu River have to discharge part of their load in advance due to draught restrictions. Some even have to back out because they are unable to turn in the river. It is obvious that this shortage causes expensive delays.

<table>
<thead>
<tr>
<th>Terminal facilities:</th>
<th>Shanghai Container Terminals (SCT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Bao Shan</td>
</tr>
<tr>
<td>Quay length (m)</td>
<td>640</td>
</tr>
<tr>
<td>Depth along the quay (m)</td>
<td>9.4</td>
</tr>
<tr>
<td>Total stacking area (m2)</td>
<td>218,000</td>
</tr>
<tr>
<td>Storage capacity (TEU)</td>
<td>15,800</td>
</tr>
<tr>
<td>Reefer points (--)</td>
<td>351</td>
</tr>
<tr>
<td>Handling equipment:</td>
<td></td>
</tr>
<tr>
<td>Ship to shore gantries (--)</td>
<td>4</td>
</tr>
<tr>
<td>Yard gantries (--)</td>
<td>12</td>
</tr>
<tr>
<td>Reach stackers (--)</td>
<td>24</td>
</tr>
<tr>
<td>Yard tractors (--)</td>
<td>15</td>
</tr>
</tbody>
</table>
The increasing demand for capacity in the Shanghai Region has led to a major development at the Waigaoqiao port area (also known as Gaoqiaozui). (See Figure 2-1 for its location)

The initial phase of the development created a quay length of 900 metre and capacity of 600,000 TEU. In 1999, as a part of phase II, 3 berths (Total length 900 metres) were completed. These 3 berths brought the total quay length to 1800 metre and doubled the terminal’s capacity to 1.2 mTEU. In March 2000, the Shanghai Port Authority, HPH and Cosco signed an agreement to further develop the Waigaoqiao in phase II and III. Work has already begun on phase III, which adds 2 more berths bringing the total capacity to 1.8 mTEU. Preparations to bring a fourth phase into the Waigaoqiao terminal are currently being made.

Figure 2-1: Picture of terminal positions Huang Pu as well as Waigaoqiao

To further develop SCT and the container terminals of Waigaoqiao area, the port of Shanghai has to enlarge the available depth of the port’s waterways while it isn’t capable of receiving the future expected vessel size.

At the end of August 2000 however, a 5,750 TEU vessel (LT Ursula) has been berthed at SCT’s Jun Gong Lu terminal. Though it was only partly loaded, handling of these vessels isn’t a problem. The Waigaoqiao berths for example have a depth along the quay of 12 metres and in the period of 1998 till 1999 four super Post-Panamax quayside cranes were delivered. The main problem therefore lies at the depth of the approach channels. The siting of the Yangtze River estuary has created a 20-km sand bar, which provides clearance of only 8.5 m at low tide, while 10.5/11.5 m is available at high tide [1].

At the end of 1997, work started to deepen the entrance to the river. The first phase was to build two 50-km long training dikes parallel to the river to narrow the flow of the river creating a natural erosion process. The entire project’s goal is to deepen the channel to 12.5 metres. This should be ready by the year 2005. Container vessels of up to 3500 TEU (3rd generation vessel) can then be received without a tidal restriction [16]. Although this depth is a big improvement, it isn’t sufficient to make Shanghai a deep-water port.
2.2 Expansion plans at Shanghai’s immediate surroundings

Shanghai needs to develop its container terminals to stay competitive as an international shipping centre. While depth of the approach channels is only 8.5 metre [30] at low tide, Panamax and higher vessels cannot call at the port fully loaded. Shanghai therefore needs to find a way to increase its container throughput regardless to depth. To achieve this goal, the port of Shanghai is aiming for a larger number of vessels. To be able to receive this larger number of vessels on short term, Shanghai plans for a quick development of container terminals.

While Huang Pu River is not able to handle larger vessels, the Shanghai Harbour Bureau now focuses on the Yangtze River estuary for development of new terminal area. At the moment Shanghai is developing the Waigaoqiao port area. Like already mentioned before, work has begun on phase 3 and phase 4 is currently being prepared.

Another possible expansion area is the Wahaogou area lying 10 kilometres to the South of Waigaoqiao. This area has been chosen for development of a four-berth container terminal with a capacity of 0.80 mTEU/year. Development of this terminal will start in 2000. Total quay length will then reach 1000 metres.

Finally, the SPA has plans to develop a new deep-water container handling facility with four berths at Jinshan Zui at the southern tip of the Shanghai municipality. These new berths should be able to handle around 0.8 mTEU.

Table 2-2: Target areas for port expansion [2]

<table>
<thead>
<tr>
<th>Target areas</th>
<th>Quay Length (m)</th>
<th>Capacity (mTEU/Year)</th>
<th>Available By</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waigaoqiao – Phase 3 and 4</td>
<td>400</td>
<td>0.3</td>
<td>2002</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>0.3</td>
<td>2004</td>
</tr>
<tr>
<td>Wahaogou</td>
<td>500</td>
<td>0.4</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>0.4</td>
<td>2005</td>
</tr>
<tr>
<td>Jinshan Zui</td>
<td>500</td>
<td>0.4</td>
<td>2002</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>0.4</td>
<td>2004</td>
</tr>
</tbody>
</table>

2.3 Container movements to and from Shanghai.

While analysing the container movements to and from Shanghai, a lot of different ways of container movements can be distinguished. Containers are transported via road, rail, waterways and oceans. All these modalities interact with each other creating a lot loading and unloading activities. To make the loading and unloading process clear, all these transport modalities can be divided over three main groups. These groups are the Ocean services, the Short sea services and the Domestic services.

To be able to get insight in these activities, results from a study on container transport processes in the Yangtze River Basin has been used (See [3]). This study has been executed in 1997 by the State Planning Commission of the People’s Republic of China in combination with the Ministry of Transport and Public works of the Netherlands. This study based its results on the year 1995. While this study does not mention any number of calls of the various vessels, data on this subject has been used from publications done by the Shanghai Municipal Statistics Bureau regarding the year 1997 [5].

Throughput

In 1997, total container throughput of the port of Shanghai reached 2.53 mTEU. This throughput figure has been established by counting all containers that have passed the
ocean and shortsea quays. While no domestic container trade takes place at Shanghai, all containers had an import or export destination.

In total there were 1.14 mTEU of import containers counting for 45 % of total throughput and 1.39 mTEU of export containers counting for the remaining 55 %.

All of these containers have been transported by the afore mentioned service groups. In general one could say that there are two "sides" of the transport of containers. An "international" side which forms the connection of China with other countries and a "domestic" side which forms the connection with the hinterland.

At the international side the containers have been transported by the ocean services group and the shortsea services group. The ocean services group carried 45 % of all containers and the shortsea services group transported the remaining part of 55 % of all containers.

At the domestic side the domestic services group transported all containers. Within this group 3 transport modalities are active. Transport by truck accounting for 80 % of all containers, transport by river barge accounting for 18 % of all containers and transport by train accounting for the remaining 2 % of all containers.

For an overview of all transport activities see the figure below.

![Diagram](image)

**Figure 2-2: Modal split for container throughput of 1997**

Now the general transport movements are made clear, a closer look can be taken at the individual services groups.
Ocean services:

The ocean services group contains the vessels that are put on the major liner services and are generally operated by the grand alliances. While more than 80 % of trade (in tonnage) with origins or destinations in developing countries is waterborne [2], these vessels could be seen as the trade connection of China with the several continents.

For Shanghai, mostly ocean liner vessels from North America and Europe call at the port. Asian countries are serviced by the Short sea services group while the smaller vessels are used to transport containers up and down the Yangtze River.

Table 2-3: Monthly calls of the ocean services group [2]

<table>
<thead>
<tr>
<th>Route</th>
<th>Calls</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Europe</td>
<td>22</td>
<td>28%</td>
</tr>
<tr>
<td>Australia</td>
<td>4</td>
<td>5%</td>
</tr>
<tr>
<td>Persian Gulf</td>
<td>9</td>
<td>11%</td>
</tr>
<tr>
<td>The Mediterranean</td>
<td>8</td>
<td>10%</td>
</tr>
<tr>
<td>North America</td>
<td>26</td>
<td>33%</td>
</tr>
<tr>
<td>South America</td>
<td>4</td>
<td>5%</td>
</tr>
<tr>
<td>Africa</td>
<td>7</td>
<td>9%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>80</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

In total, there are 80 calls per month resulting in an average number of 960 calls per year. The average capacity of these vessels lies around 3350 TEU while nowadays almost only ships of the 3rd generation and higher are put on these routes.

A quick calculation shows that these vessels were only partially (un)loaded. Normally, these ships aren’t fully (un)loaded while they sail along a route comprising more than one port. The part of the load capacity that is being “refreshed” per call is called the “parcel size”. This parcel size is expressed as a percentage of the ship’s loading capacity. When, for example, a vessel (1000 TEU capacity) has a parcel size of 75 %, then 750 containers will be unloaded and 750 containers will be loaded at the port.

For ports like Singapore and Hong Kong the parcel size lies around 50 % [4] For the ocean services group at Shanghai, this figure was only 18 %. This low value can mainly be accounted to the fact that Shanghai isn’t a hub port yet and can also partly be ascribed to the draught restrictions that these vessels face.

Another remarkable feature of Shanghai is that there are hardly any transshipment activities at the moment. This can also be ascribed to the fact that Shanghai is not a hub port yet and will probably change in the future.

Table 2-4: Division of containers over ocean and shortsea services groups

<table>
<thead>
<tr>
<th>Modality</th>
<th>Average TEU Cap.</th>
<th>Parcel size</th>
<th>Voyages per</th>
<th>Total TEU</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>3350</td>
<td>18%</td>
<td>80</td>
<td>960</td>
<td>1 138 500</td>
</tr>
<tr>
<td>Short sea</td>
<td>500</td>
<td>69%</td>
<td>168</td>
<td>2 016</td>
<td>1 391 500</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>248</strong></td>
<td><strong>2 976</strong></td>
<td><strong>2 530 000</strong></td>
<td><strong>100%</strong></td>
<td></td>
</tr>
</tbody>
</table>
**Short sea services**

This group consists of vessels that sail between Shanghai and ports in countries nearby. Nearby, in this context, are countries like Japan, Hong Kong, Korea and countries in Southeast Asia.

In 1997 the number of calls per month lay around 168.

<table>
<thead>
<tr>
<th>Route</th>
<th>Calls</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Southeast Asia</td>
<td>13</td>
<td>8%</td>
</tr>
<tr>
<td>Japan</td>
<td>86</td>
<td>51%</td>
</tr>
<tr>
<td>Hong Kong</td>
<td>42</td>
<td>25%</td>
</tr>
<tr>
<td>Korea</td>
<td>26</td>
<td>15%</td>
</tr>
<tr>
<td>Vladivostok</td>
<td>1</td>
<td>1%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>168</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

Generally the capacity of these vessels lies between 250 TEU and 1500 TEU. The average capacity of this group is 500 TEU and the parcel size of these vessels is 69%.

**Domestic services**

The domestic services comprise all container transportation modes that transport containers to and from the Chinese provinces. These transport modes consist of river, road and rail transport.

Table 2-6: Division of modalities for domestic services

<table>
<thead>
<tr>
<th>Modality</th>
<th>Average TEU Cap.</th>
<th>Parcel size</th>
<th>Voyages per</th>
<th>Total TEU</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Month</td>
<td>Year</td>
<td></td>
</tr>
<tr>
<td>Water</td>
<td>50</td>
<td>91%</td>
<td>417</td>
<td>5 004</td>
<td>4.55E+05</td>
</tr>
<tr>
<td>Road</td>
<td>2</td>
<td>75%</td>
<td>56 222</td>
<td>674 667</td>
<td>2.02E+06</td>
</tr>
<tr>
<td>Rail</td>
<td>75</td>
<td>75%</td>
<td>37</td>
<td>450</td>
<td>5.06E+04</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>56 677</strong></td>
<td><strong>680 121</strong></td>
<td></td>
<td><strong>2 530 000</strong></td>
<td></td>
</tr>
</tbody>
</table>

**Road:**

The main transportation mode of this group is the truck. This modality is taking account for 80% of the through transport handled by the domestic services group [3]. The reason for this high rate is that conditions of highways in Shanghai are comparatively good.

It is assumed that a truck has a capacity of 2 TEU and a parcel size of 75%. That means, in this case, that every second arriving truck is only fully loaded during the arrival at the port or departure from the port.

**River:**

The second largest transport mode is the river barge. Transport via waterways is taking account for 18% of the total domestic container movements [3].

Mainly there are 2 types of vessels for domestic service transport, the self-propelled barge and the push and towed barges. The self-propelled barges are mainly transformed from old vessels, and the pushed and towed fleet is composed of deck barges or trough barges. The tonnage of these vessels varies from 30 to 110 TEU and has an average of 50 TEU [3].
Most of these barges (79%) have a destination along the Yangtze River. 15% of the barges sail along the coast and the remaining 5% can be categorised as local trade sailing via p.e. the Huang Pu River [5].

Although river transport is only taking account for a small percentage of the total throughput, this modality is growing rapidly. With the design of the Waigaoqiao terminal however, berths for inland river barges have not been taken into consideration. Now barges and sea-vessels are using the same berths leading to increasing waiting times for the calling and handling of the domestic feeder barges.

Rail:

The third modality is transportation via railway. Although transportation via railway is still small, it is gradually developing. At present, rail capacity is limited, delays are common and intermodal rail services are undeveloped. Container transport is last on the list of priorities for rail, which rank passengers, ore, oil, foodstuffs and military supplies first [2]. To create a sufficient rail network, the Ministry of Railways of China has set up the China Railway Containers Transport Centre (CRCTC) in 1994. This was done in order to develop intermodal container rail terminals and links between seaports and major inland locations. At the end of 1996, 59,500 kilometres of track were in place, compared with 53,500 kilometres in 1995.

A container shuttle using a rail connection between Shanghai and Nanjing that has been opened in 1996 forms a part of this development. This railway has already been extended to Hefei in the Anhui Province lying approximately 500 km to the west of Shanghai. In this way CRCTC is developing a network of hubs and spokes, and planned to have 10 inland container terminals and 500 container yards by 1999. In 1997 the China Railway Containers Transport Centre moved 2.45 mTEU of containers and forecasted 4 mTEU by the year 2000.
3 Future situation of Shanghai

In this chapter an estimation will be made of the future situation of container throughput at Shanghai. Eventually a container throughput and a number of vessels will be calculated to be able to determine the capacity of the new terminal.

By trying to make a comparison with an existing port, an overview can be given of the future possibilities of the port. For this comparison the port of Hong Kong will be used. Although they seem very different, (Hong Kong is the world largest container port measured in container throughput) they show great resemblance. In the following part, the container port of Hong Kong will be described after which a comparison will be made with the port of Shanghai.

3.1 Comparison with port of Hong Kong

Hong Kong's features

Situated in the south of China, Hong Kong lies at the junction of the large ocean going vessels and the smaller river transport barges sailing up and down the Pearl River. This strategic location caused Hong Kong to be serving as an international trading centre for many years. Hong Kong's position as China's main hub port was, among other reasons, established while China's own ports lacked the capability to handle deep-sea vessels [7]. In 1999 Hong Kong was, with a container throughput of 16.2 mTEU, the world's largest container port.

Hong Kong started to handle containers in the early 1970's with the opening of the Kwai Chung Terminal. Around 1980 Hong Kong reached a throughput of 1.5 mTEU and has, since then, known an average annual growth of 13.6 %. This can be ascribed to the high efficiency rates of its terminals handled by well-qualified personnel. Another strong feature of the port of Hong Kong is its flexibility. The port can easily meet the customers' demands while it operates different types of container handling.

In 1998, during the Asia crisis, the annual growth was close to zero but in 1999 it rose again to 11 % reaching the earlier mentioned record of 16.2 mTEU. For the next decade, the Hong Kong Port and Maritime Board expects to reach an annual growth of 4.6 %. This will lead to a throughput figure of 27 mTEU in 2010.

Figure 3-1: Container throughput development Hong Kong 1978-1999
At present there are 8 container terminals with a combined capacity of 11.5 mTEU. For further development of container terminals able to handle future throughput expectations, Hong Kong's location provides great opportunities. The location is for instance naturally protected by shoals and islands and provides natural deep water areas. A natural disadvantage that Hong Kong faces are the yearly returning typhoon threats causing the port to close.

The hinterland of Hong Kong mainly consists of the province Guangdong. The rapid development of this province, China's wealthiest, was the driving force behind Hong Kong's remarkable growth as container port. The Pearl River estuary gains access to almost every high populated area in this province. The other areas can be accessed by means of road transport.

A major threat of Hong Kong is the high container handling costs (See Table 3-1 for an impression of p.e. container lift costs). Terminal handling costs have tripled over the past 15 years, while these costs remained the same or have been reduced in many other ports. Shipping lines have been complaining heavily during recent years about these costs and as long as the container market is a "market", shipping lines will eventually choose to call at other ports. In fact, they are already considering a switch to cheaper ports nearby such as Shenzhen and Shanghai.

According to the Hong Kong Port and Maritime Board it is very difficult to reduce their costs, while Hong Kong is the only major port in the world operating on a fully commercial basis. Other ports are generally supported by government subsidies.

Table 3-1: Container lift cost comparison (in US$) [35]

<table>
<thead>
<tr>
<th>Container port</th>
<th>20'/40'</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>125</td>
</tr>
<tr>
<td>Japan</td>
<td>100</td>
</tr>
<tr>
<td>Korea</td>
<td>40</td>
</tr>
<tr>
<td>Shanghai</td>
<td>40</td>
</tr>
<tr>
<td>Singapore</td>
<td>40</td>
</tr>
<tr>
<td>Taiwan</td>
<td>60</td>
</tr>
</tbody>
</table>

Comparison

As can be seen from the text above, Shanghai shows great resemblance with Hong Kong. In this part, a comparison will be made for some general aspects that could be responsible for the success of a port.

Figure 3-2: Location of Hong Kong and Shanghai
Location

Location near major traffic routes
Hong Kong is situated near the major east-west routes. Both ports lie in the immediate surroundings of a large river connecting them with the hinterland. Hong Kong lies in the Pearl River delta and Shanghai lies at the mouth of Yangtze River.

Deep water area:
Hong Kong lies in the immediate surroundings of deep water areas and has therefore always been able to provide service without a draught restriction. While Shanghai lies at the bank of the Yangtze River, it cannot provide a deep-water terminal but it has sufficient deep water areas nearby. Up till now these locations haven’t been exploited while there was no necessity to do this.

Hinterland connections

Stage of development of hinterland
The hinterland of both Hong Kong and Shanghai mainly consists of the more developed coastal provinces. The more inland situated provinces are starting to develop.

Modes of transport
Connection with these provinces mainly takes place via the road network even though the quality of this network is very poor. This leads to congestion and therefore cost increases. In the future it is very probable that more cargo will be transported via river barges in imitation of Europe. While the more inland situated provinces are starting to develop, the catchment area of the river is very important. At this point, the location of Shanghai is better while Yangtze River is the largest river of China. Around 400 million people rely on the economic activities deployed via this river that can be seen as the largest economic east-west connection of China with the rest of the world.

Facilities

Modes of operation
At the moment Hong Kong has 8 terminals. Shanghai has 4 terminals. Besides these terminals, Hong Kong makes use of so called "midstream operations". Vessels are (un)loaded in the Victoria harbour by barges. This reduces terminal costs, but takes more time. Further, Hong Kong has separated river barges form ocean going vessels. This has led to a higher efficiency rate.

Efficiency
The port of Hong Kong employs highly skilled personnel. In combination with automation of processes, the efficiency level of Hong Kong is very high. The port of Shanghai has also proven to be efficient, while the design capacity in 1999 was 2.03 mTEU, they handled 2.6 mTEU.

Costs

Charges
Comparing the container handling costs of Hong Kong with Shanghai, it can be seen from Table 3-1 that lifting costs of Shanghai are only a third of that of Hong Kong.

Judging from the above mentioned aspects, it seems that the ports are very much alike. The difference is that Hong Kong has had a head start and is now lying 10 years ahead
of Shanghai. Shanghai however seems to be making up for lost years fast as can be seen from .

In the following few paragraphs it will be determined if Shanghai will actually outgrow ports like Hong Kong.

### 3.2 General economic situation

World container trade has, since its establishment in 1956, been growing at a rapid pace. In fact, in the past decade world port container traffic doubled to reach 175 mTEU in 1998. It is estimated that worldwide container traffic through ports has probably reached 220 mTEUs in the year 2000 and between 418 and 455 mTEUs in the year 2012 [2]. (See Figure 3-3)

![Figure 3-3: Prognosis for world container shipping until 2012](chart)

By that time, 55 % to 60 % of this number will be moving through Asian ports. China will contribute highly to this figure while it is very probable to access the World Trade Organisation (WTO). With this in mind, China has an enormous potential to develop its economy and thus its container transports.

At present over 85 % of China’s container port throughput arises from coastal provinces on which most of China’s trade is based. With the development of its vast hinterland, China expects to double its GDP between 2000 and 2010 [6]. Prospects are even that China will be the second largest economy in the world by 2020 [29].

Shanghai is serving 7 provinces on the Yangtze River accounting for an estimated 40 % of China’s GDP and 21 % of its trade. With the prospects for China as a whole, Shanghai’s container throughput is expected to grow at a fast rate while Shanghai is serving as a hub for China’s trade. With this in mind, Shanghai will outgrow its current terminal capacity, while it is highly likely that China will get access to the WTO. Above this all China aims for Shanghai to become a regional hub.

To be able to cope with future prospects, a plan has to be made to further develop the port of Shanghai. Therefore, a forecast will be made of the container throughput until the year 2025. With this forecast the number of vessels that will call at the port can be calculated and a terminal design can be made.
3.3 Expected throughput development

The future throughput of a port in general depends on many decisions that will be made within the port, by the government of its country and even by decisions of other countries governments. In this case for example, the throughput of Shanghai depends highly on China’s accession to the WTO.

Considering this high uncertainty, most forecast study reports only make a throughput forecast for the next 5 to 10 years. For port planning it is necessary to predict further in the future. For Shanghai, a forecast for the year 2025 will be made.

Forecasts regarding GDP growth of China are generally made for a longer term. Just recently for example, a GDP forecast made by the China Economic Research Institute (CERI) until the year 2020 was quoted in Ports and Harbors (November 2000).

While no official data is available regarding container throughput of Shanghai in 2025, use will be made of GDP growth forecasts in combination with a short term container throughput forecast. This will be done considering the fact that growth of container throughput is generally connected to GDP growth of the regarded country.

Before starting to make this forecast first an important factor has to be discussed. In the future, draught restrictions imposed by the Yangtze River will probably influence the growth of throughput figures at the port of Shanghai. As was already stated before, ocean going vessels can only enter the port while partially loaded even when a tidal window is used. A study considering the loading degree versus available depth at the Yangtze River, shows that even when the Yangtze River is deepened to 12 metres below chart datum, vessels of the 5th generation still cannot enter the port fully loaded (See Figure 3-4).

![Figure 3-4: Loading degree vs. available depth per container vessel generation](image)

This draught restriction will probably cause a delay in the development of container throughput while large dredging works first have to be executed. With the aspirations of the Chinese government to turn Shanghai into a regional hub, this does not seem to be acceptable. Therefore, in this study a container throughput forecast will be made regardless to available draught.
After the forecast on container throughput, the expected number and dimensions of the vessels calling at Shanghai will be determined. With these figures, regarding the number of containers as well as vessels, a judgement can be made whether there is time to wait for the dredging works. Furthermore, with the calculations resulting from the forecast it can be judged whether a location along the Yangtze River is suitable at all considering for example spatial requirements. Therefore, after the forecast, first the dimensioning of the terminal will take place before something can be said about the terminal's location and thus use of the Yangtze River.

In the following few paragraphs the forecast will be made.

3.3.1 Forecasting method

Like already mentioned a combination will be made between forecasts regarding the annual GDP growth of China as a whole and a forecast regarding the annual container throughput growth of Shanghai.

For the GDP growth forecast of China, use will be made of predictions by the China Economic Research Institute (CERI) and the Global Economic Prospects report of Worldbank [6]. Both forecasts are quite similar and are made for the period until 2020. CERI predicts annual GDP growth to be 7 - 7.5 % in the period between 2000 and 2010 and 6 % period until 2020 while Worldbank predicts GDP growth to be 7 % annually until 2020.

The forecast regarding annual container throughput growth used in this report is made by Ocean Shipping Consultance (OSC) [2] and counts for the period until 2012. For this forecast OSC has made two scenarios in order to cope with a few possible events. These scenarios are partially based on OSC's expectation of China's GDP development. In this way a rough check can be made of the validity of OSC's forecast.

To be able to make a prediction regarding annual container throughput growth until the year 2025, the following method has been used. Until the year 2012 both GDP and container throughput growth are predicted by OSC. The multiplying factor lying between both figures will be used to extrapolate annual container growth beyond 2012 using the predicted GDP growth figures until 2020. For the period between 2020-2025 linear extrapolation of the obtained forecast until 2020 will be used.

In the following sections the 2 scenarios made by OSC will be described and expected throughput figures will accordingly be calculated.
3.3.2 Low growth scenario

For the low growth scenario OSC assumes that average annual GDP growth of China will be 7.5% until 2012. This is a result of a possible uncertain development fed by periods of political uncertainty and instability. CERI and Worldbank very much agree with this figure while they both predict a growth of 7 - 7.5% for this period.

The average annual growth of container throughput at Shanghai for the period between 2000-2012 is estimated to be 8.3% according to OSC (See Appendix I). This figure leads to a throughput of 13 mTEU by the year 2012. The factor lying between annual GDP growth and container throughput growth in this case is 1.11 and will be used in combination with the GDP forecast for the period beyond 2012.

For this period, predictions made by CERI and Worldbank differ. For this scenario, the lowest forecast of the two will be used. With 6% annually CERI has made the lowest forecast and will therefore be used. This leads to an annual container throughput growth of 6.7% and an eventual throughput of 30 mTEU in 2025. See the table below for some more details.

Table 3-2: Container throughput development for low growth scenario

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>mTEU</td>
<td>5.0</td>
<td>7.4</td>
<td>11.1</td>
<td>15.8</td>
<td>21.8</td>
<td>30.1</td>
</tr>
</tbody>
</table>

In Figure 3-5 the course of growth can be found together with the high growth scenario.

3.3.3 High growth scenario

For the high growth scenario OSC expects continued national growth at 8 to 8.5% annually until 2012. This percentage is based on continuing expansion of the southern, eastern and northern industrial zones. Furthermore it is expected that the inland provinces start to develop. The growth prediction made by OSC doesn’t agree with predictions made by CERI and Worldbank. While the predictions made by these last two institutes are more recent than the prediction made by OSC, the throughput will be calculated according to the CERI and Worldbank figures.

OSC furthermore predicts an annual container throughput growth of 10.9% until the year 2012. The factor lying between OSC’s GDP growth prediction and container throughput growth prediction is 1.28. This factor is rather high and can be accounted to the starting development of the inland provinces. Together with this development, these provinces start to containerise their products. In this report it is assumed that for the total period until 2025 the multiplier will decrease. For the period beyond 2012 the multiplier of the low growth scenario, which was 1.11, will therefore be used.

Multiplying 1.28 with the GDP growth prediction of 7.5% leads to an annual growth of 9.6%. With this growth rate a throughput of 15 mTEU will be reached by the year 2012. After this period the highest GDP growth prediction of the two institutes will be multiplied by 1.11. The prediction made by Worldbank of 7% until the year 2020 will therefore be used. This calculation leads to an annual growth of 7.8% and a throughput of almost 40 mTEU by the year 2025. See the table below for some more details.

Table 3-3: Container throughput development for low growth scenario

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>mTEU</td>
<td>5.0</td>
<td>7.9</td>
<td>12.5</td>
<td>18.8</td>
<td>27.3</td>
<td>39.7</td>
</tr>
</tbody>
</table>
3.3.4 Average growth scenario

For this scenario, the average throughput is taken of the low and high scenario. On the basis of this average scenario a design will be made of the new container terminal.

Eventually it is expected that total container throughput will reach 35 mTEU in 2025 with an average annual growth of 8.1 % over the period 2000-2025. (See Figure 3-5)

Leading ports like Singapore and Hong Kong expect to reach this throughput already in 2013 and 2016 respectively. It can be seen that Shanghai will not be able to bridge the gap between these ports as was previously suspected.

Table 3-4: Container throughput development for average growth scenario

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>mTEU</td>
<td>5.0</td>
<td>7.7</td>
<td>11.8</td>
<td>17.3</td>
<td>24.6</td>
<td>34.9</td>
</tr>
</tbody>
</table>

Figure 3-5: Three growth scenarios of Shanghai
3.4 Expected number of vessels

Now the container throughput over the next 25 years has been forecasted, the second step is to determine how many ships could be expected. Apart from the number of ships, the features of these ships (length, beam, draught etc.) are also important parameters for the design of the terminal.

To estimate the number of ships that will call at the port, today’s figures have to be altered to meet the future expectations. The figures that should be determined are the share of the total throughput figure per service group (paragraph 3.4.2), the average TEU capacity per service group (paragraph 3.4.3), and the parcel size per service group (paragraph 3.4.4). In the following paragraphs, these figures will be determined.

To give an impression of the development of container vessels, first an overview will be given over the past few decades after which the future prospects of their design capacity will be discussed.

3.4.1 Development of world container shipping

Since containershipping halfway the 1950’s was initiated by Malcolm McLean, the growth of container trade has taken a big rise and still hasn’t stopped.

First container movements were mainly restricted to the coasts of the United States. Containers weren’t standardised and general cargo ships were converted to containerships only able to take around 800 TEU at a time. Generally these ships had their own gear to load/unload at the ports because most ports lacked container-handling equipment. While containerised transport proved to be efficient in the late 1960’s, only the major shipping lines seated in industrialised countries began to develop terminals with dedicated container berths. Smaller shipping lines couldn’t face the high initial investments.

Around 1971 long distance international services covering several oceans were containerised one after another which led to a new generation of increasing capacity. This tendency to increase capacity led to the development of bigger and faster vessels able to take over 2000 TEU and sailing at 25 to 27 knots. The oil crisis of 1973 however stopped the search for vessels able to sail at a high speed due to the enormous amounts of fuel that went through.

Around 1984 a new generation that could be categorised as the fourth, began. The increase in ship size reached the limits of the Panama Canal and still the boundaries of carrying capacity weren’t reached. Post Panamax quayside cranes were installed to cope with the expected Post Panamax vessel size, which came during this generation in 1988. It was at this generation that round the world services began to take rise and automation of container handling was being developed.

As a result of severe competition among shipping lines the demand for increasing ship capacity wasn’t over at all. The construction of new ships however led to big investments. To spread the risks involved, shipping lines began to develop global alliances, which started the fifth generation.
Table 3-5: Overview of vessel generations

<table>
<thead>
<tr>
<th>Generation</th>
<th>Time period</th>
<th>Capacity (TEU)</th>
<th>Draught (m)</th>
<th>LOA (m)</th>
<th>Breadth (m)</th>
<th>Speed (knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1966 -</td>
<td>400</td>
<td>7.5 - 9</td>
<td>140</td>
<td>22</td>
<td>20-22</td>
</tr>
<tr>
<td></td>
<td>up to</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>1966 - 1971</td>
<td>700 - 1000</td>
<td>9.5</td>
<td>200</td>
<td>25 - 30</td>
<td>24</td>
</tr>
<tr>
<td>4</td>
<td>1984 - 1996</td>
<td>4000 - 4500</td>
<td>11.5 - 13</td>
<td>290</td>
<td>32</td>
<td>18</td>
</tr>
<tr>
<td>5</td>
<td>1996 -</td>
<td>4500</td>
<td>12.5 - 14.5</td>
<td>275 - 350</td>
<td>39 - 43</td>
<td>25</td>
</tr>
</tbody>
</table>

Nowadays the total capacity of the world’s containership fleet is still increasing rapidly due to the current yearly containermarket growth of 10%. Although the Panamax ships still represent the lion’s share of the world containership fleet, the post-Panamax fleet has risen in a very short time to nearly 5% by number of ships and nearly 12% by total slot capacity.

It is believed that the development of vessel capacity will continue to rise on demand of the big shipping companies in order to reduce their costs. A.P. Møller, for example, is building an 8,700 TEU vessel. It is being calculated that operational costs of a 9000 TEU vessel will be 18% less than 2 vessels of each 4400 TEUs together.

Furthermore most countries in the world will be containerised in this development era creating higher demands on the main shipping routes. In response to this continual demand for larger vessels Lloyd’s Register recently released a detailed design concept of an Ultra Large Containership (ULCS). The ULCS will be able to transport as much as 12,500 containers and could begin to enter service in 2004. Experts though think that these ships will only be operating by the year 2010 [8]. Leading shipping companies such as A.P. Møller and P&O Nedlloyd are believed to be interested in this concept. The ship’s properties will probably be:

- **Capacity**: 12,500 TEU
- **Waterline breadth**: 55 metres (22 containers abreast on deck)
- **Design draught**: 13.5 metres
- **Waterline length**: 385 metres
- **Probable design speed**: 23 Knots

Container handling equipment is already available to service these ships. In fact Zhenhua Port Machinery recently claimed to have built the world’s largest and fastest container crane. It weighs 1600 tonnes and is capable of reaching across 23 containers.

Because of Suez regulations considering maximum beam and draught it has been suggested that this ship size would be the limit of vessel capacity. It is discussed however that the Suez Canal could be dredged to receive even larger ships.

The next step will then be the maximum draught that is allowed in the Straits of Malacca. The presently available draught in this strait is 21 metres, which allows ships with a capacity of around 18,000 TEU to pass. This will be the so-called ‘Malacca-max’ generation. It is however highly unlikely that this generation will actually be in service in the next few decades because of the large demands on design. First of all there is the design of the vessel itself. Present-day propulsion technology for example cannot be easily adjusted to these kind of ships. Secondly the ability of container terminals to physically berth the ship and to service these vessels within an acceptable time isn’t there yet. For these reasons the ‘Malacca Max’ design concept is considered as a pure theoretical design.
3.4.2 Modal split

In paragraph 2.3, the number of TEUs transported by the various vessel groups was already calculated as a percentage of the total port’s throughput. This calculation was based on the throughput of the year 1997. At this year, the port of Shanghai was still a small port and the throughput was totally generated by the import and export demand of China.

While Shanghai could become a regional hub, it is expected that a certain percentage of the throughput will be generated by transshipment having no relation with Chinese mainland at all. Transshipment in this case therefore means the exchange of containers within the ocean and short sea services groups and between these two groups.

Now, two different cargo flows could be distinguished, transshipment and domestic trade. In Figure 3-6 these cargo flows can be found together with the subdivision within these groups. In Appendix III an overview can be found of the actual numbers of containers transported by the several services groups. In the following sections both branches will first be described.

Transshipment

Within hub ports it is very normal that a certain percentage of the total throughput figure consists of transshipment containers. For the Kwai Chung Terminal of Hong Kong for example, total transshipment reached 26 % of the total throughput in 1997 [4]. For the container port of Shanghai it is not very likely that this figure will be reached. China as a whole is starting to develop and Shanghai will become its main port for international trade relations. Therefore it is expected that import and export will maintain the major share of total throughput. Within this study it is assumed that the volume of transshipment will grow linearly to reach 10 % by the year 2010.

Within transshipment a few types can be distinguished. These types are the transport of containers within the ocean services group, between the short sea and ocean services group and within the short sea services group. In Figure 3-6 the shares of these types can be found within the total transshipment volume. It is assumed that transport between the ocean and short sea services group will have the largest share. The reason for this is that containers from other continents, transported by the ocean services group, will be transported to a regional hub and will be further transported to their final destination. As a regional hub, Shanghai will therefore handle containers with destinations like Taiwan and Japan.

Domestic trade

Domestic trade forms the main part of the total container throughput. Percentages within this group are based on the year 1997. In this year, a total throughput of 2.53 mTEU was reached. 45 % of this figure was transported by the ocean vessel group and 55 % by the Short sea group.

Within the import and export containers, it is expected that the ocean services group will slightly increase its share to reach 51 % by the year 2010 [3]. The total share of the Ocean and Short sea services groups together will be maintained within the import and export containers.

Within the domestic services group it is likely that the shares of the various transport modes will reposition. In 1995 transport via trucks was taking a share of 80 % of the total number of containers transported by the domestic services group. Transport by barge was only represented with 18 % of the total. The remaining part was transported by rail [3].
Within the study done by the ministry of public works and transport of the Netherlands in combination with the Chinese government as is mentioned in paragraph 2.3, it is expected that the share of trucks will decrease and the share of the barges and rail transport will increase. This can be expected while transport with barges is considerably cheaper than transport with trucks.

In the table below, the increase/ decrease of the shares can be found. Within this study it is assumed that the shares of the transport modes will change linearly to the year 2010.

**Table 3-6: Share of transport modes within the domestic services group**

<table>
<thead>
<tr>
<th>Year</th>
<th>River</th>
<th>Road</th>
<th>Rail</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>18 %</td>
<td>80 %</td>
<td>2 %</td>
</tr>
<tr>
<td>2005</td>
<td>28 %</td>
<td>64 %</td>
<td>8 %</td>
</tr>
<tr>
<td>2010-2025</td>
<td>35 %</td>
<td>51 %</td>
<td>14 %</td>
</tr>
</tbody>
</table>

**Figure 3-6: Modal Split for the year 2025**

The above mentioned shares eventually lead to an number of containers transported by the several transport modalities. In the following table these numbers can be found. In Appendix III these numbers can also be found for 2008 and 2015.

**Table 3-7: Transport volumes in mTEU of the several transport modalities for 2025**

<table>
<thead>
<tr>
<th></th>
<th>Transshipment</th>
<th>Domestic trade</th>
<th>Total transport volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Export</td>
<td>Import</td>
<td>Export</td>
</tr>
<tr>
<td>Ocean services group</td>
<td>4.2</td>
<td>8.8</td>
<td>7.2</td>
</tr>
<tr>
<td>Shortsea services group</td>
<td>2.8</td>
<td>8.5</td>
<td>6.9</td>
</tr>
<tr>
<td>Domestic services group</td>
<td>Road</td>
<td>8.8</td>
<td>7.2</td>
</tr>
<tr>
<td></td>
<td>River</td>
<td>6.0</td>
<td>5.0</td>
</tr>
<tr>
<td></td>
<td>Rail</td>
<td>2.4</td>
<td>2.0</td>
</tr>
</tbody>
</table>
3.4.3 Average TEU capacity per service group

While the importance of the port of Shanghai is growing and the container market is still growing, it is expected that the average TEU capacity of each service group will grow. In the following, this growth will be discussed per service group.

Ocean services group

At the moment the average TEU capacity is very low. With the continuing search for cheaper ways to transport containers, the used vessels become bigger and bigger. Trying to estimate the average capacity of the ocean services group in the near future, a list has been used of the current order book on vessels. (Table 3-8) In this table it can be seen that the increase of vessels having a capacity of 4000 TEU and over is growing at a faster rate than the other vessel capacities. Like already stated in paragraph 3.4.1, it is expected that by 2010 some 12,500 TEU vessels will be on service leading to a higher average capacity.

Table 3-8: Overview of currently sailing vessels and vessels on order [9]

<table>
<thead>
<tr>
<th>Capacity (TEU)</th>
<th>&lt; 1000</th>
<th>1000-1999</th>
<th>2000-2999</th>
<th>3000-3999</th>
<th>&gt; 4000</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently sailing</td>
<td>4955</td>
<td>1142</td>
<td>395</td>
<td>223</td>
<td>196</td>
<td>6911</td>
</tr>
<tr>
<td>On order</td>
<td>135</td>
<td>97</td>
<td>32</td>
<td>30</td>
<td>77</td>
<td>371</td>
</tr>
<tr>
<td>Increase</td>
<td>3 %</td>
<td>8 %</td>
<td>8 %</td>
<td>13 %</td>
<td>39 %</td>
<td>5 %</td>
</tr>
</tbody>
</table>

To determine an average ship capacity for the next 25 years, current growth figures have been used. While current growth figures are based upon the next 5 years, the average vessel capacities have been determined per 5 years.

Furthermore, only vessels with a capacity of over 2000 TEU have been taken into account. The average capacity of these ships was 3539 TEU. The current average capacity of ships calling at Shanghai, is 3350 TEU. Taking only vessels with a capacity of 2000 TEU and over into account seems therefore justified.

For the next 5 years, ships with a maximum capacity of 6500 TEU will be built. The average capacity of the 4000 TEU and over class is set at 5200 TEU for the next 5 years.

From 2010 it is expected that vessels with a capacity of 12,500 TEU will sail (See paragraph 3.4.1). The average capacity from there on is therefore set at 8200 TEU (the average of 4000 and 12,500) instead of 5200 TEU.

To gradually build up this figure, 6700 TEU is used for 2005.
In the next table the average vessel capacities can be found for the next 25 years. In Appendix II further details can be found.

Table 3-9: Average estimated ocean vessel capacity for the next 25 years

<table>
<thead>
<tr>
<th>Year</th>
<th>TEU-capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2005</td>
<td>3539</td>
</tr>
<tr>
<td>2005-2010</td>
<td>4169</td>
</tr>
<tr>
<td>2010-2015</td>
<td>4970</td>
</tr>
<tr>
<td>2015-2020</td>
<td>5278</td>
</tr>
<tr>
<td>2020-2025</td>
<td>5592</td>
</tr>
</tbody>
</table>
Short sea services group

For the Short sea services group, it is expected that vessels of up to 2000 TEU will eventually be used. These vessels used to sail on the ocean services routes, but aren’t efficient anymore for this group. It is expected that finally vessels with a capacity ranging from 500 TEU to 2000 TEU will be used. While vessels of up to 2000 TEU will be used on short term (within the next decade) the average of 1250 TEU for the Short sea services group will be reached within this decade. From there on the average will be constant.

Table 3-10: Average estimated Short sea vessel capacity for the next 25 years

<table>
<thead>
<tr>
<th>Year</th>
<th>TEU-capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2005</td>
<td>700</td>
</tr>
<tr>
<td>2005-2010</td>
<td>900</td>
</tr>
<tr>
<td>2010-2025</td>
<td>1250</td>
</tr>
</tbody>
</table>

Domestic services group

Like the other service groups, the domestic services group will also increase its capacity. This increase will, however, only take place at the modality “water”. Barges are expected to grow, while trucks and trains are already assumed to have reached their maximum capacity.

According to a report made by the state planning commission of the People’s Republic of China, it was expected that by the year 2000 the capacity had been increased to 85 TEU and would reach an optimum of 120 TEU in 2010 [3]. This report, made in 1997, based its figures on the average capacity of 1995, which was 50 TEU. In 1997 however, river barges still had an average capacity of 50 TEU. Knowing however, that an increase of the ship’s capacities is very likely and prognoses are being made for a very long term, these expectations will be followed and extended until the year 2025. Table 3-11 gives the results.

Table 3-11: Average estimated domestic vessel capacity for the next 25 years

<table>
<thead>
<tr>
<th>Year</th>
<th>TEU-capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2005</td>
<td>85</td>
</tr>
<tr>
<td>2005-2010</td>
<td>100</td>
</tr>
<tr>
<td>2010-2025</td>
<td>120</td>
</tr>
</tbody>
</table>

3.4.4 Parcel size per service group

The parcel size is, together with the ship’s capacity, a very important parameter to determine the number of vessels calling at the port. In the following sections, the parcel size per service group will therefore be determined.

Ocean services group

At the moment the average parcel size for the ocean liner service is very low. Partly this can be ascribed to draught restriction in the Yangtze River basin. This is however not the only reason. The main reason is probably that Shanghai is still a small port compared to Asian hubs such as Hong Kong and Singapore. At the moment Shanghai is only a port at which the ocean services make a stop over. This is only paying with relatively small vessels. 5th generation vessels and higher are simply too expensive to make calls to several minor ports.

When Shanghai grows out to become a regional hub, it will become the main destination of a lot of services. Many vessels will sail directly to Shanghai without making calls at
other ports. By then it could be compared with the situation in which ports like Hong Kong are in at the moment. At this port, the average parcel size lies around 50%. For this reason it is assumed that the average parcel size of the ocean services group will eventually grow to 50%.

The course of this growth also depends on the availability of sufficient water depth. Until the approaches to Shanghai are lacking sufficient waterdepth, the ocean vessel group cannot increase its parcel size. At the moment the access channels in the Yangtze River are being deepened. Parcel size will therefore gradually increase. In 2005 it is planned to have a water depth of 12.5 metres [29]. According to recent research the average parcel size could be 83% by then (See [15]). While a maximum parcel size of 50% was estimated, it turns out that the water depth will not be a slowing factor on the increase, knowing that a complete new deepwater terminal cannot be ready before the year 2005. Therefore, the status of Shanghai, still only a small port, will be the slowing factor.

As soon as Shanghai outgrows this status, the eventual figure of 50% will probably be reached. Shanghai will outgrow this status at the moment it handles almost as much containers as ports like Singapore and Hong Kong handle now. This moment lies in the year 2015 where Shanghai is expecting a throughput of 17.3 mTEU. Until 2015, the parcel size is to grow linearly to reach 50% From that year, the parcel size stays at this rate.

**Short sea services group**

Also the parcel size of the Short sea services group is expected to grow while Shanghai becomes a regional hub. Shanghai can then act as a base for the Short sea services. From here, countries like Taiwan and Japan can be served using up to 2nd generation vessels.

The parcel size of this group is assumed to increase to 75% within the next 15 years.

**Domestic services group**

The parcel size of the domestic services group will not grow while it was already dedicated to the port of Shanghai.

The estimated parcel sizes of several groups are listed in the next table.

**Table 3-12: Parcel size development per service group**

<table>
<thead>
<tr>
<th>Year</th>
<th>Ocean</th>
<th>Short sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000</td>
<td>21%</td>
<td>70%</td>
<td>75%</td>
</tr>
<tr>
<td>2008</td>
<td>34%</td>
<td>73%</td>
<td>75%</td>
</tr>
<tr>
<td>2015 - 2025</td>
<td>50%</td>
<td>75%</td>
<td>75%</td>
</tr>
</tbody>
</table>

**3.4.5 Total expected number of vessels for Shanghai**

Finally, the expected vessels can be calculated, given the above estimated figures. To give a general overview of the expected number of vessels, the results are only given for the years 2008, 2015 and 2025. (See Appendix II for further details)

**Table 3-13: Expected monthly calls per service group for Shanghai**

<table>
<thead>
<tr>
<th>Year</th>
<th>Ocean Throughput</th>
<th>Ocean Calls/month</th>
<th>Shortsea Calls/month</th>
<th>River barges Calls/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>9.94E+06</td>
<td>162</td>
<td>330</td>
<td>1,300</td>
</tr>
<tr>
<td>2015</td>
<td>1.73E+07</td>
<td>168</td>
<td>401</td>
<td>2,100</td>
</tr>
<tr>
<td>2025</td>
<td>3.49E+07</td>
<td>301</td>
<td>808</td>
<td>4,200</td>
</tr>
</tbody>
</table>
3.4.6 Expected vessels on the new terminal

In the following, it is assumed that current terminals are already at their capacity with a throughput of 5.2 mTEU. Therefore for the new terminal the prognoses will be reduced with the capacity of the current existing terminals. While it isn’t possible to construct a new terminal within a small time period, growth of container throughput will soon come to a halt while waiting on a new terminal. To allow continued growth of Shanghai as a container port, development plans for the Waigaoqiao and Wahaogou area as described in paragraph 2.2 will be carried out. These terminals can then act as a buffer until a new terminal design has been made. Development plans for the Jinshan Zui area will be stopped while they probably show great resemblance with plans being developed in this report as it is projected to be a deep water terminal.

With the development of the Waigaoqiao and Wahaogou area current capacity of the existing terminals (5.2 mTEU) will be enlarged to 6.6 mTEU within the time period 2002 - 2004. Growth of throughput figures will probably only slightly be delayed during this period as a result of capacity problems. The total existing capacity (including above mentioned new terminals) will be subtracted from the calculated total throughput. This results in the total needed extra capacity for Shanghai as a whole. In the graph below these figures can be found.

![Graph showing needed extra capacity and capacity of existing terminals.]

Figure 3-7: Resulting needed extra capacity

With the calculated needed extra capacity a number of vessels can be calculated for which a new terminal should be build. In the following table this number of vessels can be found.

Table 3-14: Expected monthly calls per service group for the new terminal area

<table>
<thead>
<tr>
<th>Year</th>
<th>Throughput</th>
<th>Ocean Calls/month</th>
<th>Shortsea Calls/month</th>
<th>River barges Calls/month</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>3.29E+06</td>
<td>54</td>
<td>109</td>
<td>443</td>
</tr>
<tr>
<td>2015</td>
<td>1.06E+07</td>
<td>103</td>
<td>247</td>
<td>1,280</td>
</tr>
<tr>
<td>2025</td>
<td>2.83E+07</td>
<td>244</td>
<td>655</td>
<td>3,400</td>
</tr>
</tbody>
</table>
3.5 **Expected dimensions of vessels**

Like already mentioned before, not only the number of vessels is important for designing a new terminal, also the dimensions of the vessels are important parameters. Therefore, for each service group an average and a maximum ship will be chosen. Again, this will only be done for the years 2008, 2015 and 2025. The average and maximum ship dimensions will, where possible, be chosen according to existing vessels.

3.5.1 **Ocean services group**

The average vessel for the ocean services group can be chosen according to existing vessels while vessels with these capacities already sail the oceans.

To ascribe a standard vessel to a calculated average (See Table 3-9), a choice has been made out of a list containing 2500 vessels. The vessel lying closest to the average capacity is pointed as the "standard" vessel. In the next table, the average ship's features are given according to the calculated average capacity.

<table>
<thead>
<tr>
<th>Table 3-15: Future standard vessels for ocean services group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average vessels</strong></td>
</tr>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td>2008</td>
</tr>
<tr>
<td>2015</td>
</tr>
<tr>
<td>2025</td>
</tr>
<tr>
<td><strong>Maximum vessels</strong></td>
</tr>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td>2008</td>
</tr>
<tr>
<td>2010-2025</td>
</tr>
</tbody>
</table>

The maximum vessel for this services group, for the year 2008, can be chosen from the list. This would be the “P&O Nedlloyd Kobe” with a capacity of 6690 TEU. For the years 2015 and 2025, a maximum has to be estimated. In paragraph 3.4.1, it was already mentioned that ships with a capacity of 12,500 TEU would probably sail in 2010. Therefore, the properties of this vessel will be chosen as the maximum vessel.

3.5.2 **Short sea services group**

Short sea services group the same has been done as for the ocean services group. A standard ship has been chosen according to the calculated averages (See Table 3-10). For this group however, only two ships have to be chosen while the average remains the same after 2010.

<table>
<thead>
<tr>
<th>Table 3-16: Future standard vessels for Short sea services group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average vessels</strong></td>
</tr>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td>2008</td>
</tr>
<tr>
<td>2015</td>
</tr>
<tr>
<td><strong>Maximum vessels</strong></td>
</tr>
<tr>
<td><strong>Year</strong></td>
</tr>
<tr>
<td>2008-2025</td>
</tr>
</tbody>
</table>
The maximum vessel that will enter service on the Short sea group will be a former ocean services vessel with a capacity of 2000 TEU. For this capacity, the vessel "Nedlloyd Clement" is chosen.

### 3.5.3 Domestic services group

For the domestic services group, the same method is used as for the other two groups. The results are listed in the following table.

#### Table 3-17: Future standard vessels for domestic services group

<table>
<thead>
<tr>
<th>Average vessels</th>
<th>Year</th>
<th>Name</th>
<th>Total TEU</th>
<th>LOA</th>
<th>Beam</th>
<th>Draft</th>
<th>Year of building</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Fu Rong Quan</td>
<td>100</td>
<td>81.2</td>
<td>15.0</td>
<td>5.2</td>
<td>1-Nov-1992</td>
<td></td>
</tr>
<tr>
<td>2015-2025</td>
<td>Kotoku Maru</td>
<td>120</td>
<td>90.8</td>
<td>15.4</td>
<td>4.4</td>
<td>1-May-1993</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maximum vessels</th>
<th>Year</th>
<th>Name</th>
<th>Total TEU</th>
<th>LOA</th>
<th>Beam</th>
<th>Draft</th>
<th>Year of building</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008-2025</td>
<td>Sunny Rose</td>
<td>280</td>
<td>106.0</td>
<td>16.0</td>
<td>5.9</td>
<td>1-Aug-78</td>
<td></td>
</tr>
</tbody>
</table>

The maximum vessel for the next 25 years will be a 280 TEU vessel. A vessel, currently sailing, that meets this number is the "Sunny Rose". This vessel will therefore be chosen as the maximum vessel.

### 3.5.4 Depth requirements

To be able to receive the expected ocean vessels, a certain depth should be guaranteed. The largest draught of the expected vessels can be found in Table 3-15 and turns out to be 14 metres while lying still (Fully loaded). The needed depth will be larger than this value because of several forces acting on the vessel. The influencing factors are squat and trim of the vessel and waves causing the vessel to pitch and roll.

The general equation that can be used to calculate the required depth is the following [10]:

\[
d = D + S_{\text{max}} + r + m
\]

In which:

- \(d\): Guaranteed depth with regard to chart datum (Lowest Astronomical Tide (LAT))
- \(D\): Draught of the design ship (14 metres)
- \(S_{\text{max}}\): Maximum sinkage due to squat and trim
- \(r\): Vertical motion due to wave agitation
- \(m\): Safety margin (underkeel clearance)

For a first estimation generally some values can be estimated on the basis of experience. Squat and trim \((S_{\text{max}})\) can be estimated to have a maximum value of 0.5 metres.

The vertical motion due to wave agitation \((r)\) can be calculated by taking half of the significant wave height [10]. The significant wave height in the Hangzhou Bay area is approximately 0.2 metres, so \(r\) will be 0.10 metres.

The safety margin depends on the soil on the bottom of the channel at the chosen location. This value is 0.3 for soft mud, 0.5 for sand and 1.0 for hard soil or rock.
Altogether, the depth below chart datum should be:

\[ d = 14 + 0.5 + 0.1 + 0.3 = 14.90 \text{ metres} \quad \text{(Soft mud)} \]
\[ d = 14 + 0.5 + 0.1 + 0.5 = 15.10 \text{ metres} \quad \text{(Sandy bottom)} \]
\[ d = 14 + 0.5 + 0.1 + 1.0 = 15.60 \text{ metres} \quad \text{(Hard soil or rock)} \]

The actual required depth depends on the soil conditions of the bottom and is thus dependent on the location.
4 Project requirements for design

The project requirements for design determine the conditions which the locations at least have to satisfy. These requirements can be divided into several categories:

Starting points: A part of the design will be based on these requirements.

Assumptions: These criteria deal with important requirements of which no data is available. While the described data is necessary for the design process, some well considered figures or scenarios are assumed.

Boundary conditions: This part describes conditions that influence the design and cannot be avoided. A distinction in this part can p.e. be made to natural boundary conditions (Islands cannot be moved) and operational boundary conditions (A vessel sailing for the ocean services group can be handled by a maximum of 5 quay cranes)

4.1 Starting points

General

- Mainline vessels never carry containers destined for only one service group
- Portainer cranes are able to reach a net(t) handling speed of 35 containers per hour
- The ratio 1 TEU versus 2 TEU containers will be 50-50. The TEU factor will therefore be 1.5
- The container terminal operates for 24 hours a day during 360 days a year.
- Chart datum equals Lowest Astronomical Tide (LAT)
- All considered locations are ready for development
- Long stretches of quay allow quay cranes to move between berths maximising operational flexibility.
- Vessels with a carrying capacity of 12,500 TEU are, with the aid of tugs, able to make an approach via the Southern side of the Zhoushan archipelago.
- Vessels sailing for the domestic services group can sail in the Hangzhou Bay area.

4.2 Assumptions

General

- Prognoses are not influenced by the development of ports. Ports are constructed according to shipping trends.
- Meteorological data available for Shanghai can be used for all considered locations.

Operational

- The time to berth a vessel is constant regardless to size developments of the vessel.
- Throughput is defined as the total number of containers that passes the terminal via the ocean or shortsea quays where the transshipment containers are counted at arrival.
- Dredged material is not polluted and can be dumped at sea.
- The significant wave height is 0.2 metres in the Hangzhou Bay area.
- The terminals will be based on handling properties of the year 2025. Possible resulting longer waiting times due to smaller vessels and thus relatively more vessels
in the year 2008 will be compensated by the fact that these vessels have smaller service times.

4.3 Boundary conditions

General
- Where possible, the natural environment should be left intact. In case this is not possible, the damage should be compensated.
- The new location must provide room for further terminal expansion after 2025.
- Direct connections with the existing port of Shanghai should be established.
- The domestic services group must be physically separated from the other services groups.

Operational
- The terminal area must be flat due to operational restrictions of the equipment.
- Vessels should be able to call at the port regardless to tidal circumstances.
- The maximum number of cranes servicing the ocean services group is 5.
- The maximum number of cranes servicing the domestic services group is 2.
- It takes 30 minutes for domestic services vessels to berth/deberth.
- It takes 60 minutes for Short sea services vessels to berth/deberth.
- It takes 100 minutes for ocean services vessels to berth/deberth.
- The waiting time for the domestic services group may not exceed 50 % of the total service time.
- The waiting time for the Short sea services group may not exceed 25 % of the total service time.
- The waiting time for the domestic services group may not exceed 10 % of the total service time.
- All vessels sailing for the several services groups should be able to reach the new terminal area.
- Vessels entering the terminal’s area should not form a threat to other berthed vessels.

Natural restrictions
- Flood season: June -September.
- The occurrence of typhoons in this area should be considered.
- The occurrence of earthquakes should be considered.
5 Needed facilities & Global dimensioning

In this paragraph the port's configuration is determined. This configuration, which includes the dimensions of the various elements, is needed to find a location that will suit the new port’s dimensions. Therefore the dimensions for the year 2025 will be used, while the necessary area will be at its largest by then.

As is calculated in paragraph 3.4.6, the new container terminal should be able to handle 28 mTEU by the year 2025. This is such a large quantity that it is better to split it into several smaller parts to keep the container handling process clear. All parts will then be handled by separate terminals handling all services groups. The advantage of this is p.e. that each terminal could be managed by a separate operator. Also, with several smaller terminals, the distances within the terminal can be kept small.

Currently Shanghai is being operated by Shanghai Container Terminals (SCT). The throughput handled by this operator is 5 mTEU. This figure is therefore regarded as a reasonable figure to be handled by one operator. For this reason a choice will be made to design a new container port consisting of several terminals with an annual capacity of 5 mTEU. The expected number of vessels already determined in paragraph 3.4.6 will be equally divided between the new terminals.

Dimensioning of the terminal unit will be executed regarding the standards for the year 2025. With the increasing vessel size of all services groups this leads to a design that counts on less vessels then could be expected by the year 2008. This is mainly due to the lower average vessel capacity in the year 2008 compared to 2025. This would probably lead to a higher number of vessels calling at the terminal. However, together with the smaller vessel’s capacity the service time will also be reduced. In this report it is therefore assumed that the larger number of vessels will be compensated by the smaller service times.

In the following sections one terminal unit will be dimensioned. This terminal roughly consists of the following elements:
The quay, the apron area (strip at and directly behind the quay for traffic and hatch cover storage purposes), the stacking area, and an exchange and transfer zone.

![General layout of a container terminal](image)

**Figure 5-1: General layout of a container terminal**
Before starting to make a design of the new terminal, the way of handling the containers needs to be chosen. The eventual design of the terminal highly depends on this feature. In the next paragraph the container handling will therefore be discussed.

5.1 Container handling system

As soon as an ocean liner vessel has berthed, the container passes through several processes. While analysing a container moving from the ocean vessel to another transport modality, the following processes can be distinguished:

- Quay handling
- Quay to yard transfer (and vice versa)
- Yard handling
- Yard to loading and unloading area transfer (and vice versa)

All these processes need their own specialised equipment while the nature of handling differs per process. Therefore, equipment is chosen per process. In the following sections the choices will be described, the actual features of the several types of equipment can be found in Appendix V.

5.1.1 Quay handling

As soon as a vessel has berthed, the containers have to be unloaded. In early days, shiptainers were used. These were cranes (installed on the ship) able to ride over the ship’s cargo to load/unload the ship. In these days it was necessary for a ship to carry its own gear while several ports weren’t able to handle the containers.

Nowadays, the major ports have dedicated container terminals and make use of so called ship to shore gantry cranes (or portainers). These cranes have evolved, together with the ships sizes, to reach gigantic proportions (See Figure 5-2). Latest developments report an outreach over the ship of 23 containers. With this outreach, the quay handling facilities are ready to handle ships of around 12,500 TEU like described in paragraph 3.4.1. These portainers are capable of handling up to 60 containers per hour. The average however is, due to activities like repositioning of the crane, a lot lower. In this case the average will be set at 35 moves/hour.

For the port of Shanghai, portainers of this size need to be installed to meet the expectations for the next few decades. One of these expectations is that a vessel needs to be serviced within 24 hours [10]. When a vessel is handled by 4 portainers, the maximum vessel capacity that can be serviced within 24 hours will be a 4620 TEU vessel (See Appendix V). From Table 3-9 it can be seen that, with this capacity at the quay, the average vessel can be serviced within 24 hours for the next 10 years. After this period of time, vessels become so big that the aim of 24 hours should be left behind or new quay handling technologies should be installed.

With the installation of these cranes, a separation of the large ocean going vessels and the smaller domestic vessels becomes necessary. Cranes of the above mentioned size aren’t able to service smaller ships in a fast way. These ships are p.e. more sensitive for waves causing them to roll, which leads to a reduction of service time. Therefore, vessels sailing for the Short sea and domestic services groups will be serviced at separate berths.
5.1.2 Quay to yard transfer (and vice versa)

For the quay to yard transfer there are many systems available. These systems vary from Fork Lift Trucks (FLT’s) to Automated Guided Vehicles (AGV’s) like used at ECT (Port of Rotterdam). Between the available systems, a distinction can be made between systems that can transfer the container to the yard and stack it, and systems that can only transfer the container to the yard. These last systems are generally used for high capacity terminals. While this terminal will become such a one, the last type of system will be chosen.

The number of systems can now be narrowed down to 2: The Multi Trailer System (MTS) and the Automated Guided Vehicle (AGV).

The MTS consists of a “train” of up to 5 trailers pulled by one yard tractor. Transferring containers in this way has the advantage of cost reduction by reducing manpower.

The AGV system consists of single trailers that are automatically guided by loops in the pavement. This leads to a further reduction of manpower and therefore costs. The maintenance costs however are high.

For the new container terminal, the MTS will be chosen while it is more flexible than the AGV system.

5.1.3 Yard handling

For the yard handling process, like for other terminal processes, a choice can be made between several systems. For high capacity terminals, leading to the need for efficient land use, one can generally choose between the following systems:

- Rubber Tired Gantry Crane (RTG)
- Rail Mounted Gantry Crane (RMG)
- Automated Stacking Crane (ASC)

The difference between the RTG and the RMG is enclosed in the title. The RTG is “rubber tired” and therefore able to deviate from its path, and the RMG is “rail mounted” and therefore restricted to its rails. For this reason the RTG is more flexible than the
RMG, but has the disadvantage that the wheel loads are very high (The RMG spreads its weight along the rails).

Both gantry systems are able to ride over a row of maximum 15 containers wide. The maximum stack height can be 7 containers. The cranes are then still able to carry a container over the stack. (1 over 7 crane)

![Figure 5-3: RTG system (6 wide 4 high)](image)

The ASC system consists of cranes that are operated by computer. This saves labour costs. At ECT (Rotterdam) this system is used in combination with the AGV’s. The required area per TEU of this system is higher than the other 2 systems.

With the low required area per TEU and the possibility to automate the system in the future, RMG’s will be used at the new terminals. A common size for this system is a 6 wide and 4 or 5 high block of containers and will therefore be used [12]. The required area per TEU with this arrangement is estimated to be 10 m²/TEU.

5.1.4 Yard to transfer modality (and vice versa)

With the use of RMG’s at the yard, containers could directly be transferred from the stack to trucks by these RMG’s. To allow this transfer, a truck lane should be located between the legs of the RMG. The width between the legs should then be able to accommodate 6 containers and one traffic lane.

5.2 Quay length

Now the way of handling the containers on the terminal is known, the total needed quay length can be determined per service group. This can normally be done in several ways;

With so called “Rules of thumb”, with the queue theory or with simulation techniques. For this terminal the queue theory will be used while the “rules of thumb” are too simplistic for a port of this size and the simulation techniques are too thorough for a development plan in this stage.

In Appendix VI the above mentioned techniques are further described after which the queue theory has been applied. In this section only the results of this theory are given.
5.2.1 Berths

By applying the queue theory for the determination of the number of berths, a maximum waiting time per service group is regarded. The number of berths should be of such quantity that the actual waiting time never exceeds this maximum. By raising or lowering the number of berths with only one berth, a great variance is established in the waiting time (See Appendix VI).

Often a waiting time is established that lies far below the maximum waiting time while one berth extra causes the waiting time to rise to an unacceptable level. With the eventual number of berths calculated with this method, the terminal isn’t fully utilised. Therefore, to make as much use as possible of the calculated berths, the number of vessels calling at the terminal will be raised until the maximum waiting time is reached. This maximisation of the waiting time cannot be done for each separate service group while the relation between the several service groups is preset. Therefore three maximalisations have been made. Each maximalisation deals with one service group according to which the other service group will be adjusted. Eventually the maximalisation of the waiting time of the domestic services group led to the lowest required number of berths and quay length.

Along with the increase of vessels during optimisation, the total throughput of 5 mTEU will also increase. In this case, it led to values that probably could not be managed by one terminal operator anymore. Therefore the number of berths calculated with the queue theory was lowered with one berth and was used as a starting point of the calculation. In Appendix VI the optimisation can be found. Total throughput will eventually reach 4.77 mTEU. The results of the queue theory and eventual total throughput can be found in the table below.

| Table 5-1: Total needed quay length per service group per year |
|---|---|---|---|
| Berths | Ocean | Short Sea | Domestic |
| Length average vessel (m) | 275 | 146 | 91 |
| Total quay length (m) | 972 | 723 | 715 |
| Throughput (TEU) | 2.48E+06 | 2.30E+06 | 1.50E+06 |
| TEU/Lq (TEU/m) | 2549 | 3174 | 2104 |

In this table also the TEU/quay length has been determined. This has been done in order to compare this ratio with values of other ports. It seems that this ratio is rather high compared to other ports in Asia. Terminals with a throughput of above 1 mTEU generally have a TEU/quay-length ratio of just above 1000 TEU/m (See table below). Only Hong Kong produces an almost equal value. This can probably be ascribed to the high efficiency of Hong Kong.

The high values calculated for the new container terminal can probably be ascribed to the increasing vessel capacity while the length of the vessels remain almost constant. Also, the shortsea berths are used to their maximum capacity.

| Table 5-2: Throughput/quay length ratio for several terminals in Asia [12] |
|---|---|---|
| Port | Throughput Capacity (mTEU) | Throughput per Quay length (TEU/m) |
| Hong Kong (Sea-Land) | 1.02 | 3329 |
| Hong Kong (HIT) | 4.50 | 1367 |
| Tanjung Priok | 1.37 | 1162 |
| Busan | 1.70 | 1344 |
| Port Klang | 0.95 | 877 |
5.3 Apron area

The apron area is the area on the quay. This area consists of the following parts:

- Service lane
- Crane track spacing
- Hatch cover/Special container zone
- Traffic lane for the Multi Trailer System (MTS)

The service lane is meant for trucks serving the vessels and to prevent damage to the cranes by the ship’s hull. This lane will be set at 4 metres for all service groups.

The crane track spacing varies per service group while the cranes are not all alike. For the ocean vessels the crane track spacing is very large whereas the cranes are designed to serve vessels with a waterline breadth of 55 metres. The cranes for the domestic services group on the other hand should only be able to reach over 16 metre wide vessels. The track spacing for the several service groups are assumed to have the following widths:

<table>
<thead>
<tr>
<th>Service group</th>
<th>Track spacing</th>
<th>Outreach of boom</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean:</td>
<td>35 metre</td>
<td>55 metres</td>
</tr>
<tr>
<td>Short sea:</td>
<td>25 metre</td>
<td>32 metres</td>
</tr>
<tr>
<td>Domestic:</td>
<td>15 metre</td>
<td>16 metres</td>
</tr>
</tbody>
</table>

The hatch cover/special container zone is meant to stall, as the name explains, hatch covers or containers with special dimensions or special cargo. Also with this area the width differs per service group. For this area the following widths are assumed:

<table>
<thead>
<tr>
<th>Service group</th>
<th>Ocean:</th>
<th>Short sea:</th>
<th>Domestic:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>25 metres</td>
<td>15 metres</td>
<td>10 metres</td>
</tr>
</tbody>
</table>

The traffic lane for the MTS should be such that the “train” can manoeuvre easily to/from the container yard and uses only little space. The MTS drives underneath the cranes and at the moment it is loaded, it turns with a wide bend to the traffic lane. While the crane track spacing and the hatch cover area are very wide, the MTS can turn on this area to proceed to the lane. The traffic lane doesn’t therefore have to be very wide. A lane (2 directions) of 20 metres should be sufficient (Assumption).

With the determination of the parts of the apron area, the lay out of the quay has been set. The total width of the quay is built up by the following sequence (From the vessel to the container yard):

<table>
<thead>
<tr>
<th>Element</th>
<th>Width per service group in meters</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ocean</td>
</tr>
<tr>
<td>Service lane</td>
<td>4</td>
</tr>
<tr>
<td>Crane track spacing</td>
<td>35</td>
</tr>
<tr>
<td>Hatch cover area</td>
<td>25</td>
</tr>
<tr>
<td>Traffic lane</td>
<td>20</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>84</strong></td>
</tr>
</tbody>
</table>
5.4 Storage area

On high capacity terminals, containers of certain types are generally divided into separate area’s in the container yard. One can therefore distinguish container stacks for:

- Export
- Import
- Empties (Empty containers)
- Reefers (Refrigerated containers)
- Hazardous cargo

Apart from these stacks a Container Freight Station (CFS) can be found. This is a warehouse for packing/unpacking containers containing goods that should p.e. be divided over several other containers.

To be able to determine the required area per type of container, first the share per type of the total should be determined. Therefore, in the following section this will be discussed.

5.4.1 Share per container type

The total throughput of the port of Shanghai can be divided into import, export and transshipment. These can be further subdivided into dry freight containers, empties, reefers and tanks.

The number of transshipment containers has already been determined in paragraph 3.4.2. For the determination of the ratio between import and export, use is made of the division of the year 1995 for the port of Shanghai. In this year the total number of import containers accounted for 45 % of the total throughput. The remaining 55 % of the containers were export containers. 21.6 % of all containers were empty at arrival (See Table 5-4).

For the subdivision of the transshipment, import and export containers into the above mentioned types, world container building statistics have been used. The share per container type of the totally built containers can be found in the table below.

| Table 5-3: World container output per type in thousands of TEUs [9] |
|---------------------|-----|-----|-----|-----|-----|
|                     | 1997 | 1998 | 1999 | Average |
| Dry freight         | 1240 | 1302 | 1275 | 1272 | 1272 |
| Reefer              | 91   | 6.8 %| 95   | 6.7 %| 87   | 6.3 %| 91   | 6.6 %| 91   | 6.6 %|
| Tank                | 16   | 1.2 %| 15.5 | 1.1 %| 12   | 0.9 %| 14.5 | 1.1 %| 14.5 | 1.1 %|
| Total               | 1347 | 100 %| 1413 | 100 %| 1374 | 100 %| 1378 | 100 %| 1378 | 100 %|

To determine the total number of containers per type and destination, it is assumed that the above mentioned shares will remain the same in the future. With these shares, the container volume per type can be found in the following table. To be able to determine the number of containers with hazardous cargo, this group will be represented by the share of the tanks.

| Table 5-4: Import/Export division of total throughput [3] |
|---------------------|-----|-----|-----|-----|-----|
|                     | Total | Transshipment | Domestic | Trade | Empties (total) |
|                     | (mTEU) | (%) | (mTEU) | Import | Export | (mTEU) |
| Dry freight         | 4.41E+06 | 92% | 4.41E+05 | 1.40E+06 | 1.71E+06 | 8.57E+05 |
| Reefer              | 3.15E+05 | 7%  | 3.15E+04 | 1.00E+05 | 1.22E+05 | 6.13E+04 |
| Tank                | 5.25E+04 | 1%  | 5.25E+03 | 1.67E+04 | 2.04E+04 | 1.02E+04 |
| Total               | 4.77E+06 | 100% | 4.77E+05 | 31.8% | 38.8% | 19.4% |
5.4.2 Required storage area

To determine the required area per type and destination the following equation is used:

\[ O = \frac{C_t \cdot t_d \cdot F}{r \cdot 365 \cdot m_i} \]

Where:
- \( O \) Required area (m²)
- \( C_t \) Number of container movements per year per type of stack in TEUs
- \( t_d \) Average dwell time in days
- \( F \) Required area per TEU
- \( r \) Average stacking height/nominal stacking height
- \( m_i \) Acceptable average occupancy rate

Of this formula, only the number of containers and the required area per TEU are known. The unknown factors within this formula will be estimated according to generally accepted values.

Average dwell time (\( t_d \))

The average dwell time varies per port depending on p.e. the available area or the storage charges (often related to each other). The following formula can be used for a quick estimation [10]:

\[ t_d = \frac{(T + 2)}{3} \]

Where \( T \) is the maximum dwell time where 98% of the containers have left the terminal.

In developing countries \( T \) lies around 20-30 days. In developed countries \( T \) lies around 10 days.

For Shanghai a maximum dwell time of 10 days will be used. Shanghai already has a lot of experience seated amongst the top ten container ports in the world. The average dwell time will now become 4 days.

Required area per TEU (\( F \))

This factor depends on the yard handling equipment which has been determined in paragraph 5.1. The required area per TEU with the use of the RMG system has been set at 10 m²/TEU.

Average stacking height/nominal stacking height (\( r \))

The nominal stacking height has been set at 4 containers in paragraph 5.1. The average stacking will be somewhat lower. Drewry [10] states that with an average stacking height in the order of 2.5 to 3, best use is made of the yard. Therefore, for this terminal, an average height of 3 will be taken. The ratio average stacking height/nominal stacking height becomes 0.75 with this figure.

Acceptable average occupancy rate (\( m_i \))

This factor represents the measure of congestion where a value of 1 indicates perfect container movement. Lower values indicate that, due to "waves" in container arrival, a certain amount of space on the terminal will not be used. A value of 0.7 can be considered as representative and will therefore be used.
Now all factors in the formula have been estimated, the actual yard area can be calculated for the several stacks. In the table below, the required areas can be found per type of container.

Table 5-5: Required area per type of container stack (ha)

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Transshipment</th>
<th>Domestic trade</th>
<th>Empties</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Import</td>
<td>Export</td>
</tr>
<tr>
<td>Dry freight</td>
<td>92.0</td>
<td>9.2</td>
<td>29.2</td>
<td>35.7</td>
</tr>
<tr>
<td>Reefer</td>
<td>6.6</td>
<td>0.7</td>
<td>2.1</td>
<td>2.6</td>
</tr>
<tr>
<td>Tank</td>
<td>1.1</td>
<td>0.1</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Total</td>
<td>99.7</td>
<td>10.0</td>
<td>31.6</td>
<td>38.7</td>
</tr>
</tbody>
</table>

The total needed storage area is equal to the stacking area extended with the area required for traffic lanes. To determine the total storage area a rough assumption will be made by assuming that the traffic lanes occupy the same area as the stacks. The total required area will then be 199 ha.

5.5 Total terminal requirements

Now all elements of the terminal have been calculated, the total number of terminals and the required area per terminal can be determined.

5.5.1 Terminal area

The area will be build up by the apron area and the storage area. In Table 5-6, the total required area can be found together with the required area per TEU. In this way the calculated terminal area can be compared to areas of other ports.

Table 5-6: Total required terminal area

| Apron area | ha     | 16.3 |
| Stacking area | ha     | 199.3 |
| Total area   | ha     | 215.6 |
| Total TEU    | #      | 4.77E+06 |
| TEU/ha       | 1/m²  | 22,143 |

As can be seen from the table above, the number of TEUs per hectare will be 22,143. This seems to be a good ratio comparing it to the port of Singapore (22,000 TEU/ha), but comparing it to the port of Hong Kong (40,000-50,000 TEU/ha), it seems to be very low. This low ratio of Shanghai compared to that of Hong Kong can be accounted to the fact that space in Hong Kong is scarce.

5.5.2 Total required terminals

While the above calculated terminal unit has a capacity of 4.77mTEU and eventually 28.3 mTEU is expected by the year 2025, it takes 6 terminals to accommodate the expected container throughput. With these 6 terminals an overcapacity is created of 0.33 mTEU by the year 2025. This "overcapacity" can be used to accommodate further container growth in the period after 2025.

The total required area for the terminals can be calculated by multiplying the required area per terminal by the number of terminals. In this case the total required area is 1294 ha. To find a suitable location for these terminals, this figure is an important factor while not all locations can meet this requirement.
6 Possible locations

Now the **required area** is determined, the **location** can be chosen for expansion of the container terminals of Shanghai. In the Yangtze River Delta, many locations are available for development, but with the criteria mentioned in the previous chapters already a rough selection can be made.

6.1 General

As can be seen from paragraph 3.3.4, container throughput will more than double every decade. Apart from this enormous growth, the size of the vessels will also increase. At the moment the enormous growth cannot be accommodated at the existing SCT terminals. Firstly there isn’t enough space to enlarge the area of the terminals while Shanghai as a city has been built around it and secondly the Huang Pu River cannot physically handle the increasing size of the vessels. Already some vessels have to back out while they are not able to turn.

The only existing terminal that could partly accommodate extra containers above the projected expansion for 2004 is the Waigaoqiao terminal. Furthermore, the projected Waigaogou area could also be further developed to partly handle future throughput figures. The problem however of these terminal areas is that they face frequently returning and thus high dredging costs and cannot accommodate the total future spatial requirements.

Considering the depth restrictions of the Yangtze River, only the smallest vessels from the ocean services and short sea services groups will in the future sail at the existing terminals of Shanghai. This measure is taken to allow a high loading degree and to avoid delays while waiting at the tide. Vessels then still have to regard a tidal window but with smaller vessels, the tidal window will enlarge. In Figure 3-4 the loading degree versus the available depth in the Yangtze River can be found of the several vessel generations to give a general idea of the current problem. At this moment the range of available depth lies between 8.5 metres at low tide and 10.5 to 11.5 metres at high tide. Plans are to deepen the approach channel to 12.5 metres and should be completed by 2005. This depth however still isn’t enough to allow all vessels to sail to Shanghai unhindered. Furthermore, to maintain this depth, high returning dredging costs would probably have to be made.

Considering the above mentioned draught restrictions and high returning dredging costs, a new location will be sought outside the Yangtze River. In this report 3 potential areas will be discussed after which one will be chosen for further development. The 3 areas are the surroundings of Nanhui Zui, the area around Ningbo and the archipelago Dayangshan and Xiaoyangshan.

For each location, a projection of the terminal at the area will be made. This projection is very rough and is only made to give a first opinion. Therefore the total required area will be projected as a rectangle.

First all three areas will be described after which a selection can be made.
6.2 Ningbo

General

200-km south west of Shanghai lies the natural deep-water port of Ningbo in Zhejiang Province. Ningbo City, with a population of 5.3 million people, lies at the point where Fenghua River and the Yao River meet forming the Yong River, which flows out into the Hangzhou Bay.

![Map of Ningbo’s surroundings](image)

At the moment, the port of Ningbo consists of three harbour areas. Ningbo river port, Zhenhai river mouth port and the main Beilun harbour. Beilun is particularly important as it is a deepwater terminal. This terminal is developed by a joint venture of Hong Kong’s Wharf Holdings and the Ningbo port Authority.

The 3 terminals together mainly handle iron ore, crude oil, coal and liquefied chemical products. Actually, the port is considered as a centre for the transfer of imported iron ore in the region. Beilun transports iron ore for 30 steel and iron factories including the Shanghai based Baoshan Steel and Iron Works.

Currently there are plans to develop Daxie Dao, an island lying just 40 km from Ningbo and only 600 metres from mainland. *(Exact location: 29° 55’ N, 121° 58’ E)*

This island provides natural coastline depths ranging from 20 metres to 46 metres. Also, the island has a flat area of approximately 1950 ha including almost 11 km of shoreline that is ready for development [16].

For the construction of the new container terminal, Daxie Dao will be further examined.

Soil conditions

Daxie Dao is a very hilly island with two peaks. The peaks lie in the South East of the island and are 333 and 329 metres high. The island itself consists of rock material and the bays at the north side of the island are filled with mudflats with a steep slope.

The natural depth around the island varies between 20 and 46 metres. The approach of the island hasn’t got any depth restrictions for deep draught vessels.
Hydraulic conditions

Waves

Waves in the Hangzhou Bay are predominantly wind induced while swell is blocked by the Zhoushan islands lying in the South East of the bay. The significant wave height in the Hangzhou Bay is 0.2 metres.

Tide

The tidal range is as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>MLWS</th>
<th>MLWN</th>
<th>MHWN</th>
<th>MHWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daxie Dao</td>
<td>0.8</td>
<td>1.6</td>
<td>2.7</td>
<td>3.4</td>
</tr>
</tbody>
</table>

(Values are above Chart Datum l = Lowest Astronomical Tide (LAT))

Tidal streams attain a speed of 3 knots at neap tides and 7 knots at spring tides [17]. The direction of the currents is as follows:

<table>
<thead>
<tr>
<th>Interval from HW at mouth of Yangtze River</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between 3 hours before and after HW</td>
<td>Westerly around the island</td>
</tr>
<tr>
<td>From 3 hours after HW and 3 hours before HW</td>
<td>Easterly around the island</td>
</tr>
</tbody>
</table>

Hinterland connections:

Road/Rail

Hinterland connections with mainland aren’t yet fully developed, but are gradually being established.

Just recently a bridge has been opened which connects Daxie with mainland by road and rail. In 1998, the Shanghai-Hangzhou-Ningbo-Beilun expressway has been put into operation and at present, some other major expressways are under construction. In addition, the railway connecting Ningbo with Hangzhou will be doubled.

There are also plans for a bridge linking Ningbo directly with Shanghai but these plans are only in an early stage of development [29].

![Figure 6-2: Infrastructural connections with Daxie Dao](image)
Water

The sailing distance to the port of Shanghai is approximately 260 kilometres. Although this is a very large distance, it can be bridged by barges sailing for the domestic services group while the wave height in the Hangzhou Bay is relatively low.

Ocean going vessels can enter the island from several directions. There are routes coming from the NW and from the SE. Presently these routes are used by deep draught vessels calling at the Beilun ore terminal to partially unload their cargo to proceed to the Baoshan terminal at Shanghai.

Projection of terminal area on location

As is mentioned earlier, the required terminal area will be projected on the location to give a general idea of the dimensions. In an overview is given of the three locations including a projection of the terminal area. The second map represents the location of Daxie Dao.

Advantages/Disadvantages

Advantages:

- Daxie Dao can easily accommodate the largest vessels while it has natural deep water areas nearby.
- The suggested area is already flat and large enough to accommodate a possible future expansion of the container terminals. (Only 1294 ha of the available 1900 ha will be used in 2025).
- The soil of the islands consists of rock with a high bearing capacity.
- The island is protected by the Zhoushan islands from natural influences.

Disadvantages:

- The distance to Shanghai is approximately 350 kilometres via road and 260 kilometres over water, which is a very long distance to drive/sail.
- Although the quality of the infrastructure network is being improved, the infrastructure isn’t yet fully developed.
- The total available shore length is relatively small. Allocating new terminals alongside the planned terminals is therefore difficult.
6.3 Nanhui Zui

General
This area is lying on mainland and is only lying at 80 km South East of Shanghai. *(Exact location: 30° 53’ N, 121° 52’ E)* At this point, the Yangtze River flows out into the East Chinese Sea (Figure 6-3). The area is flat and well cultivated.

![Figure 6-3: Location of Nanhui Zui](image)

At the moment, 50 kilometres further south down the coast of Nanhui Zui at Jinshan Zui, some industrial and shipping activities are being deployed. At that location a petrochemical industry and some deep water tanker berths are established. In the immediate surroundings of Nanhui Zui mainly agricultural activities take place.

In the future, Shanghai is planning to build a 4-berth container terminal at Jinshan Zui to expand its terminals. The planned new terminal is projected to be a deep water terminal. This is a good site for a deep water terminal while a natural depth of 15 metres can already be found at 3 kilometres from the shore. 10 kilometres from the shore however, the depth is already decreasing to approximately 7 metres below Chart Datum making large scale dredging works necessary. Therefore, for this container terminal the location around Nanhui Zui will be chosen for development. Still an approach channel has to be dredged, but it won’t be as long as it would have been from Jinshan Zui.

Soil conditions
Nanhui Zui is lying at the tip of the mouth of the Yangtze River. Soil conditions at that point are therefore largely influenced by the large sediment transport of this river (about 470 million tons of silt annually [19]). It is assumed that the soil mainly consists of sand and clay. Longshore currents provide a nett transport in southward direction.

At a distance of around 2 kilometres from the shore, the bottom of the sea reaches a depth of around 7.5 metres below chart datum. From this point the depth stays fairly constant for several kilometres. The smallest distance from the shore to a natural depth of 15 metres lies around 65 kilometres offshore in direction West South West (WSW).
Hydraulic conditions

Waves

Waves in the Hangzhou Bay are predominantly wind induced while swell is blocked by the Zhoushan islands lying in the South East of the bay. The significant wave height in the Hangzhou Bay is 0.2 metres.

Tide

The tidal range is as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>MLWS</th>
<th>MLWN</th>
<th>MHWN</th>
<th>MHWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanhui Zui</td>
<td>0.9</td>
<td>2.0</td>
<td>3.1</td>
<td>4.2</td>
</tr>
</tbody>
</table>

(Values are above Chart Datum (= Lowest Astronomical Tide (LAT))

Tidal streams attain a speed parallel to the coast of 1 knots at neap tides and 3 knots at spring tides [17]. The direction of the currents is as follows:

<table>
<thead>
<tr>
<th>Interval from HW at mouth of Yangtze River</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 hours before HW</td>
<td>Westward stream begins</td>
</tr>
<tr>
<td>Approx. 1 hour after HW</td>
<td>Eastward stream begins</td>
</tr>
</tbody>
</table>

Hinterland connections:

Road/Rail

While at Jinshan Zui already a deep water berth and a petrochemical industry have been established, road connections are already established and are of good quality. Furthermore, the distance to Shanghai via road is about 100 kilometres. Rail connections aren’t available.

Water

Nanhui Zui lies at the side of the routes leading to Shanghai and Jinshan Zui and can therefore, apart from draught restrictions, easily be reached.

Projection of terminal area on location

In 0 an overview is given of the three locations including a projection of the terminal area. The third map represents the location of Nanhui Zui.

Advantages/Disadvantages

Advantages:
- Nanhui Zui lies relatively close to Shanghai, both via waterway and via road.
- The infrastructure at the area is well developed.
- The area provides enough space for future port expansion.

Disadvantages:
- The depth offshore is relative shallow. Therefore a large approach channel must be dredged.
- The soil consists of a sand/clay mixture. The expected high wheel loads require high bearing capacity of the soil. Therefore the clay must be replaced by a sand fill.
- The location is subject to the sediment, transported by the Yangtze River. Maintenance dredging will be frequently needed.
- The location doesn’t provide any shelter in case of a typhoon.
6.4 Yangshan Islands

General
The islands Dayangshan (Big island) and Xiaoangshan (Little island), lying approximately 35 kilometres from the coast of Nanhui Zui, belong to Qigu Qundao, which itself belongs to Zhoushan Qundao. (Qundao means archipelago)

(Exact location: 30° 36’ N, 122° 04’ E)

Of this archipelago, Dayangshan is the largest. The principal village of Dayangshan is situated at the head of the bay at the East side of the island.

Shanghai already has plans to construct a 56-berth container terminal on these islands while they provide natural deep water areas at a close distance from Shanghai.

Soil conditions
Both islands are very hilly and have high peaks above sea level. Dayangshan has 2 peaks of around 200 metres high and Xiaoangshan has three peaks of around 140 metres high. The islands mainly consist of rock.

The natural depth around the islands lies around 13 metres below chart datum. At 25 kilometres in westerly direction a depth of 24 metres below CD can be reached. Until this point, the depth remains fairly constant.

Hydraulic conditions

Waves
Like at the other locations, swell coming from the pacific is blocked by the Zhoushan islands. Although Dayangshan and Xiaoangshan form part of the Zhoushan islands, there are still some islands at the East of the archipelago that block the swell.

Also for this location it is assumed that the occurring waves are mainly wind induced. With this assumption, a significant wave height of 0.2 metres is taken.

Tide
For the horizontal tidal range, the results of a wave observatory station lying about 35 kilometres to the East of the islands will be taken.

The tidal range is as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>MLWS</th>
<th>MLWN</th>
<th>MHWN</th>
<th>MHWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baijieshan</td>
<td>0.8</td>
<td>1.8</td>
<td>3.2</td>
<td>4.2</td>
</tr>
</tbody>
</table>

(Values are above Chart Datum (=Lowest Astronomical Tide (LAT))

Tidal streams attain speeds of 1 knot at neap tides and 4 knots at spring tides [17]. The direction of the currents is as follows:

<table>
<thead>
<tr>
<th>Interval from HW at mouth of Yangtze River</th>
<th>Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 hours until 3 hours before HW</td>
<td>Between SE and WSW</td>
</tr>
<tr>
<td>3 hours before HW until HW</td>
<td>Between WSW and NNW</td>
</tr>
<tr>
<td>From HW until 3 hours after HW</td>
<td>Between NNE and ENE</td>
</tr>
<tr>
<td>3 hours until 6 hours after HW</td>
<td>Between ENE and SE</td>
</tr>
</tbody>
</table>
Hinterland connections:

Road/Rail

Road connections are not available.

Water

Sailing distance to the existing terminals of Shanghai will be approximately 150 kilometres. Barges sailing for the domestic services group should be able to reach the islands without any problems.

Projection of terminal area on location

As can be seen from the picture in Appendix VII, the terminal area occupies a large space of the islands (Fourth map). Therefore, as a first estimation, a part of the bay between the islands must be filled to gain enough space.

Advantages/Disadvantages

Advantages:

- The natural depth around the islands lies around 13 metres. With the depth requirement of 15.60 metres (Rock, see paragraph 3.5.4) only a small amount of capital dredging works has to be performed.
- The soil of the islands consists of rock with a high bearing capacity.

Disadvantages:

- The terminal should also be available for road traffic. Therefore a 35 kilometre bridge should be constructed connecting the islands with mainland.
- With a bridge, the driving distance will be approximately 150 kilometres.
- As is previously mentioned, the islands are mountainous. With the fact that a container terminal can only be constructed on flat areas (due to operating restrictions), high costs have to be spend on equalising the islands.
- While the islands on their own don’t provide enough adjacent area, the bay between the islands should partly be filled.
- The soil of the islands consists of rock leading to heavy dredging works.
7 Location selection

In this chapter the location will be chosen at which the container terminal will be developed.

The selection of the location can take place in a quantitative and in a qualitative way. For this stage of development, a quantitative method is too complex while for example the eventual costs per TEU or the total benefits can hardly be calculated in a right way. In this report, the selection will therefore take place in a qualitative way. While working in this qualitative way, one should bear in mind that the selection process is subject to the user’s opinion. Further on, in paragraph 7.2, it is tried to minimise this subjectivity.

The qualitative method that will be used in this report is the so called “Multi criteria analysis”. This method uses criteria with which a judgement can be given of the location. In Appendix VIII the MCA method is explained.

In the following, first the criteria will be described after which the selection can take place.

7.1 Description of criteria

The criteria that will be used to evaluate the properties of the various locations can be divided over 4 categories. These categories are:

- Physical conditions
- Operational aspects
- Economics
- Environment

In the following, the criteria will be shortly discussed per category.

Physical conditions

The physical conditions describe the actual position of the location with regard to oceanographic and geographical influences.

Oceanographic

Waves: The significant wave height is dependent on the location of the port. When this wave height is high, the location is logically less favourable while it is harder to manoeuvre the smaller vessels.

Currents: Manoeuvring of vessels is hard when high (tidal) currents around the terminal’s area occur.

Tide: The vertical tide very much depends on the location. The Hangzhou Bay p.e. acts as a trough for the tide leading to a great variation.

Geographic

Sedimentation: A high sedimentation rate at the location leads to high maintenance dredging costs and delays, while vessels cannot berth at the quay during dredging works.

Soil conditions: The bearing condition of the soil area is important while, during operation of the terminal, use will be made of equipment with high wheel loads. Soft soil should therefore be removed leading to high costs.

Natural depth: The natural depth around the area determines the amount of capital and maintenance dredging works to be executed.
Operational aspects

The operational aspects of the area can be divided over the aspects during construction of the terminal and during operation. Both phases have their own specific requirements.

Execution phase

Dredging works: The condition of the soil is very important while dredging of rock is much harder than dredging soft soils.

Soil movement: Should the area be equalised or is it already available for construction. If the dredged material can be used for fill, then large sailing distances can be avoided.

Hinterland connections: Is the location within easy reach of hinterland connections. During construction works, a lot of movements should be made for the supply of materials and equipment.

Operational phase

Quality of hinterland connections: Is the terminal within easy reach of hinterland connections or should connections with the hinterland first be made before construction can begin.

Distance to Shanghai: What is the distance to Shanghai. A short distance to Shanghai leads to time and fuel savings.

Vessel’s approach: Is it easy for vessels to reach the terminals or are they in an early stage restricted to an approach channel.

Vessel’s manoeuvring space: Are vessels able to deviate from their path without running aground.

Shelter: Are vessels able to take shelter in case of heavy meteorological conditions.

Possibilities for port extension: Does the area provide enough space for future extension of the terminals.

Economics

The eventual construction of the terminal is highly dependent on the feasibility of the terminal. This feasibility depends both on the construction costs and the costs during operation.

Construction costs

Dredging costs: Large amounts of soil to be dredged lead to high costs. The question whether the dredged soil can be used as fill is also important while large sailing distances can be avoided.

Soil movement: A hilly environment leads to large soil movements and thus high costs unless the soil can be used for fill.

Hinterland connections: Are large investments necessary for improving the quality of the hinterland connections or are they already available.

Operational costs

Maintenance costs: A high siltation rate leads to high returning dredging costs.

Transport distance to Shanghai: A short distance to Shanghai leads to time and fuel savings.

Environment

Noise pollution: Loading and unloading activities during operation cause a lot of noise and are considered very inconvenient for nearby villages.

Traffic increase: Large distances to Shanghai lead to a lot of traffic.
7.2 Choice of location

Now the selection criteria have been described, the location alternatives can be compared with each other. As is mentioned above, the selection will take place in a qualitative manner.

To reduce the influence of the user’s opinion in this process, three scenarios have been made according to which the alternatives will be compared. These scenarios are:

- **Operational scenario** in which mainly the operational aspects during construction and use of the terminal are considered to be the most important.
- **Economical scenario** in which the costs of construction and use of the terminal are the most important.
- **Overall scenario** at which the criteria regarding the costs and operational aspects of the alternative are almost equally important.

In Appendix VIII the weights per scenario and scores per alternative can be found. In this paragraph only the results are given. As can be seen from the table below, the location at Daxie Dao is the best for two scenarios.

**Table 7-1: Results of the MCA**

<table>
<thead>
<tr>
<th>Location</th>
<th>Overall</th>
<th>Operational</th>
<th>Economical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Daxie Dao</td>
<td>344</td>
<td>339</td>
<td>342</td>
</tr>
<tr>
<td>Nanhui Zui</td>
<td>340</td>
<td>360</td>
<td>339</td>
</tr>
<tr>
<td>Yangshan</td>
<td>307</td>
<td>300</td>
<td>303</td>
</tr>
</tbody>
</table>

Only for the operational scenario, Nanhui is the best alternative. This is mainly due to the relatively small distance to Shanghai while it is lying at the mouth of the Yangtze River. This position can also be considered as the main disadvantage of this location while it faces high maintenance costs caused by the outflow of sediment from this river.

The location at the Yangshan islands is for all scenarios the least favourable. It faces a sedimentation problem while it lies in the outflow area of the Yangtze River like Nanhui Zui and it faces a problem with its hinterland connections like Daxie Dao does.

As is mentioned before and can be seen from the table, Daxie Dao offers the best location for port expansion. Nanhui Zui’s ranking however is very close to Daxie Dao’s at the economical and overall scenario that it could be called a draw. Nanhui Zui score at the operational scenario however is remarkably higher than Daxie Dao’s.

Considering the above mentioned scoring rates, Nanhui Zui will be chosen for further development of the container terminal.
8 Terminal design

Now the location has been selected, the terminal lay-out can be determined. For the configuration of all terminals, many possibilities are available dependent on the local conditions. In this chapter, first the local conditions will be described in more detail than has been done at the selection process after which a design will be made.

The design of the terminal will be preceded by the global design of the approach channel. With the position of this channel, the position of the terminal area is somewhat more restricted. For the design of this area, three rough designs will be made after which one will be chosen. At the end of this chapter a cost estimation will be made and the phasing of execution will be described.

8.1 Description of the natural condition of the area

In paragraph 6.3 already some details of the area have been described. In this part an effort will be made to describe the natural conditions in more detail while no specific data is available. The natural conditions will be split up in three parts, a geographical, a hydraulic and a meteorological part.

8.1.1 Geographical

Nanhui Zui lies at the mouth of the Yangtze River and is subject to the outflow of sediment. From the bathymetry given in Appendix IX it can be seen that the area around Nanhui Zui is relatively shallow compared to the areas lying some 100 kilometres off the coast. This can be ascribed to the constant outflow of the sediment transported by the Yangtze River. High sedimentation rates and frequent maintenance dredging could therefore be expected.

An indication of the sedimentation rate can be obtained from an article published in 1998 by Chen Xiqing [25]. This article describes the historical development of the Yangtze River Delta. In the figures below a rough sketch can be found of the annual sedimentation rate in centimetres as well as the characteristics of the surface sediments.

![Figure 8-1: Annual sedimentation rate and sediment characteristics](image-url)
Data on the soil conditions of the land area around Nanhui Zui is scarce. However from various borings along the southern bank of the Yangtze River an indication can be given of the quality and building-up of the soil. In Appendix X the soil conditions can be found.

The area in which Nanhui Zui lies, is subject to earthquakes. To prevent catastrophes such as the one in Kobe in the early 1990's, measures should be taken to prevent liquefaction at newly reclaimed areas. For this stage of the design process however, measures will not be considered while the project is still in an early stage of development.

### 8.1.2 Hydraulic

In this paragraph the hydraulic features of the area around Nanhui Zui are described. First the tidal motions will be described and then the wave climate will be described.

#### Tidal motion

The, for this project, relevant effects caused by the tide can be split up in two parts. The vertical tide and the horizontal tide. The vertical tide effects are the rise and fall of the water level and the horizontal tide effects are the arising currents. Data of the tide are obtained by a station lying some 100 kilometres in ESE direction (30°44'20 N, 122°10'10 E).

#### Vertical tide

As has already been described in paragraph 6.3, the horizontal tidal range around Nanhui Zui is as follows:

<table>
<thead>
<tr>
<th>Location</th>
<th>MLWS</th>
<th>MLWN</th>
<th>MHWN</th>
<th>MHWS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanhui Zui</td>
<td>0.9</td>
<td>2.0</td>
<td>3.1</td>
<td>4.2</td>
</tr>
</tbody>
</table>

(Values are above Chart Datum (=Lowest Astronomical Tide))

Apart from the tidal movement another vertical movement can also be distinguished. This is wind set up caused by a typhoon. Due to this phenomenon, the wind set up in the area can be as large as 2 metres.

#### Horizontal tide

Tidal streams attain a speed parallel to the coast of around 1 knot at neap tides and 3 knots at spring tides [17] The maximum speed at spring tide could reach a value of 6 knots. The direction of the currents sets as follows:

**Table 8-1: Horizontal tide values**

<table>
<thead>
<tr>
<th>Interval from HW (Hours)</th>
<th>Direction (Degrees)</th>
<th>Spring tide (Knots)</th>
<th>Neap tide (Knots)</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0600</td>
<td>097</td>
<td>3.5</td>
<td>1.3</td>
</tr>
<tr>
<td>-0400</td>
<td>200</td>
<td>1.4</td>
<td>0.5</td>
</tr>
<tr>
<td>-0200</td>
<td>243</td>
<td>2.8</td>
<td>1.1</td>
</tr>
<tr>
<td>0</td>
<td>267</td>
<td>3.0</td>
<td>1.1</td>
</tr>
<tr>
<td>+0200</td>
<td>330</td>
<td>1.6</td>
<td>0.6</td>
</tr>
<tr>
<td>+0400</td>
<td>055</td>
<td>3.4</td>
<td>1.3</td>
</tr>
<tr>
<td>+0600</td>
<td>090</td>
<td>4.5</td>
<td>1.7</td>
</tr>
</tbody>
</table>

#### Waves

Exact measurements regarding wave heights have not been executed in the area near Nanhui Zui. The closest monitoring station in the area is a pilot vessel lying approximately 65 kilometres in East North Eastern direction of Nanhui Zui. Observations
made by this vessel will therefore be used. Waterdepth at that location was 10 metres below Chart Datum during the measurements. Values observed by this vessel can be found in the table below.

Table 8-2: Seasonal wave data observed by a pilot vessel

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean wave direction</td>
<td>NW-NNW</td>
<td>SE-SSE</td>
<td>SSE-S</td>
<td>NNE-NE</td>
</tr>
<tr>
<td>Mean wave height</td>
<td>1.4</td>
<td>1.1</td>
<td>1.1-1.2</td>
<td>1.1-1.3</td>
</tr>
<tr>
<td>Monthly max mean wave height</td>
<td>2.5-2.7</td>
<td>1.9-2.1</td>
<td>1.9</td>
<td>2.0-2.2</td>
</tr>
</tbody>
</table>

In this table the mean wave height is assumed to be the average wave height observed during monitoring periods. The weather conditions at these periods are assumed to be not extreme.

The observed wave heights can be transformed into a significant wave height using the following equation:

$$H_{sw} = 1.68 \times (H_{\text{observed}})^{0.75}$$

(See PDC report 1995 [22])

The correlation between observed wave height and significant wave height is justified, based on experiences that observing waves mostly leads to an underestimation of the lower wave height and an overestimation of the higher wave heights [22]. Using this equation the following significant wave heights are obtained:

Table 8-3: Significant wave heights per season

<table>
<thead>
<tr>
<th></th>
<th>Winter</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean wave direction</td>
<td>NW-NNW</td>
<td>SE-SSE</td>
<td>SSE-S</td>
<td>NNE-NE</td>
</tr>
<tr>
<td>Mean wave height</td>
<td>2.2</td>
<td>1.8</td>
<td>1.8 - 1.9</td>
<td>1.8 - 2.0</td>
</tr>
</tbody>
</table>

The mean wave period in the area equals 3.85 seconds. During typhoons the wave period can reach value of 16.1 seconds.

8.1.3 Meteorological

In Appendix XI a climatic table can be found for Shanghai taken from the China Sea Pilot [17]. Below some additional information can be found.

Typhoons

Typhoons generally occur once or twice a year and generally appear in the period of July to September coming from the North East. Typhoons can be characterised by the wind direction, the wind speed and the duration. In the following table an indication can be found for the circumstances during a typhoon.

<table>
<thead>
<tr>
<th>Wind direction</th>
<th>Wind speed (m/s)</th>
<th>Affected days</th>
</tr>
</thead>
<tbody>
<tr>
<td>SSW</td>
<td>15.6</td>
<td>2.0</td>
</tr>
<tr>
<td>E</td>
<td>13.6</td>
<td>4.0</td>
</tr>
<tr>
<td>ENE-ESE</td>
<td>12.7</td>
<td>11.0</td>
</tr>
<tr>
<td>N</td>
<td>10.0</td>
<td>5.7</td>
</tr>
<tr>
<td>SSE</td>
<td>9.6</td>
<td>4.3</td>
</tr>
</tbody>
</table>

Fog

The annual maximum number of days with fog is 60. Fog forms frequently during the months from March to July. The maximum amount occurs in the month May.
8.2 Approach channel

The approach channel is an important element in the design of the new container terminal while it provides access to the main container providers sailing for the ocean services group. The design of the channel made in this study is, like the design of the terminal, only a conceptual one to provide insight in the amount of construction work and hence costs.

8.2.1 Alignment

By trying to determine the path of the approach channel an effort will be made to keep the channel as short as possible. This is done while it is easier for vessels to manoeuvre in areas where they are not restricted by a channel. Another consideration is the reduction of costs involved. The fact that the natural depth around Nanhui Zui is relatively small makes large scale capital dredging works necessary. Furthermore, siltation due to the Yangtze River makes frequent maintenance dredging works necessary. Furthermore, the angle of the channel with the direction of the prevailing cross current and cross winds should be kept as small as possible to avoid hindrance of the vessel’s manoeuvrability.

Figure 8-2: Possible approaches to Nanhui Zui

When looking at the map of Nanhui Zui’s surroundings it can be seen that the nearest deep water area can be found at some 35 nautical miles away in south west direction (straight lines). The second nearest location lies some 60 nautical miles in easterly direction from Nanhui Zui (dotted line). This second alternative has better properties concerning the angle with cross currents and cross winds, but it is also almost twice as long as the first alternative. This alternative also lies perpendicularly at the outflow of the Yangtze River facing a high sedimentation rate.

Considering above mentioned cost requirements, the channel in south eastern direction is chosen for further development. Within this direction 2 variants can be distinguished.
Northern approach channel

This variant logically passes the Dayangshan islands at the north side (Red line in Figure 8-2). The channel can be kept in one straight line from the deep water area up to the terminal area. The length of the channel will be approximately 31 nautical miles.

The advantage of this channel is that vessels can sail in one straight line to/from the terminals. This makes it easier for vessels to manoeuvre. Also the angle with cross currents near the terminal's area is somewhat smaller than at the other variant.

The disadvantage of this variant is that it crosses several pipelines and is lying somewhat more in the direction of the "sedimentation tongue" created by the Yangtze River than the southern variant. (See map in Appendix XIII).

Southern approach channel

This variant logically passes the Dayangshan islands at the south side (Blue line in Figure 8-2). The length of the channel is approximately 29 nautical miles and has two bends.

The advantage of this variant is that it is 2 miles shorter than the other variant and at the first part of the approach it lies almost parallel to the prevailing currents between the islands. Another advantage is that the channel lies farther from the "sedimentation tongue" created by the Yangtze River than the northern variant. (See Appendix XIII)

The disadvantage of this variant is that it contains two bends and approaches the coast almost perpendicularly. This angle means that currents due to tidal motion cross the channel almost perpendicularly. The channel furthermore passes over a gas pipeline.

While the length of both channels is almost the same, a choice could be made between both variants regarding navigational aspects. Within this aspect, the northern variant is the best option. With this option vessels can sail in a straight line towards the terminals. Also the angle of cross currents with the channel is smaller compared to the other variant.

However, as already has been described, the southern variant lies somewhat farther away from the "sedimentation tongue" created by the Yangtze River. This could lead to substantially lower costs for capital and maintenance dredging and could therefore be preferred above the northern variant. In the following few sections first the features of the channel will be calculated. After this calculation a final choice will be made for one of the two variants.

8.2.2 Number of lanes

With the determination of the features of the approach channel, the choice for a one-way or a two-way channel is very important. The importance of this choice lies in the high dredging costs involved. If possible a one-way channel should therefore be constructed. This choice however doesn’t only depend on the high dredging costs. At the moment that vessels face high waiting times due to unavailability of the channel, they could choose for other ports. Therefore the choice for the number of lanes of the channel depends both on the construction costs and the costs of vessels waiting. This choice can at best be determined using computer simulation models. Within this study, the determination will be done according to some assumptions.

Already in chapter 4.3 the assumption has been made that it will take 1.5 hours for ocean vessels to berth and deberton.

The berthing process for example, starts at the moment the approach channel is blocked due this vessels manoeuvres and ends at the moment the vessel is moored at the quay. While it is not possible to sail through the channel and moor at the quay within one hour, it is hereby assumed that the berthing/ deberthing process excludes sailing through the
approach channel. The result of this assumption is that the channel should always be available to vessels approaching the terminals. The choice for a one-way or a two-way channel is therefore dependent on the traffic intensity. In the table below this intensity can be found for the years 2008, 2015 and 2025.

<table>
<thead>
<tr>
<th>Year</th>
<th>Vessels per month</th>
<th>Total in channel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ocean</td>
<td>Short Sea</td>
</tr>
<tr>
<td>2008</td>
<td>54</td>
<td>109</td>
</tr>
<tr>
<td>2015</td>
<td>103</td>
<td>247</td>
</tr>
<tr>
<td>2025</td>
<td>244</td>
<td>655</td>
</tr>
</tbody>
</table>

With a speed of say 10 knots, which is a reasonable speed to maintain in a channel, it takes roughly 3 hours for a vessel to sail through the channel. Within this time period 7.50 vessels make use of the channel by the year 2025.

While vessels should be able to pass each other, a two-way channel should be made at the moment there are more than one vessels in the channel during a three hour period. This moment already lies in the year 2005.

8.2.3 Shape of the channel

Depth

The determination of the depth of the channel highly depends on the presence of a tidal window. For this approach channel no tidal window is regarded while in the future around 244 vessels sailing for the ocean services group will call at the port every month. The average depth of these vessels lies around 14 metres. With a tidal window, delays will probably occur.

In paragraph 3.5.4 already an estimation was made regarding the depth. This calculation however was a very rough calculation. In this paragraph a check will be made of the validity of the calculation according to PIANC design rules. The formula given earlier is still valid though:

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

In which:

- \( d \): Guaranteed depth with regard to chart datum (Lowest Astronomical Tide (LAT))
- \( D \): Draught of the design ship (14 metres)
- \( s_{\text{max}} \): Maximum sinking due to squat and trim
- \( r \): Vertical motion due to wave agitation
- \( m \): Safety margin (underkeel clearance)

All factors in this formula remain the same as in paragraph 3.5.3 except for the draught and vertical motion due wave agitation. In that paragraph these factors were estimated to have a value of 0.5 metres and 0.1 metres respectively.

The value regarding the vessel’s motion due to waves can easily be adjusted while new insight is obtained in the significant wave height. The value increases from 0.1 metres to 0.9 metres. With a mean wave period of only 3.85 seconds however, this value is could probably be somewhat lower. For this preliminary design though this value will be maintained.
The formula for the calculation of squat given by PIANC is the following:

$$Squat (m) = 2.4 \frac{\nabla}{L_{pp}} \frac{F_{nh}^2}{\sqrt{(1 - F_{nh}^2)}}$$

in which:

- $\nabla$ = Volume of displacement (m$^3$) = $C_B \cdot L_{pp} \cdot B \cdot T$
- $L_{pp}$ = Length of ship between perpendiculars (385 metres)
- $B$ = Ship’s beam (55 metres)
- $T$ = Ship’s draught (14 metres)
- $C_B$ = Block coefficient (0.70 = assumption according to PIANC tables)
- $F_{nh}$ = Froude depth number $F_{nh} = \frac{V}{\sqrt{gh}}$
- $V$ = Vessel’s speed (10 Knots = 5 m/s)
- $h$ = Water depth
- $g$ = Force of gravity (9.81 m/s$^2$)

As can be seen from the formula above, first a depth should be chosen while the squat depends on this depth. In this case the minimum depth/draught ratio of 1.1 will be chosen. With this ratio the depth becomes 15.4 metres. With this depth the Froude depth number becomes 0.41.

The volume of displacement is calculated to be 207,520 m$^3$

With these values the squat can be calculated. The squat will be approximately 0.62 metres. The previously estimated 0.5 metres was rather close, but from now on this new value will be used.

With this new value the total required depth becomes 16.0 metres. With a minimum height of 0.7 metres above Chart Datum during Mean Low Water Spring, a minimum depth of 15.3 metres below CD should be available in the channel.

**Width**

The width of the channel depends on many factors expressed as a multiple of the breadth ($B$) of the design vessel. (See paragraph 3.5.1 for the features of the design vessel) These factors have been put into a formula to determine the total width of the channel. A distinction is made for a one-way and a two-way channel:

$$w = w_{BM} + \sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} \quad \text{One-way channel}$$

$$w = 2w_{BM} + 2\sum_{i=1}^{n} w_i + w_{Br} + w_{Bg} + \sum w_p \quad \text{Two-way channel}$$

In Figure 8-3 a cross section is given of a typical channel containing the several factors of the formulae. The value of the factors can be determined with tables provided by PIANC (See [23]). These tables can be found in Appendix XII. In the following a description will be made of the factors involved for the channel until the year 2005 and after the year 2005.
Figure 8-3: Elements of the channel width

\( W_{BM} \)

\( W_{BM} \) is the factor that counts for the Basic Manoeuvring width. This width is needed while a vessel’s path is never a straight line while on manual control. This is for example due to the difference in response time of the vessel and the captain. The table below gives the values recommended by PIANC. For container vessels moderate to poor manoeuvrability could be expected. With their high superstructure they are vulnerable to cross winds. For this reason the factor for poor manoeuvrability is used.

<table>
<thead>
<tr>
<th>Ship manoeuvrability</th>
<th>Good</th>
<th>Moderate</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>( W_{BM} )</td>
<td>1.3 B</td>
<td>1.5 B</td>
<td>1.8 B</td>
</tr>
</tbody>
</table>

\( W_l \)

The \( W_l \) factor is built up of several factors depending on the natural environment of the channel. A distinction is made between inner and outer channels. According to PIANC design rules an outer channel is exposed to waves causing important vessel motions. An inner channel is not exposed to wave agitation of any significance. With a mean wave height and period of only 1.9 metres and 3.85 seconds respectively, vessels sailing through this channel will hardly be affected. As is stated by Thoresen [24], large carriers are only influenced by waves with a period of more than 10 seconds. The channel can within this respect be considered as an inner channel. However, from the table in Appendix XII it can be read that inner channels are not exposed to cross currents of more than 1.5 knots. From the horizontal tide movements mentioned above, it can be seen that this channel is exposed to an average cross current of between 1 and 2 knots. Due to this feature the channel will therefore be considered as an outer channel.

In the following, the factors will be discussed for the situation before and after the year 2015. The factors mentioned below can all be found in Table 13-27 in Appendix XII.

a) Vessel speed
The speed of the vessel is set at 10 knots. With this rate, no factor is applied.

b) Prevailing cross wind
The prevailing cross wind comes from NE direction. In Appendix XI it can be seen that the mean wind speed doesn’t exceed 12 knots and could therefore be considered as mild. With this wind speed no factor is applied.
c) Prevailing cross current
The mean speed of the prevailing cross current lies between 1 and 2 knots. This speed is considered as strong and a factor of 1.0 B is applied.

d) Prevailing longitudinal current
As well as for the cross current the mean speed between the islands lies between 1 and 2 knots. For a longitudinal current this is considered as “moderate”. A factor of 0.1 B is therefore applied.

e) Significant wave height and length
As is described above, the channel lies in a well protected area and is, within this respect, considered as an inner channel. For an inner channel no factors are applied.

f) Aids to navigation
Being one of the largest container handling ports of the world, Shanghai should in the future provide a vessel traffic information system. With this service, the aids of navigation can be considered as good. Therefore no factor will be applied.

g) Bottom surface
The depth / draught ratio of the channel is 1.10. For ratios below 1.50, the table in the appendix provides factors per type of bottom surface. For this case it is assumed that the bottom of the channel is smooth and soft due to siltation of the Yangtze River. The factor is therefore 0.1 B.

h) Depth of the waterway
While the depth / draught ratio of the channel is 1.10, a factor of 0.4 B is applied.

i) Cargo hazard level
Containers are considered as cargo with a low hazard level. No factor is therefore applied.

With all these factors added up, the \( W \) becomes 1.0 B.

\( W_B \) and \( W_S \)

\( w_B \) and \( w_S \) are the factors that comprise the effects of a vessel sailing close to the banks of the channel. To keep these effects to a controllable minimum, this factor is applied. Table 13-26 in Appendix XII distinguishes “steep and hard” embankments and “sloping edges and shoals”. In Figure 8-4 the difference between these two can be found. This channel can be considered as one of the last category. The factor that should be applied for an inner channel is 0.5 B.
Figure 8-4: Difference in embankments

$W_p$

$W_p$ considers the passing distance between two vessels and should therefore only be applied at the two-way channel. This factor consists of two parts. One part considers the speed of the vessel, the other considers the traffic intensity. The factor that counts for the vessels speed is $1.4 \, B$ for a speed of 10 knots and $1.0 \, B$ for a speed of up to 8 knots. To reduce the width of the channel and with it the dredging costs, the factor of $1.0 \, B$ will be taken. Vessels should then reduce their speed to 8 knots at maximum while passing another vessel.

The factor that regards the traffic intensity distinguishes light($<1$ per hour), moderate (between 1 and 3 per hour) and heavy traffic ($>3$ per hour). In the previous sections it was already assumed that a two-way channel is necessary after the year 2005. In 2005 a traffic intensity of 0.33 vessels per hour and in 2025 an hourly intensity of 2.50 could be expected. With these intensities a factor of $0 \, B$ and $0.2 \, B$ should be applied respectively.

In this case it is assumed that the intensity will linearly increase to 2.50 from the year 2005. From a linear interpolation it can be found that the point where the intensity switches to moderate lies in the year 2015. Until this year no factor is therefore applied and after this year a factor of $0.2 \, B$ is applied.

Within this channel overtaking is not allowed. Overtaking in this channel is not necessary while the fixed speed of 10 knots in the channel can be met by all vessels sailing through this channel.
Now all factors have been determined, the total channel width could be calculated. In the following table all factors can be found together with the total needed channel width.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic manoeuvring width</td>
<td>1.8</td>
<td>2*1.8</td>
<td>2*1.8</td>
</tr>
<tr>
<td>Cross current factor</td>
<td>1.0</td>
<td>2*1.0</td>
<td>2*1.0</td>
</tr>
<tr>
<td>Longitudinal current factor</td>
<td>0.1</td>
<td>2*0.1</td>
<td>2*0.1</td>
</tr>
<tr>
<td>Bottom surface</td>
<td>0.1</td>
<td>2*0.1</td>
<td>2*0.1</td>
</tr>
<tr>
<td>Depth of the waterway</td>
<td>0.4</td>
<td>2*0.4</td>
<td>2*0.4</td>
</tr>
<tr>
<td>Bank effects</td>
<td>0.5</td>
<td>2*0.5</td>
<td>2*0.5</td>
</tr>
<tr>
<td>Passing distance</td>
<td>0.0</td>
<td>1.6</td>
<td>1.6</td>
</tr>
<tr>
<td>Traffic intensity</td>
<td>0.0</td>
<td>0.0</td>
<td>0.2</td>
</tr>
<tr>
<td>Total</td>
<td>3.9</td>
<td>9.4</td>
<td>9.6</td>
</tr>
<tr>
<td>Vessel width</td>
<td>55 m</td>
<td>55 m</td>
<td>55 m</td>
</tr>
<tr>
<td>Channel width</td>
<td>215 m</td>
<td>517 m</td>
<td>528 m</td>
</tr>
</tbody>
</table>

The only feature dependent on the location of the channel are the extra calculations regarding the bends in this channel. In the following section these calculations will be made for the southern variant.

8.2.4 Channel bend calculation for southern variant

In this paragraph the width and the radius of the two bends of the southern variant will be calculated. The outcome of this calculation will however only be used in case the southern variant is chosen.

To determine the turning radius and width of the two bends, again some figures provided by PIANC will be used. These figures can be found in the figure below.

![Graphs for determination of bend radius and width](image)

Figure 8-5: Graphs for determination of bend radius and width
Both bends have an angle of 30 degrees. This is a relatively faint bend. When a mean rudder angle of 15 degrees is chosen, in a \( R/L_{90} \) ratio of 12 can be found. With a vessel length of 385 metres the radius of the bend becomes 4600 metres.

With the same method applied on the second graph of , the width of the channel in the bend becomes 1.15 \( B \). While this width is smaller than the width calculated for the straight legs, the width of the straight legs will be used.

### 8.2.5 Volume of capital dredging

Now the features of the channel are known, the amount of capital dredging can be determined. While no exact data on the bathymetry of the area is available, the depths will be based on an admiralty map (Map nr. 1124) of the area. On this map the areas through which both variants are located will be split up in sections with a certain height difference. The depth of each section is then taken as the average depth of the section.

The amount of capital dredging can now easily be calculated per section. Appendix XIII deals with the calculation per section for the years until 2005, between 2005 and 2015 and from 2015. Here only the results are given for the total amount of capital dredging until the year 2025.

#### Table 8-7: Amount of capital dredging per channel variant per section

<table>
<thead>
<tr>
<th>Section</th>
<th>North ( m^3 )</th>
<th>South ( m^3 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>3.85E+07</td>
<td>2.89E+07</td>
</tr>
<tr>
<td>B</td>
<td>9.77E+07</td>
<td>4.48E+07</td>
</tr>
<tr>
<td>D</td>
<td>1.91E+07</td>
<td>5.08E+07</td>
</tr>
<tr>
<td>E</td>
<td>2.86E+07</td>
<td>6.90E+06</td>
</tr>
<tr>
<td>Total</td>
<td>1.91E+08</td>
<td>1.32E+07</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>4.67E+07</td>
</tr>
</tbody>
</table>

As can be seen from the table above, the southern variant brings along a substantially lower volume of capital dredging than the northern variant. This volume however, is still very high. Also regarding the fact that these volumes are only the capital dredging volumes. Maintenance dredging still has to be added to these volumes and will probably be very high.

Having these high dredging costs in mind, another option for building new terminal capacity for the port of Shanghai appears. Within this new option a combination of the Nanhui Zui location and the Yangshan islands is established.

The location at the Yangshan islands have been deserted earlier in this report while mainly the need for a bridge connection with the shore would have been too expensive. This bridge connection was essential while 65 % of the domestic containers will be transported over land by the year 2025. The advantages of the islands are however that the natural depth around these islands is sufficient to receive the largest vessels and the turn around time of the largest vessels is smaller than in case of a shore based terminal.

Within the new combination of the two locations the ocean and short sea vessels will therefore call at Yangshan. Yangshan will now form the principal container port of Shanghai. The function of the essential bridge connection will be taken over by so called “shuttle barges”. These shuttle barges will sail between the islands and the shore to transport domestic containers to and from the islands. In the following section the new configuration will be further described.
8.3 Design of the proposed terminals on the Yangshan islands

As is described above, the Yangshan islands will handle all vessels sailing for the short sea and ocean services group. In this way no approach channel has to be dredged and high dredging costs will therefore be avoided. The connection with mainland will be established via a shuttle service consisting of barges that transport domestic containers between mainland and the islands. With this shuttle service, construction of an expensive bridge connection can be avoided.

The Yangshan islands will now act as the main hub for Shanghai and Shanghai itself will act as a satellite handling only the shuttle barges coming from Yangshan. As can be seen from the modal split in paragraph 3.4.2, the number of containers coming from and going to China’s hinterland is 90% of the total of transported containers. With a total throughput of 34.9 mTEU by the year 2025, the number of containers transported by the domestic services group will be roughly 25.4 mTEU. If Shanghai acts as a satellite for the Yangshan islands it will only be able to accommodate 6.6 mTEU as was already described in paragraph 3.4.6. For the remaining part a new terminal should be designed. For this new terminal, the area of Nanhui Zui will be used while it has proven to have the best conditions for a new terminal.

The existing terminals at Shanghai and the new terminal at Nanhui Zui will function as ports handling the exchange of containers between the shuttle barges and transport via road and rail. Barges coming from the Yangtze River will sail directly to the Yangshan islands. To give complete insight in the various transport movements, the following paragraph describes these movements according to the modal split made in paragraph 3.4.2.

8.3.1 Transport movements

In paragraph 3.3.4 it has been estimated that Shanghai will have a throughput of almost 35 mTEU by the year 2025. By that time 10% of the containers will be handled as “transshipment” and the remaining part will consist of domestic trade. See Figure 3-6 in paragraph 3.4.2 for an overview of the divisions between the several transport modalities within these two main parts. In the table below the number of containers per transport modality can be found.

<table>
<thead>
<tr>
<th>Table 8-8: Number of containers transported per transport modality</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transshipment</strong></td>
</tr>
<tr>
<td></td>
</tr>
<tr>
<td>(mTEU)</td>
</tr>
<tr>
<td>Ocean services group</td>
</tr>
<tr>
<td>Shortsea services group</td>
</tr>
<tr>
<td>Total</td>
</tr>
<tr>
<td>Domestic services group</td>
</tr>
<tr>
<td>Road</td>
</tr>
<tr>
<td>River</td>
</tr>
<tr>
<td>Rail</td>
</tr>
<tr>
<td>Total</td>
</tr>
</tbody>
</table>

As can be seen from this table, the number of containers transported via road and rail lies around 20.4 mTEU. This volume will be transported to the Yangshan islands by so called “shuttle barges” where they can be further transported by vessels sailing for the ocean or short sea services. Total throughput of the combined satellite terminals should therefore be 20.4 mTEU.
This volume should be handled by the existing terminals at Shanghai and the new terminal at Nanhui Zui. While the capacity of the existing terminals at Shanghai together with the plans for Waigaoqiao and Wahaogou is only 6.6 mTEU, the remaining part will be handled by the terminal at Nanhui Zui. In the table below an overview can be found of the volumes handled by the various terminals in the year 2025. It can also be seen that all containers transported via rail can be handled at the terminals of Shanghai. No railroad should therefore be constructed to the new terminal at Nanhui Zui saving high costs.

Table 8-9: Container handling volumes of the various terminals by the year 2025

<table>
<thead>
<tr>
<th></th>
<th>Terminal Satellite</th>
<th>Main Yangshan</th>
<th>Total mTEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shanghai</td>
<td>Nanhui Zui</td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>20.2 mTEU</td>
<td>20.2 mTEU</td>
<td></td>
</tr>
<tr>
<td>Short Sea</td>
<td>18.2 mTEU</td>
<td>18.2 mTEU</td>
<td></td>
</tr>
<tr>
<td>River barge</td>
<td>11.0 mTEU</td>
<td>11.0 mTEU</td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>2.2 mTEU</td>
<td>13.8 mTEU</td>
<td>16.0 mTEU</td>
</tr>
<tr>
<td>Rail</td>
<td>4.4 mTEU</td>
<td>4.4 mTEU</td>
<td></td>
</tr>
<tr>
<td>Shuttle barge</td>
<td>6.6 mTEU</td>
<td>13.8 mTEU</td>
<td>20.4 mTEU</td>
</tr>
<tr>
<td>Total throughput</td>
<td>6.6 mTEU</td>
<td>13.8 mTEU</td>
<td>34.9 mTEU</td>
</tr>
</tbody>
</table>

The figure below gives a clear overview of the various container movements as is stated in the table above.
Figure 8-6: Transport volumes per modality in the year 2025

Now the division of containers over the various terminals is known, the amount of calls of the various transport modes could be calculated. This will be done according to the same method used in paragraph 3.4. Within this table only the shuttlebarge is new. This vessel is completely dedicated to the above mentioned terminals. The capacity of the shuttlebarge should be as large as possible to reduce the costs per transported TEU. Its capacity however is limited by a certain maximum draught imposed by the depth of the Yangtze River and the depth around Nanhui Zui. To be able to calculate the number of calls of these shuttlebarges, first its properties will be discussed.

8.3.2 Properties of the shuttlebarge

As the draught of the shuttlebarge is the limiting factor for the capacity of these vessels, first the maximum acceptable draught should be calculated. It seems that the area around Nanhui Zui with a depth of around 7 metres, is the shallowest part of both shuttle routes while the Yangtze River has only been dredged to 8.5 meters.

While looking at the map in Appendix IX it can be seen that the depth increases quite fast to reach 7 meters. This depth is already lying at 1 kilometre off the coast and increases gradually to 9 metres up till the Yangshan islands.
For the determination of the type of vessel that can be used for the shuttlebarges, the maximum draught will be calculated. This will be done according to the same formula that has been used for the determination of the depth of the approach channel in paragraph 8.2.3. Only this time the draught of the vessel will be adjusted to the available depth. This available depth will be set at 7 meters below chart datum. The depth then becomes 7.7 metres while the lowest water level during Mean Low Water Spring reaches 0.7 metres above chart datum. A maximum draught of the shuttlebarge during sailing (including squat, trim etc.) of less than 7.7 metres should therefore be sought.

In Appendix XIV a selection of existing vessels can be found that stay below the maximum depth restriction of 7.7 metres. This selection is taken from a list containing roughly 2500 container vessels. For the shuttlebarge the vessel “Pablo Metz” will be used while it has a very large capacity. In the table below its properties can be found.

**Table 8-10: Properties of the shuttlebarge**

<table>
<thead>
<tr>
<th>Name</th>
<th>Total TEU</th>
<th>LOA</th>
<th>Beam</th>
<th>Draught</th>
<th>Parcel size</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pablo Metz</td>
<td>537</td>
<td>114.5</td>
<td>20.3</td>
<td>4.4</td>
<td>91 %</td>
</tr>
</tbody>
</table>

![Figure 8-7: Pablo Metz](image)

From the list in Appendix XIV it can be seen that only 3 vessels have a larger capacity than the Pablo Metz. These vessels however have some disadvantages. Two of them are very close to the 7.7 metres restriction and the other has a length of almost 195 metres. The Pablo Metz is therefore considered as the best vessel.

To be able to determine the number of calls of this vessel, the parcel size should be known. While this vessel is completely dedicated as a shuttle, the parcel size will be 91%. A parcel size of 100% could not be attained the number of import containers is not equal to the number of export containers.

In the following paragraph the number of calls will be determined.

**8.3.3 Determination of number of calls at the terminals**

Now the total number of containers per terminal location has been determined and the properties of the various vessels calling at these terminals are known, the number of calls can be calculated. This calculation will be done according to the same method used in paragraph 3.4. The result of this calculation can be found in the following table.

It should be noted that for the calculation the properties of the various vessels sailing in 2025 have been used. These properties can be found in paragraph 3.4.
Table 8-11: Number of monthly calls per terminal of the various transport modes

<table>
<thead>
<tr>
<th>Transport mode</th>
<th>Shanghai</th>
<th>Nanhu Zui</th>
<th>Yangshan</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>0</td>
<td>0</td>
<td>301</td>
<td>301</td>
</tr>
<tr>
<td>Short Sea</td>
<td>0</td>
<td>0</td>
<td>808</td>
<td>808</td>
</tr>
<tr>
<td>Barge</td>
<td>0</td>
<td>0</td>
<td>4,200</td>
<td>4,200</td>
</tr>
<tr>
<td>Road</td>
<td>61,100</td>
<td>384,000</td>
<td>0</td>
<td>445,200</td>
</tr>
<tr>
<td>Rail</td>
<td>3,300</td>
<td>0</td>
<td>0</td>
<td>3,300</td>
</tr>
<tr>
<td>Shuttlebarge</td>
<td>563</td>
<td>1,200</td>
<td>1,700</td>
<td>1,700</td>
</tr>
<tr>
<td>Total</td>
<td>64,400</td>
<td>384,000</td>
<td>5,300</td>
<td>453,700</td>
</tr>
</tbody>
</table>

The figure below gives a clear overview of the number of calls per transport modality to the various container terminals.

Figure 8-8: Monthly number of calls per transport modality in the year 2025

Now the total number of calls per service group at the several terminal groups has been determined, the configuration of the Yangshan terminal and the satellite terminals can be determined. In the next paragraph the configuration of the terminals can be found.
8.4 Configuration within the terminals

As has already been discussed in paragraph 5.2.1, 6 terminals are required on the "main" location of Yangshan to accommodate the total container throughput by the year 2025. These terminals will be situated at the Yangshan islands and will handle all vessel modalities as is stated in paragraph 8.3.

Apart from the terminals at Yangshan, two satellite locations are present to connect Yangshan with mainland while it lacks a bridge connection. At these satellite locations roughly 2 sides can be distinguished. A "land" side and a "sea" side. At the land side, trucks and trains arrive with export containers and leave with import containers provided by the shuttles. At the sea side, logically, the shuttles berth to unload and load the import and export containers.

At Yangshan, also roughly two sides can be distinguished, a "domestic" side and an "international" side. At the domestic side, the shuttle and river barges berth to bring export containers and pick up import containers. At the international side, the ocean and shortsea vessels are being handled. At this side domestic import and export containers and transshipment containers are handled.

While all vessel groups have different physical properties and destinations, the various groups all have their own berths and stacks. See the figure below for a schematisation of a Yangshan terminal.

![Diagram of a Yangshan terminal]

**Figure 8-9: Schematisation of a Yangshan terminal**

Apart from the distinction in vessel groups also a distinction is made according to the destinations of the ocean and shortsea vessels. Each terminal at Yangshan therefore has export stacks for a specific destination in the world. These destinations have been chosen according to the destinations of the ocean and shortsea vessels. The division of the various destinations over the 6 terminals has been done by trying to equally divide the number of containers between the terminals. In the next table the division can be found.

Ocean and shortsea vessels can now sail to the terminal that has containers destined for the vessel's next destination.

**Table 8-12: Division of destinations over the Yangshan terminals**

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Ocean stacks</th>
<th>Short Sea stacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal 1</td>
<td>Europe</td>
<td>Japan</td>
</tr>
<tr>
<td>Terminal 2</td>
<td>Europe</td>
<td>Australia</td>
</tr>
<tr>
<td>Terminal 3</td>
<td>Mediterranean</td>
<td>Africa</td>
</tr>
<tr>
<td>Terminal 4</td>
<td>North-America</td>
<td></td>
</tr>
<tr>
<td>Terminal 5</td>
<td>North-America</td>
<td>Hong Kong</td>
</tr>
<tr>
<td>Terminal 6</td>
<td>South America</td>
<td>Persian Gulf</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>South East Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Korea</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Vladivostok</td>
</tr>
</tbody>
</table>
To be able to easily supply containers from the satellite locations, also at these terminals a pre-selection of containers is made. At both satellite locations, 6 stacks are formed with containers destined for the 6 terminals at Yangshan.

At Nanhui Zui those 6 stacks are divided over 2 terminals. The stacks with containers for the Yangshan terminals 1 - 3 are situated on the first Nanhui Zui terminal and the stacks for the Yangshan terminals 4 - 6 are situated at the second Nanhui Zui terminal.

Now the division of the various vessel groups and destinations of these vessel groups over the terminals has been made, an overall view can be given of the inter relations between all elements. In the following figure a schematisation of all terminals and vessel modalities sailing to and from these terminals can be found. For the modal split per terminal see Appendix XV.

Figure 8-10: Schematisation of the inter relations between terminals and vessels

Now all inter relations are clear, a design can be made of the terminals. In the following paragraphs this process can be found.
8.5 Determination of the properties of all terminals

As the complexity of the situation around Shanghai by the year 2025 has increased with the decision to construct a "main" terminal at Yangshan and two satellite locations at Nanhui Zui and Shanghai, a choice has been made to make a simulation of the situation. The goal of this simulation is to provide data with which a design can be made for the various terminals.

Already in chapter 5 a determination of the properties of the various terminals had been made. The calculations made in that chapter however are too much a simplification of reality as it will be with the new configuration. The determination of the number of berths for example had been done according to the queuing theory as described in Appendix VI. This queuing theory however is quite inaccurate for low utilisation rates. A remark of this shortcoming had already been made in Appendix VI, but with the previous configuration this was considered as acceptable.

A simulation, in this case, can provide much more accurate information concerning the desired properties of the new terminals. For this study, the main targets are to provide information concerning the following points:

- How many berths per terminal per service group should be available?
- How many shuttles are needed to provide the Yangshan terminals with containers?
- What are the spatial requirements of the stacks?

In the following few paragraphs the simulation will roughly be described as a more detailed explanation of the simulation can be found in Appendix I.

8.5.1 Simulation

As is mentioned above, a simulation will be made of several processes at and around the 3 terminal locations to obtain data concerning the needed number of berths, the needed area per stack and the needed number of shuttles.

Up till now, the term "simulation" has been a relative vague description of what will actually happen. In principle all processes at and around the terminal locations could be simulated. However, to be able to simulate the several processes at and around the terminals within a reasonable time period, a simplification of reality should be made. The schematisation however should not be too rough while the results of the simulation could be endangered.

To start with, the model only simulates some of the processes that take place at and around Yangshan and its satellite terminals. The "outside world" is not considered. To obtain the requested data, as described in the previous paragraph, only the processes of the vessels and the directly related processes, such as the crane activities, are simulated within the model's environment. The actual stacking and shuffling of the containers between and within the stacks have been left out for complexity reasons.

Another simplification is that the currently existing individual terminals of Shanghai have not been considered. These terminals are treated as one terminal where the number of berths for the shuttles is sufficient. The reason for this very schematic approach is that monitoring of all activities at and around these terminals would unnecessarily complicate the program while the aim of this simulation is to find an optimal terminal configuration for the new terminals. Monitoring of the properties of the current Shanghai terminals in order to be able to restyle them has therefore been left out.

This representation can be justified when the following argument is considered.
At this moment Shanghai can handle an annual throughput of 6 mTEU and deals with a great variety of vessels. Among these vessels there are a lot of small vessels with a capacity of say 80 TEU. These vessels cause a relatively high inefficiency of the quay cranes while it takes relatively a lot of time to berth/deberth the vessels compared to the time to load/unload the vessel. With the large capacity of the shuttles it is expected that the crane efficiency increases and waiting times could be kept relatively small. Therefore the number of quays is not considered.

Along with these simplifications, some other smaller simplifications have been made. In Appendix I a complete overview can be found.

To simulate all processes, the programming language PROSIM has been used. This language offers facilities to easily expand the simulation if necessary and monitor the results of the several processes during the simulation.

In the following few paragraphs an overview will be given of the operation of the program.

8.5.2 PROSIM

Now the program environment has been set, the model could be written. Roughly a model consists of three stages, an input or definition stage, a stage at which the actual simulation takes place, and a stage at which the results of the simulation are being generated (See Figure 8-11).

![Diagram](image)

**Figure 8-11: General set up of the simulation**

To provide some insight in the general operation of Prosim, first the way of simulating will be described after which the input and output parts are described.

**Method of simulating**

To be able to actually simulate the several processes as is mentioned above, Prosim makes use of so called “components”. Each component represents the several elements that are being simulated. One component, for example, describes the activities of the shuttle barges sailing between Nanhui Zui and Yangshan. During a simulation run, all components work parallel to each other just like in the real life situation.
Within the components one can distinguish so called "live" components and "data" components. The live components describe the activities of the "moving" objects such as the several vessel modalities. The data components mainly keep track of the variables that are altered by the live components.

Within the live components, one can distinguish single components and class components. The single components describe single "live" elements. The class components describe a group of almost identical elements. One example of a class component is the component that describes the activities of all ocean vessels.

For now, the most important components to describe are the live components while these form the main part of the simulation. In total there are 10 live components. These components describe the following elements:

- The Shanghai terminals
- The Nanhui Zui terminals
- The Yangshan terminals
- The trucks and trains with destination Shanghai
- The trucks with destination Nanhui Zui
- The shuttle barges sailing between Shanghai and Yangshan
- The shuttle barges sailing between Nanhui Zui and Yangshan
- The river barges
- The ocean vessels
- The short sea vessels

While all components deal with more than one (almost) identical elements, they are all class components. To give some insight in the process of the components a rough description of some of the components will be given in the next section.

**Operation of the components**

To give some insight in the actual processes that, for example, the vessels go through, the main components that influence the system will be described. First the component dealing with the terminal locations will be described. Then the ocean vessel component will be described. This component is almost equal to the components representing the river barges and the short sea vessels. After this component, the component dealing with the shuttle barges will be described. Finally, the component dealing with the arrival and departure of trucks and trains will be described.

This section only gives a rough description to get some insight in the actual program. In Appendix XX, a full version of the program listing can be found.

**The terminal components**

In total there are three components dealing with the terminal locations. Two components for the satellite terminals and one component for the Yangshan terminals. The properties of all terminals mainly consist of the following elements: Terminals, berths, stacks and cranes. The quantity of each element however differs per location. The Nanhui Zui satellite location for example, has 2 terminals while at Yangshan, there are 6 terminals.

Before the simulation starts, the properties of each terminal location can be altered by the user. First the number of terminals can be given. Then, the number of berths can be given per terminal and finally the number and speed of the cranes can be given.

Having these properties set, the program can start its simulation. During the simulation, the terminal components are not active. Only some of their variables are altered by other live components. These are the number of containers in stack and the status of the berths. This status can vary from "occupied" to "available".
In what way the other components influence the stacks and berths of the various terminals can be read in the following few sections.

**Ocean vessel component**

Within this component the movements of the ocean vessels is simulated. Roughly 2 parts within the component can be distinguished. The generation part at which the vessel is generated and receives its properties, and a part at which each vessel performs its activities. In Figure 8-12, the processes of the component are schematically given. The text below gives some more information of these activities. In Appendix I more detailed flowcharts can be found together with more detailed information of the contents of the components.

The vessel generator is situated at the beginning of the component. This generator works as long as the simulation time has not passed. The generator calculates the specific inter arrival time of each ocean vessel. Together with the inter arrival time, the capacity, the parcel size, and the next destination of the vessel is determined. These properties can vary within a pre-set boundary. The mean of all of these variables however is pre-set according to the calculated values in paragraph 3.4.6. The inter arrival time for example, is determined according to an Erlang-4 distribution with a mean of 143 minutes. For further details according to the other variable boundaries of this vessel group and the other vessel groups, an overview can be found in Appendix I.

The moment the vessels' properties have been determined, the generator waits for the time to reach the calculated inter arrival time. At the moment this time is reached, the created vessel is put into the system. From this moment the generator starts again from the top to create another vessel. This procedure is repeated until the simulation time has passed.

By putting the vessel into the system, it starts to influence the other components within the program. First the ocean vessel enters the anchorage. From this point it determines whether there is an available berth at the terminal it is appointed to by the generator. Actually, the generator has only appointed a following destination to the vessel. But while each terminal has a stack with a specific destination, the generator has indirectly appointed a terminal to the vessel. If all berths are occupied by other ocean vessels, the vessel waits for the quay to be available. At the moment a berth is available the vessel sails towards this berth.
Figure 8-12: Processes within the ocean vessel component

Once the vessel has actually berthed (This takes 1.5 hours) it starts to unload the containers destined for Yangshan. These containers can be separated in two groups. The group of the domestic import containers and the group of the transshipment containers. The domestic import containers are divided over the import stacks of both shuttles and the river barges at the same terminal the ocean vessel is lying. The transshipment containers are divided over all terminals according to the destination of the stacks at these terminals.

The division of the domestic import and transshipment containers over the various destinations is pre-set according to the share of each destination within the total throughput. These shares have been determined according to the modal split made in paragraph 3.4.2. The details of the division per vessel group can be found in Appendix III.

The total time the unloading process takes, is dependent on the number and speed of the cranes the vessel is serviced by. The properties of these cranes are set within the component that deals with the terminals at Yangshan.

Once the vessel is unloaded, it can start to load its ordered containers from its stack. The total time this loading takes is, again, dependent on the ordered number of export containers and the number and speed of the cranes. Among these properties, the vessel is also dependent on the availability of containers in stack. If there are no containers in stack, the vessel waits for containers. Normally this situation never occurs while the
vessels are too expensive to wait for containers. Therefore, in this simulation, this feature has been built in to serve as a check of the system.

Now the vessel has completely loaded its ordered number of containers it can sail towards its following destination. After 1.5 hours, the needed time to clear the berth and a part of the path towards the terminal, the berth turns from the “occupied” status to the “available” status.

At the end of the component the total service time of the vessel is added up and the total waiting time (At the anchorage for an available berth) as percentage of the total service time is calculated. This time is then averaged over all vessels that have been serviced at this terminal and finally a graph is made of the average waiting time. With this graph, conclusions can be drawn with relation to the total number of berths at the specific terminal.

Finally, the vessel is terminated while it has left the system.

This total process is also described by the short sea vessels and river barges. The difference lies in the fact that these vessels have other properties and call at other areas at the terminals where they load from different stacks.

For the shuttle barges sailing between the satellite locations and Yangshan, another schedule is followed. In the following section the general activities are described for the Nanhui Zui shuttle. The activities of the Shanghai shuttle are generally the same. At the point where the activities of both shuttles differ from each other a remark will be made.

**Nanhui Zui shuttle component**

Like the components describing the other vessel modalities, this component can be subdivided in two parts, a generation part and a simulation part. The simulation part differs from the other components while the shuttles are not terminated as they leave Yangshan. Once the shuttles have been generated, the shuttles stay in the system during the simulation. In Figure 8-13 a rough schematisation can be found of the processes each shuttle goes through.

At first, every half-hour the shuttle generator creates a shuttle. This generator creates as much shuttles as is ordered by the user of the program and attaches some properties to the shuttle. These properties are the capacity and speed of the shuttle and the satellite location it belongs to.

Once a shuttle is created it is put into operation. While each shuttle sails in a "loop" between its satellite location and Yangshan, it could be put into operation at any point. For this simulation the arbitrary choice has been made to let the shuttle start from the moment the shuttle arrives fully loaded at its satellite location.

From the anchorage in front of the Nanhui Zui terminals, the shuttle determines at which terminal a berth is available. While all berths are occupied, the vessel waits for an available berth. Then, if a berth is available, it checks for the stack with the largest number of containers in it. This choice is made while the satellite terminals only act as a service hatch for Yangshan. At the moment the stacks at the satellite terminals increase, the export stacks at the Yangshan terminals decrease and eventually waiting times of the ocean and short sea vessels increase. This is unacceptable.
Figure 8-13: Processes within the shuttle components

As the vessel has determined which stack has the largest number of containers in it, it sails towards the available berth. This takes 30 minutes. Once the vessel has reached the berth, it starts to unload its containers to the import stacks of the terminal. The time this process takes is dependent on the number of containers at the shuttle and the number and speed of the cranes it is serviced by.

When the shuttle has unloaded all containers, it starts to load containers from the stack it is dedicated to. The shuttles are always fully loaded. The loading process is like the unloading process dependent on the number of containers and the cranes.

At the moment the vessel is fully loaded, it leaves the berth, this again takes 30 minutes, and sails towards the terminal at Yangshan that corresponds with the stack from which it has been loading in Nanhui Zui. Sailing time depends on the distance between the satellite terminal and Yangshan and the average speed of the shuttles. For both shuttles the average speed is 10 knots. The distance from Shanghai to Yangshan and Nanhui Zui to Yangshan is 40 miles and 19 miles respectively.

Once the shuttle has arrived at Yangshan it practically performs the same processes as the ocean vessels do. It checks for availability of a berth, then it sails towards that berth in 30 minutes and starts to unload. The export containers coming off the shuttle are divided over the ocean stacks and short sea stacks of that terminal. The division factor is dependent on the shares of each export stack within the total throughput of Yangshan. At the moment the shuttle has been unloaded it is loaded while there are containers or until the capacity of the shuttle has been reached. If no containers are available it sails back towards its satellite location and starts its cycle again.
The reason why containers are only loaded if they are available is that the total annual number of import containers is much smaller than the total number of export containers. The shuttles shouldn’t therefore wait for containers at this side of the loop while ocean or short sea vessels could be waiting for containers that are still at one of the satellite terminals.

Before the shuttle returns to its satellite, the average waiting times of the shuttle is added to the total average waiting time of the shuttles that have been at that terminal. With this information, conclusions can be drawn concerning the number of berths and shuttles.

The truck and train components

In total, there are two of these components. One for each satellite terminal. These components describe the processes of the arriving trucks and trains very schematically. At Nanhui Zui only the arrival and departure of trucks is considered and at Shanghai the arrival and departure of trucks and trains is considered.

![Diagram of truck and train processes](image)

**Figure 8-14: Processes of the trucks and trains**

The arrivals and departures are not considered in great detail. In fact, they are schematised as arriving every 10 minutes at the satellite location. At arrival a predetermined number of containers is instantly divided over the shuttle stacks. Then the trucks and trains check for the availability of containers in the import stack and leave with a predetermined number of containers.

All predetermined numbers of containers are dictated by the modal split as is described in detail in Appendix III.

Input and output

**Input**

Now all components have been described, in principal, the actual simulation can be started. However, first the variables should have a starting value. This will be done via special "input" files. In total there are 5 input files. Two files set the properties of both shuttle barges, another file sets the properties of all other transport modalities and finally there are 2 files that set the properties of Yangshan and Nanhui Zui. The variables of Shanghai are set within the program while there are only a few.

The properties that are given to the shuttles are the name, the capacity and the average speed of each shuttle. The name of the shuttle is used to be able to trace the activities
of that shuttle. The capacity has already been determined in paragraph 8.3.2 and is 537 TEU. The average sailing speed of the shuttles is 10 knots.

The file concerning the other transport modalities sets the values with which the properties of the vessels can be calculated in the program. These calculations take place in the already described generation part of the components. The values have been set in such a way that the average calculated properties eventually equal the averages as were already determined earlier in this report. The properties that are set and their average values can be found in the following table.

Table 8-13: Average values of the properties of the various vessel modalities

<table>
<thead>
<tr>
<th></th>
<th>River</th>
<th>Short sea</th>
<th>Ocean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inter arrival time</td>
<td>(minutes)</td>
<td>10.29</td>
<td>53.43</td>
</tr>
<tr>
<td>Capacity</td>
<td>TEU</td>
<td>120</td>
<td>1250</td>
</tr>
<tr>
<td>Parcel size</td>
<td>%</td>
<td>91</td>
<td>75</td>
</tr>
</tbody>
</table>

For the ocean vessel group no external input is given concerning the capacity of these vessels while the parameters are set within the component.

The files dealing with the properties of the terminals at Nanhui Zui and at Yangshan set the number and speed of the cranes at the terminals and the initial stack sizes of each terminal. The initial stack sizes of the terminals are solely given to prevent the program from having a "cold" start. This means that, for example, unrealistic waiting times could occur while initially no containers are in stack. Soon after the start of the simulation these values are altered by the other components.

Apart from the input files, the program also receives input concerning the following variables:

The number of shuttles sailing between Yangshan and the satellite terminals,
The number of berths per terminal per vessel modality.

These are the variables that will be altered each time a new simulation run is made. With these variables the "best" configuration will be sought according to the criteria given earlier in the report. To be able to determine what the "best" configuration is, the output part of the program is used. In the following section this part is described.

**Output**

The program produces a lot of output. Only a part of this output however is relevant for the target of this simulation and is saved in output files. Therefore only this part of the total output is described here.

First of all, a general output file is created in which the input parameters and some "end" values will be written. These values are:

- Annual throughput of all terminals for each simulated year.
- Total annual throughput of each transport modality divided by import, export and transshipment throughput.
- The minimum and maximum stack sizes of each terminal within the system.
- The total average waiting times of all vessel modalities calling at the Yangshan terminals.
- The cumulative numbers of arrived and departed vessels at the first and the fourth year.
These end values can give a general idea of the results of the simulation with the given input parameters. To give a more detailed view of the process there are also files in which every 4 hours some values are administered. These values are:

- The average waiting time up till then for each vessel modality per Yangshan terminal
- The total time handling time per vessel calling at Yangshan.
- The number of containers in each stack at all terminals.

To check whether the values administered in the above mentioned files are valid first a check should be made by making several test runs. In the following paragraph the check of the validity is made.

8.5.3 Determination of the validity of the program

Now the general operation of the program has been discussed the program can be used to simulate what it was made for. However, up till this point the validity of the program has not been checked. To be certain that the program actually gives reliable output this validity will first be checked.

Generally two types of checking the validity can be distinguished: Verification and Validation of the program. In the following sections these methods will be discussed.

Verification

The verification of the program deals with the check whether the program takes action as it is supposed to do. Many checks can be made easily by monitoring the processes of the various vessels while running the simulation. In this way the check can for example be made whether the program allows only 1 vessel per berth and whether the vessel makes use of its appointed berth. The validity of such rather simple procedures can hardly be proved. The check has however been made and the procedures seemed all right.

The verification regarding the container handling procedures can be checked by letting the program keep track of the movements. The check of these procedures will be performed in three different ways.

The first check is made whether the actual annual number of arriving vessels and their capacity within the model agrees with the predicted number of vessels and their capacity. This check is rather simple and can be done quickly.

The second check regards the annual container handling volumes of the different vessel types compared to the predicted annual container handling volumes.

The third check verifies that there is no production or removal of containers in the various stacks caused by sources other than vessels or trucks and trains.

In the following few sections the above mentioned verifications are made.

1. Verification of the annual number of vessels and their average capacity

Like has already been mentioned, this check can be performed quite easily. One of the output files generated by the program gives the value of the average inter arrival time and the average capacity of the ocean the shortsea and the river barges per 4 hours.

In the following table these values can be found after a simulation time of 4 years.
Table 8-14: Average values resulting from the simulation after 4 simulation years

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Shortsea</th>
<th>River</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Capacity (TEU)</td>
<td>Inter arrival (vessels/day)</td>
<td>Capacity (TEU)</td>
</tr>
<tr>
<td>Simulation</td>
<td>5558</td>
<td>10.10</td>
<td>1254</td>
</tr>
<tr>
<td>Input value</td>
<td>5592</td>
<td>10.04</td>
<td>1250</td>
</tr>
</tbody>
</table>

As can be seen from this table is that the results of the simulation do not entirely match with the input values. The values are however very close. The difference in values can be ascribed to the use of distributions within the model and will probably be equal to the input in the long run.

2. Verification of the average annual container handling volumes

The eventual goal of the simulation is to find the needed number of berths and needed container storage area for the container throughput figures by the year 2025. To reach this goal, a schematisation has been made while it takes too much time to simulate all processes at and around Shanghai in great detail.

Naturally a great effort has been made to obtain results by simulating with container volumes that lie close to the expected volumes as determined in paragraph 3.4.5. However, a watertight similarity with the expected values is not possible with this simulation. In general, the differences could be put into 3 categories:

1. Differences due differences in average values
2. Differences due round off values
3. Differences due uncertainties in the moment of observation

In the following few paragraphs the differences are tracked and if necessary corrected. This correction actually takes place within the simulation, but is illustrated here. First an explanation is sought for the first difference category.

**Difference due differences in average values**

This difference is quite good traceable. The difference arises from the fact that the average calculated values within the simulation do not match the average values as determined earlier in this report. To be more specific, within the simulation an inter arrival time and a capacity is attached to the vessels.

The inter arrival time of the ocean vessels for example, is determined according to an Erlang-4 distribution. This distribution makes use of a mean value that is determined according to the calculated annual number of ocean vessels that could be expected by the year 2025 (See paragraph 3.4.6). The mean inter arrival time in this case is 143.39 minutes.

While the simulation works with the Erlang - 4 distribution, it determines an inter arrival time for each vessel. On the long term it could be expected that the average inter arrival time matches the mean inter arrival time of 143.39 minutes. The used simulation time of 3 years however, is not long enough to establish this average. An average of 142.45 minutes is reached.

With this average, eventually more vessels arrive within the simulated period than was earlier expected. This leads to an extra number of containers that are being handled.

Furthermore, this explanation can also be used in case of the determination of the capacity of each vessel. Here also the capacity is determined according to a distribution.
The mean of this distribution was 5592 in case of the ocean vessels. After the simulation period of 3 years however an average of 5568 was reached. This leads to a smaller number of containers to be handled.

In the following table the differences can be found that were generated by the simulation.

**Table 8-15: Differences between model’s averages and calculated averages**

<table>
<thead>
<tr>
<th></th>
<th>Annual vessel # Reality</th>
<th>Annual vessel # Model</th>
<th>Capacity Reality (TEU)</th>
<th>Capacity Model (TEU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ocean</td>
<td>3615</td>
<td>3639</td>
<td>5592</td>
<td>5568</td>
</tr>
<tr>
<td>shortsea</td>
<td>9702</td>
<td>9686</td>
<td>1250</td>
<td>1254</td>
</tr>
<tr>
<td>river</td>
<td>50359</td>
<td>50195</td>
<td>120</td>
<td>120</td>
</tr>
</tbody>
</table>

These differences will not be corrected while they are no "real" differences. Due to the fact that several distribution are used, chances are always present that the average values differ from the "real" situation as is calculated for the year 2025. Altogether, the calculated "real" throughput figure is also an average.

**Difference due round off errors**

This difference is created while the simulation does not consider the destination of each container individually. Every time a vessel arrives at the port it unloads a certain number of containers. These containers are divided over several stacks with different destinations. This division is based on the share that each destination has within the total container throughput. A certain percentage of the load is therefore appointed to a destination.

For loads that are subjected to a distribution it is assumed that this effect cancels itself on the long term. (In half of the cases a value is rounded off upwards and in the other half of the cases the value is rounded off downwards.) This counts for the river vessels, the shortsea vessels, the ocean vessels and the import containers on the shuttle barges.

With a division based on percentages of the unloaded containers, it could be possible that a part of that load is lost or gained due round off errors. This error mainly occurs where the total number of unloaded containers per call is constant. For this simulation this counts for the loads of the trucks and trains calling at the satellite terminals and the shuttles loaded with export containers. In these cases a constant error is made.

To be able to control this error, the values resulting from the multiplication of the percentage with the load have been rounded off to a constant number and added to the destined stack. In this way the error is exactly known and could be rectified. In this simulation a rectification is made each simulation day for the trucks and trains and each 100 calls for the export containers on the shuttles.

In the following table an example is given of the trucks driving at the first Nanhui Zui terminal. These trucks arrive every 10 minutes with a total load of almost 75 TEU. These containers are divided over the 3 stacks with destination Yangshan terminal 1, 2 and 3. Eventually each day an error is made of almost 144 containers. This error is rectified. However, within this rectification also an error is made and annually this error is as large as 209 containers for the whole terminal. This error is not rectified as it is just a very small percentage of the total transported container volume within this terminal (0.005%).
Table 8-16: Rectification of the difference made by trucks at Nanhui Zui terminal 1

<table>
<thead>
<tr>
<th>Total TEU</th>
<th>Per stack per year</th>
<th>Per 10 min</th>
<th>Difference</th>
<th>Rectified each day</th>
<th>Remaining each year</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Share TEU</td>
<td>Actual</td>
<td>Used</td>
<td>Per 10 min</td>
<td>Per day</td>
</tr>
<tr>
<td>3,887,849</td>
<td>stack 1</td>
<td>32.75%</td>
<td>1,273,327</td>
<td>24.56</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>stack 2</td>
<td>32.25%</td>
<td>1,253,936</td>
<td>24.19</td>
<td>24.0</td>
</tr>
<tr>
<td></td>
<td>stack 3</td>
<td>35.00%</td>
<td>1,360,586</td>
<td>26.25</td>
<td>26.0</td>
</tr>
</tbody>
</table>

**Difference due uncertainties in the moment of observation**

These differences are very hard to trace and are probably due to uncertainties at the moment of monitoring. Like already mentioned before, the program simulates 4 years of which only the last 3 years are monitored (The first year is used to let the several values come to an average). At the moment the monitoring starts and at the moment the simulation is finished, there are vessels in the system. The monitoring therefore starts and ends somewhere in the middle of the process of the vessel. The exact point of the process of the vessel is not known.

On average it is assumed that the process of each vessel in the system is cut off in the middle of the time that the whole process takes. In the figure below the total process of an ocean vessel is illustrated. The difference is illustrated according to this figure and ocean services group.

![Figure 8-15: Process of an ocean vessel](image)

At the beginning of the second year there were 15 vessels in the system of which none were waiting for an available berth. These 15 vessels were somewhere in their process. It is hereby assumed that half of these vessels were at the first half of their process and the other half of the vessels were at their last half of the process.

Of the vessels being in their first half of the process it is assumed that they were at the first quarter of their process (They were busy loading containers as can be seen from the figure above). Normally, in a real life situation, a vessel takes containers from its stack before it puts them in its hold. The containers that the vessel has taken from its stack before the monitoring started will then not be taken in the monitoring process.

The schematisation of this simulation however is made in such a way that vessels first wait a time period needed to load the ordered containers and then take these containers from its stack (See the first arrow in Figure 8-15). The difference that is generated in this way is as large as the number of containers that the vessel would normally have taken before the monitoring had started. These containers have now been taken into the monitoring process.
The same counts for the vessels that were in their last half of the process. For these vessels it is assumed that they were at the beginning of the last quarter of their process. Also the first half of the loaded containers should have left out of the monitoring but have been taken.

Both differences made at the beginning of the monitoring process as described above lead to an extra number of containers during the monitoring process. This effect however, is partly cancelled while the opposite happens at the end of the monitoring after 4 years. In that situation too few containers are counted. If the same number of vessels are in the system at the beginning of the monitoring as there are at the end of the monitoring, then the difference is completely cancelled.

Too few containers are counted while the moment of influencing the stack by the program lies outside the simulation time. The stacks have not been altered where they should have been and the number of handled containers is too small.

As was already mentioned, if the number of vessels in the system is the same at the beginning and at the end of the monitoring, then the difference is cancelled. If the number of vessels however differ from each other, a difference is created. Normally a difference is always created while the loads of the vessels differ due to the distributions. For the explanation however, this effect is neglected.

Now the origin of the possible differences have been determined, it can be checked whether the differences of the simulation can be ascribed to these causes. In the following table an effort is made to explain the difference made within the model according to the above mentioned reasons.

In the first part of the table the differences between the averages calculated earlier in this report and the resulting averages of the model are compared. In the second part of this table the total differences are calculated per category. Finally, in the third part of this table, the remaining error can be found that cannot be explained with the difference in calculated averages and the averages generated by the model.

**Table 8-17: Explanation of the cause of the difference made within the model**

<table>
<thead>
<tr>
<th></th>
<th>TO Yangshan</th>
<th>FROM Yangshan</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ocean</td>
<td>Shortsea</td>
</tr>
<tr>
<td><strong>Annual number of vessels</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>3,615</td>
<td>9,702</td>
</tr>
<tr>
<td>Model</td>
<td>3,839</td>
<td>9,686</td>
</tr>
<tr>
<td><strong>Average capacity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>5,592</td>
<td>1,250</td>
</tr>
<tr>
<td>Model</td>
<td>5,568.4</td>
<td>1,254.6</td>
</tr>
<tr>
<td><strong>Unloaded/Loaded containers</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>9,306,860</td>
<td>8,325,720</td>
</tr>
<tr>
<td>Model</td>
<td>9,323,978</td>
<td>8,340,884</td>
</tr>
<tr>
<td><strong>Total annual difference</strong></td>
<td>-17,118</td>
<td>-15,164</td>
</tr>
</tbody>
</table>

**Cause of difference**

<table>
<thead>
<tr>
<th></th>
<th>Per vessel</th>
<th>Subtotal</th>
<th>Subtotal</th>
<th>Subtotal</th>
<th>Total</th>
<th>Subtotal</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Difference in AVG capacity</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Difference in vessel</td>
<td>23.64</td>
<td>-4.60</td>
<td>0.02</td>
<td>23.64</td>
<td>-4.60</td>
<td>0.02</td>
</tr>
<tr>
<td>Subtotal</td>
<td>39,616</td>
<td>-30,568</td>
<td>844</td>
<td>46,431</td>
<td>-36,221</td>
<td>691</td>
</tr>
<tr>
<td>Difference in inter arrival time</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subtotal</td>
<td>-61,538</td>
<td>13,857</td>
<td>19,713</td>
<td>-72,124</td>
<td>16,420</td>
<td>16,129</td>
</tr>
<tr>
<td><strong>Difference in distributions</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>-21,922</td>
<td>-16,711</td>
<td>20,587</td>
<td>-25,694</td>
<td>-19,802</td>
<td>16,819</td>
</tr>
</tbody>
</table>

**Remaining unexplainable difference in model**

<table>
<thead>
<tr>
<th></th>
<th>TEU</th>
<th></th>
<th></th>
<th></th>
<th>TEU</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Absolute</td>
<td>4,804</td>
<td>1,548</td>
<td>227</td>
<td>7129</td>
<td>-405</td>
<td>274</td>
<td></td>
</tr>
<tr>
<td>Relative expressed in vessels</td>
<td>1.87</td>
<td>1.80</td>
<td>1.89</td>
<td>2.37</td>
<td>0.40</td>
<td>2.79</td>
<td></td>
</tr>
<tr>
<td>Relative to the total throughput %</td>
<td>0.52</td>
<td>0.18</td>
<td>0.04</td>
<td>0.65</td>
<td>0.04</td>
<td>0.06</td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from this table there is only a relatively small number of containers that cannot be explained with the differences in distribution averages. This remaining difference can partly be explained with the difference at the moment of observation as explained above and will be regarded as acceptable.
3. Verification of the balance within the container handling volumes

With this verification item it is verified that the actual number of containers brought in by a transport mode equals the number of containers collected by another transport mode plus the net number of containers in stack or:

\[ \text{OUT} - \text{IN} + \text{net STACK} = 0 \]

First the satellite terminals are investigated. At the Shanghai satellite 3 transport modes are present. These are the truck, the train and the Shanghai shuttles. Of each of these transport modes the average annual container handling volume is calculated over a period of 3 years. Also the number of containers in the various stacks are written in an output file. By calculating the difference between the number of containers in stack at the beginning of the first year and at the end of the fourth year, the net number of containers in stack can be calculated.

Now the various volumes are known the balance can be checked. This balance is checked for both the import throughput as well as for the export throughput. In the following tables the results can be found. At the first column, the part of the above given formula can be found.

**Table 8-18: Check of the balance of the containers handled in Shanghai**

<table>
<thead>
<tr>
<th>Import</th>
<th>TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td>8,925,657</td>
</tr>
<tr>
<td>OUT</td>
<td>2,970,033</td>
</tr>
<tr>
<td>Imported by trains</td>
<td>5,938,986</td>
</tr>
<tr>
<td>Net(t) STACK</td>
<td>4,724</td>
</tr>
<tr>
<td>Net truck stack</td>
<td>10,518</td>
</tr>
<tr>
<td>Result</td>
<td>-1,396</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Export</th>
<th>TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUT</td>
<td>10,884,990</td>
</tr>
<tr>
<td>IN</td>
<td>3,627,282</td>
</tr>
<tr>
<td>Exported by trains</td>
<td>7,256,010</td>
</tr>
<tr>
<td>Net(t) STACK</td>
<td>-3,483</td>
</tr>
<tr>
<td>Net shuttle stacks</td>
<td>-1,785</td>
</tr>
</tbody>
</table>

As can be seen from this table the in and output are not in balance (Result is negative instead of zero).

The above mentioned procedure has also been applied for the Nanhui Zui satellite resulting in the following table.

**Table 8-19: Check of the balance of the containers handled in Nanhui Zui**

<table>
<thead>
<tr>
<th>Import</th>
<th>TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td>18,699,336</td>
</tr>
<tr>
<td>OUT</td>
<td>18,664,824</td>
</tr>
<tr>
<td>Net(t) STACK</td>
<td>33,542</td>
</tr>
<tr>
<td>Result</td>
<td>970</td>
</tr>
<tr>
<td>Export</td>
<td>TEU</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
</tr>
<tr>
<td>OUT</td>
<td>Exported by shuttles 22,811,223</td>
</tr>
<tr>
<td>IN</td>
<td>Exported by trucks 22,811,208</td>
</tr>
<tr>
<td>Net(t) STACK</td>
<td>Net shuttle stack 373</td>
</tr>
<tr>
<td>Result</td>
<td>Result 388</td>
</tr>
</tbody>
</table>

Also for this satellite terminal the balance is not correct.

For the Yangshan terminals the same method has been applied resulting into the following table.

**Table 8-20: Check of the balance of the containers handled at Yangshan**

<table>
<thead>
<tr>
<th>Import</th>
<th>TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>IN</td>
<td></td>
</tr>
<tr>
<td>Imported by ocean</td>
<td>21,675,597</td>
</tr>
<tr>
<td>Imported by shortsea</td>
<td>20,825,145</td>
</tr>
<tr>
<td>OUT</td>
<td></td>
</tr>
<tr>
<td>Imported by Nanhui Zui shuttles</td>
<td>18,699,336</td>
</tr>
<tr>
<td>Imported by Shanghai shuttles</td>
<td>8,925,657</td>
</tr>
<tr>
<td>Imported by river barges</td>
<td>14,796,750</td>
</tr>
<tr>
<td>Net(t) stacks</td>
<td></td>
</tr>
<tr>
<td>import stacks Nanhui Zui shuttle</td>
<td>-3,327</td>
</tr>
<tr>
<td>import stacks Shanghai shuttles</td>
<td>-588</td>
</tr>
<tr>
<td>import stacks River barges</td>
<td>78,704</td>
</tr>
<tr>
<td>Result</td>
<td>-4,210</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Export</th>
<th>TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>OUT</td>
<td></td>
</tr>
<tr>
<td>Exported by ocean</td>
<td>32,784,207</td>
</tr>
<tr>
<td>Exported by shortsea</td>
<td>29,657,169</td>
</tr>
<tr>
<td>IN</td>
<td></td>
</tr>
<tr>
<td>Imported by shortsea (transshipment)</td>
<td>4,197,507</td>
</tr>
<tr>
<td>Imported by ocean (transshipment)</td>
<td>6,296,337</td>
</tr>
<tr>
<td>Exported by Nanhui Zui shuttles</td>
<td>22,811,223</td>
</tr>
<tr>
<td>Exported by Shanghai shuttles</td>
<td>10,884,990</td>
</tr>
<tr>
<td>Exported by River barges</td>
<td>18,085,239</td>
</tr>
<tr>
<td>Net(t) stacks</td>
<td></td>
</tr>
<tr>
<td>Export stacks ocean</td>
<td>-81,803</td>
</tr>
<tr>
<td>Export stacks shortsea</td>
<td>-80,739</td>
</tr>
<tr>
<td>Result</td>
<td>3,538</td>
</tr>
</tbody>
</table>

As was the case with the satellite terminals counts for the Yangshan terminals. Also for these terminals the balance is far from perfect.

In spite of numerous efforts to find the reason for these imbalances the true reason could not have been found. All throughput figures and vessel arrivals seem to be in line with the expectations. The reason for these imbalances should therefore probably be sought in the moment of administration of the containers as was the case with the verification of the average annual container handling volumes in the section above. In that section also a relatively small difference of container volumes could not be explained. The remaining number of containers in that section also lies in the same order of the remaining numbers in this section.

With these relatively small numbers of containers it is highly expected that the differences can be explained by the moment of observation as has been explained in the previous section. This difference within the balance will therefore be regarded as acceptable.
Validation of the program

Now the verification of the program has been made and the program actually does what it is supposed to do, the program should be validated. With the validation it is checked whether the program produces reasonable results.

The best way to validate the program is to let the simulation simulate an actual year recorded by Shanghai. If the simulation returns values that match the actual values the program can be used. For this case however, there is not enough information available regarding container handling figures of the port of Shanghai. The validation should therefore be performed in a different way.

The validation will be made according to the results of the queue theory and known figures of average dwell times of containers in stacks of ports of this size. Although these values will probably not match with the results of the simulation, they can give a good indication of the required size of the values.

To be able to make this validation, first the simulation model will be used as if it were valid. With this assumption the simulation will be used to determine the "best" terminal configuration. The results following from these simulations will then be compared to the mentioned queue theory results and dwell time figures.

In the following section the methodology and results of simulating the various activities as described in the previous paragraphs will be presented.

8.5.4 Simulation methodology and results

In this section the method of altering the parameters per simulation run will be described followed by the results of a few of these simulations. To gain representative results, the choice has been made to simulate a period of 4 years. This has been done in order to obtain representative results. Normally a terminal will be build gradually through time and every now and then some parts of the terminal are released for vessels to use. With a simulation, immediately all terminals are released to be used by the vessels. While it takes time for all variables to reach a certain balance, the choice has been made to use the output values of the last 3 years. The first year is used as a starting year to let the values come to a balance.

Of all vessel modalities sailing to and from Yangshan, the ocean and short sea vessel groups can be considered as the most critical for designing the terminals. The port of Shanghai cannot afford to let these vessels wait longer than 10 % and 25 % of their total service time. If they do, these vessels will chose for another port of call and Shanghai's aspirations for being a regional hub in the future are off. Furthermore, the berths that will be constructed for these vessels are much more expensive than the berths that are constructed for the river and shuttle barges.

Ocean and short sea berths

To be able to find the best number of berths per terminal for these vessel groups, the flow of containers towards the stacks of these vessel groups should not be influenced by the other vessel groups. Therefore, the number of shuttles has been kept high and the number of berths for these shuttles and for the river barges has also been set at a high value.

As a starting value for the number of berths for the ocean and short sea vessels, the calculated number of berths with the queuing theory have been used (See paragraph 5.2.1). Although the terminal configuration at that time was not equal to the new configuration, it gives a good indication of the needed number of berths. The numbers
calculated with the queue theory were 3 berths per terminal for the ocean vessel group and 4 berths per terminal for the short sea vessel group.

While simulating with these numbers, it turned out that the values of the average waiting times of both vessel groups were too high. As long as the waiting times were too high, the number of berths have been increased until acceptable waiting times resulted. Eventually the following berth configuration should be used to satisfy the demanded waiting times:

Table 8-21: Resulting waiting times as percentage of service time

<table>
<thead>
<tr>
<th></th>
<th>Terminal number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Ocean</td>
<td></td>
</tr>
<tr>
<td>Berths</td>
<td>4.0</td>
</tr>
<tr>
<td>Average waiting time</td>
<td>6.0</td>
</tr>
<tr>
<td>Short sea</td>
<td></td>
</tr>
<tr>
<td>Berths</td>
<td>5.0</td>
</tr>
<tr>
<td>Average waiting time</td>
<td>8.0</td>
</tr>
</tbody>
</table>

As can be seen from this table, the average waiting times of the short sea vessel group is quite low. However, by decreasing the number of berths with one for all terminals, the average waiting times immediately increase to unacceptable values.

Although the above found average waiting times are within the stated limits, they do not guarantee that shipping lines will use the terminals. This is also dependent on the distribution of the total handling times over all vessels. One can imagine that a shipping company rather chooses for a port where the variation of the total handling time lies close to the average guaranteed value, than for a port where these values are widely spreaded around the guaranteed average.

To check what the distribution of the average handling times looks like, these handling times have been recorded for all ocean, shortsea and river vessels calling at Yangshan. Although these handling times have been recorded per terminal, the average values for Yangshan as a whole will be presented here for the ocean and shortsea vessels.

**Handling time distribution of the ocean vessels**

![Graph of ocean vessels handling time distribution](image)

Figure 8-16: Distribution of total handling time over the ocean vessels
The above presented distribution for the ocean vessels seems quite wide, however, the capacity range of these vessels is also quite wide. This range lies between 3000 and 12500 TEU where the 12500 TEU vessel has a total handling time at the quay of almost 60 hours (4 cranes handling 35 containers per hour).

Within this distribution the following values have been found:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average handling time</td>
<td>31.29</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>16.20</td>
</tr>
<tr>
<td>Minimum value</td>
<td>12.88</td>
</tr>
<tr>
<td>Maximum value</td>
<td>153.81</td>
</tr>
<tr>
<td>95 % value</td>
<td>59.9</td>
</tr>
<tr>
<td>Berth occupancy rate</td>
<td>52.7 %</td>
</tr>
</tbody>
</table>

The 95 % value gives the handling time below which 95 % of the vessels have been handled. This value gives an indication of the wideness of the distribution.

*Handling time distribution of the shortsea vessels*

![Graph](image)

**Figure 8-17: Distribution of total handling time over the shortsea vessels**

This distribution seems to lie close around the average value (coloured yellow). As can be seen is that a wide range of handling times is confronted by almost the same number of vessels. This could probably be ascribed to the method of generating the capacity per vessel within the simulation. For this generator a uniform distribution has been used with a range lying between 500 and 2000 TEU capacity vessels.

Within this distribution the following values have furthermore been found:

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Average handling time</td>
<td>16.96</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>5.91</td>
</tr>
<tr>
<td>Minimum value</td>
<td>7.56</td>
</tr>
<tr>
<td>Maximum value</td>
<td>111.50</td>
</tr>
<tr>
<td>95 % value</td>
<td>25.4</td>
</tr>
<tr>
<td>Berth occupancy rate</td>
<td>63.4 %</td>
</tr>
</tbody>
</table>
River berths

The next step is to find the number of berths for the river barges in such a way that waiting times can be kept acceptable. Still the number of shuttles and their berths have been kept high. Again a start has been made by using the value that has been calculated in paragraph 5.2.1. The needed number of berths according to the queue theory was 6.

While simulating with this number of berths it turned out that this value was too low. Therefore, the number of berths of all terminals have been increased until acceptable waiting times were found. With 8 berths only the average waiting time at terminal 3 was too high (See first picture of Figure 8-18). The number of berths at terminal 3 has therefore been increased to 9.

![Waiting times of river barges with 8 berths per terminal](chart1)

![Waiting times of river barges with berths according Table 8-22)](chart2)

Figure 8-18: Results of two simulations for the river barges at Yangshan

The reason for the fact that the waiting times only start to grow from 1 year (518400 minutes) is that the program only starts to count these waiting times from then. Some of the waiting times therefore start at a high level. This is probably caused by a vessel having a high waiting time at the moment the program starts its monitoring process. The average waiting time rapidly decreases afterwards.

In the following table the average waiting times as percentage of the average service time can be found per terminal.
Table 8-22: Resulting waiting times for the river barges

<table>
<thead>
<tr>
<th>Terminal number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
</tr>
</thead>
<tbody>
<tr>
<td>River Berths</td>
<td>8</td>
<td>8</td>
<td>9</td>
<td>8</td>
<td>8</td>
<td>8</td>
</tr>
<tr>
<td>Waiting time</td>
<td>%21.2</td>
<td>18.3</td>
<td>13.1</td>
<td>21.4</td>
<td>15.2</td>
<td>17.6</td>
</tr>
</tbody>
</table>

Also for the river barges the total handling time has been administered. The following graph represents the average distribution of the handling times over the river barges.

![Graph of Handling Times]

Figure 8-19: Distribution of total handling time over the river barges

This distribution is quite narrow and can probably be ascribed to the narrow range of generating the capacity of the vessels lying between 100 and 140 TEU vessels.

Within this distribution the following values have been found:

<table>
<thead>
<tr>
<th>Statistic</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average handling time</td>
<td>8.16 hours</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>3.08 hours</td>
</tr>
<tr>
<td>Minimum value</td>
<td>5.85 hours</td>
</tr>
<tr>
<td>Maximum value</td>
<td>79.22 hours</td>
</tr>
<tr>
<td>95% value</td>
<td>12.6 hours</td>
</tr>
<tr>
<td>Berth occupancy rate</td>
<td>96.7%</td>
</tr>
</tbody>
</table>

**Shuttles**

Finally the number of shuttles and their berths have been altered. While these barges only sail to provide the Yangshan terminals with containers, this has been done by looking at the stacks at the satellite locations. When the number of containers in these stacks increase, the ocean and short sea vessels will probably have to wait for containers. This situation has to be avoided.

Up till now there were too much shuttles. This resulted in almost empty stacks at the satellites. By decreasing the number of shuttles and keeping the number of berths high, the stacks will probably grow at a certain moment. This has been done until the stacks...
increased in size. With 53 shuttles sailing to and from Nanhui Zui and 26 shuttles sailing to and from Shanghai, the stacks seemed to stabilise at the satellites. For Shanghai, the change was very sudden as can be seen from Figure 8-20.

Table 8-23: Needed number of shuttles per satellite terminal

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shanghai shuttles</td>
<td>53</td>
</tr>
<tr>
<td>Nanhui Zui shuttles</td>
<td>26</td>
</tr>
</tbody>
</table>

Figure 8-20: Stack size development during 4 years at Shanghai

Now the needed number of shuttles is known, the number of berths have been decreased. This has only been done at Nanhui Zui and at the Yangshan terminals. At Nanhui Zui it turned out that the needed number of berths was 13 for Nanhui Zui terminal 1 and 12 for Nanhui Zui terminal 2. The development of the number of containers in the stacks through time at both terminals is almost the same. This is the result of the choice of the shuttle barges to load from the stack that contains the highest number of containers (if a berth is available at that terminal).

Table 8-24: Needed number of berths at the Nanhui Zui satellite terminals

<table>
<thead>
<tr>
<th></th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nanhui Zui terminal 1</td>
<td>13</td>
</tr>
<tr>
<td>Nanhui Zui terminal 2</td>
<td>12</td>
</tr>
</tbody>
</table>

The needed number of berths at the Yangshan terminals turned out to be 5 for the Shuttles sailing towards Nanhui Zui and 2 for the shuttles sailing towards Shanghai. Only terminal 3 needed 3 berths for the Shanghai shuttles (See Table 8-25 for an overview).
8.5.5 Number of berths per terminal

In the paragraph above the results of the simulation have been presented regarding the number of berths. In this paragraph an overview will be given of the above presented results and the total quay length is determined. In the table below the number of berths per terminal are given for each Yangshan terminal.

Table 8-25: Needed number of berths per terminal per vessel group

<table>
<thead>
<tr>
<th>Terminal number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>4</td>
<td>4</td>
<td>5</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>25</td>
</tr>
<tr>
<td>Short sea</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>River</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>8</td>
<td>49</td>
</tr>
<tr>
<td>Nanhui Zui Shuttle</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Shanghai shuttle</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>13</td>
</tr>
</tbody>
</table>

Validation

As had been mentioned before, the validation of the simulation model would be performed after the simulation results had been presented. Part of this validation regarded the comparison of the resulting number of berths with the number of berths following from the queue theory.

By applying the queue theory on the resulting annual number of vessels from the simulation runs, the following results have been found:

<table>
<thead>
<tr>
<th>Number of berths</th>
<th>Ocean</th>
<th>Short Sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3</td>
<td>4</td>
<td>7</td>
</tr>
</tbody>
</table>

Although the results of the simulation runs deliver one berth more than the queue theory, the numbers are quite in line and will therefore be used.

With these needed number of berths, the quay length can be determined. While the number of berths per vessel group is identical for all terminals except for terminal 3, the quay length will only be given for the terminal numbers 1 and 3. The actual calculation can be found in Appendix XVI. In this paragraph only the results are presented.

Table 8-26: Required quay length per terminal per vessel group

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Ocean</th>
<th>Short Sea</th>
<th>River</th>
<th>For shuttles sailing to</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Nanhui Zui</td>
</tr>
<tr>
<td>Terminal 1</td>
<td>(m)</td>
<td>1,300</td>
<td>900</td>
<td>950</td>
</tr>
<tr>
<td>Terminal 3</td>
<td>(m)</td>
<td>1,600</td>
<td>900</td>
<td>1,100</td>
</tr>
<tr>
<td>Yangshan total</td>
<td>(m)</td>
<td>8,000</td>
<td>5,400</td>
<td>5,800</td>
</tr>
<tr>
<td>Total throughput</td>
<td>(TEU)</td>
<td>1.8E+07</td>
<td>1.7E+07</td>
<td>5.0E+06</td>
</tr>
<tr>
<td>TEU/length</td>
<td>(TEU/m)</td>
<td>2,200</td>
<td>3,200</td>
<td>850</td>
</tr>
</tbody>
</table>

In this table also the average throughput per quay length ratio is given for all terminals at Yangshan to be able to compare the calculated results with values of other ports. This comparison has also been made in paragraph 5.2.1. Comparing these results with the values of other ports, presented in Table 5-2, the values are quite high. These high values can probably be ascribed to the fact that vessel capacities increase while the vessel lengths do not increase accordingly (See paragraph 3.5 for the vessels dimensions).
8.5.6 Apron area

The apron area is the area lying directly at the waterfront and consists of the following elements:
- Service lane
- Crane track spacing
- Hatch cover/Special container zone
- Traffic lane for the multi trailer system (MTS)

The width of these elements for the ocean, short sea and river vessels has already been determined in paragraph 5.3. These values were:

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Short sea</th>
<th>River</th>
<th>Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Service lane</td>
<td>(m)</td>
<td></td>
<td>(m)</td>
<td>(m)</td>
</tr>
<tr>
<td>Crane track spacing</td>
<td>(m)</td>
<td></td>
<td>(m)</td>
<td>(m)</td>
</tr>
<tr>
<td>Hatch cover area/special container zone</td>
<td>(m)</td>
<td></td>
<td>(m)</td>
<td>(m)</td>
</tr>
<tr>
<td>Traffic lane</td>
<td>(m)</td>
<td></td>
<td>(m)</td>
<td>(m)</td>
</tr>
<tr>
<td>Total:</td>
<td>(m)</td>
<td></td>
<td>(m)</td>
<td>(m)</td>
</tr>
</tbody>
</table>

The width of the apron area along the shuttle berths is almost equal to the width of the apron area along the river berths. Only the crane track spacing is different. While the beam of the shuttles (20.3 m) lies between the beams of the short sea vessels (25.0 m) and the river barges (15.4 m), it is assumed that the crane dimensions servicing the shuttles will be lying between these values. Therefore, the crane track spacing is assumed to be 20 meters.

8.5.7 Storage area

The required area for storage follows from a part of the results of the simulation in combination with the following formula:

\[ O = \frac{C_i \cdot t_d \cdot F}{r \cdot 365 \cdot m_i} \]

This formula has already been used in paragraph 5.4. In that paragraph all parameters were determined and the required area was calculated. While no data was available regarding the development of the stacks through time, the dwell times were assumed to lie around 4 days. With the results of the simulation however, it is possible to determine the average dwell times per terminal. With this determination also the validity can be checked as was already mentioned.

Before the average dwell times are calculated the following should be mentioned. Within the model the supply and discharge of containers has been regulated according to the average values that could be expected by the year 2025. Due to the fact that almost all of these movements are regulated via certain distribution functions it could happen that, for example, the supply of import containers by the ocean vessels is higher than the demand of import containers by the domestic vessels. In that case the containers will pile up at the import terminals. The scenario of a gradually decreasing stack size could of course also be expected.

Normally this will not appear while the domestic transportation modalities are regulated by the ocean and shortsea arrivals. To still be able to determine the needed storage area, the difference between supply and demand of containers has been determined and discounted over the year concerned.
At this point the average dwell time will first be calculated with the results of the simulation. With the following formula the average dwell times have been calculated.

\[
\text{Average Dwell time} = \frac{\text{Average stacksize} \times \text{Working days}}{\text{Annual throughput}}
\]

In the next table, the calculated values have been averaged over all terminals. In Appendix XVI the calculated values per terminal can be found.

Table 8-27: Average dwell times per vessel type at Yangshan

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Average Dwell times</th>
<th>Average vessel capacities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Standard of 2025</td>
<td>Standard of 2025</td>
</tr>
<tr>
<td>Ocean</td>
<td>9.4</td>
<td>5592</td>
</tr>
<tr>
<td>Short sea</td>
<td>4.8</td>
<td>1250</td>
</tr>
<tr>
<td>River</td>
<td>8.2</td>
<td>120</td>
</tr>
<tr>
<td>NZ Shuttle</td>
<td>2.8</td>
<td>537</td>
</tr>
<tr>
<td>SH Shuttle</td>
<td>2.8</td>
<td>537</td>
</tr>
</tbody>
</table>

As can be seen from this table, the average dwell times are quite high. Especially for the ocean and river stacks the average dwell time is high. Already in paragraph 5.4.2 it had been determined that an average dwell time of around 4 days could be considered acceptable. The increase in dwell time could probably be ascribed to the increase of vessel capacity. In 2025 it takes a relative smaller number of vessels to transport the same number of containers than it would with the current vessel capacities. Therefore they call less frequently and containers have a longer stay on the terminal.

To check this statement, two simulations have been made with the container handling volumes of 2025. One simulation with the average vessel capacities of the year 1997 leading to smaller inter arrival times and one with the vessel capacities of the year 2025. Both simulations have been made with an equal number of berths in such a way that no waiting times occur. In this way the difference in average vessel capacity can be checked.

In the table below the results can be found of both simulations together with the used average vessel capacities.

Table 8-28: Difference in average dwell times due vessel capacities

<table>
<thead>
<tr>
<th>Vessel type</th>
<th>Standard of 1997</th>
<th>Standard of 2025</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Vessel Capacity</td>
<td>Average dwell time</td>
</tr>
<tr>
<td>Ocean</td>
<td>3,350</td>
<td>6.9</td>
</tr>
<tr>
<td>Short sea</td>
<td>500</td>
<td>2.6</td>
</tr>
<tr>
<td>River</td>
<td>50</td>
<td>6.0</td>
</tr>
<tr>
<td>Nanhui Zui Shuttle</td>
<td>537</td>
<td>2.1</td>
</tr>
<tr>
<td>Shanghai shuttle</td>
<td>537</td>
<td>2.3</td>
</tr>
</tbody>
</table>

As can be seen from the table above, the high dwell times can partly be ascribed to the increase in vessel capacity. The average dwell times however are still too high (Except for the short sea vessel group). This is probably due to the way of container supply by the shuttles. The shuttles sail to and from Yangshan regardless of the presence of an ocean or short sea vessel. The same counts for the arrival of trucks and trains at the satellite terminals, initiating the movements of the shuttles.
Normally the ocean and short sea vessels sail according to a tight schedule. According to this schedule, trucks, trains and river barges arrive at the terminals to provide the vessel with containers in advance of its arrival. In this way the average dwell time and thus costs of the stay of the containers can stay low.

To be able to calculate the required area for the stacks, use will be made of the acceptable average dwell time of 4 days in combination with the probable increase in average dwell time due to the increase of vessel capacity. The acceptable value of 4 days will therefore be multiplied with the factor lying between the dwell times as presented in Table 8-28.

The resulting acceptable average dwell times can be found in the following table.

<table>
<thead>
<tr>
<th></th>
<th>Average dwell time</th>
<th>Multiplication factor</th>
<th>Acceptable average dwell time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1997</td>
<td>2025</td>
<td></td>
</tr>
<tr>
<td>Ocean</td>
<td>6.9</td>
<td>9.4</td>
<td>1.37</td>
</tr>
<tr>
<td>Short sea</td>
<td>2.6</td>
<td>4.9</td>
<td>1.86</td>
</tr>
<tr>
<td>River</td>
<td>6.0</td>
<td>8.4</td>
<td>1.39</td>
</tr>
<tr>
<td>Nanhu Zui Shuttle</td>
<td>2.1</td>
<td>2.7</td>
<td>1.30</td>
</tr>
<tr>
<td>Shanghai shuttle</td>
<td>2.3</td>
<td>2.8</td>
<td>1.25</td>
</tr>
</tbody>
</table>

As can be seen from this table the average dwell times all lie between 5 and 5.5 days except for the average dwell times of the short sea stacks. While the calculated 7.4 days is not a reasonable average dwell time for this vessel group, the average of 5.5 days is used.

Now the average dwell times are known, the required area per stack can be calculated. This calculation takes place according to the same formula as was used in paragraph 5.4:

\[ O = C_i \cdot t_d \cdot F \cdot r \cdot 365 \cdot m_t \]

The parameters of the formula have been kept the same. These parameters were:

- \( O \) Required area (m²)
- \( C_i \) Number of container movements per year per type of stack in TEUs
- \( t_d \) Average dwell time in days
- \( F \) Required area per TEU (10 m²)
- \( r \) Average stacking height/nominal stacking height (0.75)
- \( m_t \) Acceptable average occupancy rate (0.7)

In the following table the calculated required area per type of stack can be found for each terminal.

<table>
<thead>
<tr>
<th></th>
<th>Ocean (ha)</th>
<th>Short sea (ha)</th>
<th>River (ha)</th>
<th>NZ Shutts (ha)</th>
<th>SH Shutts (ha)</th>
<th>Total area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Terminal 1</td>
<td>49.3</td>
<td>48.9</td>
<td>23.7</td>
<td>27.8</td>
<td>12.8</td>
<td>162.5</td>
</tr>
<tr>
<td>Terminal 2</td>
<td>48.2</td>
<td>49.3</td>
<td>23.6</td>
<td>27.6</td>
<td>12.7</td>
<td>161.4</td>
</tr>
<tr>
<td>Terminal 3</td>
<td>57.1</td>
<td>49.8</td>
<td>25.8</td>
<td>30.2</td>
<td>13.9</td>
<td>176.8</td>
</tr>
<tr>
<td>Terminal 4</td>
<td>50.1</td>
<td>49.7</td>
<td>24.1</td>
<td>28.2</td>
<td>13.0</td>
<td>165.1</td>
</tr>
<tr>
<td>Terminal 5</td>
<td>50.1</td>
<td>48.2</td>
<td>23.8</td>
<td>27.8</td>
<td>12.8</td>
<td>162.7</td>
</tr>
<tr>
<td>Terminal 6</td>
<td>49.3</td>
<td>46.7</td>
<td>23.2</td>
<td>27.2</td>
<td>12.5</td>
<td>158.9</td>
</tr>
<tr>
<td><strong>Total area</strong></td>
<td><strong>304.14</strong></td>
<td><strong>292.69</strong></td>
<td><strong>144.13</strong></td>
<td><strong>168.82</strong></td>
<td><strong>77.64</strong></td>
<td><strong>987.4</strong></td>
</tr>
</tbody>
</table>
8.5.8 Total terminal area

With the above calculated results the total required area per terminal can be found. In paragraph 5.4.2, the storage area was multiplied by 2 to include traffic lanes and additional spaces at the terminal. With the current configuration there are no truck or train movements on the terminal. Additional spaces concerning these transport modalities can therefore be left behind. A factor should however still be applied. The used factor 2 used in paragraph 5.4.2 was a rough assumption. For the new terminal configuration this rough assumption is altered to a factor 1.5. This means that the area required for example buildings will be half of the area required for the stacks.

With this assumption, the total required area per terminal can be calculated. In the following table the required areas are added up per terminal.

Table 8-31: Total required area per terminal

<table>
<thead>
<tr>
<th></th>
<th>Terminal</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Apron area</td>
<td>(ha)</td>
<td>26.8</td>
<td>26.8</td>
<td>30.9</td>
<td>26.8</td>
<td>26.8</td>
</tr>
<tr>
<td>Storage area</td>
<td>(ha)</td>
<td>162.5</td>
<td>161.4</td>
<td>176.8</td>
<td>165.1</td>
<td>162.7</td>
</tr>
<tr>
<td>Additional area</td>
<td>(ha)</td>
<td>81.2</td>
<td>80.7</td>
<td>88.4</td>
<td>82.6</td>
<td>81.4</td>
</tr>
<tr>
<td>Total</td>
<td>(ha)</td>
<td>270.5</td>
<td>268.9</td>
<td>296.1</td>
<td>274.5</td>
<td>270.9</td>
</tr>
<tr>
<td>Throughput</td>
<td>(TEU)</td>
<td>5.8E +06</td>
<td>5.7E +06</td>
<td>6.3E +06</td>
<td>5.9E +06</td>
<td>5.8E +06</td>
</tr>
<tr>
<td>Throughput/area ratio</td>
<td>(TEU/ha)</td>
<td>21,443</td>
<td>21,195</td>
<td>21,275</td>
<td>21,493</td>
<td>21,411</td>
</tr>
</tbody>
</table>

As can be seen from this table, the area/throughput ratio lies around 21,000 TEU per hectare. This ratio seems quite in line with the ratio of the port of Singapore (22,000 TEU/ha) but it is quite low compared to the port of Hong Kong (48,000 TEU/ha). This could probably be ascribed to the fact that space in Hong Kong is scarce and very expensive.

8.6 Terminal lay-out

Now the area requirements have been determined, the lay-out of the terminals can be made. Within this report the study will from now on focus on the Yangshan islands. The reason for this is that the Nanhui Zui terminals require their own investigation due to their specialised way of container handling. These terminal will in the future have a throughput of almost 14 mTEU dealing solely with shuttle barges and trucks.

While the Yangshan islands offer a lot of space to build the container terminals, many layouts are possible. However, with the restrictions imposed by the various user groups, only a few layouts will match the requirements. These restrictions can generally be summarised in the following requirements:

- Construction and maintenance costs should be kept to a minimum.
- Terminals should be connected to each other to be able to exchange transshipment containers.
- The terminals should be designed in such a way that vessels can easily enter and leave its terminal’s water basins.
- Vessels need to be protected against strong currents and waves.
- Distances on the terminals to be covered by containers should be kept to a minimum.
- Where possible, berths should be constructed in one line to allow more than one vessel per berth.

During the design process it turns out that the above mentioned criteria cannot always be fully met. A cheap design for example, cannot always meet the criterion to let the vessels enter the terminal basins easily. Therefore, during the design process, some
compromises should be made. These compromises will probably not always meet all criteria at their fullest, but an effort is made to meet all criteria at best.

In the following paragraph, 4 concept designs will be presented. Each design naturally meets all criteria and has its own positive and negative points that will be described in the next few sections.

8.6.1 Design concepts for the Yangshan terminals

Figure 8-21: General overview of design proposals

The above presented designs will be further examined within the next few paragraphs. In these paragraphs also an enlargement of these proposals can be found.

8.6.2 Description of the proposed designs

To be able to choose a final design for the terminals at Yangshan, first the above presented designs will be discussed. While these designs have quite some properties in common, these general properties will first be discussed after which the individual designs will be described.

General properties of all terminals

As can be seen from the above presented designs, the majority of the terminals lies between the former islands. This is partly a result of the criterion that all terminals should be connected to each other and partly a result of the lack of space at the main islands. These conditions lead to large water areas to be filled. While some terminals are projected on the still hilly islands, use can be made of the outcoming rock to fill the water areas between the islands. In this way the construction costs can stay relatively low. It is however assumed that the outcoming rock and soil of the islands is suitable to
be used as fill. This assumption needs to be checked while it is a quite important element within the total construction costs.

To keep capital dredging costs as low as possible, the entrances leading to the terminals are located at the natural deep water areas. Concerning these entrances, two types of design could be distinguished within the four design proposals. The first two designs clearly separate the ocean and shortsea traffic from the domestic traffic and within the last two designs all vessels make use of the same terminal basins. Both design types have their advantages and disadvantages.

The advantage of separating the vessel groups for example is that the traffic intensity in the port's basins are much smaller than with vessels of all sizes sailing in different directions. Safety increases and manoeuvring of the vessels becomes easier. The disadvantage of this type of design however is that expensive constructions such as breakwaters have to be constructed at both the domestic side as well as on the ocean and shortsea side of the terminal. Another important disadvantage is that transshipment containers have to be transported across several terminals before reaching their destination. While annually almost 3 million TEU transshipment containers are transported between the several terminals, these transports will probably block the container movements within the terminals.

The advantage of the terminal designs with combined terminal basins is that they allow for a peripheral road for transport of transshipment containers. The movement of containers on the terminals will not be blocked in this way. Furthermore, breakwaters should only be constructed for the single entrance of the port. The "back" side of the terminals, with the peripheral road, can be used as physical separation against influences coming from sea.

**Properties of design nr 1:**

![Diagram of design number 1](image)

**Figure 8-22: Lay out of design number 1**
Terminal design

Occupied area

This design is situated around the natural deep water area between the former islands. Within this design the island of Dayangshan is almost completely occupied by terminal number 3. With the rock gained by flattening this island, the area occupied by the terminal numbers 1 and 2 could probably be filled.

On the other side of the natural deep water area, the terminal numbers 4 to 6 are situated. These terminals are mainly projected on the small islands opposite to Dayangshan. These islands only have a few peaks that probably won’t provide enough fill between these islands.

The terminal numbers 1 to 3 and 4 to 6 are connected to each other by a dam. This dam runs through the deep water area where a maximum depth of 36 meters below chart datum is reached. A lot of fill is therefore needed. This could have been avoided by a bridge connection. However, to prevent strong currents due tidal motion along the islands, the choice has been made to block the passage of currents.

Berths

At the outside boundaries of the terminals, the berths for the domestic vessels (Shuttles and river barges) are situated. The natural depth at these areas is sufficient for these vessels and dredging works are unnecessary. At the inside boundaries of the terminals the ocean and shortsea berths are constructed. Also at this area the natural depth is sufficient for these vessels except for one small peak between the terminals 3 and 4.

At both sides of the terminals the berths are designed as almost straight quays. These straight quays allow for a more efficient use of the berths. Portainers for example can be exchanged in case of the presence of a 12500 TEU vessel.

Storage areas

Within the design an effort is made to keep the storage areas as square as possible. At terminal 3 however this was not possible without generation of extra costs. The storage areas of each terminal are projected directly behind the berths for efficient loading of the vessels. The domestic stacks are separated from the ocean and shortsea stacks by the road for transshipment containers.

Breakwaters

With this design, breakwaters with a total length of around 23 kilometres are necessary to protect the harbour basins from currents and waves. The average depth around these breakwaters lies around 11 meters.
Properties of design nr 2:

![Map of design nr 2 with symbols for Ocean & Shortsea berths and Domestic berths]

**Figure 8-23: Lay out of design number 2**

**Occupied area**

This design forms on almost straight line across Xiaoyangshan and its adjacent islands. The water areas between the islands have to be filled up. Partly the rock coming off Xiaoyangshan and some peaks of the other used areas can be used as fill but it probably won’t be sufficient. By using the island of Dayangshan as a rock supplier probably a large area can be filled.

**Berths**

Within this design the domestic vessels are separated from the ocean and shortsea vessels. At the northern side of the terminals the domestic berths can be found and at the southern side of the terminals the ocean and shortsea berths can be found. The southern side provides sufficient natural depth along the quays of the terminals 2 till 6. At the northern side dredging is necessary while the natural depth is not sufficient.

At both sides the berths are designed as one straight quay allowing for the exchange of unloading equipment.

**Storage areas**

The storage areas are situated directly behind the berths. Distances to be travelled from the domestic side to the ocean and shortsea side have been kept to a minimum. The road for exchange of transshipment containers however divides the terminals in two parts.
Breakwaters

With the great length of the terminal area also long breakwaters are needed. In total a length of 30 kilometres is needed. Apart from blocking wave penetration, the western breakwater at the ocean and shortsea side is needed to block off tidal currents along the terminals.

Properties of design nr 3:

![Diagram of terminal design with labels]

Figure 8-24: Lay out of design number 3

Occupied area

This design is projected on top of the archipelago and occupies a large part of both Dayangshan and Xiaoyangshan. By flattening these islands probably a large amount of rock fill will become available. These amounts however, will probably not be enough to fill the projected terminals between these islands.

Berths

Within this design all vessels make use of the same entrance and basins. Vessels enter the port at the south western side where sufficient natural depth is available. From there, the vessels enter the main basin forming the connection of all terminal’s basins. This main basin has width of approximately 1200 meters while a large number of vessels will be sailing through this basin.

Ocean berths are situated at each side of the main basin. To create sufficient quay length for the other vessel groups, basins have been created perpendicular to the main basin. These smaller basins still have a width of 400 meters to allow the large ocean and shortsea vessels to turn within these basins. This width also allows the domestic vessels to sail to and from their berths without guidance.
The berths for the domestic vessels are situated at the end of the smaller basins while they are much easier to manoeuvre than the largest vessels.

**Storage areas**

The storage areas are situated directly behind the berths and are rectangular in shape. At this design the transshipment containers are transported between the terminals over a peripheral road lying at the back of the terminals. The internal transport of containers isn’t disturbed in this way.

**Breakwaters**

While use is made of only one port entrance, the breakwaters can be combined for all terminals leading to a relative short breakwater of only 7 kilometres. The terminals themselves form a barrier against natural influences. Also the islands alongside the entrance form a natural barrier resulting in shorter breakwaters.

**Properties of design nr 4:**

![Map Diagram](image)

Figure 8-25: Lay out of design number 4

**Occupied area**

This design is situated around the natural deep water area lying at the eastern side of Dayangshan. Within this design half of the terminals are situated at islands. Outcoming rock will therefore be used as fill for the other half of the terminals. This fill will probably not be enough.

As can be seen is that the terminals at both sides of the natural deep water area are connected to each other with a dam. This dam runs through a deep trough between the former islands. A large amount of rock is therefore needed. The reason why no bridge is used is that with a solid dam currents are blocked creating calm terminal basins.
**Berths**
This design combines the largest vessel groups with the smallest vessel groups. All vessels enter and leave the port via the entrance lying in the south east. While alongside the natural deepwater area not enough quay length is available, extra basins have been created. Each basin can either handle the domestic vessels or the ocean and shortsea vessels. In this way the traffic is somewhat separated.

**Storage areas**
The storage areas are rectangular shaped despite the shape of some of the terminals. With the transshipment road lying around the terminals, the internal transport of containers is not disturbed. Distances to be travelled by containers at the terminals 1, 2, 4 and 6 are minimal while at one side the ocean and shortsea vessels are handled and at the other side the domestic vessels are handled.

**Breakwaters**
Like at design number 3 the total length of the breakwaters can be kept quite small (9 kilometres). The terminals themselves form a barrier against external influences. The breakwaters are situated outside the trough between the islands saving large amounts of construction materials.

**8.6.3 Choice for a design**
With the general description of all designs, finally a choice can be made for one of these designs to be further developed. During the evaluation several aspects play a role that all have a different "weight" within the decision. These aspects can roughly be grouped within 2 categories, an operational and a financial category. To let all aspects proportionally decide which design is considered to be the best, a multi criteria analysis (MCA) is used.

Within this MCA the following aspects are considered:

**Operational category:**
- **Service level vessels:**
  The ability of the vessels to safely and easily enter the terminal's basins is considered.
- **Ease of use for terminal operator**
  The ease of container handling for the terminal operator is considered. The position of the road for exchange of transshipment containers for example highly contributes to this aspect. The positions of the stacks are furthermore considered.
- **Possibility for future expansion**
  The possibility of construction of extra terminals without large difficulties in case of higher expected throughput scenarios is considered.
- **Protection against external influences**
  The protection of the terminals and their basins against extreme weather conditions is considered within this aspect.

**Financial category**
- **Capital investments**
  The capital investments aspect is based on the total area to be filled and the total length of the breakwaters. (High investments like investments in equipment or pavement are considered the same for each design.) In case the outcoming rock from the islands is sufficient for the areas to be filled, the total reclamation costs go down. The decisions concerning costs are, in this stage, mainly based on assumptions.
- **Possibility of phasing of the execution**
  Phasing of the delivery of the several terminals through time is highly desired. This however is not always easy to establish while vessels should at all times be protected against currents and waves.

- **Exchangeability of the berths**
  If berths are exchangeable, a smaller number of quay cranes is needed.

- **Safety of the vessels**
  In case of collisions between vessels, the terminal could be down for some time due blocking of the basins.

- **Safety on the terminal**
  There are high costs involved in case of an accident. Not only the direct damage such as loss of lives and or materials are costly, also the indirect costs such as downtime due to unavailability of the terminal brings along high costs.

With the use of the MCA the remark should be made that the results of this method are quite dependent on the ratings per aspect given to the designs. While eventually the choice for one of the designs will be made by the future port authorities and investors, the ratings should actually be given by these parties.

To still be able to make a comparison between the different designs, 2 scenarios have been made. Within the first scenario the total costs is the most import aspect and within the second scenario the serviceability is the most import aspect. Furthermore an overall scenario is made where both aspects account for the same weight within the decision. The future port authorities can now decide for themselves which aspect is the most important.

While costs has always been a very important factor within decision making, the importance of the level of serviceability has been increased with the increasing competition among ports. As was already mentioned, the final decision lies in the hands of the investors. Within this study the overall scenario will be used as a middle course between both factors to make the final decision.

In the following table the results of the MCA can be found using the above mentioned scenarios. In Appendix XVII the actual valuation of each aspect per design can be found.

**Table 8-32: Results of the MCA for the design proposals**

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Design 1</th>
<th>Design 2</th>
<th>Design 3</th>
<th>Design 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Serviceability</td>
<td>326</td>
<td>358</td>
<td>355</td>
<td>347</td>
</tr>
<tr>
<td>Financial</td>
<td>280</td>
<td>302</td>
<td>335</td>
<td>343</td>
</tr>
<tr>
<td>Overall</td>
<td>288</td>
<td>325</td>
<td>360</td>
<td>350</td>
</tr>
</tbody>
</table>

Again, it should be noted that the results of the MCA are quite dependent on the ratings given to all aspects. Furthermore, exact details per design are not available. Ratings are therefore based on assumptions. Due to all these uncertainties within this method the figures presented above should therefore not be rated as exact. This method therefore gives a general overview of the relations between the different designs.

As can be seen from this table the values of the last 3 designs are quite the same for the serviceability scenario. At the financial scenario and the overall scenario the last two designs can be considered to be the best. For the further design within this report, design number 3 will be chosen.
8.7 Details of the chosen design

Within this paragraph the chosen design will be further discussed. While this study is in the masterplan stage, the discussion of the design will not be very detailed. Only general dimensions and important aspects of the several elements within the port will be given to be able to calculate the costs involved in the construction of the port. In the following few paragraphs the elements of the port will be discussed.

8.7.1 Anchorage

An anchorage for the ocean and shortsea vessels will be situated at approximately 18 kilometres east of the port’s entrance (See Figure 8-26). In this area, the vessels can wait if no berths are available. The average water depth lies between 20 and 30 meters. At this area the vessels are protected from wind generated waves from the main directions by the surrounding islands. The vessels are not protected against swell coming from the ocean.

The smaller domestic vessels can wait either on the north or at the south side of the Yangshan islands dependent on the prevailing currents and waves.

8.7.2 Approach to the terminals basins

The shortest distance to open sea lies west south west of the port’s entrance. Between the anchorage and the port’s entrance the average depth lies around 12 meters below CD. With a required depth of 15.3 meters below chart datum (CD) (See paragraph 8.2.3), an approach channel is therefore needed (See figure below).

An approach channel is required over a length of 10 kilometres. The width of the channel has been calculated to be 530 meters (Two way channel). While only an extra depth of 3.3 meters has to be dredged it is assumed that dredging works will be relatively easy due to soft top layers. In total a volume of 18.3 million m³ should be dredged.

Figure 8-26: Approach to the terminals basins
8.7.3 Port entrance

The port’s entrance is the area that allows the vessels to enter the port’s basins that are protected from strong currents and waves coming from the main wave directions (See figure below). This protection is provided by two breakwaters.

![Figure 8.27: Principal directions of wave attack](image)

Swell coming from the pacific ocean is largely blocked by the Zhoushan islands of which the Yangshan islands form a part. As can be seen in this figure is that swell that gets through will probably approach the port from the east. This swell could enter the port’s entrance, but cannot enter the port’s basin. Also, with the varying bathymetry along the path of the swell, the swell will probably change course due to refraction.

The total length of the breakwaters approach 2 kilometres. Lying in waters with an average depth of 30 meters below CD this leads to a relative expensive construction. However, while these breakwaters form the protection of 6 terminals with a combined throughput capacity of 35 mTEU, the costs of these breakwaters can be easily divided over the terminals.

The length of the port’s main basin is about 6 kilometres. This length is sufficient for the largest vessels to come to a halt within the protected area if necessary. The stopping length of these vessels has been calculated to be 2 kilometres. This length follows from a minimum speed of 4 knots where it takes 10 minutes for the tug boats to tie up to the vessel (1200 metres) and a stopping length of 2 times the vessel’s length (770 metres). With the relatively calm wave climate around the Zhoushan islands however, tug boats can tie up to the largest vessels before they have entered the port’s entrance. These vessels can now enter the ports’ basins under control of the tug boats.

8.7.4 Basins

From the moment the ocean or shortsea vessel is under control of the tug boats it proceeds to its appointed berth. As can be seen from Figure 8.28, the berths for the ocean and shortsea vessels are situated at the front of the terminal basins while these vessels are quite hard to manoeuvre. At the terminals 4, 5 and 6 there is no sufficient quay length available at the front of the terminals. Therefore, at these terminals, a part of the total quay length is positioned along the basins between the terminals 3 and 4 and terminals 5 and 6. These berths will be used by the shortsea vessels while these vessels have smaller space requirements than the ocean vessels. At the back of the basins the berths for the domestic vessels and the shuttles are situated.
Figure 8-28: Placement of the berths per terminal

The main basin that connects all basins that lie between the several terminals has a width of approximately 1200 meters. This large width has been imposed by the placement of the terminals while trying to build the terminals as much as possible on the islands. This large width has the advantage that, with the high traffic intensity by the year 2025, vessels can pass each other easily even when for example an ocean vessel is being turned.

The basins that contain the domestic vessels are 400 meters wide. While these basins are quite long (2.5 kilometres) the vessels should be able to turn within the basins. Also with this width, 2 way traffic is possible.

The natural available depths in the projected basins is almost everywhere sufficient. At the areas where the basins cross parts of the original islands a certain depth should be guaranteed. This depth requirement has been calculated according to the same method as has been applied in paragraph 3.5.4 while this method proved to be quite accurate for the ocean vessels.

The used formula was:

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

Where:

- \( d \) : Guaranteed depth below chart datum
- \( D \) : Draught of the design ship
- \( s_{\text{max}} \) : Squat & trim (0.5 meters)
- \( r \) : Vertical motion due to waves (0.5 meters)
- \( m \) : Safety margin (1 meter for hard soil or rock)
All factors except for the draught of the design ship have been kept the same as used in paragraph 3.5.4. These values are quite high while initially these values had been determined for ocean vessels sailing through an approach channel. The factor for squat for example could probably be somewhat lower while the speed of the vessels within the harbour basins remains low. The above factors will however still be used as they provide a safe margin.

For the draught of the vessels the maximum draughts presented in paragraph 3.5 will be used. These draughts were as follows: For ocean vessels 14 meters, for shortsea vessels 12 meters, for the river barges 6 meters and for the shuttles 4.4 meters (Paragraph 8.3.2).

Together with these draughts and a minimum tidal level of 0.9 meters above CD, a required depth can be calculated. These depths are:

15.1 meters below CD along the ocean berths
13.1 meters below CD along the shortsea berths
7.1 meters below CD along the domestic berths
5.5 meters below CD along the shuttle berths

8.7.5 Quay constructions

For all terminals combined a quay length of 25.6 kilometres should be constructed. This great length can be subdivided into ocean quays (8.1 km), shortsea quays (5.4 km), river quays (5.8 km) and shuttle quays (6.3 km). The type of quay wall to be installed depends on a large extend on the local conditions. Within these conditions the expected wheel loads on the quay and the retaining height are important design aspects. While the wheel loads are quite predictable (Each vessel group has its own dedicated crane), the retaining height depends very much on the location of the quay.

In general one could say that the depth along the quays that face the main basin lies around 16 meters below CD. For all other quays the depth is quite variable. Along most of the quays a larger natural depth is available than required. This leads to more expensive structures than with the required depth. In further stages of the design process the possibility of filling up parts of the natural depths along the quays to decrease the costs should therefore be examined.

The total retaining height of the quay structure is apart from the depth along the quay also determined by the height of the quay structure itself. This height is determined by the demand that the quay should not be flooded at extreme conditions. These extreme conditions occur during spring tide in combination with waves generated during a south eastern storm.

The spring tide causes the water to rise to 4.2 meters above CD (See paragraph 8.1.2)

The influence of waves can be calculated with the following formula:

\[ \tilde{H} = 0.24 \tanh(0.015 \tilde{F}^{0.45}) \]

In which:

\[ \tilde{H} = \frac{gH_s}{U^2} \]
\[ \tilde{F} = \frac{gF}{U^2} \]

\( F = \text{Fetchlength} \)
\( U = \text{Windspeed} \)
\( H_s = \text{Significant waveheight} \)
With the above stated formulas the wave height can be calculated that are generated within the port's basin during a certain wind speed. By using these formulas the assumption has been made that the breakwaters have highly dampened the waves coming from the sea.

The fetch length starts at the beginning of the breakwaters and ends at the end of the main basin. This distance is 6000 meters. Within the calculation furthermore a wind force of 6 Beaufort (12 m/s) is taken. Container handling activities have been stopped by that time. By using these values a significant wave height $H_s$ of approximately 0.8 meters is found. This wave height will be reached at the end of the basin and will gradually be developed along the total fetch length.

With a tidal level of 4.2 meters above CD and a wave height of 0.8 meters, the top of the quay should lie at a minimum height of 5 meters above CD.

While the conditions along the various quay locations is quite different, the quays will not be designed in this stage of the design process. The actual design depends too much on the local conditions of which no exact data is available at the moment. For the quay walls with a large retaining depth, covering most of the total quay length, a design proposal is however made. For these quays a combined quay wall can be considered as is presented below.

This quay wall consists of a concrete superstructure founded on tubular steel and prefabricated concrete piles. This type of structure has evolved from a large number of designs made by Gemeentewerken Rotterdam.

![Diagram](image)

Figure 8-29: Design proposal for the quays [27]
8.7.6 Stack areas

The stack areas are, where possible, situated directly behind the quay to make the loading of vessels as efficient as possible. The storage areas lie at the same level as the quays (5 meters above CD) and are flat.

It should furthermore be noted that at the locations where land reclamation has been taken place, the soil should be stabilised to provide a good foundation for the stacks. High loads could be expected at times that containers are stacked 4 high.

8.7.7 Building and services per terminal

At the back of the terminals the buildings are situated from where the processes on the terminal are monitored and repairs are executed. At this area also a container freight station (CFS) is situated. To safe space on the terminals this CFS only deals with containers that are transported by the river barges. Containers that are transported by the shuttles that should be packed or unpacked will be dealt with by CFS’s near the satellite terminals.

The area required for the CFS’s can be calculated using the following formula [10]:

\[ O_{\text{CFS}} = \frac{C_1 V t_{d} f_1 f_2}{h_a m_i 365} \]

In which:
- \( C_1 \) = Annual throughput of the CFS
- \( V \) = Contents of 1 TEU = (29 m³)
- \( t_d \) = Average dwell time = (5.6 days (See paragraph 8.5.7))
- \( f_1 \) = Ratio of gross area to net area = (Usually 1.4)
- \( f_2 \) = Bulking factor = (Usually in the order of 1.1 to 1.2)
- \( h_a \) = Average stack height within the station = (2 is taken)
- \( m_i \) = Acceptable occupancy rate = (0.7)

To be able to calculate the required area per CFS the assumption has been made that only 10% of the throughput transported by the river barges passes the CFS. On average a total number of 180,000 containers per terminal pass through the CFS. With this number an area of 10 ha is required per terminal.

For the remaining buildings an equal area will be reserved.

8.7.8 General services

Traffic information Centre

To monitor and guide the large number of vessels safely and efficiently, a traffic information centre should be available. This centre keeps track of all vessels approaching the Yangshan islands. The buildings containing the traffic control centre is situated at the port’s’ mouth. With this position, the traffic information centre also has a visual control of the vessels sailing in and out the port’s’ entrance.

Pilot service and tugs

To let the ocean and shortsea vessels enter the port’s basins safely a pilot service is necessary. The pilots work closely with the tug boats once the vessel approaches the port’s entrance. The placement of the pilot buildings and tug harbour will be near the port’s entrance.
The needed number of tug boats for all terminals combined follows from the total required tug-boat hours per year. To calculate this number, the total annual number of vessels that enter and leave the terminals and require assistance by tug boats should be counted. This number will be multiplied by the average duration of this assistance and the average number of tugs per vessel. In the following table these values have been summed up and the total needed number of tug boats is calculated.

**Table 8-33: Calculation of the needed number of tug boats**

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Shortsea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual number of vessels arriving at Yangshan</td>
<td>3640</td>
<td>9670</td>
</tr>
<tr>
<td>Average number of tugs per vessel</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Required time per vessel to berth</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Required time per vessel to deberth</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Required time in tug hours per vessel type</td>
<td>32760</td>
<td>38680</td>
</tr>
<tr>
<td>Total required tug hours</td>
<td>71440</td>
<td></td>
</tr>
<tr>
<td>Available hours per tugboat</td>
<td>6480</td>
<td></td>
</tr>
<tr>
<td>Minimal required tugs</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from the table above the required number of tugs is 11. Within this calculation the assumption has been made that there are, on average, 2 and 3 tug boats necessary for shortsea and ocean vessels respectively. The tug boats are furthermore operational during 75% of their time.

A small basin for these tug boats will be constructed between the southern breakwater and terminal number 1.

**Transshipment road**

To be able to transport transshipment containers between the several terminals a peripheral road will be constructed. By the year 2025 an annual number of almost 3 mTEU will probably be exchanged between the terminals. A two way traffic road of 2 lanes will probably be sufficient.

**Typhoon shelter**

With the large width and length of the main basin, this basin can also be used to provide shelter for the smaller vessels during a typhoon.
8.8 Phasing of execution

The execution of projects of this size is usually phased. Phasing is mainly built in to spread the investments involved over time while these investments are returned by the exploitation of the terminals. An effort is therefore made to deliver parts of the terminal through time to avoid creating too much expensive overcapacity. The deliverance takes place just before the capacity of the, at that time present, terminals reach their capacity.

Like already mentioned in chapter 3, the existing terminals at Shanghai will probably reach their capacity by the year 2004. From that time the terminals at Yangshan should take over part of the total throughput. In principle the Yangshan terminals could, from that time on, take over the remaining throughput that cannot be dealt with anymore by the terminals of Shanghai. While the Yangshan terminals need a satellite terminal to operate, the Nanhui Zui satellite capacity can accordingly grow with Yangshan.

To postpone the investments in a new Nanhui Zui satellite area as long as possible, first Shanghai will be partly used as a satellite location. In this way the function of Shanghai as a port dealing with the main vessels will gradually be taken over by the Yangshan terminals (See ).

While Shanghai (maximum capacity of 6.6 mTEU) handles "regular" throughput as well as "satellite" throughput by then, Yangshan should grow faster than with the use of Nanhui Zui as a satellite. This is however still assumed to be more cost efficient than constructing the Nanhui Zui satellite from the beginning. In this way the construction of a satellite location at Nanhui Zui will be postponed until the capacity of Shanghai as a satellite has been reached and all throughput will be handled at Yangshan.

![Figure 8-30: Throughput development of the various terminals](image)

Up till now the required capacity through time has been discussed. To avoid stagnation of the growth of container throughput, new parts of the terminals should be delivered just before the moment that the capacity of the, at that time, present terminals is reached.
Within this study the terminals will be delivered in two parts. Each representing half of that terminal’s capacity. Furthermore the assumption has been made that construction of each terminal takes 4 years. To further detail the in this report presented design, 2 years is assumed. Therefore, with a planning time and construction time of 2 years each, the first half of terminal number 1 can be delivered by the year 2005.

With this planning the total capacity will be too small to deal with the estimated throughput figures for the year 2004. This scenario cannot be avoided. Although this lack of capacity will probably cause some customers to choose for other ports of call, it is assumed that growth figures will be picked up again with the delivery of a new terminal.

In the following figure the delivery schedule is given.

![Delivery Schedule of Yangshan Terminals](image)

**Figure 8-31: Schedule of delivery of Yangshan terminals**

**Table 8-34: Delivery schedule of Yangshan terminals**

<table>
<thead>
<tr>
<th>Start</th>
<th>Terminal</th>
<th>Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>Terminal 1</td>
<td>1st half</td>
</tr>
<tr>
<td>2004</td>
<td></td>
<td>2nd half</td>
</tr>
<tr>
<td>2005</td>
<td>Terminal 2</td>
<td>1st half</td>
</tr>
<tr>
<td>2007</td>
<td></td>
<td>2nd half</td>
</tr>
<tr>
<td>2008</td>
<td>Terminal 3</td>
<td>1st half</td>
</tr>
<tr>
<td>2011</td>
<td></td>
<td>2nd half</td>
</tr>
<tr>
<td>2014</td>
<td>Terminal 4</td>
<td>1st half</td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td>2nd half</td>
</tr>
<tr>
<td>2018</td>
<td>Terminal 5</td>
<td>1st half</td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td>2nd half</td>
</tr>
<tr>
<td>2021</td>
<td>Terminal 6</td>
<td>1st half</td>
</tr>
<tr>
<td>2022</td>
<td></td>
<td>2nd half</td>
</tr>
</tbody>
</table>

With the delivery of the various parts of the terminals notice should be taken of the fact that the Nanhui Zui terminals should be delivered as well while from the year 2010 the
capacity of Shanghai as a satellite has been reached. If these two terminals are, like the Yangshan terminals, delivered per half then the following schedule should be regarded.

Table 8-35: Delivery schedule of Nanhui Zui terminals

<table>
<thead>
<tr>
<th>Start</th>
<th>Terminal 1</th>
<th>1st half</th>
<th>Delivery</th>
<th>2nd half</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>Terminal 1</td>
<td>1st half</td>
<td>2010</td>
<td>2015</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>Terminal 2</td>
<td>1st half</td>
<td>2020</td>
<td>2021</td>
<td>2023</td>
</tr>
</tbody>
</table>
9.1.3 Reclamation of the terminals' areas

In this section an estimation will be made of the costs of equalising and reclamation of terminal area. While large parts of the several terminals lie in a water area large amounts of fill are needed. The rock available in the several mountains spreaded over the islands could be used to reduce costs. Also the outcoming rock while dredging the basins could probably be used. Rock is furthermore required for the breakwaters as calculated above and for the shore protection along the terminals.

To get an overview of the outcoming and requested soil volumes, in the next few sections an inventory will be made regarding the several soil consuming en soil generating elements.

Terminals

For the estimation of the volumes of outcoming rock during equalising the mountains on the islands these mountains are schematised as pyramids. The assumption is thereby made that all outcoming rock could be used as rock fill for the terminals.

To calculate the total volumes of soil needed to reclaim parts of the terminals, the areas to be filled are multiplied with an average estimated depth with regard to the top level of the terminals (5 meters above CD). This depth is increased with one meter while the top soil layer could probably not be used as a foundation for the fill. In the following table the above mentioned volumes are calculated per terminal.

<table>
<thead>
<tr>
<th></th>
<th>Deficit of rock</th>
<th>Total</th>
<th>Net result</th>
<th>Outcoming non useable soil</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Surface area m²</td>
<td>Depth below terminal surface m</td>
<td>m³</td>
<td>m³</td>
</tr>
<tr>
<td>terminal 1</td>
<td>1.00E+06</td>
<td>15</td>
<td>1.50E+07</td>
<td>1.00E+06</td>
</tr>
<tr>
<td>terminal 2</td>
<td>3.40E+06</td>
<td>15</td>
<td>5.10E+07</td>
<td>3.40E+06</td>
</tr>
<tr>
<td>terminal 3</td>
<td>4.60E+06</td>
<td>10</td>
<td>4.60E+07</td>
<td>4.60E+06</td>
</tr>
<tr>
<td>terminal 4</td>
<td>3.20E+06</td>
<td>12</td>
<td>3.84E+07</td>
<td>3.20E+06</td>
</tr>
<tr>
<td>terminal 5</td>
<td>3.30E+06</td>
<td>14</td>
<td>4.62E+07</td>
<td>3.30E+06</td>
</tr>
<tr>
<td>terminal 6</td>
<td>2.60E+06</td>
<td>5</td>
<td>1.30E+07</td>
<td>2.60E+06</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td>2.10E+08</td>
<td>1.81E+07</td>
</tr>
</tbody>
</table>

From this table it appears that a total volume of fill of 170 million m³ is required.

Shore protection along the terminals

To protect the terminals against natural influences (currents and waves) a shore protection is needed. In total a length of 11 kilometres along the terminals boundaries should be protected. To be able to estimate a total volume of needed rock a rough cross section has been made.

![Figure 9-2: Rough cross section of the shore protection along the terminals](image)
While this cross section is very rough it only gives an indication of the needed amount of rock fill within this protection. With a length of 11 kilometres a total volume of 20 million m$^3$ is required.

While the basins should be protected from the beginning of the use of the Yangshan islands, the shape is triangularly chosen. With this shape it can protect the basins and later on in the project it can act as a dike during reclamation of the terminals.

**Basins**

As can be seen from Figure 8-28 a large volume of rock should be dredged from the basin between terminals 5 and 6. In the table below these volumes will be calculated. Also for this calculation the top layer of 1 meters cannot be used as fill but still has to be dredged.

**Table 9-2: Calculated dredging volumes within the terminals’ basins**

<table>
<thead>
<tr>
<th>Location</th>
<th>Area</th>
<th>Depth below CD</th>
<th>Required depth</th>
<th>Difference</th>
<th>Total Dredging</th>
<th>Non useable soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quay front of terminal 1</td>
<td>2.28E05</td>
<td>5</td>
<td>15.1</td>
<td>10.1</td>
<td>2.31E+06</td>
<td>2.28E+05</td>
</tr>
<tr>
<td>Domestic basin between terminal 1 and 2</td>
<td>1.37E05</td>
<td>0</td>
<td>5.5</td>
<td>5.5</td>
<td>7.55E+05</td>
<td>1.37E+05</td>
</tr>
<tr>
<td>Ocean basin between terminal 3 and 4</td>
<td>3.04E05</td>
<td>5</td>
<td>15.1</td>
<td>10.1</td>
<td>3.07E+06</td>
<td>3.04E+05</td>
</tr>
<tr>
<td>Domestic basin between terminal 3 and 4</td>
<td>9.25E04</td>
<td>2</td>
<td>7.1</td>
<td>5.1</td>
<td>4.72E+05</td>
<td>9.25E+04</td>
</tr>
<tr>
<td>Ocean basin between terminal 5 and 6</td>
<td>1.30E06</td>
<td>3</td>
<td>15.1</td>
<td>12.1</td>
<td>1.57E+07</td>
<td>1.30E+06</td>
</tr>
<tr>
<td>Domestic basin between terminal 5 and 6</td>
<td>1.92E05</td>
<td>0</td>
<td>7.1</td>
<td>7.1</td>
<td>1.36E+06</td>
<td>1.92E+05</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2.37E+07</td>
<td>2.25E+06</td>
</tr>
</tbody>
</table>

From this table it appears that a total volume of 20 million m$^3$ could be used as fill.

**Dayangshan mountain**

Like already mentioned in paragraph 9.1.2 a volume of 36 million m$^3$ could be exploited from the main mountain at Dayangshan.

**Total**

Now the inventory of the several elements has been made the total volumes could be calculated. In the table on the next page an overview can be found.
Table 9-3: Soil volumes to be displaced

<table>
<thead>
<tr>
<th>Element:</th>
<th>Dredging production</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Required fill</td>
<td>Useable</td>
<td>Non useable</td>
<td></td>
</tr>
<tr>
<td></td>
<td>m³</td>
<td>Rock m³</td>
<td>Soil m³</td>
<td>Soil m³</td>
</tr>
<tr>
<td>Approach channel</td>
<td>1.10E+07</td>
<td></td>
<td>5.38E+06</td>
<td></td>
</tr>
<tr>
<td>Breakwaters</td>
<td>1.00E+07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminal 1</td>
<td>1.50E+07</td>
<td>1.15E+07</td>
<td></td>
<td>1.00E+06</td>
</tr>
<tr>
<td>Terminal 2</td>
<td>5.10E+07</td>
<td></td>
<td>3.40E+06</td>
<td></td>
</tr>
<tr>
<td>Terminal 3</td>
<td>4.60E+07</td>
<td>2.55E+07</td>
<td></td>
<td>4.60E+06</td>
</tr>
<tr>
<td>Terminal 4</td>
<td>3.84E+07</td>
<td>0.20E+07</td>
<td></td>
<td>3.20E+06</td>
</tr>
<tr>
<td>Terminal 5</td>
<td>4.62E+07</td>
<td></td>
<td>3.30E+06</td>
<td></td>
</tr>
<tr>
<td>Terminal 6</td>
<td>1.30E+07</td>
<td>0.36E+07</td>
<td></td>
<td>2.60E+06</td>
</tr>
<tr>
<td>Shore protection</td>
<td>1.00E+07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Basins</td>
<td>2.14E+07</td>
<td></td>
<td>2.25E+06</td>
<td></td>
</tr>
<tr>
<td>Dayangshan mountain</td>
<td>3.60E+07</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>230E+06</td>
<td>100E+06</td>
<td>11E+06</td>
<td>26E+06</td>
</tr>
</tbody>
</table>

As can be seen from the table above a total volume of 120 million m³ is needed to fill up the terminals. For the terminals, both rock fill and sand fill can be used. For the breakwaters and shore protection only rock fill can be used. Therefore the rock fill needed for these elements is reserved after which the remaining part can be used for the terminals.

To be able to estimate the costs of the total soil displacement the results of the Drewry investigation will be used. Drewry however has only investigated the costs regarding dredging in relative weak soil layers. The following results were found: Dredging in a confined space restricted by existing berthing requirements ($2.25 per m³). Dredging without these restrictions ($7.5 per m³).

For the remaining dredging works an assumption will therefore be made. Dredging of rock normally is an expensive and slow proceeding job. For this reason the most expensive value found by Drewry ($7.5 per m³) will be multiplied by a factor 2. The costs of dredging of rock will therefore be set at $15 per m³.

From the table above it can be found that only a small part of rock is obtained by dredging. The main volume can be gained from the mountains at the Yangshan islands. For the exploitation of these volumes a quarry should be made. Normally the rock delivered by a quarry will be cheaper than the rock delivered by a cutter dredger. However, due to the construction of a quarry especially for this project the costs per m³ will be set equal to the costs of rock delivered by a cutter dredger.

Before the costs of the volumes are mentioned an important issue should be discussed first. This is the issue of to whom the costs of the dredged volumes that can be used as fill are charged. In this case the costs are charged to the user that first makes use of the volume.

For an overview of the costs per element the table below can be used. The costs are actually charged to the element within the same row.
Table 9-4: Costs per reclamation element in million US$ (Price level of 1997)

<table>
<thead>
<tr>
<th></th>
<th>Cost elements</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rock fill</td>
<td>Sand fill</td>
<td>Non useable soil</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Approach channel</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakwaters</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>200</td>
</tr>
<tr>
<td>Shore protection</td>
<td>300</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Terminal 1</td>
<td>338</td>
<td>34</td>
<td>2</td>
<td></td>
<td>374</td>
</tr>
<tr>
<td>Terminal 2</td>
<td></td>
<td>115</td>
<td>8</td>
<td></td>
<td>122</td>
</tr>
<tr>
<td>Terminal 3</td>
<td>383</td>
<td>104</td>
<td>10</td>
<td></td>
<td>496</td>
</tr>
<tr>
<td>Terminal 4</td>
<td>30</td>
<td>86</td>
<td>7</td>
<td></td>
<td>124</td>
</tr>
<tr>
<td>Terminal 5</td>
<td>396</td>
<td>45</td>
<td>7</td>
<td></td>
<td>448</td>
</tr>
<tr>
<td>Terminal 6</td>
<td>54</td>
<td>29</td>
<td>6</td>
<td></td>
<td>89</td>
</tr>
</tbody>
</table>

9.1.4 Quay structure

While investigating the costs of the quay walls Drewry found that the prices of quay structures are considerably consistent among the various ports. For a 35 meter wide berth a price of US$ 54,000 per meter quay length is found. Drewry estimated that a variation could be expected of 15 % at most.

While roughly half of the total required quay length only needs to have a structure such as investigated by Drewry the price will be used for all quays. The reason for this assumption is that the local conditions around the quays are very much uncertain as is described in paragraph 8.7.5. Although the required berth width will not be 35 meters for the domestic vessels, a large retaining height and thus solid construction could be needed.

The total costs for the quays are calculated per terminal and can be found in the following table:

Table 9-5: Costs of quay structures per terminal

<table>
<thead>
<tr>
<th>Quay length</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>m</td>
<td>million US$</td>
</tr>
<tr>
<td>terminal 1</td>
<td>4171</td>
</tr>
<tr>
<td>terminal 2</td>
<td>4171</td>
</tr>
<tr>
<td>terminal 3</td>
<td>4740</td>
</tr>
<tr>
<td>terminal 4</td>
<td>4171</td>
</tr>
<tr>
<td>terminal 5</td>
<td>4171</td>
</tr>
<tr>
<td>terminal 6</td>
<td>4171</td>
</tr>
</tbody>
</table>
9.1.5 Yard pavement and infrastructure

Like for the costs for quay structures Drewry found rather consistent figures concerning the prices of terminal pavement. The price per square meter is 63.8 US$. While the terminals do not vary much compared to each other this price will be used for all terminals. In the following table these costs have been determined per terminal.

Table 9-6: Yard pavement and infrastructural costs per terminal

<table>
<thead>
<tr>
<th>Terminal area</th>
<th>Costs (million US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ha</td>
<td></td>
</tr>
<tr>
<td>terminal 1</td>
<td>270.5</td>
</tr>
<tr>
<td>terminal 2</td>
<td>268.9</td>
</tr>
<tr>
<td>terminal 3</td>
<td>296.1</td>
</tr>
<tr>
<td>terminal 4</td>
<td>274.5</td>
</tr>
<tr>
<td>terminal 5</td>
<td>270.9</td>
</tr>
<tr>
<td>terminal 6</td>
<td>265.1</td>
</tr>
</tbody>
</table>

9.1.6 Buildings and services

Considering this cost element within the terminals’ costs Drewry does not mention detailed construction costs. It only mentions the cost of sheds ($375 per m²). It is assumed that Drewry accounts container freight stations to ‘‘sheds’’.

In paragraph 8.7.7. the total area of the container freight station was calculated to be 10 ha. For the remaining buildings, such as work shops and administration buildings, an equal area has been reserved. The price of these buildings will probably be higher than the price calculated for sheds. The price of the remaining buildings is assumed to be twice as high as the price for sheds.

While each terminal has the same area occupied with buildings the costs will be the same per terminal.

Table 9-7: Costs per terminal of buildings and services

<table>
<thead>
<tr>
<th>Terminal area</th>
<th>Costs (million US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ha</td>
<td></td>
</tr>
<tr>
<td>CFS</td>
<td>10</td>
</tr>
<tr>
<td>Container freight station</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
</tbody>
</table>

9.1.7 Equipment

As has been determined in paragraph 5.1, containers are (un)loaded with portainers and brought to the stacks using a Multi Trailer System (MTS). Once at the stack, the container is handled by a RMG system.

The needed amount per terminal of each of these equipment types can also be estimated according to study done by Drewry. Within this study typical values regarding the number of quay cranes, RMG’s and tractors/trailers have been evaluated for many terminals with an annual throughput of 500.000 TEU and more. These typical values will therefore be used within this report.
A typical value for the number of quay cranes is 1 quay crane per 120,000 TEU per year. While the average annual throughput value of the terminals lies around 5.8 mTEU, the needed number of quay cranes is 49.

A typical value for the number of RMG's is determined to be 3 per quay crane. In total 150 RMG's should therefore be installed.

The number of Multi Trailers to transport the containers to and from the quay is not evaluated within the Drewry report. Within this report the assumption is made that per quay crane 3 Multi trailers are needed. In total 150 Multi trailers are therefore needed per terminal.

Although the above mentioned numbers per terminal are quite rough, these values can be used as a first estimation.

With the needed number per equipment type, the total costs of the equipment can be calculated. For a quay crane with an outreach of 45 meters an amount of $ 7.1 million is determined. For a quay crane of 35 meters an amount of $ 6.2 million has been determined. While by the year 2025 most ocean and shortsea vessels can be handled by cranes with an outreach of 45 meters the costs of this crane will be used for these vessels. For the domestic cranes the value of the crane with an outreach of 35 meters will be taken. The division of cranes between the domestic services group and the ocean and shortsea services groups will be 50-50.

The costs regarding the RMG system are set at $ 1.2 million per unit by Drewry. Costs of the multi trailer system have not been determined. Prices of a tractor trailer system however are set at $ 120,000 per unit. While the multi trailer system can be regarded as an extended tractor trailer unit the costs of such a system are estimated to be $ 200,000 per unit. Although this amount seems rather low compared to the other equipment costs it does count while a large amount of these units is required.

In the following table the equipment costs are given together with their unit prices.

<table>
<thead>
<tr>
<th>Terminal</th>
<th>Throughput</th>
<th>Portainer cranes</th>
<th>RMG</th>
<th>MTS</th>
<th>Other</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>TEU</td>
<td>Domestic</td>
<td>Ocean</td>
<td>million US$</td>
<td>million US$</td>
<td>million US$</td>
</tr>
<tr>
<td>terminal 1</td>
<td>5.76E+06</td>
<td>24</td>
<td>24</td>
<td>319</td>
<td>144</td>
<td>173</td>
</tr>
<tr>
<td>terminal 2</td>
<td>5.72E+06</td>
<td>24</td>
<td>24</td>
<td>317</td>
<td>143</td>
<td>172</td>
</tr>
<tr>
<td>terminal 3</td>
<td>6.26E+06</td>
<td>26</td>
<td>26</td>
<td>347</td>
<td>157</td>
<td>188</td>
</tr>
<tr>
<td>terminal 4</td>
<td>5.85E+06</td>
<td>24</td>
<td>24</td>
<td>324</td>
<td>146</td>
<td>176</td>
</tr>
<tr>
<td>terminal 5</td>
<td>5.76E+06</td>
<td>24</td>
<td>24</td>
<td>319</td>
<td>144</td>
<td>173</td>
</tr>
<tr>
<td>terminal 6</td>
<td>5.63E+06</td>
<td>23</td>
<td>23</td>
<td>312</td>
<td>141</td>
<td>169</td>
</tr>
</tbody>
</table>

Within the table above also an item called “other” has been taken up. This item counts for all other equipment that should be available at the terminal. Within the Drewry report these various other types have been outdated and account for approximately 10 % of the total equipment costs. Within this report the value of 10 % is accurate enough while these costs form only a small part of the total terminal costs.
9.1.8 Shuttle barges

Another piece of equipment necessary to operate the Yangshan terminals is the shuttle barge. By the year 2025 a total number of 79 shuttles will be in operation. To be able to make a cost estimation use will be made of known prices of trailing suction hopper dredgers.

For the comparison with these vessels a hopper dredger with a carrying capacity of 5000 ton is taken. According to the price standards of NIVAG stated in the lecture notes “Bagger techniek” [28] a hopper with this capacity costs $16 million. While trailer suction hopper dredgers are very complicated vessels due to the presence of highly specialised equipment, this price is probably too high for the shuttle barge. For the shuttle barge therefore half of this number will be taken.

Like with the estimation of the costs of the breakwater and the shore protection the assumption is quite rough but it can give good indication of the costs involved.

The deliverance of shuttle barges will grow according to the throughput development of the Yangshan terminals.

9.1.9 Nanhu Zui satellite terminal

While in paragraph 8.6 it was stated that the Nanhu Zui terminals require their own investigation due to their specialised way of container handling, these terminals should be taken within the total cost estimation. To be able to make a cost estimation a comparison will be made with a Yangshan terminal. The Nanhu Zui terminal will probably be much cheaper while the local geometry is less hostile.

First the total costs will be calculated for Yangshan terminal number 1. Within the next table the costs for this terminal are added up according to the items discussed in the previous paragraphs. Behind these figures the assumed costs per Nanhu Zui terminal is presented. These figures will be justified below.

<table>
<thead>
<tr>
<th></th>
<th>Terminal 1</th>
<th>Nanhu Zui terminal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>million $</td>
<td>million $</td>
</tr>
<tr>
<td>Land reclamation</td>
<td>300</td>
<td>150</td>
</tr>
<tr>
<td>Quay length</td>
<td>225</td>
<td>45</td>
</tr>
<tr>
<td>Terminal area</td>
<td>173</td>
<td>173</td>
</tr>
<tr>
<td>Buildings</td>
<td>113</td>
<td>113</td>
</tr>
<tr>
<td>Equipment costs</td>
<td>579</td>
<td>265</td>
</tr>
<tr>
<td>General costs</td>
<td>373</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>1,390</td>
<td>1,119</td>
</tr>
</tbody>
</table>

The above presented assumptions of the values for the Nanhu Zui terminal are based on the following considerations.

**Land reclamation**

While the area around Nanhu Zui is not as rocky as the environment of Yangshan the costs involved in dredging are far less. The assumption has been made that these costs are half of the costs involved in reclamation of a Yangshan terminal. For an exact figure of these costs a design should be available.
Quay length

While the required number of berths and the length of the vessels are known, the quay length can be determined. The following formula is used:

\[ L_q = 1.1 \times n \times (L_v + 15) + 15 \]

in which:
- \( L_q \) = Length of the quay
- \( n \) = Number of berths (= 13 and 12 berths for terminals 1 and 2 respectively)
- \( L_v \) = Length of the vessel (= 115 meters)

With these parameters a total quay length of 1730 and 1875 meters should be available. With a price of $25,000 million per meter the costs per terminal are $43 million and $47 million respectively.

Terminal area

The total terminal area could probably be compared with a Yangshan terminal and will therefore be taken over.

Buildings

Like with the terminal area it is estimated that the costs for buildings will gradually be the same for the Nanhui Zui terminal. These costs will therefore be taken over.

Equipment costs

These costs will be estimated according to the same method as is applied for the Yangshan terminals. It is estimated that one quay crane per 120,000 TEU is needed. With this ratio a total of 58 cranes per terminal are needed. However, previously it had been determined that each vessel will be handled by two cranes. With 13 berths a total of only 26 cranes is needed. This figure will therefore be chosen.

While the outreach of these cranes does not have to be high, $5 million per crane seems a good value. Also for this terminal a RMG in combination with a multi trailer system (MTS) is estimated. With the ratio of 3 RMG’s and 3 MTS’s per crane a total number of 78 RMG’s and MTS’s should be available.

The total costs per terminal are now:
- $130 million for the quay cranes,
- $94 million for the RMG system and
- $16 million for the MTS. With an extra 10% for remaining equipment the total equipment costs amount $265 million per terminal.

General costs

Together with the cost per terminal also some general costs should be made. The main costs are costs for a breakwater, an approach channel and infrastructural costs to connect the satellite with Shanghai.

For these costs the rough assumption will be made that it accounts for 25% of the cost of both satellite terminals leading to an amount of $373 million.

Now the several elements of the terminals have been calculated, the total height of the investments can be calculated.
9.2 Scheduling of investments

In paragraph 8.8 a schedule for phasing of the execution has been given. Within this report the required investments throughout the years will be determined. While the way of acquiring the investments and the method of returning these investments should be determined by the future users, only the height of the expected investments are given within this report.

The moment of making an investment will be set at the beginning of the construction of a certain element. For example, at the moment that the construction of the first half of Yangshan terminal number one will begin, the investment will be calculated. The investment will in this case also be only half of the total terminal’s costs. (Only half of the terminal is delivered.)

For the cost estimation described within the sections above, the price level of 1997 is used. To convert these prices to the year where the investment will be done, the above estimated costs will be multiplied with an annual inflation factor of 5%. This factor is quite high but China is still considered to be a developing country though it stands at the threshold of entering the WTO.

In the following tables the schedule of investments can be found per major cost element. Appendix XVII gives a somewhat more detailed overview of the investments per element.

Table 9-9: Total investments throughout the years

<table>
<thead>
<tr>
<th>Year of expenditure</th>
<th>General</th>
<th>Yangshan</th>
<th>Nanhui Zui</th>
<th>Shuttles</th>
<th>Total</th>
<th>Price level 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>million $</td>
<td>million $</td>
<td>million $</td>
<td>million $</td>
<td>million $</td>
<td>million $</td>
</tr>
<tr>
<td>2002</td>
<td>25</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>737</td>
<td>978</td>
<td>37</td>
<td>1,752</td>
<td>1,589</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>1,027</td>
<td>42</td>
<td></td>
<td>1,069</td>
<td>924</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>890</td>
<td>48</td>
<td>939</td>
<td>993</td>
<td>772</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>55</td>
<td>55</td>
<td></td>
<td></td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>981</td>
<td>63</td>
<td>1,045</td>
<td>1,108</td>
<td>780</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>1,443</td>
<td>955</td>
<td>73</td>
<td>2,471</td>
<td>1,756</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>11</td>
<td>11</td>
<td></td>
<td></td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>39</td>
<td>39</td>
<td></td>
<td></td>
<td>25</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>1,671</td>
<td>36</td>
<td>1,707</td>
<td>1,743</td>
<td>1,048</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>41</td>
<td>41</td>
<td></td>
<td></td>
<td>24</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>1,219</td>
<td>46</td>
<td>1,265</td>
<td>1,311</td>
<td>705</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>1,400</td>
<td>52</td>
<td>1,452</td>
<td>1,504</td>
<td>770</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>59</td>
<td>59</td>
<td></td>
<td></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>1,543</td>
<td>66</td>
<td>1,609</td>
<td>1,675</td>
<td>774</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>75</td>
<td>75</td>
<td></td>
<td></td>
<td>34</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>2,146</td>
<td>1,562</td>
<td>84</td>
<td>3,792</td>
<td>1,654</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>95</td>
<td>95</td>
<td></td>
<td></td>
<td>39</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>2,366</td>
<td>107</td>
<td>2,473</td>
<td>2,580</td>
<td>979</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>1,874</td>
<td>1,808</td>
<td>120</td>
<td>3,802</td>
<td>1,433</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>1,967</td>
<td>135</td>
<td>2,103</td>
<td>2,238</td>
<td>755</td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>153</td>
<td>153</td>
<td></td>
<td></td>
<td>52</td>
<td></td>
</tr>
</tbody>
</table>

Total (based on the price level of 2001): 14,217

In the last column of the table above, the present day values (2001) of the total investments have been calculated. With this value a comparison can be made with other project variants.
10 Conclusions

The conclusions drawn in this report will be summarised in the following few sections.

Container throughput of the port of Shanghai has reached a value of 5.6 million TEU (mTEU) in the year 2000. With this throughput Shanghai positioned itself at the 6th place of the largest container ports of the world. This throughput however also caused the current 3 available terminals to have reached their container handling capacity. While the current terminals are physically unable to expand and the rivers along which the terminals are situated are not able to receive the largest vessels, a new terminal location should be sought to build new container handling capacity on short term.

In the masterplan made in this report an average annual growth of between 6.9 % and 8.2 % is expected until the year 2025. With these figures a throughput of between 30 and 40 million TEU can be expected by that time. For further investigation the average of these figures has been taken leading to a throughput of 35 mTEU by the year 2025.

To be able to deal with this throughput a new terminal location has been sought outside the Yangtze River delta. A combination of the Yangshan islands and the shore location of Nanhui Zui turned out to be a good location for expansion. The largest vessels coming from the continents and the shortsea vessels coming from countries nearby will directly call at terminals at the Yangshan islands. The Nanhui Zui location and the currently available terminals at Shanghai will function as satellites of the Yangshan terminals. These satellites will deal with the domestic containers transported by trucks and trains coming from and going to the Yangshan islands. The containers transported by these modalities will be further transported by shuttle vessels that sail between the Yangshan islands and the satellite terminals. In total 79 shuttle vessels with an individual capacity of 537 TEU will be necessary to transport the domestic containers. Domestic containers transported by barges via the Yangtze River will be directly brought to the Yangshan islands.

By the year 2025 the container terminals at Shanghai will deal with 6.6 mTEU annually and the satellite terminal at Nanhui Zui will deal with 13.8 mTEU annually. The Yangshan islands will form the main container port of Shanghai dealing with 35 mTEU annually. This throughput can be dealt with by 6 terminals having an average annual capacity of 5.8 mTEU (See figure below).

Figure 10-1: Overview of the Yangshan terminals
Each terminal requires a total area of around 270 ha. The total quay length of each terminal lies around 4.2 kilometres which can be divided over ocean berths (1.3 km), shortsea berths (0.9 km), river berths (1.0 km) and shuttle berths (1.0 km).

These 6 terminals will be delivered in phases. The first half of terminal number 1 can be delivered in 2005 and the second half of the last terminal, terminal number 6, has to be delivered by the year 2024. While the container handling capacity of the current terminals of Shanghai and the outstanding projects combined will be reached by the year 2004, the container handling capacity in 2004 will not be sufficient. While the lack of sufficient capacity is only relatively small (0.5 mTEU) it is assumed that this will not affect container growth figures.

The total required investments for construction of all terminals and shuttle vessels has been calculated at $14.4 billion accounting for the price level of 2001. This investment can be spreaded over the period between 2002 and 2023.
11 Recommendations

While detailed information of the exact situation at Shanghai and its environment is unavailable, many assumptions have been made within this report. Although these assumptions have eventually led to an indication of the situation by the year 2025, further investigation should be executed to gain more detailed information about the local situation. In the following few sections some suggestions will be made to further investigate.

Firstly the environmental conditions around the islands should be checked. The most important factors are the current conditions, wave climate and soil conditions around the islands.

The current conditions around the Yangshan islands are very important while the availability of the terminals for the various vessels could be dependent on these conditions. Apart from the present-day flow velocity and patterns, the future flow patterns and velocities should also be checked using appropriate computer models. This is necessary while these patterns will probably change due to the closing of the gap between the Yangshan islands.

The wave climate is also an important environmental condition while it could influence the availability of the terminals. The largest vessels calling at Yangshan will probably not be affected by the waves. The shuttle vessels and the vessels sailing up and down the Yangtze River however could be hindered by these waves. Data of the wave climate should therefore be collected.

The soil conditions of the islands are a very important factor regarding the construction of the terminals at the Yangshan islands. The assumption has been made that the islands will mainly consist of rock. This will probably be a good assumption regarding the various steep peaks at the islands. In case the surrounding soil conditions are very different however, the consequences for the construction of the terminals will be high. Therefore data on these conditions should be gained.

Secondly the prices used in this report should be checked. Prices used in this report have been estimated according to unit prices gained by experience at other projects around the world multiplied by estimated quantities of the design. Price levels in China could however be very different due to for example a different scale of wages. The estimated quantities such as the required rock fill should be rechecked according to the feedback generated by the investigation on the local conditions as suggested above.

Finally the benefits generated by the project should be checked. Up till now only the costs have been determined while the benefits form an important factor within the feasibility of the project. This feasibility highly depends on the subsidising of the project by the Chinese government and is therefore hard to check.
12 References

12.1 Literature:

[4] Final report Hong Kong harbour study, Dutch Harbour design, 2000
[7] Agenda 21,
[14] Port management and operations, P. Alderton, Lloyd's practical shipping guides, 1999
[16] Daxie island, A deep water port for central China, Bechtel Enterprises, Sept 1995
[18] Port expansion Shanghai, J.J. van de Looij, 1997
[22] Regulation of the Yangtze Estuary, Volume A part 1, Port and Delta Consortium, 1995
12.2 Magazines:

[29] Dredging and port construction, November 2000


[31] Cargonews China, January 5 2000


[34] Containerisation International, May 1999


[36] China today, April 1999
Appendices
Table of contents

Appendix I  Forecasting method ................................................................. 2
Appendix II  Calculating the average vessel capacity .................................. 5
Appendix III  Modal Split ............................................................................. 6
Appendix IV  Expected number of vessels per services group .................... 8
Appendix V  Terminal operating system ...................................................... 9
Appendix VI  Quay length determination ..................................................... 11
Appendix VII  Projection of terminal’s area on locations ............................. 22
Appendix VIII  Location selection with the MCA ....................................... 24
Appendix IX   Bathymetry of the area around Nanhui Zui ......................... 28
Appendix X   Soil conditions Nanhui Zui .................................................... 30
Appendix XI  Meteorological conditions ..................................................... 33
Appendix XII  PIANC design tables for approach channels ....................... 35
Appendix XIII  Calculation of volume of capital dredging ......................... 37
Appendix XIV  Choice of shuttlebarge ......................................................... 40
Appendix XV  Modal split per terminal....................................................... 41
Appendix XVI  Dwell times ........................................................................ 44
Appendix XVII  MCA for design proposals ................................................. 45
Appendix XVIII Schedule of investments .................................................. 49
Appendix XIX  Detailed module description .............................................. 53
Appendix XX  Program listing ..................................................................... 65
Appendix I  Forecasting method

This appendix provides the results from a forecast that have been made by Ocean Shipping Consultance (OSC).

It should be noted that OSC does not make forecasts per port, but makes forecasts per region. For Shanghai, the "China port region" is used. This region consists of three parts: Hong Kong, Taiwan and more general, East/South East China. Shanghai is part of East/South East China and can therefore be calculated.

Over the past decade the share of Shanghai in this part of China has decreased from 62 % in 1990 to 44 % in 2000. Over the past 5 years the share of Shanghai seems to stabilise around a share of 42 %. This percentage has therefore been used to calculate the throughput of Shanghai.

The following tables are established as follows.
OSC makes a prediction of the throughput for the years 2004, 2008 and 2012 (Table 1). With these throughput figures the annual growth percentages can be calculated for the years between 2004, 2008 and 2012 (Table 2). Between these years, the assumption is made of linear growth. With these percentages an annual throughput figure can be calculated (Table 3).

With the above mentioned share of Shanghai within the Chinese Port Region (Table 4), the annual throughput of Shanghai can be calculated (Table 5).

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>14.54</td>
<td>14.69</td>
<td>16.15</td>
<td>18.95</td>
<td>22.05</td>
<td>25.80</td>
</tr>
<tr>
<td>Taiwan</td>
<td>8.48</td>
<td>8.82</td>
<td>9.90</td>
<td>13.21</td>
<td>17.00</td>
<td>20.80</td>
</tr>
<tr>
<td>S&amp;E China</td>
<td>6.19</td>
<td>8.06</td>
<td>11.85</td>
<td>19.24</td>
<td>27.45</td>
<td>37.25</td>
</tr>
<tr>
<td>Chinese port region</td>
<td>29.21</td>
<td>31.57</td>
<td>37.90</td>
<td>51.40</td>
<td>66.50</td>
<td>83.85</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>14.54</td>
<td>14.69</td>
<td>16.15</td>
<td>17.90</td>
<td>19.20</td>
<td>21.90</td>
</tr>
<tr>
<td>Taiwan</td>
<td>8.48</td>
<td>8.82</td>
<td>9.90</td>
<td>12.85</td>
<td>15.75</td>
<td>18.65</td>
</tr>
<tr>
<td>S&amp;E China</td>
<td>6.19</td>
<td>8.06</td>
<td>11.85</td>
<td>14.25</td>
<td>19.55</td>
<td>27.42</td>
</tr>
<tr>
<td>Chinese port region</td>
<td>29.21</td>
<td>31.57</td>
<td>37.90</td>
<td>45.00</td>
<td>54.50</td>
<td>67.97</td>
</tr>
</tbody>
</table>
Table 2: Forecast OSC annual container throughput growth (%)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>1.0%</td>
<td>4.9%</td>
<td>4.8%</td>
<td>4.1%</td>
<td>4.1%</td>
<td>4.1%</td>
<td>3.9%</td>
<td>3.9%</td>
<td>3.9%</td>
<td>3.9%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
<td>4.0%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>4.0%</td>
<td>5.9%</td>
<td>5.9%</td>
<td>7.5%</td>
<td>7.5%</td>
<td>7.5%</td>
<td>7.5%</td>
<td>6.5%</td>
<td>6.5%</td>
<td>6.5%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>6.4%</td>
</tr>
<tr>
<td>S&amp;E China</td>
<td>30.2%</td>
<td>21.3%</td>
<td>21.3%</td>
<td>12.9%</td>
<td>12.9%</td>
<td>12.9%</td>
<td>9.3%</td>
<td>9.3%</td>
<td>9.3%</td>
<td>9.3%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>10.9%</td>
</tr>
<tr>
<td>Chinese port region</td>
<td>8.1%</td>
<td>9.6%</td>
<td>9.6%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>7.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>1.0%</td>
<td>4.9%</td>
<td>4.9%</td>
<td>2.6%</td>
<td>2.6%</td>
<td>2.6%</td>
<td>2.6%</td>
<td>1.8%</td>
<td>1.8%</td>
<td>1.8%</td>
<td>1.8%</td>
<td>3.3%</td>
<td>3.3%</td>
<td>3.3%</td>
<td>3.3%</td>
<td>2.7%</td>
</tr>
<tr>
<td>Taiwan</td>
<td>4.0%</td>
<td>5.9%</td>
<td>5.9%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>6.7%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>5.2%</td>
<td>4.3%</td>
<td>4.3%</td>
<td>4.3%</td>
<td>4.3%</td>
<td>5.5%</td>
</tr>
<tr>
<td>S&amp;E China</td>
<td>30.2%</td>
<td>21.3%</td>
<td>21.3%</td>
<td>4.7%</td>
<td>4.7%</td>
<td>4.7%</td>
<td>4.7%</td>
<td>8.2%</td>
<td>8.2%</td>
<td>8.2%</td>
<td>8.2%</td>
<td>8.8%</td>
<td>8.8%</td>
<td>8.8%</td>
<td>8.8%</td>
<td>8.3%</td>
</tr>
<tr>
<td>Chinese port region</td>
<td>8.1%</td>
<td>9.6%</td>
<td>9.6%</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.4%</td>
<td>4.9%</td>
<td>4.9%</td>
<td>4.9%</td>
<td>4.9%</td>
<td>5.7%</td>
<td>5.7%</td>
<td>5.7%</td>
<td>5.3%</td>
</tr>
</tbody>
</table>

Table 3: Forecast OSC annual container throughput (mTEU)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>14.69</td>
<td>15.40</td>
<td>16.15</td>
<td>16.81</td>
<td>17.49</td>
<td>18.21</td>
<td>18.95</td>
<td>19.68</td>
<td>20.44</td>
<td>21.23</td>
<td>22.05</td>
<td>22.85</td>
<td>23.65</td>
<td>24.45</td>
<td>25.25</td>
<td>298.50</td>
</tr>
<tr>
<td>Taiwan</td>
<td>8.82</td>
<td>9.34</td>
<td>9.90</td>
<td>10.64</td>
<td>11.44</td>
<td>12.29</td>
<td>13.21</td>
<td>14.07</td>
<td>14.99</td>
<td>15.96</td>
<td>17.00</td>
<td>17.88</td>
<td>18.80</td>
<td>19.78</td>
<td>20.78</td>
<td>214.92</td>
</tr>
<tr>
<td>S&amp;E China</td>
<td>8.06</td>
<td>9.77</td>
<td>11.85</td>
<td>13.38</td>
<td>15.10</td>
<td>17.04</td>
<td>19.24</td>
<td>21.03</td>
<td>22.98</td>
<td>25.12</td>
<td>27.45</td>
<td>29.63</td>
<td>31.98</td>
<td>34.51</td>
<td>37.25</td>
<td>324.39</td>
</tr>
<tr>
<td>Chinese port region</td>
<td>31.57</td>
<td>34.59</td>
<td>37.90</td>
<td>40.90</td>
<td>44.14</td>
<td>47.63</td>
<td>51.40</td>
<td>54.82</td>
<td>58.46</td>
<td>62.35</td>
<td>66.50</td>
<td>70.47</td>
<td>74.67</td>
<td>79.13</td>
<td>83.85</td>
<td>838.38</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Hong Kong</td>
<td>14.69</td>
<td>15.40</td>
<td>16.15</td>
<td>16.57</td>
<td>17.00</td>
<td>17.45</td>
<td>17.90</td>
<td>18.22</td>
<td>18.54</td>
<td>18.87</td>
<td>19.20</td>
<td>19.84</td>
<td>20.51</td>
<td>21.19</td>
<td>21.90</td>
<td>273.42</td>
</tr>
<tr>
<td>Chinese port region</td>
<td>31.57</td>
<td>34.59</td>
<td>37.90</td>
<td>39.56</td>
<td>41.30</td>
<td>43.11</td>
<td>45.00</td>
<td>47.21</td>
<td>49.52</td>
<td>51.95</td>
<td>54.50</td>
<td>57.59</td>
<td>60.86</td>
<td>64.32</td>
<td>67.97</td>
<td>726.96</td>
</tr>
</tbody>
</table>
### Table 4: Share of Shanghai in S&E China during last decade

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>S&amp;E China</td>
<td>0.73</td>
<td>1.02</td>
<td>1.34</td>
<td>1.87</td>
<td>2.64</td>
<td>3.38</td>
<td>4.68</td>
<td>6.37</td>
<td>8.06</td>
<td>9.77</td>
<td>11.85</td>
</tr>
<tr>
<td>Shanghai</td>
<td>0.46</td>
<td>0.57</td>
<td>0.72</td>
<td>0.94</td>
<td>1.19</td>
<td>1.53</td>
<td>1.96</td>
<td>2.53</td>
<td>3.06</td>
<td>4.21</td>
<td>5.25</td>
</tr>
<tr>
<td>Share</td>
<td>62.7%</td>
<td>55.7%</td>
<td>53.7%</td>
<td>50.3%</td>
<td>45.0%</td>
<td>45.3%</td>
<td>41.9%</td>
<td>39.7%</td>
<td>38.0%</td>
<td>43.1%</td>
<td>44.3%</td>
</tr>
</tbody>
</table>

### Table 5: Throughput Shanghai (mTEU) according OSC when Shanghai counts for 42% of S&E China

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>High scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mTEU</td>
<td>3.39</td>
<td>4.10</td>
<td>4.98</td>
<td>5.62</td>
<td>6.34</td>
<td>7.16</td>
<td>8.08</td>
<td>8.83</td>
<td>9.65</td>
<td>10.55</td>
<td>11.53</td>
<td>12.44</td>
<td>13.43</td>
<td>14.50</td>
<td>15.65</td>
</tr>
<tr>
<td>Annual growth</td>
<td>%</td>
<td>21.3%</td>
<td>21.3%</td>
<td>12.9%</td>
<td>12.9%</td>
<td>12.9%</td>
<td>12.9%</td>
<td>9.3%</td>
<td>9.3%</td>
<td>9.3%</td>
<td>9.3%</td>
<td>9.3%</td>
<td>7.9%</td>
<td>7.9%</td>
<td>7.9%</td>
</tr>
<tr>
<td>Low scenario</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>mTEU</td>
<td>3.39</td>
<td>4.10</td>
<td>4.98</td>
<td>5.21</td>
<td>5.46</td>
<td>5.72</td>
<td>5.99</td>
<td>6.48</td>
<td>7.01</td>
<td>7.59</td>
<td>8.21</td>
<td>8.94</td>
<td>9.72</td>
<td>10.58</td>
<td>11.52</td>
</tr>
<tr>
<td>Annual growth</td>
<td>%</td>
<td>21.3%</td>
<td>21.3%</td>
<td>4.7%</td>
<td>4.7%</td>
<td>4.7%</td>
<td>4.7%</td>
<td>8.2%</td>
<td>8.2%</td>
<td>8.2%</td>
<td>8.2%</td>
<td>8.8%</td>
<td>8.8%</td>
<td>8.8%</td>
<td>8.8%</td>
</tr>
</tbody>
</table>
Appendix II  Calculating the average vessel capacity

The average vessel capacity for the ocean services group has been calculated regarding the order book of vessels for the period 2000-2005. As can be seen from the orders in the table below, the trend leads towards vessels with a high transport capacity.

Table 13-1: Overview of currently sailing vessels and vessels on order

<table>
<thead>
<tr>
<th>Vessel’s class</th>
<th>Under 1000</th>
<th>1000-2000</th>
<th>2000-3000</th>
<th>3000-4000</th>
<th>over 4000</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Currently sailing</td>
<td>4,955</td>
<td>1,142</td>
<td>395</td>
<td>223</td>
<td>196</td>
<td>6911</td>
</tr>
<tr>
<td>On order</td>
<td>135</td>
<td>97</td>
<td>32</td>
<td>30</td>
<td>77</td>
<td>371</td>
</tr>
<tr>
<td>Increase</td>
<td>2.7 %</td>
<td>8.5 %</td>
<td>8.1 %</td>
<td>13.5 %</td>
<td>39.3 %</td>
<td>5.4 %</td>
</tr>
<tr>
<td>% of total</td>
<td>71.7 %</td>
<td>16.5 %</td>
<td>5.7 %</td>
<td>3.2 %</td>
<td>2.8 %</td>
<td>100 %</td>
</tr>
</tbody>
</table>

To be able to calculate the future average vessel capacity, the order book for 2000-2005 have been used. It is assumed that the average vessel size will linearly grow according to the growth figures of this order book.

It is further assumed that vessels able to transport up till 2000 TEUs will not be sailing in the Ocean services group anymore (Shaded figures in Table 13-2). The results of the calculation can be found in the table below.

Table 13-2: Calculation of expected vessel capacity

<table>
<thead>
<tr>
<th>Vessel’s class</th>
<th>Under 1000</th>
<th>1000-2000</th>
<th>2000-3000</th>
<th>3000-4000</th>
<th>over 4000</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>2000-2005</td>
<td>5,090</td>
<td>1,239</td>
<td>427</td>
<td>253</td>
<td>273</td>
<td>953</td>
</tr>
<tr>
<td>Average TEU</td>
<td>550</td>
<td>1,500</td>
<td>2,500</td>
<td>3,500</td>
<td>5,200</td>
<td>3,539</td>
</tr>
<tr>
<td>Total TEU</td>
<td>2,799,500</td>
<td>1,858,500</td>
<td>1,067,500</td>
<td>885,500</td>
<td>1,419,600</td>
<td>3,372,600</td>
</tr>
<tr>
<td>2005-2010</td>
<td>5,229</td>
<td>1,344</td>
<td>462</td>
<td>287</td>
<td>380</td>
<td>1,129</td>
</tr>
<tr>
<td>Average TEU</td>
<td>550</td>
<td>1,500</td>
<td>2,500</td>
<td>3,500</td>
<td>6,700</td>
<td>4,169</td>
</tr>
<tr>
<td>Total TEU</td>
<td>2,875,773</td>
<td>2,016,359</td>
<td>1,153,981</td>
<td>1,004,626</td>
<td>2,547,675</td>
<td>4,706,282</td>
</tr>
<tr>
<td>2010-2015</td>
<td>5,371</td>
<td>1,458</td>
<td>499</td>
<td>326</td>
<td>530</td>
<td>1,354</td>
</tr>
<tr>
<td>Average TEU</td>
<td>550</td>
<td>1,500</td>
<td>2,500</td>
<td>3,500</td>
<td>8,200</td>
<td>4,970</td>
</tr>
<tr>
<td>Total TEU</td>
<td>2,954,124</td>
<td>2,187,625</td>
<td>1,247,468</td>
<td>1,139,777</td>
<td>4,342,998</td>
<td>6,730,243</td>
</tr>
<tr>
<td>2015-2020</td>
<td>5,517</td>
<td>1,582</td>
<td>539</td>
<td>369</td>
<td>738</td>
<td>1,647</td>
</tr>
<tr>
<td>Average TEU</td>
<td>550</td>
<td>1,500</td>
<td>2,500</td>
<td>3,500</td>
<td>8,200</td>
<td>5,278</td>
</tr>
<tr>
<td>Total TEU</td>
<td>3,034,610</td>
<td>2,373,440</td>
<td>1,346,529</td>
<td>1,293,110</td>
<td>6,049,176</td>
<td>8,690,815</td>
</tr>
<tr>
<td>2020-2025</td>
<td>5,688</td>
<td>1,717</td>
<td>583</td>
<td>419</td>
<td>1,028</td>
<td>2,030</td>
</tr>
<tr>
<td>Average TEU</td>
<td>550</td>
<td>1,500</td>
<td>2,500</td>
<td>3,500</td>
<td>8,200</td>
<td>5,592</td>
</tr>
<tr>
<td>Total TEU</td>
<td>3,117,288</td>
<td>2,575,036</td>
<td>1,457,777</td>
<td>1,467,071</td>
<td>8,425,638</td>
<td>11,350,486</td>
</tr>
<tr>
<td>2025-2030</td>
<td>5,822</td>
<td>1,863</td>
<td>630</td>
<td>476</td>
<td>1,431</td>
<td>2,537</td>
</tr>
<tr>
<td>Average TEU</td>
<td>550</td>
<td>1,500</td>
<td>2,500</td>
<td>3,500</td>
<td>8,200</td>
<td>5,903</td>
</tr>
<tr>
<td>Total TEU</td>
<td>3,202,219</td>
<td>2,793,757</td>
<td>1,575,875</td>
<td>1,664,435</td>
<td>11,735,710</td>
<td>14,976,020</td>
</tr>
<tr>
<td>% of total</td>
<td>229.5 %</td>
<td>73.4 %</td>
<td>24.8 %</td>
<td>18.7 %</td>
<td>56.4 %</td>
<td>100 %</td>
</tr>
<tr>
<td>Incr. Compared to 2000</td>
<td>118 %</td>
<td>163 %</td>
<td>160 %</td>
<td>213 %</td>
<td>730 %</td>
<td>148 %</td>
</tr>
</tbody>
</table>
Appendix III  Modal Split

In this appendix the modal split of the total container throughput of Shanghai for the years 2008, 2015 and 2025 will be given together with the expected number of containers handled per service group.

Table 13-3: Modal split for the year 2008

<table>
<thead>
<tr>
<th>Total throughput</th>
<th>TEU</th>
<th>%</th>
<th>TEU</th>
<th>%</th>
<th>TEU</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>9 936 000</td>
<td>794 880</td>
<td>8%</td>
<td>Ocean - Ocean</td>
<td>238 464</td>
<td>30%</td>
<td>Ocean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ocean - Shortsea</td>
<td>476 928</td>
<td>60%</td>
<td>Shortsea</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shortsea - Shortsea</td>
<td>79 488</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Domestic trade</td>
<td>9 141 120</td>
<td>92%</td>
<td>Import</td>
<td>4 113 504</td>
<td>45%</td>
<td>Ocean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shortsea</td>
<td>2 056 752</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Export</td>
<td>5 027 616</td>
<td>55%</td>
<td>Ocean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shortsea</td>
<td>2 513 808</td>
<td>50%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>9 936 000</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td>9 936 000</td>
</tr>
</tbody>
</table>

Table 13-4: Container volumes in mTEU per transport modality for the year 2008

<table>
<thead>
<tr>
<th>Transshipment</th>
<th>Domestic trade</th>
<th>Total transport volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean services group</td>
<td>953 856</td>
<td>2 513 808</td>
</tr>
<tr>
<td>Shortsea services group</td>
<td>635 904</td>
<td>2 513 808</td>
</tr>
<tr>
<td>Total</td>
<td>1 589 760</td>
<td>5 027 616</td>
</tr>
<tr>
<td>Domestic services group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>2 865 741</td>
<td>2 344 697</td>
</tr>
<tr>
<td>River</td>
<td>1 608 837</td>
<td>1 316 321</td>
</tr>
<tr>
<td>Rail</td>
<td>553 038</td>
<td>452 486</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>5 027 616</td>
</tr>
</tbody>
</table>

Table 13-5: Modal split for the year 2015

<table>
<thead>
<tr>
<th>Total throughput</th>
<th>TEU</th>
<th>%</th>
<th>TEU</th>
<th>%</th>
<th>TEU</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>17 298 000</td>
<td>1 729 800</td>
<td>10%</td>
<td>Ocean - Ocean</td>
<td>518 940</td>
<td>30%</td>
<td>Ocean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ocean - Shortsea</td>
<td>1 037 880</td>
<td>60%</td>
<td>Shortsea</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shortsea - Shortsea</td>
<td>172 980</td>
<td>10%</td>
<td></td>
</tr>
<tr>
<td>Domestic trade</td>
<td>15 558 200</td>
<td>90%</td>
<td>Import</td>
<td>7 005 690</td>
<td>45%</td>
<td>Ocean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shortsea</td>
<td>3 432 788</td>
<td>49%</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Export</td>
<td>8 562 510</td>
<td>55%</td>
<td>Ocean</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Shortsea</td>
<td>4 195 630</td>
<td>49%</td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>17 298 000</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td>17 298 000</td>
</tr>
</tbody>
</table>

Table 13-6: Container volumes in mTEU per transport modality for the year 2015

<table>
<thead>
<tr>
<th>Transshipment</th>
<th>Domestic trade</th>
<th>Total transport volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean services group</td>
<td>2 075 760</td>
<td>4 366 880</td>
</tr>
<tr>
<td>Shortsea services group</td>
<td>1 383 840</td>
<td>4 195 630</td>
</tr>
<tr>
<td>Total</td>
<td>3 459 600</td>
<td>8 562 510</td>
</tr>
<tr>
<td>Domestic services group</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road</td>
<td>4 366 880</td>
<td>3 572 902</td>
</tr>
<tr>
<td>River</td>
<td>2 996 879</td>
<td>2 451 992</td>
</tr>
<tr>
<td>Rail</td>
<td>1 198 751</td>
<td>980 797</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>8 562 510</td>
</tr>
</tbody>
</table>
### Table 13-7: Modal split for the year 2025

<table>
<thead>
<tr>
<th>Total throughput</th>
<th>TEU</th>
<th>%</th>
<th>TEU</th>
<th>%</th>
<th>TEU</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>34 916 000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transshipment</td>
<td>3 491 600</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ocean - Ocean</td>
<td>1 047 480</td>
<td>30%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ocean - Shortsea</td>
<td>2 094 960</td>
<td>60%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shortsea - Shortsea</td>
<td>3 491 600</td>
<td>10%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Domestic trade</td>
<td>31 424 400</td>
<td>90%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Import</td>
<td>14 140 980</td>
<td>45%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Export</td>
<td>17 283 420</td>
<td>55%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ocean</td>
<td>7 211 900</td>
<td>51%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shortsea</td>
<td>6 929 080</td>
<td>49%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Export</td>
<td>8 814 544</td>
<td>51%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Shortsea</td>
<td>8 468 876</td>
<td>49%</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Total: 34 916 000 100%  
34 916 000 100%  
34 916 000 100%

### Table 13-8: Container volumes in mTEU per transport modality for the year 2025

<table>
<thead>
<tr>
<th></th>
<th>Transshipment</th>
<th>Domestic trade</th>
<th>Total transport volume</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Export</td>
<td>Import</td>
<td></td>
</tr>
<tr>
<td>Ocean services group</td>
<td>4 189 920</td>
<td>8 814 544 7 211 900</td>
<td>20 216 384</td>
</tr>
<tr>
<td>Shortsea services group</td>
<td>2 793 280</td>
<td>8 468 876 6 929 080</td>
<td>18 191 236</td>
</tr>
<tr>
<td>Total</td>
<td>6 983 200</td>
<td>17 283 420 14 140</td>
<td>38 407 600</td>
</tr>
<tr>
<td>Domestic services group</td>
<td>Road</td>
<td>8 814 544 7 211</td>
<td>16 026 444</td>
</tr>
<tr>
<td></td>
<td>River</td>
<td>6 049 197 4 949 343</td>
<td>10 998 540</td>
</tr>
<tr>
<td></td>
<td>Rail</td>
<td>2 419 679 1 979 737</td>
<td>4 399 416</td>
</tr>
<tr>
<td>Total</td>
<td>0</td>
<td>17 283 420 14 140</td>
<td>31 424 400</td>
</tr>
</tbody>
</table>

980
Appendix IV  Expected number of vessels per services group

In the following tables the expected number of vessels can be found for the years 2008, 2015 and 2025. The calculation of the number of vessels is split up in a group containing the ocean and shortsea vessels and a group containing the transport modalities that serve the domestic services group.

### Situation for 2008

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Parcel Size</th>
<th>Voyages</th>
<th>Total TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Monthly</td>
<td>Annual</td>
</tr>
<tr>
<td>Ocean services group</td>
<td>4169</td>
<td>34%</td>
<td>162</td>
<td>1 949</td>
</tr>
<tr>
<td>Short sea services group</td>
<td>900</td>
<td>73%</td>
<td>330</td>
<td>3 962</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>493</td>
<td>5911</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of domestic calls</th>
<th>Capacity</th>
<th>Parcel Size</th>
<th>Voyages</th>
<th>Total TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Monthly</td>
<td>Annual</td>
</tr>
<tr>
<td>Road</td>
<td>2</td>
<td>75%</td>
<td>144 734</td>
<td>1 736 813</td>
</tr>
<tr>
<td>River</td>
<td>100</td>
<td>91%</td>
<td>1 339</td>
<td>16 072</td>
</tr>
<tr>
<td>Rail</td>
<td>75</td>
<td>75%</td>
<td>745</td>
<td>8 938</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>146 819</td>
<td>1 761 823</td>
</tr>
</tbody>
</table>

### Situation for 2015

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Parcel Size</th>
<th>Voyages</th>
<th>Total TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Monthly</td>
<td>Annual</td>
</tr>
<tr>
<td>Ocean services group</td>
<td>4970</td>
<td>50%</td>
<td>168</td>
<td>2 015</td>
</tr>
<tr>
<td>Short sea services group</td>
<td>1250</td>
<td>75%</td>
<td>401</td>
<td>4 807</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>568</td>
<td>6822</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of domestic calls</th>
<th>Capacity</th>
<th>Parcel Size</th>
<th>Voyages</th>
<th>Total TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Monthly</td>
<td>Annual</td>
</tr>
<tr>
<td>Road</td>
<td>2</td>
<td>75%</td>
<td>220 550</td>
<td>2 646 594</td>
</tr>
<tr>
<td>River</td>
<td>120</td>
<td>91%</td>
<td>2 079</td>
<td>24 949</td>
</tr>
<tr>
<td>Rail</td>
<td>75</td>
<td>75%</td>
<td>1 614</td>
<td>19 374</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>224 243</td>
<td>2 690 917</td>
</tr>
</tbody>
</table>

### Situation for 2025

<table>
<thead>
<tr>
<th></th>
<th>Capacity</th>
<th>Parcel Size</th>
<th>Voyages</th>
<th>Total TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Monthly</td>
<td>Annual</td>
</tr>
<tr>
<td>Ocean services group</td>
<td>5592</td>
<td>50%</td>
<td>301</td>
<td>3 615</td>
</tr>
<tr>
<td>Short sea services group</td>
<td>1250</td>
<td>75%</td>
<td>808</td>
<td>9 702</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1110</td>
<td>13317</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of domestic calls</th>
<th>Capacity</th>
<th>Parcel Size</th>
<th>Voyages</th>
<th>Total TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Monthly</td>
<td>Annual</td>
</tr>
<tr>
<td>Road</td>
<td>2</td>
<td>75%</td>
<td>445 179</td>
<td>5 342 148</td>
</tr>
<tr>
<td>River</td>
<td>120</td>
<td>91%</td>
<td>4 197</td>
<td>50 360</td>
</tr>
<tr>
<td>Rail</td>
<td>75</td>
<td>75%</td>
<td>3 259</td>
<td>39 106</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>452 634</td>
<td>5 431 614</td>
</tr>
</tbody>
</table>
Appendix V  Terminal operating system

Assumptions:

- An ocean vessel will be serviced by 4 portainer cranes
- These cranes have a gross production of 35 moves/hour [2]
- It takes one hour to berth a vessel and one hour to let the vessel depart
- There are 24 (hours/day) * 360 (days/year) = 6240 working hours/year
- The ratio 1 TEU/2 TEU containers will be set according to the world’s ratio. This ratio is 50-50 [2]. Therefore the TEU factor is 1.5.

\[
TEU - factor : f = \frac{N_{20'} + 2 \cdot N_{40'}}{N_{tot}}
\]

The maximum size vessel that can be serviced within 24 hours can be calculated with the following formula:

\[p \cdot f \cdot N_b \cdot h_{eff} = 2 \cdot c_s \cdot shipscapacity\]

Where:

- \(P\) = Gross production per crane (35 containers/hour)
- \(f\) = TEU factor (1.5)
- \(N_b\) = Number of cranes per berth (4)
- \(h_{eff}\) = Effective working hours per day (22 = 24 - 2 for berthing/departure)
- \(c_s\) = Parcel size (50 %)

The number of containers is doubled in the formula, because the parcel size states the percentage of the ships capacity that will be unloaded/loaded. For example, when a 1000 TEU capacity vessel has a parcel size of 75 %, then 750 containers will be loaded and 750 containers will be unloaded.

This calculation eventually leads to a maximum vessel capacity of 4620 TEU that can be handled within 24 hours by 4 cranes.

At the moment this number of cranes can be considered as a maximum for the average vessel size as is mentioned before.

Yard handling

For yard handling several option are available. For high capacity terminals one can choose between:

- Rubber Tired Gantry Crane (RTG)
- Rail Mounted Gantry Crane (RMG)
- Automated Stacking Crane (ASC)

The advantages/disadvantages are given below:

**RTG**

**Advantages:**
- Good space utilisation
- Flexible system
- High productivity

**Disadvantages:**
- High maintenance costs
- Needs good soil conditions
- High qualified personnel needed

**RMG**

**Advantages:**

**Disadvantages:**
Good space utilisation  
Reliable system  
Low maintenance costs  
Automation is possible  

ASC  
**Advantages:**  
Minimum labour costs  
High capacity  

**Disadvantages:**  
High investment costs  
Inflexible due to rail  
High investment and maintenance costs
Appendix VI  Quay length determination

In this appendix the quay length will be determined. This can normally be done in several ways;

With so called “rules of thumb”. These rules provide very rough information while they are only based on the expertise of the user. This method can generally be used for small ports.

With the queue theory. This theory has been developed between 1910-1920 by the Danish mathematician Erlang for queuing problems at telephone exchanges. It turned out that this theory could be used for any problem concerning queues. Although this theory is rather old, it provides good insight in the port’s system. While working with this theory one should bear in mind that the theory also has its limitations while working with the modern ports.

Limitations on the queueing theory are [2]:

- It assumes that ships arrive in a random order. Nowadays ships sail at fixed schedules where they can predict their arrival within an accuracy of one hour. Due to seasonal changes it is also possible that ships arrive in “waves”.
- It also assumes that berths are not interchangeable and can only cope with individual berths. It cannot cope with p.e. one long berth designed for the maximum ship, which is able to handle more than one smaller vessels.
- It assumes that arriving vessels will be served according to the “First In First Out” method. The port authority can always decide to service vessels with p.e. valuable cargo first.

With simulation techniques. This is a very reliable method of determining the port’s processes. Usually the simulation is done with a computer model while for large ports the number of calculations can be very high. The disadvantage of this method is that simulation models could be very expensive while it is made especially for the port concerned.

The quay length is a very important element of the terminal layout. Experiences in other ports have shown that it is the most critical part of the terminal’s capacity. Other import features such as the container yard capacity can generally always be increased by means of extra space outside the terminal’s area or to increase the storage charges. A quay cannot be easily enlarged.

For this case the queue theory will be used. The “rules of thumb” method is just too simplistic for a terminal like this and simulation techniques are too drastic for a project in this stage of development.

The queue theory

This queue theory consists of 3 elements: An arrival pattern, a service pattern and an number of berths. Generally these elements can be noted down as X/Y/n where X is the arrival pattern, Y is the service pattern and n is the number of berths. (See Groenveld [11]) for a detailed description of the various service and arrival patterns) For the design of the container terminal, assumptions have been made for the arrival and service patterns of the various service groups. This has been done due to lack of statistical data for the port of Shanghai. In the following section the assumptions per service group are explained.
Ocean services group
The arrival of vessels in this services group can be predicted rather accurate. Vessels sailing in this group sail at fixed schedules and are therefore able to predict their arrival within the hour. Therefore an Erlang-4 arrival distribution is used. The service pattern is modelled with an Erlang-2 distribution. The queue notation for this group can now be noted as $E_4/E_2/n$.

Short sea services group
For the Short sea services group an $E_2/E_2/n$ will be used. The arrival pattern of this group cannot be predicted as accurate as for the ocean group. Furthermore, the service pattern will be almost the same as in the ocean services group. Crane type, working hours and vessel features will be generally the same as in the ocean services group.

Domestic services group
For the Domestic services group a $M/E_2/n$ is used while the arrival of these ships is less predictable than the other service groups, but better predictable than a random arrival pattern. This can be ascribed to the fact that these vessels don’t have the high costs that the vessels in the other services groups face.

In paragraph 5.1, a choice has been made to separate the service groups at the terminal while the ship’s dimensions vary a lot by 2025. To eventually be able to calculate the quay length, first the number of berths should be calculated. In the following part, the formulas will be described after which the actual figures will be calculated.

While the method of calculation is similar for all service groups, the calculation will be described with parameters. After this description, the values per service group will be given in a table.

Service time ($h_{\text{eff}}$)
Service time per vessel includes the total time for a vessel to sail to and from the berth and the total handling time of the containers:

The total sailing time will be set at 2 hours for the ocean services group. One hour sailing time to the berth and one from the berth. (Assumption)
For the Short sea and domestic services group the sailing time will be set at 1 hour and 0.5 hour respectively (Assumption). These times are less than that of the ocean services group due to the fact that these vessels are smaller and can manoeuvre more easily.

The total handling time per vessel can be calculated with the following formula:

$$p \cdot f \cdot N_b \cdot h_{\text{eff}} = 2 \cdot c_s \cdot \text{shipscapacity} \quad \text{(See Appendix V)}$$

Where:

- $p$ = Gross production per crane
- $f$ = TEU factor
- $N_b$ = Number of cranes per berth
- $h_{\text{eff}}$ = Effective working hours per day
- $C_s$ = Parcel size

After the service time has been calculated, the servicerate ($\mu$) can be calculated.
**Servicerate (μ)**

The service rate calculates the number of vessels that can be handled by one berth per year.  
\[ \mu = \frac{\text{hours / year}}{\text{servicetime}} \]

**Ro (ρ)**

While the expected number of vessels (λ) is known and the servicerate has been calculated, Ro can be calculated as follows:

\[ \rho = \frac{\lambda}{\mu} = \frac{\text{Calls / year}}{\text{Servicerate}} \]

In the tables below, the above mentioned figures are calculated.

**Table 13-9: Parameters queue theory for 5 mTEU terminal**

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Short sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time needed for berthing</td>
<td>t (h)</td>
<td>1.5</td>
<td>1</td>
</tr>
<tr>
<td>Gross production per crane</td>
<td>p (Containers/h)</td>
<td>35</td>
<td>30</td>
</tr>
<tr>
<td>TEU factor</td>
<td>f (%)</td>
<td>1.5</td>
<td>1.5</td>
</tr>
<tr>
<td>Number of cranes per berth</td>
<td>Nb (%)</td>
<td>4</td>
<td>3</td>
</tr>
<tr>
<td>Average vessel capacity</td>
<td>TEU (TEU)</td>
<td>5592</td>
<td>1250</td>
</tr>
<tr>
<td>Parcel size</td>
<td>Cs (%)</td>
<td>50%</td>
<td>75%</td>
</tr>
<tr>
<td>Service time/vessel</td>
<td>Heff (h/vessel)</td>
<td>28.13</td>
<td>14.89</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Short sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hours/day</td>
<td>t (h)</td>
<td>24</td>
<td>24</td>
</tr>
<tr>
<td>Days/year</td>
<td>t (d)</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>Hours/year</td>
<td>t (h)</td>
<td>8640</td>
<td>8640</td>
</tr>
<tr>
<td>Service Rate</td>
<td>μ (vessel/year)</td>
<td>307.16</td>
<td>580.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Short sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected calls/month</td>
<td>λ (vessel/month)</td>
<td>43.1</td>
<td>115.6</td>
</tr>
<tr>
<td>Expected calls/year</td>
<td>λ (vessel/year)</td>
<td>517.7</td>
<td>1389.3</td>
</tr>
</tbody>
</table>

While the service system per service group has already been determined earlier in this appendix, now the acceptable waiting times will be chosen per service groups.

**Acceptable waiting times per service group**

The acceptable waiting times are generally expressed in units of service time.

**Ocean services group**

The vessels in this group are very expensive and every hour they lay still in a port can be considered as a loss of money. The waiting time should therefore be minimised. However, without a waiting time, the port faces high costs due to low berth occupancy. In this compromise is illustrated with fictive figures.
Figure 13-1: Cost minimisation for berth construction [14]

A cost minimisation as is mentioned above can be reached relatively easy at the moment that the ship’s operator is the same as the terminal operator. For this case this is not true, but the terminal operator should still be looking for an optimum, while vessels won’t call at the port if the waiting times are high. The maximum waiting time for the ocean services group will be set at 10 % of the service time (Assumption).

**Short sea services group**

This group consists of vessels that are less expensive than the ocean services group and therefore allow longer waiting times. For this group the waiting time will be set at 25 %. (Assumption)

**Domestic services group**

This services group is the most inexpensive services group. The total service time of this group is only 3 hours at its maximum. The waiting time of this group will therefore be set at 50 %. (Assumption)

**Number of berths**

Now, together with the arrival/service distribution system already determined above, the number of berths can be iteratively found by using for the M\d\E\in system, for the E\d\E\in system and for the E\d\E\in system. These figures are used in the following way.

As a first estimation an number of berths is estimated which implicates a utilisation via the following formula:

\[ u = \frac{\lambda}{n} \]

In this formula, the “n” accounts for the number of berths. The utilisation stands for the calculated percentage that the terminal is occupied. For example, if the utilisation is 0.75 then the berths are idle for 25 % of their time. In Table 13-2 the utilisation has been calculated for all services groups and several berths.
Table 13-10: Utilisation per service group per berth

<table>
<thead>
<tr>
<th>Berths</th>
<th>Ocean</th>
<th>Short Sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1.69</td>
<td>2.39</td>
<td>5.28</td>
</tr>
<tr>
<td>2</td>
<td>0.84</td>
<td>1.20</td>
<td>2.64</td>
</tr>
<tr>
<td>3</td>
<td>0.56</td>
<td>0.80</td>
<td>1.76</td>
</tr>
<tr>
<td>4</td>
<td>0.42</td>
<td>0.60</td>
<td>1.32</td>
</tr>
<tr>
<td>5</td>
<td>0.34</td>
<td>0.48</td>
<td>1.06</td>
</tr>
</tbody>
</table>

With this utilisation an average waiting time (in units of the service time) can be found in the figures. In case the found value is unacceptable, the number of berths should be raised (more berths lead logically to smaller waiting times). This should be repeated until an acceptable waiting time has been reached with a minimum of berths.

In the following sections, the calculations will be explained for the 5 mTEU terminal based on the features of the year 2025.

**Ocean services group**

With a $E_2/E_2/n$ system an equation can be used to determine the necessary number of berths. This equation is denoted as follows:

$$W_n(v_s,v_e,u) = (1-v_s) \cdot v_e \cdot W_n(0,1,u) + v_s \cdot W_n(1,0,u) + v_e \cdot v_s \cdot W_n(1,1,u)$$

This equation calculates an approximation of the average waiting time using the following queue systems:

- $D/M/n$ denoted as $W_n(0,1,u)$
- $M/D/n$ denoted as $W_n(1,0,u)$
- $M/M/n$ denoted as $W_n(1,1,u)$

These systems are equally arranged as the systems that have been used for the several service groups in which the first letter states the arrival distribution, the second letter the service time distribution and the third letter the number of berths.

In the distributions stated above the letter M stands for a negative exponential distribution and the letter D stands for a deterministic distribution.

Furthermore, the two constants $v_s$ and $v_e$ have the following values due to the chosen service system:

$v_s = 0.25$ and $v_e = 0.50$  
(See Groenveld [11] for details on these values)

Now the elements in the formula have been determined, the needed number of berths can be calculated. This calculation has been done for several berths and utilisations.

First a utilisation has to be filled in. With this utilisation, and thus number of berths, the waiting times for the used service systems can be looked up in tables regarding the several service systems. The combined results of these tables form an average waiting time for the $E_2/E_2/n$ system according to the above mentioned formula. For several utilisations and number of berths the results have been calculated and put into a graph. See for the results. For the tables regarding the several service systems forming the above mentioned formula see Groenveld [11].

When we start with 2 berths, a utilisation of 0.84 will be reached (See
Table 13-10). The waiting time will then be 65% of the total service time. This is too high. With 3 berths a utilisation of 0.56 can be found which implies a waiting time of 6.53% of the total service time. This is acceptable and will therefore be applied.

![Graph showing waiting time vs. utilisation rate for E1/E2/n system per number of berths](image)

**Figure 13-2: Waiting time vs. utilisation rate for E1/E2/n system per number of berths**

It should be mentioned that this method is quite inaccurate (+/- 3% for a high utilisation and about 20% with a utilisation of around 0.60) and results are an overestimation of reality. The alternative for this formula however is using a simulation. While it is already mentioned that simulation techniques are far too thorough for a study in this stage of development, the above mentioned formula will be used.

**Short sea services group**

For this group an E2/E2/n system is chosen. In , the average waiting times can be found corresponding to an number of berths and therefore utilisation. The utilisation should be altered until an number of berths is reached that satisfies the demanded maximum waiting time.

As a first estimation 3 berths will be taken leading to a utilisation of 0.80. From it can be seen that with this utilisation the waiting time is 46% of the service time. This is unacceptable. Therefore 4 berths is tried. 4 berths lead to a utilisation of 0.60 and a waiting time of only 6%. This is acceptable and will be chosen.
**Domestic services group**

For the domestic services group a M/E\_2/n system is used. As for the Short sea services group, a utilisation should be estimated after which the number of berths can be calculated. With the utilisation rate, the average waiting time can be found in . With 6 berths, a utilisation of 0.88 will be reached, which leads to an average waiting time of more than 76 %. This rate is too high while the maximum waiting time was set at 50 %. If 7 berths are constructed then a utilisation of 0.75 will be reached leading to an average waiting time of only 17 % of the service time. This is acceptable. For this reason, 7 berths will be constructed.
Optimisation of berth utilisation:

As can be seen from the sections above, the berths aren’t utilised at their full capacity while waiting times are far from their maximum. This causes the terminal to operate inefficiently. In this section the use of the already calculated number of berths is optimised. This has been done by raising the number of vessels calling at the terminal until the maximum utilisation is reached.

While the relation between the several service groups has been preset, the maximalisation of the waiting times cannot be done simultaneously. Therefore, the optimisation has been done three times for the whole terminal. Each time the waiting time of only one service group has been maximised according to which the other service groups were adjusted. In the following table the maximum waiting times can be found with which the three optimisations have been made. The “actual” figures in this table represent the original calculated values without optimisation.

<table>
<thead>
<tr>
<th></th>
<th>Waiting time</th>
<th>Vessels</th>
<th>Throughput (mTEU)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual</td>
<td>Maximum</td>
<td>Actual</td>
</tr>
<tr>
<td>Ocean</td>
<td>6.25%</td>
<td>10%</td>
<td>40.9</td>
</tr>
<tr>
<td>Short Sea</td>
<td>6.0%</td>
<td>25%</td>
<td>109.1</td>
</tr>
<tr>
<td>Domestic</td>
<td>17.0%</td>
<td>50%</td>
<td>601</td>
</tr>
<tr>
<td>Road</td>
<td></td>
<td></td>
<td>1.14E+06</td>
</tr>
<tr>
<td>Rail</td>
<td></td>
<td></td>
<td>3.14E+05</td>
</tr>
<tr>
<td>Capacity terminal</td>
<td></td>
<td></td>
<td>5.00E+06</td>
</tr>
</tbody>
</table>

As has been described above, three optimisations have been made according to the maximum number of vessels as can be found in the table above. These optimisations however logically led to a higher throughput per terminal than the 5 mTEU with which the initial calculations have been made. In the table below an overview can be found of the results of the optimisations.

<table>
<thead>
<tr>
<th>Required berths per terminal</th>
<th>Optimisation according to:</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ocean</td>
</tr>
<tr>
<td>Ocean</td>
<td>3</td>
</tr>
<tr>
<td>Short Sea</td>
<td>4</td>
</tr>
<tr>
<td>Domestic</td>
<td>7</td>
</tr>
<tr>
<td>Throughput per terminal</td>
<td>5.52E+06</td>
</tr>
<tr>
<td>Required terminals</td>
<td>6</td>
</tr>
<tr>
<td>Total required berths</td>
<td>84</td>
</tr>
</tbody>
</table>

As was already stated in chapter 5, a throughput of around 5 mTEU is regarded as manageable by one terminal operator. The results of the optimisation led all to higher throughput values. For this reason the maximalisation has been adjusted.

At first the number of vessels of one service group calling at a terminal has been raised until the maximum waiting time of this service group was reached. With the new maximalisation, the calculated needed number of berths for a 5 mTEU terminal has been lowered with one berth. Then, for each service group, the maximum number of calls has been determined and a throughput has been calculated. This again has been done per service group according to which the other service groups were adjusted (The service groups are inter related).
In the following three tables the optimisations can be found.

### Table 13-13: Optimalisation according to the ocean services group

<table>
<thead>
<tr>
<th>Modality</th>
<th>Berths (#)</th>
<th>Waiting time (%)</th>
<th>Utilisation (-)</th>
<th>Vessels (#)</th>
<th>Volume (mTEU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>2</td>
<td>10%</td>
<td>0.51</td>
<td>26.1</td>
<td>1.75E+06</td>
</tr>
<tr>
<td>Short Sea</td>
<td>3</td>
<td>5%</td>
<td>0.48</td>
<td>70.1</td>
<td>1.58E+06</td>
</tr>
<tr>
<td>Domestic</td>
<td>5</td>
<td>11%</td>
<td>0.64</td>
<td>363.7</td>
<td>9.53E+05</td>
</tr>
</tbody>
</table>

Road: 1.39E+06  
Rail: 3.81E+05  
Throughput Capacity terminal: 3.03E+06

### Table 13-14: Optimalisation according to the short sea services group

<table>
<thead>
<tr>
<th>Modality</th>
<th>Berths (#)</th>
<th>Waiting time (%)</th>
<th>Utilisation (-)</th>
<th>Vessels (#)</th>
<th>Volume (mTEU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>3</td>
<td>4.0%</td>
<td>0.50</td>
<td>38.4</td>
<td>2.58E+06</td>
</tr>
<tr>
<td>Short Sea</td>
<td>3</td>
<td>25.0%</td>
<td>0.71</td>
<td>103.0</td>
<td>2.32E+06</td>
</tr>
<tr>
<td>Domestic</td>
<td>6</td>
<td>28.0%</td>
<td>0.78</td>
<td>534.6</td>
<td>1.40E+06</td>
</tr>
</tbody>
</table>

Road: 2.04E+06  
Rail: 5.60E+05  
Throughput Capacity terminal: 4.45E+06

### Table 13-15: Optimalisation according to the domestic services group

<table>
<thead>
<tr>
<th>Modality</th>
<th>Berths (#)</th>
<th>Waiting time (%)</th>
<th>Utilisation (-)</th>
<th>Vessels (#)</th>
<th>Volume (mTEU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>3</td>
<td>5.7%</td>
<td>0.54</td>
<td>41.19</td>
<td>2.76E+06</td>
</tr>
<tr>
<td>Short Sea</td>
<td>4</td>
<td>6.0%</td>
<td>0.57</td>
<td>110.55</td>
<td>2.49E+06</td>
</tr>
<tr>
<td>Domestic</td>
<td>6</td>
<td>50.0%</td>
<td>0.84</td>
<td>573.81</td>
<td>1.50E+06</td>
</tr>
</tbody>
</table>

Road: 2.19E+06  
Rail: 6.02E+05  
Throughput Capacity terminal: 4.77E+06

With the results presented above, it seems that the maximalisation of the waiting times of the ocean services group leads to the most promising terminal arrangement judging by the needed number of berths per terminal. This representation however could be tricky while eventually the total quay length of all terminals combined is the most important factor.

As can be seen from the tables above, the maximalisation of the domestic services group leads to 13 berths per terminal while the maximalisation of the ocean services group leads to only 10 berths per terminal. This optimisation however leads to a throughput of 3.03 mTEU and eventually 10 terminals while the maximalisation of the short sea services group leads to a throughput of 4.77 mTEU and 6 terminals.

To give a clear overview of these figures and consequences, the following table gives the results of the optimisations.
Table 13-16: Results of maximisation of the waiting times per service group

<table>
<thead>
<tr>
<th>Required berths per terminal</th>
<th>Optimalisation according to:</th>
<th>Ocean</th>
<th>Short Sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ocean</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Short Sea</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Domestic</td>
<td>5</td>
<td>6</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Throughput per terminal</td>
<td>3.03E+06</td>
<td>4.45E+06</td>
<td>4.77E+06</td>
<td></td>
</tr>
<tr>
<td>Required terminals</td>
<td>10</td>
<td>7</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Total required berths</td>
<td>100</td>
<td>84</td>
<td>78</td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from this table the optimalisation according to the domestic services group leads to the least number of berths. It even leads to a smaller number of berths than with the maximisation of the waiting times of the number of berths calculated for a 5 mTEU terminal (See Table 13-12).

This however still doesn’t determines the optimal terminal arrangement while the quay lengths per service group haven’t been calculated. In the following section the total quay length will be determined with which the most promising terminal can be determined.

**Quay length**

Now the number of berths have been determined, the total needed quay length can be calculated. For a multiple berth terminal the quay length is based on the average length of the vessel according to the following formula:

\[ L_q = 1.1 \cdot n \cdot (\bar{L_s} + 15) + 15 \]

Where:
- \( L_q \): Quay length
- \( n \): Number of berths
- \( \bar{L_s} \): Average vessel length

The length of the quays per service group can now be calculated. The tables on the next page give the values per optimalisation as is described in the section above.
Table 13-17: Quay length of optimisation according to the ocean services group

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Short Sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berths (#)</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Length average vessel (m)</td>
<td>275</td>
<td>146</td>
<td>91</td>
</tr>
<tr>
<td>Quay length (m)</td>
<td>653</td>
<td>546</td>
<td>588</td>
</tr>
<tr>
<td>Throughput (TEU)</td>
<td>1.75E+06</td>
<td>1.58E+06</td>
<td>9.53E+05</td>
</tr>
<tr>
<td>Throughput (TEU/m)</td>
<td>2883</td>
<td>2886</td>
<td>1594</td>
</tr>
<tr>
<td>Total quay length (m)</td>
<td>6530</td>
<td>5463</td>
<td>5980</td>
</tr>
<tr>
<td>Total (m)</td>
<td>17973</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13-18: Quay length of optimisation according to the short sea services group

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Short Sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berths (#)</td>
<td>3</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Length average vessel (m)</td>
<td>275</td>
<td>146</td>
<td>91</td>
</tr>
<tr>
<td>Quay length (m)</td>
<td>972</td>
<td>546</td>
<td>715</td>
</tr>
<tr>
<td>Throughput (TEU)</td>
<td>3.25E+06</td>
<td>3.01E+06</td>
<td>1.30E+06</td>
</tr>
<tr>
<td>Throughput (TEU/m)</td>
<td>3345</td>
<td>5516</td>
<td>2762</td>
</tr>
<tr>
<td>Total quay length (m)</td>
<td>6804</td>
<td>3824</td>
<td>5002</td>
</tr>
<tr>
<td>Total (m)</td>
<td>15630</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13-19: Quay length of optimisation according to the domestic services group

<table>
<thead>
<tr>
<th></th>
<th>Ocean</th>
<th>Short Sea</th>
<th>Domestic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berths (#)</td>
<td>3</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Length average vessel (m)</td>
<td>275</td>
<td>146</td>
<td>91</td>
</tr>
<tr>
<td>Quay length (m)</td>
<td>972</td>
<td>723</td>
<td>715</td>
</tr>
<tr>
<td>Throughput (TEU)</td>
<td>2.76E+06</td>
<td>2.49E+06</td>
<td>1.50E+06</td>
</tr>
<tr>
<td>Throughput (TEU/m)</td>
<td>2844</td>
<td>3438</td>
<td>2104</td>
</tr>
<tr>
<td>Total quay length (m)</td>
<td>5832</td>
<td>4340</td>
<td>4287.6</td>
</tr>
<tr>
<td>Total (m)</td>
<td>14460</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

As can be seen from the tables above, the terminal arrangement according to the maximisation of the domestic services group still leads to the most cost efficient terminal and will therefore be chosen.
Appendix VII  Projection of terminal’s area on locations

On the next few pages in this appendix, the terminal’s area is projected on the locations.

At the first map a general overview of the total area at which the locations are situated is given.

The second map is the projection of the terminal’s area on Daxie Dao.

The third map is the projection of the terminal’s area on Nanhui Zui

The fourth map is the projection of the terminal’s area on the Yangshan archipelago
Appendix VIII  Location selection with the MCA

Explanation of the method

In this part, the Multi Criteria Analysis (MCA) is used to select the location at which the container terminal will be built. The MCA is a method in which several alternatives can be compared according to some user-defined criteria. These criteria have already been described and can be found in paragraph 7.1.

All criteria have a certain "weight" that describes their importance compared to the other criteria. In this method, a criterion with a higher value is more important than a criterion with a lower value.

When the criteria have been given a certain weight, the alternatives can be compared. First each alternative will be evaluated per criterion and, according to their features, will then receive a grade for that criterion. The alternative receives a "5" when it fully meets the criterion and a "1" when it doesn't meet the criterion.

This grade will be multiplied with the weight of the criterion leading to a score for the alternative on that criterion. All scores added, leads to the total score of the criterion. This total score can be compared to the other alternatives in which the alternative with the highest score logically is the "best" alternative.

Location selection:

Normally the MCA method is somewhat subjective. The scores are always related to the user's opinion. This influence can be reduced by taking several scenarios. These scenarios have different weight spreadings possibly leading to a different ranking of the alternatives. The scenarios used in this report are defined as an operational scenario an economical scenario and an overall scenario that combines these two scenarios.

The operational scenario gives a high value to the operational aspects in both the execution phase as well as in the operational phase of the terminal. The economical scenario gives a high value to cost aspects in short term, during construction, and in long term, during operation.

In the following few pages the tables with the outcome of the several scenarios can be found:
The operational scenario:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Criterion</th>
<th>Daxie Dao</th>
<th>Nanhui</th>
<th>Yangshan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical conditions:</td>
<td>20</td>
<td>Weight</td>
<td>Score</td>
<td>Total</td>
</tr>
<tr>
<td>Oceanographic</td>
<td>8</td>
<td>2.4</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Waves</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Horizontal tide</td>
<td></td>
<td>3.2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Vertical tide</td>
<td></td>
<td>2.4</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Geographic</td>
<td>12</td>
<td>6.0</td>
<td>5</td>
<td>30</td>
</tr>
<tr>
<td>Sedimentation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil conditions</td>
<td></td>
<td>3.6</td>
<td>3</td>
<td>11</td>
</tr>
<tr>
<td>Natural depth</td>
<td></td>
<td>2.4</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>Operational aspects:</td>
<td>45</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Execution phase</td>
<td>13.5</td>
<td>4.1</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Dredging works</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil movement</td>
<td>4.1</td>
<td>4</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Hinterland connections</td>
<td></td>
<td>5.4</td>
<td>5</td>
<td>27</td>
</tr>
<tr>
<td>Operational phase</td>
<td>31.5</td>
<td>6.3</td>
<td>3</td>
<td>19</td>
</tr>
<tr>
<td>Quality of hinterland connections</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distance to Shanghai</td>
<td></td>
<td>7.9</td>
<td>2</td>
<td>16</td>
</tr>
<tr>
<td>Vessel's approach</td>
<td></td>
<td>3.2</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Vessel's manoeuvring space</td>
<td></td>
<td>3.2</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Shelter</td>
<td></td>
<td>3.2</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td>Possibilities for extension</td>
<td></td>
<td>7.9</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>Economics:</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction costs</td>
<td>10</td>
<td>4.0</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Dredging works</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Soil movement overland</td>
<td></td>
<td>3.0</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Hinterland connections</td>
<td></td>
<td>3.0</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Operational costs</td>
<td>15</td>
<td>7.5</td>
<td>5</td>
<td>38</td>
</tr>
<tr>
<td>Maintenance costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport distance to Shanghai</td>
<td></td>
<td>7.5</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Environment:</td>
<td>10</td>
<td>3.0</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Noise</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic increase</td>
<td>7.0</td>
<td>1</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>80</td>
<td>339</td>
</tr>
</tbody>
</table>

As can be seen from this table, Nanhui Zui is the best location according to the operational scenario. The reason for this is mainly due to the good hinterland connections and the relatively short distance to Shanghai. Furthermore, the vessel’s approach is relatively easy while Nanhui Zui lies in the vicinity of the approach channels of Shanghai.

The location on the Yangshan islands doesn’t score very high while it is lying very isolated. At this moment, it can only be reached by boat.
The economical scenario:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Criterion</th>
<th>Weight</th>
<th>Score</th>
<th>Total</th>
<th>Weight</th>
<th>Score</th>
<th>Total</th>
<th>Weight</th>
<th>Score</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physical conditions:</strong> 20</td>
<td>Oceanographic 8</td>
<td>2.4</td>
<td>5</td>
<td>12</td>
<td>3</td>
<td>7</td>
<td>40</td>
<td>2.4</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>Waves</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Horizontal tide</td>
<td>3.2</td>
<td>2</td>
<td>6</td>
<td>3</td>
<td>10</td>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Vertical tide</td>
<td>2.4</td>
<td>4</td>
<td>10</td>
<td>4</td>
<td>10</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Geographic</strong></td>
<td>Sedimentation</td>
<td>6.0</td>
<td>5</td>
<td>30</td>
<td>1</td>
<td>6</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil conditions</td>
<td>3.6</td>
<td>3</td>
<td>11</td>
<td>3</td>
<td>11</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Natural depth</td>
<td>2.4</td>
<td>5</td>
<td>12</td>
<td>2</td>
<td>5</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Operational aspects:</strong> 25</td>
<td>Execution phase 7.5</td>
<td>2.3</td>
<td>5</td>
<td>11</td>
<td>3</td>
<td>7</td>
<td>2</td>
<td>15</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Dredging works</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil movement</td>
<td>2.3</td>
<td>4</td>
<td>9</td>
<td>3</td>
<td>7</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Hinterland connections</td>
<td>3.0</td>
<td>5</td>
<td>15</td>
<td>5</td>
<td>15</td>
<td>1</td>
<td>30</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Operational phase 17.5</td>
<td>3.5</td>
<td>3</td>
<td>11</td>
<td>4</td>
<td>14</td>
<td>1</td>
<td>40</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Quality of hinterland connections</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distance to Shanghai</td>
<td>4.4</td>
<td>2</td>
<td>9</td>
<td>5</td>
<td>22</td>
<td>4</td>
<td>18</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Vessel’s approach</td>
<td>1.8</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>9</td>
<td>5</td>
<td>9</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Vessel’s manoeuvring space</td>
<td>1.8</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>9</td>
<td>4</td>
<td>7</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Shelter</td>
<td>1.8</td>
<td>5</td>
<td>9</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>5</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Possibilities for extension</td>
<td>4.4</td>
<td>3</td>
<td>13</td>
<td>5</td>
<td>22</td>
<td>3</td>
<td>18</td>
<td>3</td>
<td>13</td>
</tr>
<tr>
<td><strong>Economics:</strong></td>
<td>Construction costs 18</td>
<td>7.2</td>
<td>5</td>
<td>36</td>
<td>2</td>
<td>14</td>
<td>3</td>
<td>22</td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td></td>
<td>Dredging works</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Soil movement overland</td>
<td>5.4</td>
<td>4</td>
<td>22</td>
<td>3</td>
<td>16</td>
<td>2</td>
<td>11</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Hinterland connections</td>
<td>5.4</td>
<td>4</td>
<td>22</td>
<td>4</td>
<td>22</td>
<td>2</td>
<td>11</td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Operational costs 27</td>
<td>13.5</td>
<td>5</td>
<td>68</td>
<td>2</td>
<td>27</td>
<td>3</td>
<td>41</td>
<td>13.5</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Maintenance costs</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Transport distance to Shanghai</td>
<td>13.5</td>
<td>1</td>
<td>14</td>
<td>5</td>
<td>68</td>
<td>3</td>
<td>41</td>
<td>13.5</td>
<td>1</td>
</tr>
<tr>
<td><strong>Environment:</strong></td>
<td>Noise</td>
<td>3.0</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>4</td>
<td>12</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Traffic increase</td>
<td>7.0</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>28</td>
<td>4</td>
<td>28</td>
<td>7</td>
<td>1</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td>100</td>
<td>80</td>
<td>342</td>
<td>76</td>
<td>339</td>
<td>68</td>
<td>303</td>
<td>100</td>
<td>80</td>
</tr>
</tbody>
</table>

For this scenario, the location on Daxie Dao is considered to be the best. While this location offers natural deep water and good hinterland connections, no money has to be spent on these topics. The distance to Shanghai however is very large.

Nanhui Zui is the second best option for this scenario lying only 3 points behind. This is mainly due to the relative small distance to Shanghai.

Again for this scenario, the location on the Yangshan islands is the least favourable. A large amount of money has to be spent on the bridge connecting these islands with mainland. Also a large land reclamation has to be performed while the gap between the islands has to be filled.
The overall scenario:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Weight</th>
<th>Score</th>
<th>Total</th>
<th>Score</th>
<th>Total</th>
<th>Score</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical conditions:</td>
<td>25</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oceanographic</td>
<td>10</td>
<td>3.0</td>
<td>5</td>
<td>15</td>
<td>3</td>
<td>9</td>
<td>4</td>
</tr>
<tr>
<td>Waves</td>
<td>4.0</td>
<td>2</td>
<td>8</td>
<td>3</td>
<td>12</td>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>Horizontal tide</td>
<td>3.0</td>
<td>4</td>
<td>12</td>
<td>4</td>
<td>12</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Vertical tide</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geographic</td>
<td>15</td>
<td>7.5</td>
<td>5</td>
<td>38</td>
<td>1</td>
<td>8</td>
<td>3</td>
</tr>
<tr>
<td>Sedimentation</td>
<td>4.5</td>
<td>3</td>
<td>14</td>
<td>3</td>
<td>14</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td>Soil conditions</td>
<td>3.0</td>
<td>5</td>
<td>15</td>
<td>2</td>
<td>6</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Natural depth</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operational aspects:</td>
<td>30</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Execution phase</td>
<td>9</td>
<td>2.7</td>
<td>5</td>
<td>14</td>
<td>3</td>
<td>8</td>
<td>2</td>
</tr>
<tr>
<td>Dredging works</td>
<td>2.7</td>
<td>4</td>
<td>11</td>
<td>3</td>
<td>8</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Soil movement</td>
<td>3.6</td>
<td>5</td>
<td>18</td>
<td>5</td>
<td>18</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Operational phase</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quality of hinterland connections</td>
<td>4.2</td>
<td>3</td>
<td>13</td>
<td>4</td>
<td>17</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Distance to Shanghai</td>
<td>5.3</td>
<td>2</td>
<td>11</td>
<td>5</td>
<td>26</td>
<td>4</td>
<td>21</td>
</tr>
<tr>
<td>Vessel’s approach</td>
<td>2.1</td>
<td>3</td>
<td>6</td>
<td>5</td>
<td>11</td>
<td>5</td>
<td>11</td>
</tr>
<tr>
<td>Vessel’s manoeuvring space</td>
<td>2.1</td>
<td>2</td>
<td>4</td>
<td>5</td>
<td>11</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Shelter</td>
<td>2.1</td>
<td>5</td>
<td>11</td>
<td>2</td>
<td>4</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>Possibilities for extension</td>
<td>5.3</td>
<td>3</td>
<td>16</td>
<td>5</td>
<td>26</td>
<td>3</td>
<td>16</td>
</tr>
<tr>
<td>Economics:</td>
<td>35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Construction costs</td>
<td>14</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dredging works</td>
<td>5.6</td>
<td>5</td>
<td>28</td>
<td>2</td>
<td>11</td>
<td>3</td>
<td>17</td>
</tr>
<tr>
<td>Soil movement overland</td>
<td>4.2</td>
<td>4</td>
<td>17</td>
<td>3</td>
<td>13</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Hinterland connections</td>
<td>4.2</td>
<td>4</td>
<td>17</td>
<td>4</td>
<td>17</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Operational costs</td>
<td>21</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maintenance costs</td>
<td>10.5</td>
<td>5</td>
<td>53</td>
<td>2</td>
<td>21</td>
<td>3</td>
<td>32</td>
</tr>
<tr>
<td>Transport distance to Shanghai</td>
<td>10.5</td>
<td>1</td>
<td>11</td>
<td>5</td>
<td>53</td>
<td>3</td>
<td>32</td>
</tr>
<tr>
<td>Environment</td>
<td>10</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Noise</td>
<td>3.0</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>9</td>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>Traffic increase</td>
<td>7.0</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td>28</td>
<td>4</td>
<td>28</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>100</td>
<td>80</td>
<td>344</td>
<td>76</td>
<td>340</td>
<td>68</td>
</tr>
</tbody>
</table>

For the overall scenario, the location at Daxie Dao is again the best location and the Yangshan islands are the worst location for port development. Nanhui Zui is, with only 4 points, again lying very close to Daxie Dao’s first position.

The main advantages of Daxie Dao are its sheltered position and natural deep-water conditions leading to low construction and maintenance costs. The operational aspects however are not very good compared to the second best location Nanhui Zui.

The main disadvantage of the Yangshan islands is that this location lacks a bridge connection with mainland.
Appendix IX  Bathymetry of the area around Nanhui Zui
Appendix X  Soil conditions Nanhui Zui

On the following page the soil conditions of the area around Nanhui Zui can be found based on several borings at the southern banks of the Yangtze River.
Table 13-20: Soil conditions around Nanhui Zui

<table>
<thead>
<tr>
<th>Level</th>
<th>Type of soil</th>
<th>Soil properties</th>
<th>Consistency</th>
<th>Permeability</th>
<th>Shear strength</th>
<th>Consolidation</th>
<th>Field test (SPT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>γ</td>
<td>γ'</td>
<td>G</td>
<td>e</td>
<td>w</td>
<td>wL</td>
</tr>
<tr>
<td>KN/m³</td>
<td>KN/m³</td>
<td>KN/m³</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>cm/s</td>
<td>cm/s</td>
</tr>
<tr>
<td>Surface to -10</td>
<td>CL/ML</td>
<td>19.0</td>
<td>9.0</td>
<td>27.0</td>
<td>0.9</td>
<td>23.0</td>
<td>34.0</td>
</tr>
<tr>
<td>-10 to -20</td>
<td>CL</td>
<td>17.0</td>
<td>7.5</td>
<td>27.5</td>
<td>1.4</td>
<td>48.5</td>
<td>45.0</td>
</tr>
<tr>
<td>-20 to -30</td>
<td>CL</td>
<td>18.5</td>
<td>8.5</td>
<td>27.0</td>
<td>1.0</td>
<td>33.0</td>
<td>35.5</td>
</tr>
<tr>
<td>-30 to -45</td>
<td>CL</td>
<td>18.5</td>
<td>9.0</td>
<td>27.5</td>
<td>1.0</td>
<td>32.5</td>
<td>37.0</td>
</tr>
</tbody>
</table>

The following abbreviations have been used in the table:

- CL = Inorganic clay of low to medium plasticity, sandy clays, silty clays, lean clays.
- ML = Inorganic silts, silty or clayey fine sands with slight plasticity.
- γ = Unit weight of soil
- γ' = Unit weight of submerged soil
- G = Specific gravity of solid particles
- e = Void ratio
- w = Water content
- wL = Liquid limit
- wP = Plastic limit
- Ι' = Plasticity index
- l = Liquidity index
- kv = Vertical coefficient of permeability
- kh = Horizontal coefficient of permeability
- cu = Apparent cohesion intercept
- c' = Cohesion intercept
- Φ' = Angle of internal friction
- aγ = Compressibility coefficient
- Eγ = Modulus of elasticity
- Cγ = Compression index
- cv = Coefficient of consolidation
- N = Number of blows per foot
Appendix XI    Meteorological conditions

In the table on the next page some meteorological conditions of Shanghai can be found obtained from the China Sea Pilot. These values are presumed to be valid for the area around Nanhui Zui.
### SHANGHAI (31° 10' N, 121° 26' E) Height above MSL, 5 m
Climatic Table for the period 1920 to 1970

<table>
<thead>
<tr>
<th>Month</th>
<th>Average pressure at MSL</th>
<th>Temperature</th>
<th>Average humidity</th>
<th>Average cloud cover</th>
<th>Precipitation</th>
<th>Wind direction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean daily max. °C</td>
<td>Mean daily min. °C</td>
<td>Mean highest °C</td>
<td>Mean lowest °C</td>
<td>0600 mm</td>
<td>0700 mm</td>
</tr>
<tr>
<td>January</td>
<td>1027</td>
<td>8</td>
<td>0</td>
<td>17</td>
<td>-7</td>
<td>88</td>
</tr>
<tr>
<td>February</td>
<td>1025</td>
<td>9</td>
<td>1</td>
<td>19</td>
<td>-5</td>
<td>90</td>
</tr>
<tr>
<td>March</td>
<td>1021</td>
<td>14</td>
<td>4</td>
<td>25</td>
<td>-2</td>
<td>90</td>
</tr>
<tr>
<td>April</td>
<td>1016</td>
<td>20</td>
<td>10</td>
<td>29</td>
<td>3</td>
<td>92</td>
</tr>
<tr>
<td>May</td>
<td>1011</td>
<td>25</td>
<td>15</td>
<td>33</td>
<td>9</td>
<td>93</td>
</tr>
<tr>
<td>June</td>
<td>1007</td>
<td>29</td>
<td>20</td>
<td>35</td>
<td>15</td>
<td>95</td>
</tr>
<tr>
<td>July</td>
<td>1005</td>
<td>33</td>
<td>24</td>
<td>37</td>
<td>20</td>
<td>94</td>
</tr>
<tr>
<td>August</td>
<td>1006</td>
<td>33</td>
<td>24</td>
<td>37</td>
<td>21</td>
<td>94</td>
</tr>
<tr>
<td>September</td>
<td>1013</td>
<td>29</td>
<td>19</td>
<td>34</td>
<td>14</td>
<td>94</td>
</tr>
<tr>
<td>October</td>
<td>1020</td>
<td>24</td>
<td>13</td>
<td>30</td>
<td>7</td>
<td>93</td>
</tr>
<tr>
<td>November</td>
<td>1023</td>
<td>18</td>
<td>8</td>
<td>25</td>
<td>0</td>
<td>91</td>
</tr>
<tr>
<td>December</td>
<td>1026</td>
<td>12</td>
<td>2</td>
<td>20</td>
<td>-5</td>
<td>89</td>
</tr>
<tr>
<td>Means</td>
<td>1017</td>
<td>21</td>
<td>12</td>
<td>38*</td>
<td>-8</td>
<td>92</td>
</tr>
<tr>
<td>Extreme values</td>
<td>240</td>
<td>-40</td>
<td>40</td>
<td>-121</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No of years' observations</td>
<td>25</td>
<td>30</td>
<td>21</td>
<td>20</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

*Mean of highest each year.

<table>
<thead>
<tr>
<th>No of days with gates</th>
<th>No of days with fog</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mean wind speed</th>
<th>0630</th>
<th>1330</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

| Knots | 2 |

*Highest recorded temperature.

<table>
<thead>
<tr>
<th>Mean wind speed</th>
<th>0630</th>
<th>1330</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

| Knots | 2 |

*Mean wind speed.

<table>
<thead>
<tr>
<th>Mean wind speed</th>
<th>0630</th>
<th>1330</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

| Knots | 2 |

*Mean wind speed.

<table>
<thead>
<tr>
<th>Mean wind speed</th>
<th>0630</th>
<th>1330</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

| Knots | 2 |

*Mean wind speed.

<table>
<thead>
<tr>
<th>Mean wind speed</th>
<th>0630</th>
<th>1330</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

| Knots | 2 |

*Mean wind speed.

<table>
<thead>
<tr>
<th>Mean wind speed</th>
<th>0630</th>
<th>1330</th>
</tr>
</thead>
<tbody>
<tr>
<td>8</td>
<td>11</td>
<td></td>
</tr>
</tbody>
</table>

| Knots | 2 |

*Mean wind speed.
Appendix XII  PIANC design tables for approach channels

The following tables have been used for the determination of the features of the approach channel. These tables have been attained from design rules given by PIANC in "Approach channels a guide for design" [23]. In the main document these tables have already been described. Therefore, in this appendix the tables are given without explanation.

Table 13-21: Basis manoeuvring width

<table>
<thead>
<tr>
<th>Ship manoeuvrability</th>
<th>Good</th>
<th>Moderate</th>
<th>Poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basic manoeuvring lane, W_{m}</td>
<td>1.3 B</td>
<td>1.5 B</td>
<td>1.8 B</td>
</tr>
</tbody>
</table>

Table 13-22: Traffic density table

<table>
<thead>
<tr>
<th>Category</th>
<th>Traffic density (Vessels per hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Light</td>
<td>0-1.0</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;1.0-3.0</td>
</tr>
<tr>
<td>Heavy</td>
<td>&gt;3.0</td>
</tr>
</tbody>
</table>

Table 13-23: Cargo hazard

<table>
<thead>
<tr>
<th>Category</th>
<th>Cargo</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Dry Bulk, Break Bulk, Containers, passengers, General Freight, Trailer Freight</td>
</tr>
<tr>
<td>Medium</td>
<td>Oil in Bulk</td>
</tr>
<tr>
<td>High</td>
<td>Aviation Spirit, LPG, LNG, Chemicals of all classes</td>
</tr>
</tbody>
</table>

Table 13-24: Additional width for passing distance in two-way traffic

<table>
<thead>
<tr>
<th>Width for passing distance, wp</th>
<th>Outer Channel exposed to open water</th>
<th>Inner Channel protected water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessel speed (Knots)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fast</td>
<td>&gt;12</td>
<td>2.0 B</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;8-12</td>
<td>1.6 B</td>
</tr>
<tr>
<td>Slow</td>
<td>5-8</td>
<td>1.2 B</td>
</tr>
<tr>
<td>Encounter traffic density</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Light</td>
<td></td>
<td>0.0 B</td>
</tr>
<tr>
<td>Moderate</td>
<td></td>
<td>0.2 B</td>
</tr>
<tr>
<td>Heavy</td>
<td></td>
<td>0.5 B</td>
</tr>
</tbody>
</table>

Table 13-25: Additional width for bank clearance

<table>
<thead>
<tr>
<th>Width for bank clearance (W_{b} or W_{w})</th>
<th>Vessel speed</th>
<th>Outer Channel exposed to open water</th>
<th>Inner Channel protected water</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sloping channel edges and shoals</td>
<td>Fast</td>
<td>0.7 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>0.5 B</td>
<td>0.5 B</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>0.3 B</td>
<td>0.3 B</td>
</tr>
<tr>
<td>Steep and hard embankments, structures</td>
<td>Fast</td>
<td>1.3 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.0 B</td>
<td>1.0 B</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>0.5 B</td>
<td>0.5 B</td>
</tr>
</tbody>
</table>
Table 13-26: Additional widths for straight channel sections

<table>
<thead>
<tr>
<th></th>
<th>Width W</th>
<th>Vessel speed</th>
<th>Outer Channel Exposed to open water</th>
<th>Inner Channel Protected water</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Vessel speed (Knots)</td>
<td>Fast</td>
<td>&gt;12</td>
<td>0.1 B</td>
<td>0.1 B</td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>&gt;8-12</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>5-8</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>(b) Prevailing cross wind (Knots)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mild</td>
<td>&lt;15</td>
<td>All</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;15-30</td>
<td>Fast</td>
<td>0.3 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.4 B</td>
<td>0.4 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
<td>0.5 B</td>
<td>0.5 B</td>
</tr>
<tr>
<td>Severe</td>
<td>&gt;33-48</td>
<td>Fast</td>
<td>0.8 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.8 B</td>
<td>0.8 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
<td>1.0 B</td>
<td>1.0 B</td>
</tr>
<tr>
<td>(c) Prevailing cross current (Knots)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Negligible</td>
<td>&lt;0.2</td>
<td>All</td>
<td>0.0</td>
<td>0.0 B</td>
</tr>
<tr>
<td>Low</td>
<td>0.2-0.5</td>
<td>Fast</td>
<td>0.1 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.2 B</td>
<td>0.1 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
<td>0.3 B</td>
<td>0.2 B</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;0.5-1.5</td>
<td>Fast</td>
<td>0.5 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.7 B</td>
<td>0.5 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
<td>1.0 B</td>
<td>0.8 B</td>
</tr>
<tr>
<td>Strong</td>
<td>&gt;1.5-2.0</td>
<td>Fast</td>
<td>0.7 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>1.0 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
<td>1.3 B</td>
<td>- B</td>
</tr>
<tr>
<td>(d) Prevailing longitudinal current (Knots)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td>&lt;1.5</td>
<td>All</td>
<td>0.0</td>
<td>0.0 B</td>
</tr>
<tr>
<td>Moderate</td>
<td>&gt;1.5-3</td>
<td>Fast</td>
<td>0.0</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.1 B</td>
<td>0.1 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
<td>0.2 B</td>
<td>0.2 B</td>
</tr>
<tr>
<td>Strong</td>
<td>&gt;3</td>
<td>Fast</td>
<td>0.1 B</td>
<td>- B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Moderate</td>
<td>0.2 B</td>
<td>0.2 B</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Slow</td>
<td>0.4 B</td>
<td>0.4 B</td>
</tr>
<tr>
<td>(e) Sign. wave height Hs and length λ (m)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hs&lt;1 and yl&lt;λ</td>
<td>All</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast</td>
<td>2.0 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.0 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>0.5 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>3&gt;Hs&gt;1 and yl = λ</td>
<td>All</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast</td>
<td>2.0 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.0 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>0.5 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Hs&gt;3 and yl&gt;λ</td>
<td>All</td>
<td>0.0</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast</td>
<td>2.0 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Moderate</td>
<td>1.0 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slow</td>
<td>1.5 B</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>(f) Aids to navigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excellent with shore traffic control</td>
<td></td>
<td>0.0 B</td>
<td>0.0 B</td>
<td></td>
</tr>
<tr>
<td>Good</td>
<td></td>
<td>0.1 B</td>
<td>0.1 B</td>
<td></td>
</tr>
<tr>
<td>Moderate with infrequent poor visibility</td>
<td>0.2 B</td>
<td>0.2 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Moderate with frequent poor visibility</td>
<td>&gt;0.5 B</td>
<td>&gt;0.5 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(g) Bottom surface</td>
<td>if depth &gt;1.5T</td>
<td>0.0 B</td>
<td>0.0 B</td>
<td></td>
</tr>
<tr>
<td>if depth &lt;1.5T then</td>
<td>-smooth and soft</td>
<td>0.1 B</td>
<td>0.1 B</td>
<td></td>
</tr>
<tr>
<td>-smooth and sloping or hard</td>
<td>0.1 B</td>
<td>0.1 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-rough and hard</td>
<td>0.2 B</td>
<td>0.2 B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(h) Depth of the waterway</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&gt;1.5T</td>
<td></td>
<td>0.0 B</td>
<td>&gt;1.5T 0.0 B</td>
<td></td>
</tr>
<tr>
<td>1.5T - 1.25T</td>
<td></td>
<td>0.1 B</td>
<td>&lt;1.5T-1.15T 0.2 B</td>
<td></td>
</tr>
<tr>
<td>&lt;1.25T</td>
<td></td>
<td>0.2 B</td>
<td>&lt;1.15T 0.4 B</td>
<td></td>
</tr>
<tr>
<td>(i) Cargo hazard level</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low</td>
<td></td>
<td>0.0 B</td>
<td>0.0 B</td>
<td></td>
</tr>
<tr>
<td>Medium</td>
<td></td>
<td>0.5 B</td>
<td>0.4 B</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td></td>
<td>1.0 B</td>
<td>0.8 B</td>
<td></td>
</tr>
</tbody>
</table>
Appendix XIII  Calculation of volume of capital dredging

In this chapter the total volume of capital dredging will be calculated for both channel variants. While the shape of the channel has already been calculated, the only unknown factor is the exact bathymetry of the area. While no exact data is available, admiralty map number 1124 is used for an estimation. On the next page the relevant part of this map can be found including some depth isolines. With these isolines the influence of the Yangtze River on the sedimentation in the area can be seen. Especially from the CD - 8 meter isoline a clear “tongue” shape can be distinguished.

On the map on the next page both channel variants have been drawn in. To be able to determine the volume to be dredged for each variant, the channels have been split up in several sections. Each section starts at an isoline and finishes at another. The depth per section is then taken as the mean depth of the total section.

Together with the shape of the channel as was already calculated in paragraph 8.2.3, now the total volume of capital dredging can be calculated. In the following tables the calculation can be found. The “Extra” width of the channel is the width of the embankments. The slope of these embankments is assumed to have a ratio of 1:10.

Within these tables the minimum value can be found regarding several years. This is a result of the changing requirements during the years. For the years until 2005 no two-way channel is needed and between the years 2005 and 2015 the width of the channel is smaller than for the years after 2015. This distinction can also be used to make a phasing of the total project.

Table 13-27: Channel dimensions for the northern variant

<table>
<thead>
<tr>
<th>Section</th>
<th>Length Miles</th>
<th>Length (km)</th>
<th>Depth below CD available (m)</th>
<th>Depth below CD extra needed (m)</th>
<th>Width &gt; 2005 (m)</th>
<th>Width 2005-2015 (m)</th>
<th>Width &gt; 2015 (m)</th>
<th>Extra Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NA</td>
<td>4.0</td>
<td>7.2</td>
<td>6.3</td>
<td>8.7</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>174.0</td>
</tr>
<tr>
<td>NB</td>
<td>12.0</td>
<td>21.6</td>
<td>7.5</td>
<td>7.5</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>150.0</td>
</tr>
<tr>
<td>NC</td>
<td>3.0</td>
<td>5.4</td>
<td>9.0</td>
<td>6.0</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>120.0</td>
</tr>
<tr>
<td>ND</td>
<td>7.0</td>
<td>12.6</td>
<td>11.0</td>
<td>4.0</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>80.0</td>
</tr>
<tr>
<td>NE</td>
<td>5.0</td>
<td>9.0</td>
<td>13.5</td>
<td>1.5</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>30.0</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>55.8</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13-28: Total volume to be dredged for northern variant

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Section</td>
<td>m³</td>
<td>m³</td>
<td>m³</td>
<td>m³</td>
<td>m³</td>
</tr>
<tr>
<td>NA</td>
<td>1.35E+07</td>
<td>1.89E+07</td>
<td>6.89E+05</td>
<td>5.45E+06</td>
<td>3.85E+07</td>
</tr>
<tr>
<td>NB</td>
<td>3.48E+07</td>
<td>4.89E+07</td>
<td>1.78E+06</td>
<td>1.22E+07</td>
<td>9.77E+07</td>
</tr>
<tr>
<td>NC</td>
<td>6.97E+06</td>
<td>9.78E+06</td>
<td>3.56E+05</td>
<td>1.94E+06</td>
<td>1.91E+07</td>
</tr>
<tr>
<td>ND</td>
<td>1.08E+07</td>
<td>1.52E+07</td>
<td>5.54E+05</td>
<td>2.02E+06</td>
<td>2.86E+07</td>
</tr>
<tr>
<td>NE</td>
<td>2.90E+06</td>
<td>4.08E+06</td>
<td>1.49E+05</td>
<td>2.03E+05</td>
<td>7.33E+06</td>
</tr>
<tr>
<td>Total</td>
<td>6.90E+07</td>
<td>9.69E+07</td>
<td>3.53E+06</td>
<td>2.18E+07</td>
<td>1.91E+08</td>
</tr>
</tbody>
</table>
Table 13-29: Channel dimensions for the southern variant

<table>
<thead>
<tr>
<th>Section</th>
<th>Length available (miles)</th>
<th>Length available (km)</th>
<th>Extra needed (m)</th>
<th>Depth below CD</th>
<th>Width &gt;2005 (m)</th>
<th>Width 2005-2015 (m)</th>
<th>Width &gt;2015 (m)</th>
<th>Width Extra (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SA</td>
<td>3.0</td>
<td>5.4</td>
<td>6.3</td>
<td>8.7</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>174.0</td>
</tr>
<tr>
<td>SB</td>
<td>5.5</td>
<td>9.9</td>
<td>7.5</td>
<td>7.5</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>150.0</td>
</tr>
<tr>
<td>SC</td>
<td>8.0</td>
<td>14.4</td>
<td>9.0</td>
<td>6.0</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>120.0</td>
</tr>
<tr>
<td>SD</td>
<td>3.5</td>
<td>6.3</td>
<td>13.0</td>
<td>2.0</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>40.0</td>
</tr>
<tr>
<td>SE</td>
<td>9.0</td>
<td>16.2</td>
<td>13.5</td>
<td>1.5</td>
<td>215.0</td>
<td>517.0</td>
<td>528.0</td>
<td>30.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>29</strong></td>
<td><strong>52.2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 13-30: Total volume to be dredged for southern variant

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m$^3$</td>
<td>m$^3$</td>
<td>m$^3$</td>
<td>m$^3$</td>
<td>m$^3$</td>
</tr>
<tr>
<td>SA</td>
<td>1.01E+07</td>
<td>1.42E+07</td>
<td>5.17E+05</td>
<td>4.09E+06</td>
<td>2.89E+07</td>
</tr>
<tr>
<td>SB</td>
<td>1.60E+07</td>
<td>2.24E+07</td>
<td>8.17E+05</td>
<td>5.57E+06</td>
<td>4.48E+07</td>
</tr>
<tr>
<td>SC</td>
<td>1.86E+07</td>
<td>2.61E+07</td>
<td>9.50E+05</td>
<td>5.18E+06</td>
<td>5.08E+07</td>
</tr>
<tr>
<td>SD</td>
<td>2.71E+06</td>
<td>3.81E+06</td>
<td>1.39E+05</td>
<td>2.52E+05</td>
<td>6.90E+06</td>
</tr>
<tr>
<td>SE</td>
<td>5.22E+06</td>
<td>7.34E+06</td>
<td>2.67E+05</td>
<td>3.65E+05</td>
<td>1.32E+07</td>
</tr>
<tr>
<td></td>
<td>5.26E+07</td>
<td>7.38E+07</td>
<td>2.69E+06</td>
<td>1.55E+07</td>
<td>1.45E+08</td>
</tr>
</tbody>
</table>

Table 13-31: Difference in capital dredging volumes between variants

<table>
<thead>
<tr>
<th>Section</th>
<th>North</th>
<th>South</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>m$^3$</td>
<td>m$^3$</td>
<td>m$^3$</td>
</tr>
<tr>
<td>A</td>
<td>3.85E+07</td>
<td>2.89E+07</td>
<td>9.63E+06</td>
</tr>
<tr>
<td>B</td>
<td>9.77E+07</td>
<td>4.48E+07</td>
<td>5.29E+07</td>
</tr>
<tr>
<td>D</td>
<td>1.91E+07</td>
<td>5.08E+07</td>
<td>-3.18E+07</td>
</tr>
<tr>
<td>D</td>
<td>2.86E+07</td>
<td>6.90E+06</td>
<td>2.17E+07</td>
</tr>
<tr>
<td>E</td>
<td>7.33E+06</td>
<td>1.32E+07</td>
<td>-5.86E+06</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>1.91E+08</strong></td>
<td><strong>1.45E+08</strong></td>
<td><strong>4.67E+07</strong></td>
</tr>
</tbody>
</table>
## Appendix XIV  Choice of shuttlebarge

<table>
<thead>
<tr>
<th>Vessel name</th>
<th>Capacity</th>
<th>Length (m)</th>
<th>Beam (m)</th>
<th>Draught (m)</th>
<th>Displacement (m³)</th>
<th>Squat (m)</th>
<th>Total (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mint Ace</td>
<td>367</td>
<td>101</td>
<td>17.1</td>
<td>6.20</td>
<td>7,473</td>
<td>0.72</td>
<td>8.12</td>
</tr>
<tr>
<td>Mint Accord</td>
<td>367</td>
<td>101</td>
<td>17.1</td>
<td>6.20</td>
<td>7,473</td>
<td>0.72</td>
<td>8.12</td>
</tr>
<tr>
<td>Atlantic Island</td>
<td>468</td>
<td>118</td>
<td>19.2</td>
<td>6.20</td>
<td>9,866</td>
<td>0.68</td>
<td>8.08</td>
</tr>
<tr>
<td>Sunny Maple</td>
<td>342</td>
<td>107</td>
<td>17.2</td>
<td>6.20</td>
<td>8,021</td>
<td>0.68</td>
<td>8.08</td>
</tr>
<tr>
<td>Mint Action</td>
<td>364</td>
<td>101</td>
<td>16.1</td>
<td>6.20</td>
<td>7,040</td>
<td>0.67</td>
<td>8.07</td>
</tr>
<tr>
<td>Mint Arrow</td>
<td>367</td>
<td>101</td>
<td>17.1</td>
<td>6.12</td>
<td>7,377</td>
<td>0.71</td>
<td>8.03</td>
</tr>
<tr>
<td>MCC Vantage</td>
<td>486</td>
<td>120</td>
<td>20.3</td>
<td>6.03</td>
<td>10,282</td>
<td>0.69</td>
<td>7.92</td>
</tr>
<tr>
<td>HMS Goodwill</td>
<td>356</td>
<td>97</td>
<td>17.8</td>
<td>5.96</td>
<td>7,218</td>
<td>0.75</td>
<td>7.91</td>
</tr>
<tr>
<td>Uraga Maru</td>
<td>450</td>
<td>137</td>
<td>20.0</td>
<td>6.10</td>
<td>11,726</td>
<td>0.60</td>
<td>7.90</td>
</tr>
<tr>
<td>Hamburg</td>
<td>343</td>
<td>97</td>
<td>15.8</td>
<td>6.02</td>
<td>6,443</td>
<td>0.67</td>
<td>7.89</td>
</tr>
<tr>
<td>Rendsburg</td>
<td>343</td>
<td>97</td>
<td>15.8</td>
<td>6.01</td>
<td>6,433</td>
<td>0.67</td>
<td>7.88</td>
</tr>
<tr>
<td>Tyne Bridge</td>
<td>448</td>
<td>108</td>
<td>15.9</td>
<td>6.06</td>
<td>7,268</td>
<td>0.61</td>
<td>7.87</td>
</tr>
<tr>
<td>San Sebastian</td>
<td>397</td>
<td>93</td>
<td>15.0</td>
<td>6.00</td>
<td>5,872</td>
<td>0.66</td>
<td>7.86</td>
</tr>
<tr>
<td>Ute Johanna</td>
<td>366</td>
<td>97</td>
<td>16.9</td>
<td>5.95</td>
<td>6,845</td>
<td>0.70</td>
<td>7.85</td>
</tr>
<tr>
<td>Iberlan Bridge</td>
<td>448</td>
<td>111</td>
<td>15.9</td>
<td>6.06</td>
<td>7,456</td>
<td>0.59</td>
<td>7.85</td>
</tr>
<tr>
<td>Pampero</td>
<td>510</td>
<td>113</td>
<td>16.6</td>
<td>6.05</td>
<td>7,972</td>
<td>0.60</td>
<td>7.85</td>
</tr>
<tr>
<td>Alteland</td>
<td>350</td>
<td>100</td>
<td>16.5</td>
<td>5.96</td>
<td>6,884</td>
<td>0.67</td>
<td>7.83</td>
</tr>
<tr>
<td>Jenna Catherine</td>
<td>366</td>
<td>98</td>
<td>16.9</td>
<td>5.93</td>
<td>6,905</td>
<td>0.69</td>
<td>7.82</td>
</tr>
<tr>
<td>Qing Hong</td>
<td>498</td>
<td>118</td>
<td>18.0</td>
<td>6.00</td>
<td>8,921</td>
<td>0.62</td>
<td>7.82</td>
</tr>
<tr>
<td>Mathilda</td>
<td>448</td>
<td>108</td>
<td>16.4</td>
<td>5.99</td>
<td>7,420</td>
<td>0.62</td>
<td>7.81</td>
</tr>
<tr>
<td>City of Oppor to</td>
<td>510</td>
<td>113</td>
<td>16.4</td>
<td>6.00</td>
<td>7,783</td>
<td>0.59</td>
<td>7.79</td>
</tr>
<tr>
<td>Turakina</td>
<td>390</td>
<td>100</td>
<td>16.5</td>
<td>5.90</td>
<td>6,801</td>
<td>0.66</td>
<td>7.76</td>
</tr>
<tr>
<td>OPDR Douro</td>
<td>390</td>
<td>101</td>
<td>16.5</td>
<td>5.90</td>
<td>6,855</td>
<td>0.66</td>
<td>7.76</td>
</tr>
<tr>
<td>Wing Lee No 1</td>
<td>544</td>
<td>119</td>
<td>17.8</td>
<td>5.92</td>
<td>8,778</td>
<td>0.60</td>
<td>7.72</td>
</tr>
<tr>
<td>Jin Lu</td>
<td>544</td>
<td>119</td>
<td>17.8</td>
<td>5.90</td>
<td>8,748</td>
<td>0.60</td>
<td>7.70</td>
</tr>
<tr>
<td>CMBT Caravel</td>
<td>390</td>
<td>101</td>
<td>16.5</td>
<td>5.80</td>
<td>6,743</td>
<td>0.65</td>
<td>7.65</td>
</tr>
<tr>
<td>Takikmu</td>
<td>356</td>
<td>97</td>
<td>17.6</td>
<td>5.70</td>
<td>6,819</td>
<td>0.70</td>
<td>7.60</td>
</tr>
<tr>
<td>Min Yuan 1</td>
<td>384</td>
<td>108</td>
<td>15.9</td>
<td>5.60</td>
<td>6,756</td>
<td>0.56</td>
<td>7.36</td>
</tr>
<tr>
<td>Hai Tun</td>
<td>398</td>
<td>93</td>
<td>15.8</td>
<td>5.40</td>
<td>5,563</td>
<td>0.62</td>
<td>7.22</td>
</tr>
<tr>
<td>Iduna</td>
<td>361</td>
<td>99</td>
<td>16.3</td>
<td>5.40</td>
<td>6,087</td>
<td>0.61</td>
<td>7.21</td>
</tr>
<tr>
<td>Baltic Tern</td>
<td>357</td>
<td>107</td>
<td>15.8</td>
<td>5.42</td>
<td>6,384</td>
<td>0.55</td>
<td>7.17</td>
</tr>
<tr>
<td>Geest Merchant</td>
<td>340</td>
<td>94</td>
<td>16.4</td>
<td>5.04</td>
<td>5,431</td>
<td>0.60</td>
<td>6.84</td>
</tr>
<tr>
<td>Ady</td>
<td>340</td>
<td>99</td>
<td>16.2</td>
<td>5.05</td>
<td>5,688</td>
<td>0.56</td>
<td>6.81</td>
</tr>
<tr>
<td>Geest Atlas</td>
<td>340</td>
<td>99</td>
<td>16.4</td>
<td>5.04</td>
<td>5,768</td>
<td>0.57</td>
<td>6.81</td>
</tr>
<tr>
<td>Johan Emerald</td>
<td>358</td>
<td>117</td>
<td>18.0</td>
<td>5.00</td>
<td>7,396</td>
<td>0.52</td>
<td>6.72</td>
</tr>
<tr>
<td>Kitt</td>
<td>616</td>
<td>194</td>
<td>27.0</td>
<td>5.00</td>
<td>18,324</td>
<td>0.47</td>
<td>6.67</td>
</tr>
<tr>
<td>Geest Trader</td>
<td>340</td>
<td>99</td>
<td>16.4</td>
<td>4.91</td>
<td>5,606</td>
<td>0.55</td>
<td>6.66</td>
</tr>
<tr>
<td>Thea B</td>
<td>340</td>
<td>99</td>
<td>16.2</td>
<td>4.90</td>
<td>5,519</td>
<td>0.54</td>
<td>6.64</td>
</tr>
<tr>
<td>Skybridge</td>
<td>486</td>
<td>120</td>
<td>20.3</td>
<td>4.80</td>
<td>8,185</td>
<td>0.55</td>
<td>6.55</td>
</tr>
<tr>
<td>Pablo Metz</td>
<td>537</td>
<td>115</td>
<td>20.3</td>
<td>4.40</td>
<td>7,159</td>
<td>0.53</td>
<td>6.13</td>
</tr>
<tr>
<td>Jowi II</td>
<td>396</td>
<td>135</td>
<td>17.0</td>
<td>3.20</td>
<td>5,141</td>
<td>0.27</td>
<td>4.67</td>
</tr>
<tr>
<td>Jowi</td>
<td>396</td>
<td>135</td>
<td>17.0</td>
<td>3.20</td>
<td>5,141</td>
<td>0.27</td>
<td>4.67</td>
</tr>
</tbody>
</table>
Appendix XV  Modal split per terminal

Within this appendix an effort has been made to explain the modal split for the terminals by the year 2025. While dealing with a large number of terminals this has been done schematically. In this schematisation, first the division of the ocean and short sea vessels over the various terminals will be given.

As can be seen from the figure below the ocean and shortsea vessels will be divided over the various terminals according to a preset division. This division is based on the division of export containers over the various destinations. An ocean vessel, for example, that will be sailing to Australia after it has called at Yangshan will be handled at Yangshan terminal 2.

![Modal split diagram]

*Figure 13-5: Division of ocean and shortsea vessels over Yangshan terminals*

Now the division over the terminals has been made, the division of containers on the Yangshan terminals can be made. In the next two figures one of the Yangshan terminals has been given schematically. While each Yangshan terminal annually deals with almost the same amount of containers the modal split of only the first terminal has been given.

The container movements on the terminal have been split up in 2 types, domestic container transport and transshipment. In the figure below, the modal split of the domestic containers has been given. In total, the domestic containers account for 90% of the total throughput of the terminal. With an annual throughput of 5.8 mTEU the number of domestic containers that are handled at the terminal is 5.3 mTEU. This volume is divided over import and export according to the division given in the figure below.
Figure 13-6: Modal split for domestic containers on Yangshan terminal number 1

The annual transshipment container handling volume accounts for the remaining 10% of the throughput. For the Yangshan terminal number 1 this implies an annual throughput of 0.6 mTEU. The division of these transshipment containers is given in the following figure.

Figure 13-7: Modal split for transshipment containers on Yangshan terminal number 1

At the satellite terminals the modal split is easier to give while only a few transport modalities use the terminals. As can be seen from the schematisation of the Nanhui Zui terminal in the figure below, import containers are brought to the terminals by shuttle
barge and are picked up by trucks. For export containers the opposite happens. The total annual throughput of Nanhui Zui is 13.8 mTEU.

The situation at Shanghai is basically the same except for the fact that containers are picked up by trucks and train. The total annual throughput of Nanhui Zui is 6.6 mTEU.

Figure 13-8: Modal split for the satellite terminals
Appendix XVI  Dwell times

In this appendix, the average stack contents of all stacks and the resulting average dwell times (td) can be found. While a period of 3 years has been simulated, results can be found for each simulated year. In the last table the average values can be found of the average stack sizes per vessel group.

<table>
<thead>
<tr>
<th>Second Year</th>
<th>Ocean</th>
<th>Shortsea</th>
<th>River</th>
<th>NZ Shuttle</th>
<th>SH Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
</tr>
<tr>
<td>Terminal 1</td>
<td>39,142</td>
<td>4.9</td>
<td>36,454</td>
<td>4.6</td>
<td>20,587</td>
</tr>
<tr>
<td>Terminal 2</td>
<td>73,035</td>
<td>9.3</td>
<td>25,252</td>
<td>3.1</td>
<td>18,053</td>
</tr>
<tr>
<td>Terminal 3</td>
<td>78,988</td>
<td>8.4</td>
<td>47,555</td>
<td>5.9</td>
<td>20,818</td>
</tr>
<tr>
<td>Terminal 4</td>
<td>77,634</td>
<td>9.5</td>
<td>32,965</td>
<td>4.1</td>
<td>18,845</td>
</tr>
<tr>
<td>Terminal 5</td>
<td>70,361</td>
<td>8.8</td>
<td>12,849</td>
<td>1.6</td>
<td>17,503</td>
</tr>
<tr>
<td>Terminal 6</td>
<td>78,422</td>
<td>9.8</td>
<td>36,880</td>
<td>4.9</td>
<td>8,903</td>
</tr>
<tr>
<td>Average</td>
<td>69,488</td>
<td>8.4</td>
<td>32,014</td>
<td>4.0</td>
<td>17,466</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Third Year</th>
<th>Ocean</th>
<th>Shortsea</th>
<th>River</th>
<th>NZ Shuttle</th>
<th>SH Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
</tr>
<tr>
<td>Terminal 1</td>
<td>121,003</td>
<td>15.1</td>
<td>33,011</td>
<td>4.2</td>
<td>19,963</td>
</tr>
<tr>
<td>Terminal 2</td>
<td>66,015</td>
<td>8.4</td>
<td>65,473</td>
<td>8.2</td>
<td>20,005</td>
</tr>
<tr>
<td>Terminal 3</td>
<td>98,101</td>
<td>10.5</td>
<td>49,822</td>
<td>6.2</td>
<td>18,164</td>
</tr>
<tr>
<td>Terminal 4</td>
<td>40,634</td>
<td>5.0</td>
<td>25,337</td>
<td>3.1</td>
<td>11,965</td>
</tr>
<tr>
<td>Terminal 5</td>
<td>56,073</td>
<td>6.9</td>
<td>18,231</td>
<td>2.3</td>
<td>12,005</td>
</tr>
<tr>
<td>Terminal 6</td>
<td>112,021</td>
<td>13.9</td>
<td>37,331</td>
<td>4.9</td>
<td>25,322</td>
</tr>
<tr>
<td>Average</td>
<td>82,307</td>
<td>10.0</td>
<td>38,200</td>
<td>4.8</td>
<td>18,670</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Fourth Year</th>
<th>Ocean</th>
<th>Shortsea</th>
<th>River</th>
<th>NZ Shuttle</th>
<th>SH Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
</tr>
<tr>
<td>Terminal 1</td>
<td>101,650</td>
<td>12.6</td>
<td>38,488</td>
<td>4.8</td>
<td>24,649</td>
</tr>
<tr>
<td>Terminal 2</td>
<td>64,615</td>
<td>8.2</td>
<td>31,755</td>
<td>4.0</td>
<td>13,974</td>
</tr>
<tr>
<td>Terminal 3</td>
<td>130,241</td>
<td>14.0</td>
<td>34,781</td>
<td>4.3</td>
<td>10,620</td>
</tr>
<tr>
<td>Terminal 4</td>
<td>61,694</td>
<td>7.6</td>
<td>37,037</td>
<td>4.6</td>
<td>13,873</td>
</tr>
<tr>
<td>Terminal 5</td>
<td>55,706</td>
<td>6.8</td>
<td>24,133</td>
<td>3.1</td>
<td>28,771</td>
</tr>
<tr>
<td>Terminal 6</td>
<td>77,120</td>
<td>9.6</td>
<td>48,978</td>
<td>6.4</td>
<td>36,653</td>
</tr>
<tr>
<td>Average</td>
<td>81,821</td>
<td>9.8</td>
<td>35,862</td>
<td>4.5</td>
<td>21,425</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average over 3 years</th>
<th>Ocean</th>
<th>Shortsea</th>
<th>River</th>
<th>NZ Shuttle</th>
<th>SH Shuttle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
<td>td</td>
<td>Stack size</td>
</tr>
<tr>
<td>All terminals</td>
<td>77,876</td>
<td>9.4</td>
<td>35,359</td>
<td>4.5</td>
<td>18,987</td>
</tr>
</tbody>
</table>
Appendix XVII MCA for design proposals

The evaluation of the designs has been done according to a Multi Criteria Analysis (MCA). With this method no exact judgement can be given whether a design is the best, but a general idea can be given regarding the relation between the designs.

This MCA uses several aspects according to which the designs are compared to each other. These aspects can generally be divided into 2 categories. An operational and a financial category. Within these categories the following aspects are evaluated:

Operational category:

- **Service level vessels:**
  The ability of the vessels to easily enter the terminal's basins is considered. In case the vessels have to manoeuvre and turn in relatively confined spaces the service level is considered as "low". Furthermore the traffic intensity is considered.

- **Ease of use for terminal operator**
  The ease of container handling for the terminal operator is considered. The position at the boundary of the terminals of the road for exchange of transshipment containers for example, highly contributes to this aspect. The positions of the stacks are furthermore considered. The distances travelled by containers from the domestic berths to the sea berths is also an important aspect.

- **Possibility for future expansion**
  The possibility of construction of extra terminals without large difficulties in case of higher expected throughput scenarios is considered. After the year 2025 the number of terminals will probably have to be expanded due to ongoing growth of container traffic.

- **Protection against external influences**
  The protection of the terminals and their basins against extreme weather conditions is considered within this aspect.

Financial category

- **Capital investments**
  The capital investments aspect is based on the total area to be filled and the total length of the breakwaters. (High investments like investments in equipment or pavement are considered the same for each design.) In case the outcoming rock from the islands is sufficient for the areas to be filled, the total reclamation costs go down. The decisions concerning costs are, in this stage, mainly based on assumptions.

- **Possibility of phasing of the execution**
  Phasing of the delivery of the several terminals through time is highly desired. This however is not always easy to establish while vessels should at all times be protected against currents and waves.

- **Exchangeability of the berths**
  If berths are exchangeable, a smaller number of quay cranes is needed leading to a reduction of costs.

- **Safety of the vessels**
  In case of collisions between vessels, the terminal could be down for some time due to blocking of the basins.

- **Safety on the terminal**
  There are high costs involved in case of an accident. Not only the direct damage such as loss of lives and or materials are costly, also the indirect costs such as downtime due to unavailability of the terminal brings along high costs.
Each aspect individually has a certain weight according to its importance relative to the other aspects within the category. To be able to evaluate the several designs a score is given per aspect to each design. A design receives a 1 if that design performs badly on that aspect and a 5 if it performs well on that aspect. This score multiplied with the relative weight of the aspect and added up to the scores of all other aspects finally results in a total score per design. The design having the highest score can be considered as the "best".

To make the MCA somewhat more flexible, three scenarios have been applied. Within the first scenario the total costs is the most import aspect and within the second scenario the serviceability is the most import aspect. The third scenario is an overall scenario in which both aspects account for the same weight within the decision. The valuation of each design per aspect remains the same while this is independent of the scenario.

In the following three tables the valuations per design can be found together with the scores per scenario.

Table 13-32: Valuations and results per design within the MCA

<table>
<thead>
<tr>
<th>Serviceability scenario</th>
<th>Design 1</th>
<th>Design 2</th>
<th>Design 3</th>
<th>Design 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>Aspect</td>
<td>Weight</td>
<td>Score</td>
<td>Total</td>
</tr>
<tr>
<td>70</td>
<td>Service level vessels</td>
<td>40</td>
<td>5</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>Ease of use for terminal operator</td>
<td>40</td>
<td>2</td>
<td>56</td>
</tr>
<tr>
<td></td>
<td>Possibility for future expansion</td>
<td>10</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Protection against external influences</td>
<td>10</td>
<td>3</td>
<td>21</td>
</tr>
<tr>
<td>30</td>
<td>Capital investments</td>
<td>50</td>
<td>2</td>
<td>30</td>
</tr>
<tr>
<td></td>
<td>Possibility of phasing of the execution</td>
<td>30</td>
<td>2</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Exchangeability of the berths</td>
<td>10</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Safety of the vessels</td>
<td>5</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Safety on the terminal</td>
<td>5</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>326</td>
<td>358</td>
<td>355</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs scenario</th>
<th>Design 1</th>
<th>Design 2</th>
<th>Design 3</th>
<th>Design 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>Aspect</td>
<td>Weight</td>
<td>Score</td>
<td>Total</td>
</tr>
<tr>
<td>30</td>
<td>Service level vessels</td>
<td>40</td>
<td>5</td>
<td>60</td>
</tr>
<tr>
<td></td>
<td>Ease of use for terminal operator</td>
<td>40</td>
<td>2</td>
<td>24</td>
</tr>
<tr>
<td></td>
<td>Possibility for future expansion</td>
<td>10</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>Protection against external influences</td>
<td>10</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>70</td>
<td>Capital investments</td>
<td>50</td>
<td>2</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>Possibility of phasing of the execution</td>
<td>30</td>
<td>2</td>
<td>42</td>
</tr>
<tr>
<td></td>
<td>Exchangeability of the berths</td>
<td>10</td>
<td>5</td>
<td>35</td>
</tr>
<tr>
<td></td>
<td>Safety of the vessels</td>
<td>5</td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td>Safety on the terminal</td>
<td>5</td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Total</td>
<td>100</td>
<td>280</td>
<td>302</td>
<td>335</td>
</tr>
</tbody>
</table>
As has already been mentioned in paragraph 8.6.3, the scores given to the various design options very much depend on the users opinion. To give some insight in the decisions made during scoring the design options, the following section will give a short explanation per design aspect.

**Operational category:**

- **Service level vessels:**
  For this design aspect the first two design options have been given the highest score. Within these designs the various vessel categories have been separated leading to an increase of safety and ease to reach the dedicated berths.

- **Ease of use for terminal operator**
  Design 2, 3 and 4 score high on this aspect. At designs 3 and 4 the main advantage is formed by the transshipment road that lies around the terminals. In this way the transport of containers across the terminals is not disturbed. At design number 2 the transshipment road lies straight through the terminals which is a disadvantage. This disadvantage is however corrected by the relative short distance to be travelled by the containers across the terminals.

- **Possibility for future expansion**
  At this aspect the designs number 1 and 3 score high while expansion could probably easily be established by removing the barriers at the end of the central basin and constructing extra terminals adjacent to the outer terminals.

- **Protection against external influences**
  With the combined basins of design options number 3 and 4 the terminal's basins are quite well protected against natural influences coming from sea. These designs have only one entrance through which waves could enter the basins. Within this respect design number 3 is slightly worse than design number 4. This is caused by the rectangular shape of design number 3 which could allow seiches.
Financial category

- **Capital investments**
  At this aspect only the third design option scores quite good. The reason for this is that the terminals are projected onto the existing islands. Furthermore, the total length of the breakwaters could be kept low leading to a reduction of costs.

- **Possibility of phasing of the execution**
  Phasing of execution of the several design options is quite hard while the terminals should at all times be protected against natural influences. To establish this protection, large investments should initially be made to create a protected area. Terminal numbers 2 and 4 can be constructed from the west side to the east side where the terminals themselves form a natural protection.

- **Exchangeability of the berths**
  The first two design options allow the exchange of quay cranes between many berths and are therefore better rated than the other two designs.

- **Safety of the vessels**
  Regarding the safety of the vessels sailing through the terminal's basins, the first two options are considered to be the best. In these options the various vessel classes are separated leading to lower traffic intensity.

- **Safety on the terminal**
  Regarding the safety on the terminals the options 3 and 4 are the best. This is mainly due to the location of the transshipment road. In the first two design options this road is lying through the terminals and therefore causes the transport of containers across the terminals to be blocked. This blockage could lead to collisions.
Appendix XVIII Schedule of investments

In this appendix an overview will be given of the investments that should be made throughout the years per element as described in 9.2.

Within each table the last two columns represent the costs based on the price level of 1997 and the converted price for the year of expenditure. For conversion an inflation of 5% is taken.

Table 13-33: General elements investments

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>Cost element</th>
<th>1997 level million $</th>
<th>Year of expenditure 2003 million $</th>
</tr>
</thead>
<tbody>
<tr>
<td>2003</td>
<td>Approach channel</td>
<td>12</td>
<td>16</td>
</tr>
<tr>
<td>2003</td>
<td>Breakwaters</td>
<td>200</td>
<td>268</td>
</tr>
<tr>
<td>2003</td>
<td>Shore protection</td>
<td>300</td>
<td>402</td>
</tr>
</tbody>
</table>

Table 13-34: Yangshan terminals investments

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>1997 level</th>
<th>Year of expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>million $</td>
<td>million $</td>
</tr>
<tr>
<td>2003</td>
<td>730</td>
<td>978</td>
</tr>
<tr>
<td>2004</td>
<td>730</td>
<td>1,027</td>
</tr>
<tr>
<td>2005</td>
<td>603</td>
<td>890</td>
</tr>
<tr>
<td>2007</td>
<td>603</td>
<td>981</td>
</tr>
<tr>
<td>2008</td>
<td>844</td>
<td>1,443</td>
</tr>
<tr>
<td>2011</td>
<td>844</td>
<td>1,671</td>
</tr>
<tr>
<td>2014</td>
<td>611</td>
<td>1,400</td>
</tr>
<tr>
<td>2016</td>
<td>611</td>
<td>1,543</td>
</tr>
<tr>
<td>2018</td>
<td>770</td>
<td>2,146</td>
</tr>
<tr>
<td>2020</td>
<td>770</td>
<td>2,366</td>
</tr>
<tr>
<td>2021</td>
<td>581</td>
<td>1,874</td>
</tr>
<tr>
<td>2022</td>
<td>581</td>
<td>1,967</td>
</tr>
</tbody>
</table>

Table 13-35: Nanhui Zui terminals investments

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>1997 level</th>
<th>Year of expenditure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>million $</td>
<td>million $</td>
</tr>
<tr>
<td>2008</td>
<td>559</td>
<td>955</td>
</tr>
<tr>
<td>2013</td>
<td>559</td>
<td>1,219</td>
</tr>
<tr>
<td>2018</td>
<td>561</td>
<td>1,562</td>
</tr>
<tr>
<td>2021</td>
<td>561</td>
<td>1,808</td>
</tr>
</tbody>
</table>
### Table 13-36: Investment in shuttles

<table>
<thead>
<tr>
<th>Year of construction</th>
<th>Shuttles number</th>
<th>1997 level million $</th>
<th>Year of expenditure million $</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>2</td>
<td>19</td>
<td>27</td>
</tr>
<tr>
<td>2003</td>
<td>3</td>
<td>28</td>
<td>41</td>
</tr>
<tr>
<td>2004</td>
<td>4</td>
<td>30</td>
<td>47</td>
</tr>
<tr>
<td>2005</td>
<td>4</td>
<td>33</td>
<td>53</td>
</tr>
<tr>
<td>2006</td>
<td>4</td>
<td>36</td>
<td>61</td>
</tr>
<tr>
<td>2007</td>
<td>5</td>
<td>39</td>
<td>70</td>
</tr>
<tr>
<td>2008</td>
<td>5</td>
<td>42</td>
<td>80</td>
</tr>
<tr>
<td>2009</td>
<td>1</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>2010</td>
<td>3</td>
<td>21</td>
<td>44</td>
</tr>
<tr>
<td>2011</td>
<td>2</td>
<td>18</td>
<td>40</td>
</tr>
<tr>
<td>2012</td>
<td>2</td>
<td>20</td>
<td>45</td>
</tr>
<tr>
<td>2013</td>
<td>3</td>
<td>21</td>
<td>51</td>
</tr>
<tr>
<td>2014</td>
<td>3</td>
<td>23</td>
<td>57</td>
</tr>
<tr>
<td>2015</td>
<td>3</td>
<td>24</td>
<td>65</td>
</tr>
<tr>
<td>2016</td>
<td>3</td>
<td>26</td>
<td>73</td>
</tr>
<tr>
<td>2017</td>
<td>4</td>
<td>28</td>
<td>82</td>
</tr>
<tr>
<td>2018</td>
<td>4</td>
<td>30</td>
<td>93</td>
</tr>
<tr>
<td>2019</td>
<td>4</td>
<td>32</td>
<td>104</td>
</tr>
<tr>
<td>2020</td>
<td>4</td>
<td>35</td>
<td>118</td>
</tr>
<tr>
<td>2021</td>
<td>5</td>
<td>37</td>
<td>133</td>
</tr>
<tr>
<td>2022</td>
<td>5</td>
<td>40</td>
<td>149</td>
</tr>
<tr>
<td>2023</td>
<td>5</td>
<td>43</td>
<td>168</td>
</tr>
</tbody>
</table>

### Table 13-37: Total investments in the several elements throughout the years

<table>
<thead>
<tr>
<th>Year of expenditure</th>
<th>General million $</th>
<th>Yangshan million $</th>
<th>Nanhui Zui million $</th>
<th>Shuttles million $</th>
<th>Total million $</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>25</td>
<td>978</td>
<td>37</td>
<td>1,589</td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>737</td>
<td>1,027</td>
<td>42</td>
<td>1,069</td>
<td></td>
</tr>
<tr>
<td>2004</td>
<td>890</td>
<td>48</td>
<td>35</td>
<td>1,248</td>
<td></td>
</tr>
<tr>
<td>2005</td>
<td>55</td>
<td>55</td>
<td>11</td>
<td>1,121</td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td>63</td>
<td>1,443</td>
<td>73</td>
<td>2,471</td>
<td></td>
</tr>
<tr>
<td>2007</td>
<td>39</td>
<td>955</td>
<td>11</td>
<td>1,045</td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td>36</td>
<td>1,671</td>
<td>11</td>
<td>1,707</td>
<td></td>
</tr>
<tr>
<td>2009</td>
<td>41</td>
<td>1,219</td>
<td>11</td>
<td>1,265</td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td>41</td>
<td>1,400</td>
<td>11</td>
<td>1,452</td>
<td></td>
</tr>
<tr>
<td>2011</td>
<td>39</td>
<td>59</td>
<td>11</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td>39</td>
<td>59</td>
<td>11</td>
<td>59</td>
<td></td>
</tr>
<tr>
<td>2013</td>
<td>41</td>
<td>1,543</td>
<td>75</td>
<td>1,609</td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td>41</td>
<td>2,146</td>
<td>75</td>
<td>3,792</td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td>41</td>
<td>1,562</td>
<td>75</td>
<td>3,792</td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td>41</td>
<td>1,874</td>
<td>120</td>
<td>3,802</td>
<td></td>
</tr>
<tr>
<td>2017</td>
<td>41</td>
<td>1,808</td>
<td>120</td>
<td>3,802</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td>41</td>
<td>1,967</td>
<td>135</td>
<td>2,103</td>
<td></td>
</tr>
<tr>
<td>2019</td>
<td>41</td>
<td>1,53</td>
<td>153</td>
<td>153</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td>41</td>
<td>2,366</td>
<td>107</td>
<td>2,473</td>
<td></td>
</tr>
<tr>
<td>2021</td>
<td>41</td>
<td>1,874</td>
<td>120</td>
<td>3,802</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td>41</td>
<td>1,967</td>
<td>135</td>
<td>2,103</td>
<td></td>
</tr>
<tr>
<td>2023</td>
<td>41</td>
<td>1,53</td>
<td>153</td>
<td>153</td>
<td></td>
</tr>
</tbody>
</table>
Simulation model
Appendix XIX  Detailed module description

In this appendix the detailed programming will be discussed. First, to give more insight in
the program, the main assumptions made within the simulation will be given. With these
assumptions in mind, the below described processes can be better understood.

Assumptions:
- Containers, coming off a vessel, are dumped all at once in the various stacks after
  the vessel has waited during the total unloading time.
- Containers to be loaded, are taken from the stack all at once after the vessel has
  waited during the total loading time.
- The cranes that serve the vessels have a constant speed of handling.
- Internal transport and transport between the terminals is not considered within the
  model.
- For the ocean and shortsea vessels it takes 100 and 60 minutes respectively to
  reach the berth from the anchorage.
- For the River barges and shuttles it takes 30 minutes to reach the berth from the
  anchorage.
- The anchorage and approach channel can hold an unlimited number of vessels.
- Quay length is not considered, only berths are.
- Each berth can hold only one vessel.
- The vessel's length is not considered.
- The average distance from the terminals of Shanghai to Yangshan is 41 miles.
- The trucks and trains arrive at the satellite terminals regardless of the presence of an
  ocean or shortsea vessel.

Programming:
Along with these assumptions the detailed programming can be described. As has
already been discussed in paragraph 8.5.2, Prosim works with components that take
care of the processes of several almost identical elements. The actual programming of
these components can be found in so called “modules”. In total there are 12 modules. Of
these 12 modules, 5 modules deal with processes like the generation of input and
output. These modules are:

1. Mainmod  (Handles the activation of all other modules)
2. Controlbox (Handles the way some input is given by the user)
3. Storemod  (Handles the storage of data in files during simulation)
4. Justifier  (Handles the correction of round off errors)
5. Outputmod (Handles the storage of data in files at the end of a simulation)

The other 7 are used for programming the components that are discussed in paragraph
0. These modules are:

6. Extocmod  (Handles the ocean vessel component)
7. Extshortvmod (Handles the shortsea vessel component)
8. Extrivermod (Handles the river vessel component)
9. Nzshuttlemod (Handles the Nanhui Zui shuttle component)
10. Shshuttlemod (Handles the Shanghai shuttle component)
11. Trucknzm (Handles the Nanhui Zui truck component)
12. Truckshmod (Handles the Shanghai truck and train component)

In the following few sections the modules are described. To be able to find the actual
programming of the described processes, the description is made according to the
programming lines within the modules. These “lines” are all numbered and can be found
in Appendix XX. For a rough visual description of the activities of some of the modules, some flowcharts have been added to the description.

The module called "MAINMOD" is the module in which the "core" of the program is written. This module initialises the other modules and activates them. While this module forms the starting point of the simulation, it will be described as first here.

**Mainmod**

As has already been discussed, this module sets the main variables of the program and activates the other modules. In the following sections only a rough description can be found of the elements within this module. The actual programming lines can be found in Appendix XX.

For a general overview a flowchart of the several processes can be found in .

![Flowchart](image)

**Figure 13-9: General overview of the module Mainmod**

Line 1 – 22  
In this first part of the module the module “Controlbox” is activated with which the user can give input to the program. Once the user has given the input, this input is being processed.

Line 24 – 40  
Between these lines the properties of the terminals of Shanghai are given. These properties are the initial stack sizes of all stacks, and the number and speed of the cranes servicing the Shanghai shuttles.

Line 41 – 64  
Between these lines the same variables are set for the properties of Nanhui Zui as for the properties of Shanghai. Only this time the variables are read from an input file.

Line 65 – 143  
Between these lines the variables are set for all Yangshan terminals. Like for the Nanhui Zui terminals this is done via input files.

Line 144 – 159  
At this point the variables of the shuttle barges sailing between Nanhui Zui and Yangshan are set according to the values of an input file.

Line 161 – 176  
The same for the shuttles sailing to Shanghai
Line 178 – 203
Between these lines the properties of the river barges, the ocean vessels and the shortsea vessels are set according to an input file.

Line 205 – 317
Between these lines some monitoring facilities of the program are set.

Line 319 – 338
At this point some distributions are attached to variables that later on take care of the inter arrival times and loads of the various vessels.

Line 340 – 349
Between these lines all other modules are activated and the program starts the simulation.

Line 351 – 356
At this point the module concerning the generation of output is activated and the simulation is ended.

**Controlbox**
This module gives the user the opportunity to manually give input to the simulation. This input concerns the following variables:
- The number of shuttles sailing to and from both satellite terminals
- The number of berths per terminal at Nanhui Zui
- The number of berths per terminal at Yangshan
- The simulation time in months

**Storemob**
This module takes care of registering some variables according to which each simulation is altered.

Line 3 – 8
The registering takes place every 4 hours.

Line 9 – 30
Between these lines the registration of the average waiting times of the various vessels takes place.

Line 31 – 91
Between these lines the registration of the number of containers in stack of all stacks takes place.

Line 93 – 101
Between these lines the registration of the average properties of the various vessel groups takes place. These properties are the average capacity and the average inter arrival time.

**Justifier**
In this module the known error per day as has been determined in 8.5.3 is rectified.

Line 4 – 23
The error made in the supply and removal of containers at Nanhui Zui is rectified.

Line 24 – 45
The error made in the supply and removal of containers at Shanghai is rectified.
Outputmod

In this module the output is generated and put into output files.

Line 1 – 47
The annual throughput of all transport modalities and terminals is calculated.

Line 48 – 82
Between these lines the output files are created.

Line 84 – 222
Between these lines the data generated by the program is converted to data that can be put in the output files.

Line 225 – 371
Between these lines some general values are put into the file "general.txt". This file is filled with data concerning the following variables:
- Input parameters with which the program has been simulating
- Total annual throughput of the transport modalities and the terminals
- Maximum stack sizes of each stack
- Minimum stack sizes of each stack
- Average waiting time per Yangshan terminal per transport modality
- Number of arrivals and departures at Yangshan

Line 373 – 387
Between these lines the stack sizes per 4 hours of the satellite terminals are put into the file "nzhstacks.txt"

Line 390 – 402
Between these lines the stack sizes per 4 hours of all Yangshan terminals are put into 6 different files.

Line 416 – 424
Between these lines the average waiting times of the shuttles at Nanhui Zui are put into the file "wtoutnzterms.txt".

Line 426 – 436
Between these lines the average values of the various vessel properties are put into the file "avgvalues.txt". These properties are the average capacity and the inter arrival time of the vessel.

Exttoceanmod

Line 11 – 22
Before the ocean vessel can be put into the program, its arrival time should be determined. For the ocean vessel group an Erlang-4 distribution is therefore used.

Line 24 – 74
Between these lines the destination of the vessel is determined. Dependent on the next destinations after Shanghai, a terminal will be chosen while all terminals have stacks for a specific destination. These choices depend on the division of containers over the various Yangshan terminals.

Line 75 – 90
Between these lines the capacity of the vessel is determined. A linear distribution is used where the lower boundary is set at 2000 TEU and the upper boundary is set at 12500 TEU. The average capacity of these vessels is 5592 TEU.
Line 91 - 102
With use of the parcel size, an number of containers is calculated that will be disposed off at Yangshan. At this part also the number of containers that will be taken from Yangshan is calculated. Furthermore these values are monitored.

Line 104 - 113
The properties of the vessel are used to determine the average values for all ocean vessels to be able to determine the error caused by the deviating averages (See 8.5.3).

Line 114 - 121
The vessel is activated and put into the system.

Line 126 - 142
The vessel enters the anchorage and determines whether there is a berth available at its terminal. If no berth is available, the vessel waits for 10 minutes and then repeats this procedure until a berth is available. This available berth will then turn from the "available" status to the "occupied" status. When a vessel has to wait, it adds the waiting time to its total waiting time.

Now the vessel has found a berth it sails towards that berth. This takes 100 minutes and will be recorded as a part of the total service time of this vessel.

Line 144 - 192
Once the vessel has berthed, it starts to unload its containers destined for Yangshan. The containers coming off the vessel are divided over the various stacks. This division is preset. Only a small part of the containers coming off the ocean and short sea vessels will be distributed to other terminals as they are transshipment containers. The time to unload the vessel is added up to the total service time of the vessel. Furthermore the number of containers is added up to the total throughput of the vessel group and the terminal.

Line 194 - 293
In this part it is determined whether the various stacks have reached a maximum or a minimum up till now. If so, this stack size will be recorded as the largest or the smallest.

Line 295 - 330
In this part the loading process of the vessel is described. (See also Error! Reference source not found. for a quick overview of this process). The vessel starts to load containers from its own stack. In case there are no containers available, the vessel waits at the quay until there are enough containers to be loaded. The amount of time this loading process takes is added up to the total service time of the vessel. Also the number of loaded containers is added up to the total throughput of the ocean services group and the terminal.
Figure 13-10: Flowchart of the loading process of the ocean vessels

At the moment the vessel has received its ordered containers, it sails away. This process takes approximately 100 minutes and will be added up to the total service time of the vessel. During this time the berth remains occupied. After this time, the berth will become available for other ocean vessels.

Line 332 – 350
In the first part the total waiting time of the vessel, determined during waiting for a quay and for containers, will be divided by the total service time of this vessel. After this calculation, the total waiting time as percentage of the total service time of all ocean vessels calling at this terminal is calculated.

Line 352
Finally the vessel will be terminated while it has left the terminal.

Extshortseamod
While this module is almost the same as Extoceanmod, this module is described according to that module. At the moment this module differs from Extoceanmod a remark will be made.

Line 11 – 22
(See lines 11 – 22 of Extoceanmod)
For the Short sea services group an Erlang-2 distribution is used. For the river barges a terminal is chosen for which that barge carries containers.

Line 24 - 70
(See Extoceanmod lines 24 – 74)
Line 71 – 76
(See Extocceanmod lines 75 – 90)
For the Short sea vessels a uniform distribution is used to determine the capacity. The boundaries of this distribution lie between 500 and 2000 TEU.

Line 77 – 88
(See Extocceanmod lines 91 – 102)

Line 90 – 99
(See Extocceanmod lines 104 – 113)

Line 100 – 107
(See Extocceanmod lines 114 – 121)

Line 116 – 126
(See Extocceanmod lines 126 – 142)
It takes 60 minutes for the shortsea vessel to reach the berth.

Line 128 – 175
(See Extocceanmod lines 144 – 192)

Line 177 – 275
(See Extocceanmod lines 194 – 293)

Line 277 – 313
(See Extocceanmod lines 295 – 330)
It takes 60 minutes for the shortsea vessel to leave the berth.

Line 315 – 336
(See Extocceanmod lines 332 – 350)

Line 338
Finally the vessel is terminated while it has left the terminal

Extrivermod
While this module is almost the same as Extocceanmod, this module is described according to that module. At the moment this module differs from Extocceanmod a remark will be made.

Line 11 – 22
(See lines 11 – 22 of Extocceanmod)
For the river barges a negative exponential distribution is used.

Line 24 – 54
(See Extocceanmod lines 24 – 74)

Line 57 – 61
(See Extocceanmod lines 75 – 90)
For the river barges a uniform distribution is used to determine the capacity. The boundaries of this distribution lie between 100 and 140 TEU.

Line 63 – 74
(See Extocceanmod lines 91 – 102)

Line 76 – 85
(See Extocceanmod lines 104 – 113)
Line 86 – 93
(See Ext-oceanmod lines 114 – 121)

Line 96 – 110
(See Ext-oceanmod lines 126 – 142)
For the river barges it takes 30 minutes to sail towards the berth.

Line 112 – 165
(See Ext-oceanmod lines 144 – 192)

Line 167 – 219
(See Ext-oceanmod lines 194 – 293)

Line 221 – 253
(See Ext-oceanmod lines 295 – 330)
For the river barges it takes 30 minutes to sail away from the berth.

Line 255 – 276
(See Ext-oceanmod lines 332 – 350)

Line 278
Finally the river barge is terminated while it has left the terminal

NZshuttlemod
Line 1 – 66
Between these lines the shuttle makes a choice for a terminal at Nanhui Zui. At the moment no quay is available, the shuttle waits for 10 minutes at the anchorage and then checks the availability again. When a quay and stack has been found, the shuttle reserves the quay and a part of the stack and sails in 30 minutes to the berth (See flowchart in Error! Reference source not found.).

Figure 13-11: Process of the arrival of a shuttle at its satellite terminal

Line 67 – 76
The shuttle unloads its containers. All containers are stacked in the truck stack of that terminal.

Line 79 – 93
In this part it is determined whether the various stacks have reached a maximum or a minimum up till now. If so, this stack size will be recorded as the largest or the smallest.

Line 95 - 120
In this part the shuttle is loaded from the stack it has chosen. If the stack holds enough containers to load the shuttle to capacity, it takes these containers from the stack and loads the vessel. If the stack does not hold enough containers to fill the shuttle completely, the shuttle is only partially loaded with all containers in stack. As long as the shuttle is not fully loaded it checks for containers every 10 minutes until it is fully loaded.
At the moment the shuttle is loaded it takes 30 minutes to deberth and sail away from the berth. After this period of time the quay turns from the "occupied" status to the "available" status.

Line 122 – 138
Between these lines the total waiting time of the shuttle and average waiting time of the terminal in minutes is calculated to monitor the queues. Furthermore the loaded containers are added up to the total throughput of the terminal and the Nanhui Shuttle service.

Line 140 – 144
While fully loaded, the shuttle sails towards Yangshan.

Line 145 – 155
Once the shuttle has arrived at Yangshan, it sails towards the terminal it has been appointed to. If a berth is available, the shuttle sails towards this berth in 30 minutes and the berth will become "occupied". In case no berth is available, it wait for 10 minutes and then checks again. The shuttle will repeat this until a berth is available. Every time the shuttle has to wait for a berth, the waiting time is added up to the total waiting time of the shuttle.

Line 157 – 231
The shuttle unloads its contents to the several ocean stacks and short sea stacks at the terminal it has berthed according to a preset division.

Line 233 – 285
Within these lines a check is made whether the ocean and short sea stacks are at their maximum up till now. If they are, the maximum stack sizes are updated.

Line 287 – 318
The shuttle loads containers from its stack and sails towards Nanhui Zui at the moment it is fully loaded or the stack is empty. At the moment the shuttle sails away, it takes 30 minutes to deberth and sail away from the quay. After this time the berth will become available.
Figure 13-12: Loading process of the Nanhui Zui shuttle at Yangshan.

Line 320 – 331
Between these lines the total waiting time of the shuttle and the average waiting time of the terminal are calculated in minutes. Furthermore the loaded number of containers is added up to the total throughput of the terminal and of the Nanhui Zui shuttle service.

Line 333 – 339
The shuttle sails towards the Nanhui Zui terminal.

Line 341 – 350
In this part the shuttles are generated and released every half hour.

SHshuttlemod
While this module is almost the same as NZshuttlemod, this module is described according to that module. At the moment this module differs from NZshuttlemod a remark will be made.

Line 1 - 40
(See NZshuttlemod lines 1-66)
The SHshuttlemod differs at this point from the NZshuttlemod while the Shanghai shuttle does not choose a terminal at Shanghai. Only a stack is chosen and the shuttle directly sails towards this stack.

Line 42 - 54
(See NZshuttlemod lines 67 - 76)
For the shuttles sailing to Shanghai, the import contents of the shuttle will be divided over the truck stack and the train stack.

Line 56 - 76
(See NZshuttlemod lines 79 – 93)

Line 78 - 99
(See NZshuttlemod lines 95 - 120)

Line 101 - 104
(See NZshuttlemod lines 122 - 138)
Line 106 - 109
(See NZshuttlemod lines 140 - 144)

Line 111 - 121
(See NZshuttlemod lines 145 - 155)

Line 125 - 198
(See NZshuttlemod lines 157 - 231)

Line 200 - 251
(See NZshuttlemod lines 233 - 285)

Line 253 - 282
(See NZshuttlemod lines 287 - 318)

Line 284 - 297
(See NZshuttlemod lines 320 - 331)

Line 299 - 305
(See NZshuttlemod lines 333 - 339)

Line 307 - 316
(See NZshuttlemod lines 341 - 350)

**TruckNZmod**

![Flowchart](image)

**Figure 13-13: Flowchart for the general activities of the trucks at Nanhui Zui**

Line 3 - 12
The containers brought in by the trucks every 10 minutes are divided over the various shuttle stacks at Nanhui Zui terminal 1. These containers are added to the total throughput of the terminal and the truck service.

Line 13 - 18
The trucks check whether there are containers in their stack. If there are, they take a preset number of containers with them as they leave the terminal.

Line 20 - 46
In this part it is determined whether the various stacks have reached a maximum or a minimum up till now. If so, this stack size will be recorded as the largest or the smallest.

Line 48 - 57
The containers brought in by the trucks every 10 minutes are divided over the various shuttle stacks at Nanhui Zui terminal 2. These containers are added to the total throughput of the terminal and the shuttle service.

Line 59 - 64
The trucks check whether there are containers in their stack. If there are, they take a preset number of containers with them as they leave the terminal.

Line 66 - 91
In this part it is determined whether the various stacks have reached a maximum or a minimum up till now. If so, this stack size will be recorded as the largest or the smallest.

Line 93
The module waits for 10 minutes and then repeats its process.

**TruckSHmod**

Line 3 - 15
(See TruckNZmod lines 3 - 12)

Line 17 - 22
(See TruckNZmod lines 13 - 18)

Line 24 - 36
The containers brought in by the trains every 10 minutes are divided over the various shuttle stacks. These containers are added to the total throughput of the terminal and the train service.

Line 38 - 43
The trains check whether there are containers in their stack. If there are, they take a preset number of containers with them as they leave the terminal.

Line 45 - 89
(See TruckNZmod lines 20 - 46)

Line 91
The module waits for 10 minutes and then repeats its process.
Appendix XX  Program listing

In the following few pages first the used variables are listed after which the actual programming can be found. It should be noted that some programming lines are longer than the width of the pages allows. To still be able to read these lines a disk has been added to this report at which a copy of the program can be found. At this disk also the input files can be found.
Programming
Parameters
DEFINE

COMPONENT

MAIN

INTEGER
I
J
NR_TERM_YS
NR_TERM_NZ
DIST_SH_YS
DIST_NZ_YS
N
L
K
MAXST
OCEANJUSTIFIER
SHJUSTIFIER
NZJUSTIFIER
NR_NZ_SHUT_Q[2]
Z
NR_NZSHUTYS_Q[6]
NR_SHSHUTYS_Q[6]
NR_OCEAN_Q[6]
NR_SS_Q[6]
NR_RIVER_Q[6]
TERCOUNT
TOOFEW_RIVER[6]

LONG
TOTANUTPSH
TOTANUTPZN
TOTANUTPOEXP
TOTANUTPOIMP
TOTANUTPTRANS
TOTANUTPO
TOTANUTPSSEX
TOTANUTPSSIMP
TOTANUTPSTRANS
TOTANUTPSS
TP_SH
TP_SSEX
TP_SSIMP
TP_STRANS
TP_SS
TP_TRUCKSIMP
TP_TRUCKNZIMP
TP_TRAINSHIMP
TOTPTRUCKSHIMP
TOTPTRUCKNZIMP
TOTPTRAINSHIMP
TOTPTRUCKSHEXP
TOTPTRUCKNZEXP
TOTPTRAINSNZEXP
TP_TRUCKNZEXP
TP_TRUCKSHEXP
TP_TRAINSHEXP
TP_RIVEREXP
TP_RIVERIMP
TOTANUTPRIVERIMP
TOTANUTPRIVEREXP
TOTANUTPSHUTNZIMP
TOTANUTPSHUTNZEXP
TOTANUTPSHUTSHIMP
TOTANUTPSHUTSHEXP
TP_OTRANS
TP_OIMP
TP_OEXP
TP_O
S
O
RIV
AMRIV
AMO
AMS
TOTANNTPYS[5]
SHORTNR
RIVNR
OCNR
REAL
ERLANGSAMPLE[4]
INTERARR
SIMTIME
TIME
CHARACTER
CHAR[5]
TERMCOUNT[2]
RUNSTR[4,1]
INPUTSTR[9,7,3]
TOTANNTPSTR[23,8]
TIMER[43200,7]
STNZ[43200,16,7]
STSH[43200,9,7]
AVGDATA[43200,6,6]
SHPCOUNTOUT[7,5,6]
SHPCOUNTIN[7,5,6]
COUNTIN[7,5,6]
COUNTOUT[7,5,6]
ANNUTPTSTR[7,5,8]
REFERENCE TO DASTREAM
TERMPROPYS
TERMPROP
TRANSOP
SHUTNZPROP
SHUTSHPROP
TERMPROPNZ
NZSTACKSOUT
GENERAL
WTOUTYS[7]
WTOUTN
AVGVALUES
YSSSTACKOUT[7]
INDIVIWTSYS[6]
REFERENCE TO DISTRIBUTION
UNIFS
UNIFOCEAN
UNIFRIVER
REFERENCE TO WINDOW
CONTROL
VESEL_LOADS
REFERENCE TO WOB
B_OK
STR_AMTERMYS
PRM_AMTERMYS
PRM_AMTERMNZ
STR_AMTERMNZ
STR_SIMTIME
PRM_SIMTIME
PRM_AMNZQYS
PRM_AMRIVERQ
PRM_AMOCEANQ
PRM_AMSSQ
PRM_SHUTS
STR_AMNZQ[2]
PRM_AMNZQ
PRM_YS
PRM_NANHUI
PRM_TERMNRNZ[2]
PRM_AMSHQYS
PRM_TERMNRYS[6]
STR_AMNZQYS[6]
STR_AMRIVERQ[6]
STR_AMSHQYS[6]
STR_AMOCEANQ[6]
STR_AMSSQ[6]
REFERENCE TO NANHUI_TERM
TERM_NZ[2]
REFERENCE TO YANGSHAN_TERM
TERM_YS[6]

SHANGHAITERM
INTEGER
SH_SHUT_CRANE
LONG
SH_RAIL_ST
SH_TRUCK_ST
MIN_SH_RAIL_ST
MAX_SH_RAIL_ST
MIN_SH_TRUCK_ST
MAX_SH_TRUCK_ST
SH_TERM_ST[6]
MIN_SH_TERM_ST[6]
MAX_SH_TERM_ST[6]
REAL
SH_SHUT_CRANES
CHARACTER
MINSTACKSH[8,7]
MAXSTACKSH[8,7]
ANNUTPSTSRSH[8]
REFERENCE TO POINTSTREAM
SHSHUTST[6]

OGEN
INTEGER
BIGGESTOSTNR
LONG
BIGGESTOST
COUNTO
WKDIFF_OC[6]
WKTP_OC[6]
REAL
INTARR_OCEAN
MN_ARR_OCEAN
OCEANLSAMPLE
PS_IMP_OCEAN
PS_EXP_OCEAN
DETOCEAN
AVG_O_CAP
AVG_O_INTARR
TOT_O_INTARR
TOT_O_CAP
REFERENCE TO POINTSTREAM
PSTROCEANLEXP

PSTROCEANLIMP
REFERENCE TO DISTRIBUTION
OCEANL
REFERENCE TO WINDOW
WTOQ
WTOANC
ST_SIZE02
ST_SIZE01
REFERENCE TO OCEAN
NEXT_OCEAN
SSGEN
INTEGER
MIN_L_SS
MAX_L_SS
BIGGESTSSSTNR
LONG
BIGGESTSSST
COUNTSS
WKDIFF_SS[6]
WKTP_SS[6]
REAL
MN_ARR_SS
INTARR_SS
PS_IMP_SS
PS_EXP_SS
DESTSS
AVG_SS_CAP
AVG_SS_INTARR
TOT_SS_CAP
TOT_SS_INTARR
REFERENCE TO POINTSTREAM
PSTRSSL_EXP
PSTRSSL_IMP
REFERENCE TO DISTRIBUTION
SSL
REFERENCE TO WINDOW
WTSSANC
WTSSQ
ST_SIZESS2
ST_SIZESS1
REFERENCE TO SS
NEXT_SS
RIVERGEN
INTEGER
MAX_L_RIVER
MIN_L_RIVER
LONG
COUNTRIVER
REAL
INTARR_RIVER
MN_ARR_RIVER
PS_IMP_RIVER
PS_EXP_RIVER
DESTRIVER
AVG_RIVER_CAP
AVG_RIVER_INTARR
TOT_RIVER_CAP
TOT_RIVER_INTARR
EXTRARIV_OC[6]
EXTRARIV_SS[6]
AVGEXTRARIV[6]
NEWAMRIV[6]
DELAYRIV[6]
REFERENCE TO POINTSTREAM
PSTRIVERL_EXP
PSTRIVERL_IMP
REFERENCE TO DISTRIBUTION
RIVERL
REFERENCE TO WINDOW
WTRIVERANC
WTRIVERQ
ST_SIZERIVER
REFERENCE TO RIVER
NEXT_RIVER
NZSHUTGEN
INTEGER
NR_SHUT_NZ
SHUTCREATENZ
BIGGESTNZTERMNR
BIGGESTNZSTNR
NZST
LONG
BIGGESTNZST
CHARACTER
AVGWTNZ[43200,2,10]
REFERENCE TO WINDOW
USEDNZTERMSYS
AVWTNZSHUT
AVWTNZSHUTYS
WTNZQ
NZSHUTSTSYS
SHUTSTSNNZ2
SHUTSTSNNZ1
REFERENCE TO WOB
PRM_AMNZSHUT
STR_AMNZSHUT
REFERENCE TO NZSHUT
MNZSHUT[100]

SHSHUTGEN
INTEGER
NR_SHUT_SH
SHUTCREATESH
BIGGESTSHSTNR
SHST
LONG
BIGGESTSHST
REFERENCE TO WINDOW
USEDSHTERMSYS
AVWTSHSHUTYS
SHUTSTSSSH
SHSHUTSTSYS
REFERENCE TO WOB
PRM_AMSHSHUT
STR_AMSHSHUT
REFERENCE TO SHSHUT
MSHSHUT[100]

TRUCKGENNZ
TRUCKGENSH
STORING
JUSTIFY
COUNTING

CLASS
NANHUI_TERM
INTEGER
NZ_SHUT_CRANEA
NZ_SHUT_Q
NZ_SHUT_OCCQ
LONG
NZ_TRUCK_ST
MIN_NZ_TRUCK_ST
MAX_NZ_TRUCK_ST
ANNU_TP_NZ
TP_NZ
NZ_TERM_ST[6]
MIN_NZ_TERM_ST[6]
MAX_NZ_TERM_ST[6]
NRARRIVALNZ
REAL
NZ_SHUT_CRANES
AVGWT_NZSHUTNZ
TWT_NZSHUTNZ
CHARACTER
MINSTACKNZ[7,7]
MAXSTACKNZ[7,7]
ANNUTPSTRNZ[8]
REFERENCE TO POINTSTREAM
W_TIME_NZQNZ
W_TIME_NZ
NZSHUTST[6]
YANGSHAN_TERM
INTEGER
YS_SS_CRANE
YS_OCEAN_CRANE
YS_SHUT_SH_CRANE
YS_SHUT_NZ_CRANE
YS_RIVER_CRANE
YS_OCEAN_Q
YS_SHUT_SH_Q
YS_RIVER_Q
YS_SHUT_SH_OCCQ
YS_SHUT_NZ_OCCQ
YS_RIVER_OCCQ
YS_SS_OCCQ
YS_OCEAN_OCCQ
YS_SHUT_NZ_OCCQ
YS_SS_Q
LONG
YS_SHUT_NZ_ST
YS_RIVER_ST
YS_SHUT_SH_ST
MIN_YN_SHUT_NZ_ST
MAX_YN_SHUT_NZ_ST
MIN_YN_RIVER_ST
MAX_YN_RIVER_ST
MIN_YN_SHUT_SH_ST
MAX_YN_SHUT_SH_ST
ANNU_TP_NY
YS_OCEAN_ST[2]
YS_SS_ST[2]
MIN_YN_OCEAN_ST[2]
MAX_YN_OCEAN_ST[2]
MIN_YN_SS_ST[2]
MAX_YN_SS_ST[2]
OCEANCOUNTIN
OCEANCOUNTOUT
SSCOUNTIN
SSCOUNTOUT
RIVERCOUNTIN
RIVERCOUNTOUT
NRNZARRIVALYS
NRSHARRIVALYS
OCIN
OCOUT
SSIN
SSOUT
RIIIN
RIOUT
AM_YSHUT_NZ
AM_YSHUT_SH
OLDIMPORT_0
EXPORT_0
IMPORT_0
OLDIMPORT_SS
EXPORT_SS
IMPORT_SS
TP_YS[5]

REAL
YS_OCEAN_CRANES
YS_SS_CRANES
YS_RIVER_CRANES
YS_SHUT_SH_CRANES
YS_SHUT_NZ_CRANES
AVG_OCEANALL
AVG_SSALL
AVG_RIVERALL
AVGWT_NZSHUTYS
AVGWT_SHSHUTYS
WPERC_OCEANALL
WPERC_SSALL
WPERC_RIVERALL
TWT_NZSHUTYS
TWT_SHSHUTYS

CHARACTER
MINSTACKYS[8,7]
MAXSTACKYS[8,7]
ANNUTPSTRYS[8]
STYS[43200,7,7]
AVGWTCHAR[43200,5,10]
TERMEXPORT[2,8]
TERMIMPORT[2,8]
HTCHAR[30000,3,7]

REFERENCE TO POINTSTREAM
NZSHUTSTYS
SHSHUTSTYS
RIVERST
W_TIME_SHYS
W_TIME_NZYS
OCEANST[2]
SSST[2]
W_TIME_OQ
W_TIME_0
W_TIME_SS
W_TIME_SSQ
W_TIME_RIVER
W_TIME_RIVERQ

OCEAN
INTEGER
YSFOUNDOCEAN
OCEANDISTRI
ACTDESTOCEAN
ACTTERMEOCEAN
ORDOCEANL_EXP
NZTRIPCOUNT
ACT_NZSHUT_L_EXP
ACT_NZSHUT_L_IMP
LONG
TP_NZSHUTEXP
TP_NZSHUTIMP
REAL
MNSPEED_NZSHUT
WT_NZSHUTNZANC
WT_NZSHUTYSANC
WT_NZSHUTNZQ
REFERENCE TO POINTSTREAM
USEDYSTERMSNZ
SHSHUT
INTEGER
MAXSHSHUTCONT
YSFOUNDSHUTSH
ACTTERMSSHUTYS
SHTRIPCOUNT
ACTSTSHUTSH
ACT_SSHUT_L_IMP
ACT_SSHUT_L_EXP
LONG
TP_SSHUTEXP
TP_SSHUTIMP
REAL
MNSPEED_SSHUT
WT_SSHUTYSANC
REFERENCE TO POINTSTREAM
USEDYSTERMSSH
EXTERNAL
TIMEUNIT
MINUTE
Module

Mainmod
JUMP TO controlbox

FOR i=1 TO 2
   nr nz_shut_q[i] ← nr nz_shut_q[i]
END

FOR i=1 TO 6
   nr ocean_q[i] ← nr ocean_q[i]
   nr ss_q[i] ← nr ss_q[i]
   nr nzshutys_q[i] ← nr nzshutys_q[i]
   nr river_q[i] ← nr river_q[i]
   nr nzshutys_q[i] ← nr nzshutys_q[i]
END

HIDE control

FOR i=1 TO nr term ys
   sh term st[i] ← NEW POINTSTREAM
   min sh term_st[i] ← NEW POINTSTREAM
   shshutst[i] ← NEW POINTSTREAM
END

ATTACH "nanhui_zui.properties.txt" TO termpropnz

OPEN termpropnz FOR INPUT

FOR i=1 TO nr term nz
   term NZ[i] ← NEW nanhui_term CALLED READ FROM termpropnz
   NZ shut_q ← term NZ[i] ← NEW POINTSTREAM
   NZ shut cranes ← term NZ[i] ← READ FROM termpropnz
   NZ shut cranes ← term NZ[i] ← READ FROM termpropnz
   NZ truck st ← term NZ[i] ← READ FROM termpropnz
   min NZ truck st ← term NZ[i] ← 100000
END

FOR j=1 TO nr term ys
   NZ term st[j] ← READ FROM termpropnz
   min NZ term st[j] ← 100000
END

w time nzqnz ← NEW POINTSTREAM
w time nz ← NEW POINTSTREAM
CLOSE termpropnz

termprops ← NEW DATASTREAM

ATTACH "yangshanproperties.txt" TO termprops

OPEN termprops FOR INPUT

FOR i = 1 TO nr_term_y

    term_y[i] ← NEW yangshan_term CALLED READ FROM termprops

    ys_ocean_cranea OF term_y[i] ← READ FROM termprops

    ys_ocean_cranes OF term_y[i] ← READ FROM termprops

    ys_ss_cranea OF term_y[i] ← READ FROM termprops

    ys_ss_cranes OF term_y[i] ← READ FROM termprops

    ys_shut_nz_cranea OF term_y[i] ← READ FROM termprops

    ys_shut_nz_cranes OF term_y[i] ← READ FROM termprops

    ys_river_cranea OF term_y[i] ← READ FROM termprops

    ys_river_cranes OF term_y[i] ← READ FROM termprops

    ys_shut_sh_cranea OF term_y[i] ← READ FROM termprops

    ys_shut_sh_cranes OF term_y[i] ← READ FROM termprops

    ys_ocean_st[1] OF term_y[i] ← READ FROM termprops

    min_y_ocean_st[1] OF term_y[i] ← 1000000

    IF i = 2

        min_y_ocean_st[2] OF term_y[i] ← 1000000

    END

    IF i = 3

        min_y_ocean_st[2] OF term_y[i] ← 1000000

    END

    IF i = 6

        min_y_ocean_st[2] OF term_y[i] ← 1000000

    END

    ys_ss_st[1] OF term_y[i] ← READ FROM termprops

    min_y_ss_st[1] OF term_y[i] ← 1000000

    IF i = 5


    END

    IF i = 6


    END

    ys_shut_nz_st OF term_y[i] ← READ FROM termprops

    min_y_shut_nz_st OF term_y[i] ← 1000000

    ys_river_st OF term_y[i] ← READ FROM termprops

    min_y_river_st OF term_y[i] ← 1000000

    ys_shut_sh_st OF term_y[i] ← READ FROM termprops

    min_y_shut_sh_st OF term_y[i] ← 1000000

    ys_ocean_q OF term_y[i] ← nr_ocean_q[i]

    ys_ss_q OF term_y[i] ← nr_ss_q[i]

    ys_shut_nz_q OF term_y[i] ← nr_nzshutys_q[i]

    ys_river_q OF term_y[i] ← nr_river_q[i]

    ys_shut_sh_q OF term_y[i] ← nr_shshutys_q[i]

    w_time_o OF term_y[i] ← NEW POINTSTREAM
w_time_ss  OF term_ys[i]  - NEW POINTSTREAM
w_time_river  OF term_ys[i]  - NEW POINTSTREAM
w_time_nzys  OF term_ys[i]  - NEW POINTSTREAM
w_time_shys  OF term_ys[i]  - NEW POINTSTREAM
w_time_oq  OF term_ys[i]  - NEW POINTSTREAM
w_time_ssq  OF term_ys[i]  - NEW POINTSTREAM
w_time_riverq  OF term_ys[i]  - NEW POINTSTREAM
riverst  OF term_ys[i]  - NEW POINTSTREAM
nzshutstys  OF term_ys[i]  - NEW POINTSTREAM
shshutstys  OF term_ys[i]  - NEW POINTSTREAM

END

CLOSE termpropys

@----------------------------------------@
Nanhui Zui shuttle properties @
@----------------------------------------@

shutnzprop  - NEW DATASTREAM
ATTACH "shuttle.nzproperties.txt" TO shutnzprop
OPEN shutnzprop FOR INPUT

FOR i - 1 TO nr_shut.nz
Mnzshut[i]  - NEW nzshut CALLED READ FROM shutnzprop
maxnzhutcont  OF Mnzshut[i]  - READ FROM shutnzprop
mnspeed_nzshut  OF Mnzshut[i]  - READ FROM shutnzprop
nztripcount  OF Mnzshut[i]  - 0
usedystermnsz  OF Mnzshut[i]  - NEW POINTSTREAM
END

CLOSE shutnzprop

dist_NZ_YS  - 19  @miles@

@----------------------------------------@
Shanghai shuttle properties @
@----------------------------------------@

shutshprop  - NEW DATASTREAM
ATTACH "shuttle.shproperties.txt" TO shutshprop
OPEN shutshprop FOR INPUT

FOR i - 1 TO nr_shut.sh
Mshshut[i]  - NEW shshut CALLED READ FROM shutshprop
maxshshutcont  OF Mshshut[i]  - READ FROM shutshprop
mnspeed_shshut  OF Mshshut[i]  - READ FROM shutshprop
shtripcount  OF Mshshut[i]  - 0
usedystermssh  OF Mshshut[i]  - NEW POINTSTREAM
END

CLOSE shutshprop

dist_sh_YS  - 40  @miles@

@----------------------------------------@
Transport properties of various modalities @
@----------------------------------------@

transprop  - NEW DATASTREAM
ATTACH "transport.properties.txt" TO transprop
OPEN transprop FOR INPUT

mn_arr_river  - READ FROM transprop
mn_arr_ocean  - READ FROM transprop
mn_arr_ss ← READ FROM transprop
min_l_river ← READ FROM transprop
min_l_ss ← READ FROM transprop
max_l_river ← READ FROM transprop
max_l_ss ← READ FROM transprop
ps_imp_river ← READ FROM transprop
ps_imp_ocean ← READ FROM transprop
ps_imp_ss ← READ FROM transprop
ps_exp_river ← READ FROM transprop
ps_exp_ocean ← READ FROM transprop
ps_exp_ss ← READ FROM transprop

CLOSE transprop

@  ---------------------------@
@  Sets to monitor the transport modalities  @
@  ---------------------------@

pstroceanlimp ← NEW POINTSTREAM
pstroceanlexp ← NEW POINTSTREAM
pstrssel_imp ← NEW POINTSTREAM
pstrssel_exp ← NEW POINTSTREAM
pstrrverl_imp ← NEW POINTSTREAM
pstrrverl_exp ← NEW POINTSTREAM

wtoq ← NEW WINDOW CALLED "WT Oceang"
wtanc ← NEW WINDOW CALLED "WT Oceang"
wtssq ← NEW WINDOW CALLED "WT Shortsq"
wtssanc ← NEW WINDOW CALLED "WT ShortSanc"
wtrverq ← NEW WINDOW CALLED "WT Riverq"
wtrveranc ← NEW WINDOW CALLED "WT Riveranc"

awtwnzshut ← NEW WINDOW CALLED "W nzshutnz"
wtznq ← NEW WINDOW CALLED "W nzq"
awtwnzshutys ← NEW WINDOW CALLED "W nzshutys"
awtwshshutys ← NEW WINDOW CALLED "W shshutys"

vessel_loads ← NEW WINDOW CALLED "V loads"

st_sizeo1 ← NEW WINDOW CALLED "St ocean1"
st_sizeo2 ← NEW WINDOW CALLED "St ocean2"
st_sizeriver ← NEW WINDOW CALLED "St river"
st_sizess1 ← NEW WINDOW CALLED "St short1"
st_sizess2 ← NEW WINDOW CALLED "St short2"

shutstsnz1 ← NEW WINDOW CALLED "St shutnznz1"
shutstsnz2 ← NEW WINDOW CALLED "St shutnznz2"
shutstssh ← NEW WINDOW CALLED "St shutsh"

nzshutstsys ← NEW WINDOW CALLED "NZstackYS"
shshutstsys ← NEW WINDOW CALLED "SHstackYS"

usednztermsys ← NEW WINDOW CALLED "Usednz ysterms"
usedshtermsys ← NEW WINDOW CALLED "Usedsh ysterms"

@  ---------------------------@
@  Attachen van de pointstreams aan de verschillende windows  @
@  ---------------------------@
@Total average waiting times of various vesselmods@
@--------------------------------------------------------------@
FOR i-1 TO nr_term_nz
  ATTACH w_time_nzqanz OF term_nz[i] TO wtnqz
  ATTACH w_time_nzqz OF term_nz[i] TO avwtnqzshut
END

FOR i-1 TO nr_term_ys
  ATTACH w_time_0 OF term_ys[i] TO wtoanc
  ATTACH w_time_q OF term_ys[i] TO wtq
  ATTACH w_time_sq OF term_ys[i] TO wtssanc
  ATTACH w_time_sqq OF term_ys[i] TO wtssq
  ATTACH w_time_river OF term_ys[i] TO wtriveranc
  ATTACH w_time_riverq OF term_ys[i] TO wtriverq
  ATTACH w_time_nzys OF term_ys[i] TO avwtnqshutys
  ATTACH w_time_shys OF term_ys[i] TO avwtshutys
END

@Loads of the various vesselmods@
@----------------------------------@
ATTACH pstroceanlimp TO vesselloads
ATTACH pstroceanlexp TO vesselloads
ATTACH pstresslimp TO vesselloads
ATTACH pstressl_exp TO vesselloads
ATTACH pstriverlimp TO vesselloads
ATTACH pstriverl_exp TO vesselloads

@ Stacks per terminal of YS @
@-------------------------------@
FOR i-1 TO nr_term_ys
  ATTACH oceannst[1] OF term_ys[i] TO st_size01
  ATTACH oceannst[2] OF term_ys[i] TO st_size02
  ATTACH ssst[1] OF term_ys[i] TO st_size1
  ATTACH riverst OF term_ys[i] TO st_sizeriver
END

@ Stacks of NZ and SH @
@------------------------@
FOR i-1 TO 3
  ATTACH nzshustst[i] OF term_nz[1] TO shutstszn1
END

FOR i-4 TO 6
END

FOR i-1 TO nr_term_ys
  ATTACH shshustst[i] TO shutstssh
END

@ NZ shuttle Stacks on YS @
@-----------------------------@
FOR i-1 TO nr_term_ys
  ATTACH nzshustsys OF term_ys[i] TO nzshustsys
  ATTACH shshustsys OF term_ys[i] TO shshustsys
END

@ Door NZ shut gebruikte terms op YS @
@----------------------------------------@
FOR i-1 TO 15
  ATTACH usedxtermesz OF mnzshut[i] TO usednxtermysz
END

@  Door SH shut gebruikte terms op YS @
@-------------------------------------@
FOR i=1 TO 10
ATTACH usedystermssh OF mshut[i]  TO usedshtermsys
END

@-------------------------------------@
@  Activering van het programma @
@-------------------------------------@

322 unifocean ← NEW DISTRIBUTION
323 unifss  ← NEW DISTRIBUTION
324 unifriver  ← NEW DISTRIBUTION
325 ATTACH UNIFORM(0,1) TO unifocean
326 ATTACH UNIFORM(0,1) TO unifss
327 ATTACH UNIFORM(0,1) TO unifriver
328 SEED OF unifocean  ← 18533
329 SEED OF unifss  ← 232576
330 SEED OF unifriver  ← 34923424
331
332 oceanl  ← NEW DISTRIBUTION
333 ssl  ← NEW DISTRIBUTION
334 riverl  ← NEW DISTRIBUTION
335
336 SEED OF oceanl  ← 3400
337 SEED OF ssl  ← 85008
338 SEED OF riverl  ← 123512
339
340 ACTIVATE truckgenn FROM createtrucknz  IN truckknzmod
341 ACTIVATE truckgensh FROM createtrucksh  IN truckshmod
342 ACTIVATE nzshutgen FROM createanzshuts  IN nzshuttemod
343 ACTIVATE shshutgen FROM createeshshuts  IN shshuttemod
344 ACTIVATE ogen FROM createocean  IN extoceanmod
345 ACTIVATE ssgen FROM createss  IN extshortseamod
346 ACTIVATE rivergen FROM createrriver  IN extrivermod
347 ACTIVATE storng FROM storedata  IN storemod
348 ACTIVATE justfiry FROM top  IN justifier
349 ACTIVATE counting FROM count  IN counterm
350
351 WAIT simtime  MONTH + 0.01 MINUTE
352
353 JUMP TO outputmod
354
355 JUMP TO filewritemod
356
357 CANCEL ALL
358 TERMINATE
Module

Extoceanmod
createocean:
next_ocean ← NEW ocean
wt_ocean.Anchor OF next_ocean ← 0
wt_ocean_q OF next_ocean ← 0
st_ocean OF next_ocean ← 0
oceandistri OF next_ocean ← 4

FOR j ← 1 TO oceandistri OF next_ocean
erlangsample[j] ← SAMPLE FROM unifocean
END

interarr ← 0
FOR j ← 1 TO oceandistri OF next_ocean
interarr ← interarr + LOG(erlangsample[j])
END

intarr_ocean ← (interarr*mn_arr_ocean)/(oceandistri OF next_ocean)

destoean ← SAMPLE FROM unifocean

IF destoean ≥ 0 & destoean < 0.1650 @Europe (Terminal 1) 16.50% @
actermoean OF next_ocean ← 1
actdestoean OF next_ocean ← 1
GOTO further1

END

IF destoean ≥ 0.1650 & destoean < 0.2750 @Europe (Terminal 2) 11.00% @
actermoean OF next_ocean ← 2
actdestoean OF next_ocean ← 1
GOTO further1

END

IF destoean ≥ 0.2750 & destoean < 0.3250 @Australia  5.00% @
actermoean OF next_ocean ← 2
actdestoean OF next_ocean ← 2
GOTO further1

END

IF destoean ≥ 0.3250 & destoean < 0.4375 @Persian Gulf 11.25% @
actermoean OF next_ocean ← 6
actdestoean OF next_ocean ← 2
GOTO further1

END

IF destoean ≥ 0.4375 & destoean < 0.5375 @Mediterranean 10.00% @
actermoean OF next_ocean ← 3
actdestoean OF next_ocean ← 1
GOTO further1

END

IF destoean ≥ 0.5375 & destoean < 0.7025 @N-America (Terminal 4) 16.50% ()
actermoean OF next_ocean ← 4
actdestoean OF next_ocean ← 1
GOTO further1

END

IF destoean ≥ 0.7025 & destoean < 0.8625 @N-America (Terminal 5) 16.00% ()
actermoean OF next_ocean ← 5
actdestoean OF next_ocean ← 1
GOTO further1

END
63 END
64 IF destocean ≥ 0.8625 & destocean < 0.9125 @S-America 5.00% @
65 actermocean OF next_ocean= 6
66 actdestocean OF next_ocean= 1
67 GOTO further1
68 END
69 IF destocean ≥ 0.9125 & destocean ≤ 1 @Africa 8.75% @
70 actermocean OF next_ocean= 3
71 actdestocean OF next_ocean= 2
72 END
73
74 further1:
75 @-------------------------------------@
76 @ Bepalen van de capaciteit van het schip mbv lineaire functie @
77 @-------------------------------------@
78 ATTACH UNIFORM(0.001,1) TO oceanl
79 oceansample ← SAMPLE FROM oceanl
80 IF oceansample < 0.287
81 oceancap OF next_ocean ← (oceansample*(1000/0.287) + 2000)
82 END
83 IF oceansample ≥ 0.287 & oceansample ≤ 0.4991
84 oceancap OF next_ocean ← ((oceansample-0.287)*(1000/(0.4991-0.287)) + 3000)
85 END
86 IF oceansample > 0.4991
87 oceancap OF next_ocean ← ((oceansample-0.4991)*(8500/(1-0.4991)) + 4000)
88 END
89
90 @------------------------------------------------------------------@
91 @ Bepalen van de importlading en exportlading @
92 @------------------------------------------------------------------@
93 ordoceanl_imp OF next_ocean ← ps_imp_ocean * oceancap OF next_ocean
94 ordoceanl_exp OF next_ocean ← ps_exp_ocean * oceancap OF next_ocean
95 actoceanl_imp OF next_ocean ← ordoceanl_imp OF next_ocean
96 actoceanl_exp OF next_ocean ← ordoceanl_exp OF next_ocean
97
98 @------------------------------------------------------------------@
99 @ Bijhouden van de lading van het schip @
100 @------------------------------------------------------------------@
101 STORE ordoceanl_imp OF next_ocean IN pstroceanlimp
102 STORE ordoceanl_exp OF next_ocean IN pstroceanelexp
103
104 @------------------------------------------------------------------@
105 @ Checken van de gemiddelde waarden van het schip @
106 @------------------------------------------------------------------@
107 IF NOW ≥ 12 MONTH
108 counto ← counto + 1
109 tot_o_intarr ← tot_o_intarr + interr_ocean
110 avg_o_intarr ← tot_o_intarr/counto
111 tot_o_cap ← tot_o_cap + oceancap OF next_ocean
112 avg_o_cap ← tot_o_cap/counto
113 END
114 @------------------------------------------------------------------@
115 @ Activeren van het schip @
116 @------------------------------------------------------------------@
117 WAIT interr_ocean MINUTES
118
119 ACTIVATE next_ocean FROM oceansail
120
121 REPEAT FROM createocean
122
123
124
EXTOCEANMOD - page 3

125 oceansail:
126
128 oceancountin OF term ys[acttermocean] + oceancountin OF term ys[acttermocean] -
130 @ Bepalen de beschikbaarheid van een kade @
132 @----------------------------------------@
133 WHILE ys_ocean_occq OF term ys[acttermocean] ≥ ys_ocean_q OF term ys[acttermocean]
134 WAIT 10 MINUTES
135 wt_ocean_anchor = wt_ocean_anchor + 0.16667
136 END
137
138 ys_ocean_occq OF term ys[acttermocean] - ys_ocean_occq OF term ys[acttermocean] -
139 st_ocean = st_ocean + 1.66667
140 WAIT 100 MINUTES @ For sailing to the berth@
141
142 @-----------------------------------------------------------------------------------
143 @ lossen van de (volle) ocean op Yangshan @
144 @-----------------------------------------------------------------------------------
145 WAIT (actocean)_imp/((ys_ocean_cranes OF term ys[acttermocean])) * (ys_ocean_cran
146 @Domestic containers @
147 @----------------------------------------------------------------------@
149 ys_river_st OF term ys[acttermocean] - ys_river_st OF term ys[acttermocean] -
150 ys_shut_sh_st OF term ys[acttermocean] - ys_shut_sh_st OF term ys[acttermocean] -
151
152 impo = (0.340935 * actocean)_imp) + (0.271216 * actocean)_imp) + (0.162751 *
154
155 @Transhipment containers @
156 @----------------------------------------------------------------------@
157
167
176
177 transo = (0.018571 * actocean)_imp) + (0.012380 * actocean)_imp
178 transo = transo + (0.019133 * actocean)_imp) + (0.019133 * actocean)_
179
180 IF NOW ≤ 12 MONTH
182 END
183 IF NOW > 12 MONTH & NOW ≤ 24 MONTH
185 END
186 IF NOW > 24 MONTH & NOW ≤ 36 MONTH
EXTERNALMOD - page 4

188  END
189  IF NOW > 36 MONTH & NOW < 48 MONTH
191  END
192
193  IF NOW > 12 MONTH
194     tp_oimp = tp_oimp + impo @Puur import van domestic cs @
195     tp_oTRANS = tp_oTRANS + transo @Puur import van transhipment cs@
196     tp_o = tp_o + impo + transo
197     o = o + actocean1_imp
198     amo = amo + 1
199  END
200
201  st_ocean = st_ocean + actocean1_imp/((ys_ocean_cranes OF term_yS[acttermocean])
202  actocean1_imp = 0
203
204  IF NOW > 12 MONTH
205     @Bijhouden van de maximale stackgrootte van alle terms @
206     @---------------------------------------------------------------------@
207     IF ys_shut_nz_st OF term_yS[acttermocean] > max_yS_shut_nz_st OF term_yS[acttermocean]
208      max_yS_shut_nz_st OF term_yS[acttermocean] = ys_shut_nz_st
209     END
210     IF ys_river_st OF term_yS[acttermocean] > max_yS_river_st OF term_yS[acttermocean]
211      max_yS_river_st OF term_yS[acttermocean] = ys_river_st
212     END
213     IF ys_shut_sh_st OF term_yS[acttermocean] > max_yS_shut_sh_st OF term_yS[acttermocean]
214      max_yS_shut_sh_st OF term_yS[acttermocean] = ys_shut_sh_st
215     END
216
217     FOR maxst-1 TO nr_term_yS
220     END
223     END
224     IF maxst = 2
227     END
228     GOTO further3
229
230     GOTO further3
231     IF maxst = 3
234     END
235     GOTO further3
236
237     IF maxst = 5
240     END
241     GOTO further3
242
243     IF maxst = 6
246     END
max\_ys\_ss\_st[2] \ OF \ term\_ys[maxst] \ + \ ys\_ss\_st[2] \ OF \ term\_ys[mi]

END

further3:

END

@ Blijhouden van de minimale stackgrootte van alle terms @

@ ---------------------------------------------------------------@

IF \ ys\_shut\_nz\_st \ OF \ term\_ys[acttermocean] < min\_ys\_shut\_nz\_st \ OF \ term\_ys[acttermocean] \ - \ ys\_shut\_nz\_st \ OF \ term\_ys[acttermocean] \ - \ ys\_shut\_nz\_st

END

IF \ ys\_shut\_sh\_st \ OF \ term\_ys[acttermocean] < min\_ys\_shut\_sh\_st \ OF \ term\_ys[acttermocean] \ - \ ys\_shut\_sh\_st

END

FOR maxst-1 \ TO \ nr\_term\_ys

IF \ ys\_ocean\_st[1] \ OF \ term\_ys[maxst] < min\_ys\_ocean\_st[1] \ OF \ term\_ys[maxst] \ - \ ys\_ocean\_st[1]

END

IF \ ys\_ss\_st[1] \ OF \ term\_ys[maxst] < min\_ys\_ss\_st[1] \ OF \ term\_ys[maxst] \ - \ ys\_ss\_st[1]

END

IF maxst = 2

IF \ ys\_ocean\_st[2] \ OF \ term\_ys[maxst] < min\_ys\_ocean\_st[2] \ OF \ term\_ys[maxst] \ - \ ys\_ocean\_st[2]

END

GOTO further4

END

IF maxst = 3

IF \ ys\_ocean\_st[2] \ OF \ term\_ys[maxst] < min\_ys\_ocean\_st[2] \ OF \ term\_ys[maxst] \ - \ ys\_ocean\_st[2]

END

GOTO further4

END

IF maxst = 5


END

GOTO further4

END

IF maxst = 6

IF \ ys\_ocean\_st[2] \ OF \ term\_ys[maxst] < min\_ys\_ocean\_st[2] \ OF \ term\_ys[maxst] \ - \ ys\_ocean\_st[2]

END


END

GOTO further4

END

further4:

END

@-----------------------------------------------@

@ laden van de ocean op Yangshan @

@-----------------------------------------------@

WHILE actocean\_exp < ordocean\_exp

IF \ ys\_ocean\_st[actdestocean] \ OF \ term\_ys[acttermocean] \leq 0
WAIT 10 MINUTES  
w_t_ocean_q <- w_t_ocean_q + 0.16667

END

IF ys_ocean_st[actdestocean] OF term ys[acttermocean] > 0
  IF ys_ocean_st[actdestocean] OF term ys[acttermocean] >= (ordocean1_exp -
  ys_ocean_st[actdestocean] OF term ys[acttermocean] + ys_ocean_st[act-
  destocean] WAIT ((ordocean1_exp-actocean1_exp)/(ys_ocean_crane oy term ys[ac-
  tocean1_exp-ys_ocean_st[actdestocean] OF term ys[acttermocean] - 0
  WAIT ((ys_ocean_st[actdestocean] OF term ys[acttermocean] + st_ocean -
  st_ocean + (ys_ocean_st[actdestocean] OF term ys[acttermocean] + expo)

END

END

IF actocean1_exp = ordocean1_exp & ys_ocean_st[actdestocean] OF term ys[
  actocean1_exp - actocean1_exp + ys_ocean_st[actdestocean] OF term ys
  ys_ocean_st[actdestocean] OF term ys[acttermocean] = 0
  WAIT ((ys_ocean_st[actdestocean] OF term ys[acttermocean])/(ys_ocean
  st_ocean - st_ocean + (ys_ocean_st[actdestocean] OF term ys[acttermo-

END

END

EXPO = actocean1_exp

export o OF term ys[acttermocean] + export o OF term ys[acttermocean] = expo

IF NOW <= 12 MONTH
END

IF NOW > 12 MONTH & NOW <= 24 MONTH
END

IF NOW > 24 MONTH & NOW <= 36 MONTH
END

IF NOW > 36 MONTH & NOW <= 48 MONTH
END

IF NOW >= 12 MONTH
  totale export incl. transshipment =
  tp oexp = tp oexp + expo
  tp o = tp o + expo

END

ys ocean occq OF term ys[acttermocean] = ys ocean occq OF term ys[acttermocean]

oceancountout OF term ys[acttermocean] = oceancountout OF term ys[acttermocean]

IF NOW >= 12 MONTH
  totale export incl. transshipment =
  tp oexp = tp oexp + expo
  tp o = tp o + expo

END

@ Bepalen van de individuele ocean wacht tijd als perc van de servicetijd
@ total ocean wacht tijd als perc van de servicetijd

ttw t_ocean = w_t_ocean + anchor st
wt perc ocean = (twt_ocean)/(st oce an)
th oce an = w_t_ocean + anchor + st ocean

@ Bepalen van het gemiddelde van de wacht tijd
@ Bepalen van het gemiddelde van de wacht tijd

wperc ocean all OF term ys[acttermocean] = wperc ocean all OF term ys[
avg ocean all OF term ys[acttermocean] = (wperc ocean all OF term ys[
ocnr = ((oceancountout OF term ys[acttermocean])-(ocout OF term ys[
@ Gegevens in pointstreams storen @
STORE wt_ocean_q    IN w_time_oq    OF term_ys[acttermocean]
IF ocnr <= 30000
  CONVERT tht_ocean TO htc[ocnr,1] OF term_ys[acttermocean] FIELDDLEN
END
END
TERMINATE
Module

Extshortseamod
EXTSHORTSEMOD - page 1

@-------------------------------------@
ss generation
@-------------------------------------@
createss:
next_ss + NEW ss
wt_ss_anchor OF next_ss = 0
wt_ss_q OF next_ss = 0
st_ss OF next_ss = 0
ssdistri OF next_ss = 2
@-------------------------------------@
Bepalen van de aankomsttijd van het schip
@-------------------------------------@
FOR j = 1 TO ssdistri OF next_ss
erlangsample[j] = SAMPLE FROM unifss
END
FOR j = 1 TO ssdistri OF next_ss
interarr = interarr + LOG(erlangsample[j])
END
intarr_ss = -(interarr*mn_arr_ss)/(ssdistri OF next_ss)
@-------------------------------------@
Bepalen van de bestemming van het schip
@-------------------------------------@
destss = SAMPLE FROM unifss

IF destss ≥ 0 & destss < 0.08
acttermss OF next_ss = 5
actdestss OF next_ss = 2
GOTO further1
END
IF destss ≥ 0.08 & destss < 0.25
acttermss OF next_ss = 1
actdestss OF next_ss = 1
GOTO further1
END
IF destss ≥ 0.25 & destss < 0.42
acttermss OF next_ss = 2
actdestss OF next_ss = 1
GOTO further1
END
IF destss ≥ 0.42 & destss < 0.59
acttermss OF next_ss = 3
actdestss OF next_ss = 1
GOTO further1
END
IF destss ≥ 0.59 & destss < 0.76
acttermss OF next_ss = 4
actdestss OF next_ss = 1
GOTO further1
END
IF destss ≥ 0.76 & destss < 0.84
acttermss OF next_ss = 5
actdestss OF next_ss = 1
GOTO further1
END
IF destss ≥ 0.84 & destss < 0.99
acttermss OF next_ss = 6
actdestss OF next_ss = 1
GOTO further1
END
@SE Asia 8.00%@
@Japan (Terminal 1) 17.00%@
@Japan (Terminal 2) 17.00%@
@Japan (Terminal 3) 19.00%@
@Hong Kong (Terminal 4) 17.00%@
@Hong Kong (Terminal 5) 8.00%@
@Korea 15.00%@
EXTSHORTSEAMOD - page 2

63   END
64   IF destss > 0.99 & destss ≤ 1  @vladivostok  1.00%  @
65       acttermss OF next_ss-  6
66       actdestss OF next_ss-  2
67   END
68
69   further1:
70
71   @--------------------------------------------@
72   @ Bepalen van de capaciteit van het schip mbv uniforme verdeling @
73   @--------------------------------------------@
74   ATTACH UNIFORM(min_1_ss,max_1_ss) TO ssl
75       shortseacap OF next_ss - SAMPLE FROM ssl
76
77   @--------------------------------------------@
78   @ Bepalen van de import/export lading mbv lineaire functie @
79   @--------------------------------------------@
80       ordssl_imp OF next_ss - ps_imp_ss * shortseacap OF next_ss
81       ordssl_exp OF next_ss - ps_exp_ss * shortseacap OF next_ss
82       actssl_imp OF next_ss - ordssl_imp OF next_ss
83
84   @--------------------------------------------@
85   @ Bijhouden van de lading van het schip @
86   @--------------------------------------------@
87   STORE ordssl_imp OF next_ss IN pstrssl_imp
88   STORE ordssl_exp OF next_ss IN pstrssl_exp
89
90   @--------------------------------------------@
91   @ Checken van de gemiddelde waarden van het schip @
92   @--------------------------------------------@
93   IF NOW ≥ 12 MONTH
94       countss ← countss + 1
95       tot_ss_intarr ← tot_ss_intarr + intarr_ss
96       avg_ss_intarr ← tot_ss_intarr/countss
97       tot_ss_cap ← tot_ss_cap + shortseacap OF next_ss
98       avg_ss_cap ← tot_ss_cap/countss
99   END
100  @--------------------------------------------@
101  @ Activeren van het schip @
102  @--------------------------------------------@
103   WAIT intarr_ss MINUTES
104
105   ACTIVATE next_ss FROM sssail
106
107   REPEAT FROM createss
108
109
110   sssail:
111
112   sscountin OF term ys[acttermss] ← sscountin OF term ys[acttermss] + 1
113
114   @--------------------------------------------@
115   @ Bepaling van de beschikbaarheid van een kade @
116   @--------------------------------------------@
117   WHILE ys ss_occq OF term ys[acttermss] ≥ ys ss_q OF term ys[acttermss]
118       WAIT 10 MINUTES
119       wt ss_anchor ← wt ss_anchor + 0.16667
120   END
121
122   ys ss_occq OF term ys[acttermss] ← ys ss_occq OF term ys[acttermss] + 1
123   st ss ← st ss + 1
124   WAIT 60 MINUTES  @  For sailing to the berth@
WAIT (actssl_imp/((ys_ss_cranea OF term_y:ys[acttermss]) * (ys_ss_cranes OF term_y:ys[acttermss]) +

131 @ Domestic containers @
132 --------------------------------@
136 impss - (0.366167 * actssl_imp) + (0.291287 * actssl_imp) + (0.174796 * actssl_imp)
138 @ Transshipment containers @
139 --------------------------------@
154 transss - (0.020759 * actssl_imp) + (0.013839 * actssl_imp)
155 transss + transss + (0.007129 * actssl_imp) + (0.007129 * actssl_imp)
156 IF NOW <= 12 MONTH
158 END
159 IF NOW > 12 MONTH & NOW <= 24 MONTH
161 END
162 IF NOW > 24 MONTH & NOW <= 36 MONTH
164 END
165 IF NOW > 36 MONTH & NOW <= 48 MONTH
167 END
168 IF NOW >= 12 MONTH
169 tp_ssimport - tp_ssimport + impss Puur import van domestic cs (1
170 tp_sstrans - tp_sstrans + transss Puur import van transshipment cs(1
171 tp_sss + tp_sss + impss + transss
172 s - s + actssl_imp
173 ams - ams + 1
174 st_ss - st_ss + actssl_imp/((ys_ss_cranea OF term_y:ys[acttermss]) * (ys_ss_cranes OF term_y:ys[acttermss]) +
175 actssl_imp - 0
187 IF NOW ≥ 12 MONTH
188 @------------------------@
189 @ Bijhouden van de maximale stackgrootte van alle terms @
190 @------------------------@
191 IF ys_shut_nz_st max ys_shut_nz_st OF term ys [acttermss] > max ys_shut_nz_st OF term:
192 max ys_shut_nz_st OF term ys [acttermss] - ys_shut_nz_st OF term:
193 END
194 IF ys_river_st max ys_river_st OF term ys [acttermss] > max ys_river_st OF term:
195 max ys_river_st OF term ys [acttermss] - ys_river_st OF term:
196 END
197 IF ys_shut_sh_st max ys_shut_sh_st OF term ys [acttermss] > max ys_shut_sh_st OF term:
198 max ys_shut_sh_st OF term ys [acttermss] - ys_shut_sh_st OF term:
199 END
200
201 FOR maxst-1 TO nr_term ys
204 END
207 END
208 IF maxst = 2
211 END
212 GOTO further3
213 END
214 IF maxst = 3
217 END
218 GOTO further3
219 END
220 IF maxst = 5
223 END
224 GOTO further3
225 END
226 IF maxst = 6
229 END
232 END
233 END
234 END
235
236 END
237
238 @-------------------------------------------@
239 @ Bijhouden van de minimale stackgrootte van alle terms @
240 @-------------------------------------------@
241 IF ys_shut_nz_st min ys_shut_nz_st OF term ys [acttermss] < min ys_shut_nz_st OF term:
242 min ys_shut_nz_st OF term ys [acttermss] - ys_shut_nz_st OF term:
243 END
244 IF ys_river_st min ys_river_st OF term ys [acttermss] < min ys_river_st OF term:
245 min ys_river_st OF term ys [acttermss] - ys_river_st OF term:
246 END
247 IF ys_shut_sh_st min ys_shut_sh_st OF term ys [acttermss] < min ys_shut_sh_st OF term:
248 min ys_shut_sh_st OF term ys [acttermss] - ys_shut_sh_st OF term:
FOR maxst-1 TO nr_term_yy
   END
   END
   IF maxst = 2
      END
      GOTO further4
   END
   IF maxst = 3
      END
   END
   IF maxst = 5
      END
      GOTO further4
   END
   IF maxst = 6
      END
      END
   END
   GOTO further4:
END

WHILE act_ssl_exp < ord_ssl_exp
   IF ys_ss_st[actdestss] OF term_yy[acttermss] ≤ 0
      WAIT 10 MINUTES
      wt_ssl_q = wt_ssl_q + 0.16667
   END
   IF ys_ss_st[actdestss] OF term_yy[acttermss] > 0
      END
      WAIT ((ord_ssl_exp - act_ssl_exp)/(ys_ss_crane OF term_yy[acttermss])) / (act_ssl_exp + ord_ssl_exp)
      ys_ssl = ys_ssl + (ord_ssl_exp - act_ssl_exp)/(ys_ss_crane OF term_yy[acttermss])
      act_ssl_exp = ord_ssl_exp
   END
      act_ssl_exp = act_ssl_exp + ys_ss_st[actdestss] OF term_yy[acttermss]
   END
   IF act_ssl_exp = ord_ssl_exp
      WAIT ((ys_ss_st[actdestss] OF term_yy[acttermss])/(ys_ss_crane OF term_yy[acttermss]))
      act_ssl_exp = ord_ssl_exp
   END
   IF act_ssl_exp = ord_ssl_exp
      WAIT ((ys_ss_st[actdestss] OF term_yy[acttermss])/(ys_ss_crane OF term_yy[acttermss]))
      act_ssl_exp = ord_ssl_exp
   END
   IF act_ssl_exp = ord_ssl_exp
WAIT 60 MINUTES @the vessel needs time to sail away@

st_ss = st_ss + 1

END

expss = actssl_exp
export_ss OF term ys[acttermss] - export ss OF term ys[acttermss] + expss

IF NOW \leq 12 MONTH
END

IF NOW > 12 MONTH \& NOW \leq 24 MONTH
END

IF NOW > 24 MONTH \& NOW \leq 36 MONTH
END

IF NOW > 36 MONTH \& NOW \leq 48 MONTH
END

IF NOW \geq 12 MONTH
  tp ssexp = tp ssexp + expss @ Totale export incl. transhipment@
  tp ss = tp ss + ordssl_exp
END


@ Bepalen van de wachttijden
@ sscountout OF term ys[acttermss] - sscountout OF term ys[acttermss] + 1

IF NOW > 12 MONTH
@ Bepalen van de individuele ss wachttijden als perc van de servicetijd
@
twt ss = wt ss_anchor
w perc ss = (twt ss)/(st ss)
ths ss = wt ss anchor + st ss
@ Bepalen van het gewogen gemiddelde van de wachttijd
@
wpers ss all OF term ys[acttermss] = wpers ss all OF term ys[acttermss]
avg ss all OF term ys[acttermss] = (wpers ss all OF term ys[acttermss])
shortnr = (sscountout OF term ys[acttermss]) - (ssout OF term ys[acttermss])
@
Gegevens in pointstreams storen
@
STORE wt ss q IN w time ssq OF term ys[acttermss]

IF shortnr \leq 30000
CONVERT tht ss TO htchr[shortnr,2] OF term ys[acttermss] FIELDDLENGTH:
END

END

TERMINATE
Module

Extrivermod
EXTRIVERMOD - page 1

1 @-----------------------------------------------------------@
2 @   river generation @
3 @-----------------------------------------------------------@
4 create river:
5 next river ← NEW river
6 wt river anchor OF next river ← 0
7 wt river q OF next river ← 0
8 st river OF next river ← 0
9 river distrri OF next river ← 1
10 @-----------------------------------------------------------@
11 @   Bepalen van de aankomsttijd van het schip @
12 @-----------------------------------------------------------@
13 FOR j ← 1 TO river distrri OF next river @
14    erlangs sample[j] ← SAMPLE FROM unif river @
15 END
16 inter arr ← 0
17 FOR j ← 1 TO river distrri OF next river @
18    inter arr ← inter arr + LOG(erlangs sample[j])
19 END
20 @-----------------------------------------------------------@
21 intarr river ← (inter arr* mn arr river)/(river distrri OF next river)
22 @-----------------------------------------------------------@
23 @   Bepalen van de bestemming van het schip @
24 @-----------------------------------------------------------@
25 destriver ← SAMPLE FROM unif river
26 IF destriver ≥ 0 & destriver < 0.167450 @
27    act term river OF next river ← 1
28 END
29 @-----------------------------------------------------------@
30 IF destriver ≥ 0.167450 & destriver < 0.332350 @
31    act term river OF next river ← 2
32 END
33 @-----------------------------------------------------------@
34 IF destriver ≥ 0.332350 & destriver < 0.511275 @
35    act term river OF next river ← 3
36 END
37 @-----------------------------------------------------------@
38 IF destriver ≥ 0.511275 & destriver < 0.678725 @
39    act term river OF next river ← 4
40 END
41 @-----------------------------------------------------------@
42 IF destriver ≥ 0.678725 & destriver < 0.838725 @
43    act term river OF next river ← 5
44 END
45 @-----------------------------------------------------------@
46 IF destriver ≥ 0.838725 & destriver ≤ 1 @
47    act term river OF next river ← 6
48 END
49 @-----------------------------------------------------------@
50 further1:
51 @-----------------------------------------------------------@
52 @   Bepalen van de capaciteit m.b.v een uniforme verdeling @
53 @-----------------------------------------------------------@
54 ATTACH UNIFORM(min l river, max l river) TO river1
55 @-----------------------------------------------------------@
56 river cap OF next river ← SAMPLE FROM river1
57 @-----------------------------------------------------------@
58 @-----------------------------------------------------------@
59 @   Bepalen van de import en export lading van het schip @
60 @-----------------------------------------------------------@
61 ordriver1 exp OF next river ← ps exp river * river cap OF next river
EXTRIVERMOD - page 2

63 ordriver1_imp OF next_river = ps_imp_river * rivercap OF next_river
64 actriver1_exp OF next_river = ordriver1_exp OF next_river

66 @---------------------------------------------------------------------@
67 @ Bijhouden van de lading van het schip @
68 @---------------------------------------------------------------------@
69 STORE ordriver1_imp OF next_river IN pstrriver1_imp
70 STORE ordriver1_exp OF next_river IN pstrriver1_exp

71 @---------------------------------------------------------------------@
72 @ Checken van de gemiddelde waarden van het schip @
73 @---------------------------------------------------------------------@
74 IF NOW >= 12 MONTH
75    countriver = countriver + 1
76    tot_river_intarr = tot_river_intarr + intarr_river
77    avg_river_intarr = tot_river_intarr/countriver
78    tot_river_cap = tot_river_cap + rivercap OF next_river
79    avg_river_cap = tot_river_cap/countriver
80 END
81
82 @---------------------------------------------------------------------@
83 @ Activeren van het schip @
84 @---------------------------------------------------------------------@
85 WAIT intarr_river MINUTES
86
87 ACTIVATE next_river FROM riversail
88
89 REPEAT FROM creatoriver
90
91 riversail:
92
93 rivercountin OF term_ys[acttermriver] = rivercountin OF term_ys[acttermriver] +:
94 @---------------------------------------------------------------------@
95 @Bepalen van de beschikbaarheid van de term op Yangshan @
96 @---------------------------------------------------------------------@
97 WHILE ys_river_occq OF term_ys[acttermriver] >= ys_river_q OF term_ys[acttermriver]
98  WHEN ys_river_occq OF term_ys[acttermriver] <= ys_river_q OF term_ys[acttermriver]

100  WAIT 10 MINUTES
101  wt_river_anchor = wt_river_anchor + 0.16667
102 END
103
104 ys_river_occq OF term_ys[acttermriver] = ys_river_occq OF term_ys[acttermriver];
105 WAIT 30 MINUTES @ For sailing to the berth@
106 st_river = st_river + 0.50
107
108 @---------------------------------------------------------------------@
109 @ losser van de (volle) river op Yangshan @
110 @---------------------------------------------------------------------@
111 WAIT (actriver1_exp/((ys_river_crane OF term_ys[acttermriver]) * (ys_river_cran,)
112 IF acttermriver = 1
115     expriver = (0.502538 * actriver1_exp) + (0.497462 * actriver1_exp)
116 GOTO further2
117 END
118 IF acttermriver = 2
122     expriver = (0.340206 * actriver1_exp) + (0.154639 * actriver1_exp) + (0.505:
125 IF acttermriver = 3
129  expriver ← (0.285036 * actriver1_exp) + (0.249406 * actriver1_exp) + (0.4651
130  GOTO further2
131
132 END
133 IF acttermriver = 4
136  expriver ← (0.502538 * actriver1_exp) + (0.497462 * actriver1_exp)
137  GOTO further2
138
139 END
140 IF acttermriver = 5
143  expriver ← (0.510000 * actriver1_exp) + (0.245000 * actriver1_exp) + (0.24500
144  GOTO further2
145
146 END
147 IF acttermriver = 6
150  expriver ← (0.158115 * actriver1_exp) + (0.355759 * actriver1_exp) + (0.4557
151  END
152
153 further2:
154  st_river ← st_river + actriver1_exp/((ys_river_cranes OF term ys[acttermriver])
155
156 IF NOW ≥ 12 MONTH
157  tp_riverexp ← tp_riverexp + expriver
158  riv ← riv + actriver1_exp
159  amriv ← amriv + 1
160 END
161
162 actriver1_exp ← 0
163
164 IF NOW ≥ 12 MONTH
165  δ------------------------
166  @ Bijhouden van de maximale stackgrootte van alle terms @
167  δ------------------------
168
171  END
174 END
175 IF acttermriver = 3 & ys_ocean_st[2] OF term ys[acttermriver] > max:
177 END
180 END
181
184 END
END

END

@ Bijhouden van de minimale stackgrootte van alle terms

END

END

END

END

END

END

WHILE actriver1_imp < ordriver1_imp
    IF ys river_st OF term ys[acttermriver] ≤ 0
        WAIT 10 MINUTES
        wt river_q ← wt river_q + 0.16667
    END

    IF ys river_st OF term ys[acttermriver] > 0
        IF ys river_st OF term ys[acttermriver] ≥ (ordriver1_imp - actriver1_imp):
            ys river_st OF term ys[acttermriver] ← ys river_st OF term ys[acttermriver]
            WAIT ((ordriver1_imp - actriver1_imp)/((ys river cranes OF term ys[acttermriver] + st river - st river + (ordriver1_imp - actriver1_imp)/((ys river cranes OF actriver1_imp + ordriver1_imp)
        ELSE
            actriver1_imp ← ordriver1_imp
        END

        IF actriver1_imp = ordriver1_imp & ys river_st OF term ys[acttermriver]
            actriver1_imp ← actriver1_imp + ys river_st OF term ys[acttermriver]
            ys river_st OF term ys[acttermriver] ← 0
            WAIT ((ys river_st OF term ys[acttermriver])/(ys river cranes OF term ys[acttermriver] + st river - st river + (ys river_st OF term ys[acttermriver])/(ys river cranes OF acttermriver)))
    END

END

impriver ← actriver1_imp
WAIT 30 MINUTES @the vessel needs time to sail away@
st river ← st river + 0.50
ych river_occq OF term ys[acttermriver] ← ys river_occq OF term ys[acttermriver]
IF NOW $\geq$ 12 MONTH

\[ tp\_riverimp = tp\_riverimp + impriver \]

END

---------------------------------------------------------------------

@ Opslaan van gegevens

---------------------------------------------------------------------

rivercountout OF term\_ys[acttermriver] = rivercountout OF term\_ys[acttermriver]

---------------------------------------------------------------------

IF NOW $\geq$ 12 MONTH

---------------------------------------------------------------------

@ Bepalen van de individuele river wachttijden als perc van de servicetijd

---------------------------------------------------------------------

\[ \text{twt\_river} = \text{wt\_river\_anchor} \]

\[ \text{w\_perc\_river} = (\text{twt\_river})/(\text{st\_river}) \]

\[ \text{tht\_river} = \text{wt\_river\_anchor} + \text{st\_river} \]

---------------------------------------------------------------------

@ Bepalen van het gewogen gemiddelde van de wachtijd

---------------------------------------------------------------------

\[ \text{wperc\_riverall} OF term\_ys[acttermriver] = \text{wperc\_riverall} OF term\_ys[acttermriver] \]

\[ \text{avg\_riverall} OF term\_ys[acttermriver] = (\text{wperc\_riverall} OF term\_ys[acttermriver]) \]

\[ \text{rivnr} = ((\text{rivercountout} OF term\_ys[acttermriver])-(\text{riout} OF term\_ys[acttermriver])) \]

---------------------------------------------------------------------

@ Gegevens in pointstreams van Yangshan storen

---------------------------------------------------------------------

STORE wt\_river\_q IN w\_time\_riverq OF term\_ys[acttermriver]

IF rivnr $\leq$ 30000

CONVERT tht\_river TO htc\_char[rivnr,3] OF term\_ys[acttermriver] FIELDLARGEN

END

END

TERMINE
Module

Trucknzmod
TRUCKNZMOD - page 1

1 create truck nz:

2 @-------------------------------------------@
3 @ Aankomst trucks per 10 minuten in nz_1 @
4 @-------------------------------------------@
8 IF NOW >= 12 MONTH
9     tp_trucknzexp = tp_trucknzexp + 74
10 END

13 IF NOW >= 12 MONTH
14     tp_trucknzimp = tp_trucknzimp + 61
15 END

16 END

17 IF NOW >= 12 MONTH
18 @-------------------------------------------@
19 @ Bepaling van de maximale stackgrootte van alle term 1 @
20 @-------------------------------------------@
23 END

26 END

29 END

30 @-------------------------------------------@
31 @ Bepaling van de minimale stackgrootte van alle term 1 @
32 @-------------------------------------------@
35 END

38 END

41 END

42 END

43 END

44 @-------------------------------------------@
45 @ Aankomst trucks in nz_2 @
46 @-------------------------------------------@
50 IF NOW >= 12 MONTH
51     tp_trucknzexp = tp_trucknzexp + 70
52 END

55 IF NOW >= 12 MONTH
56     tp_trucknzimp = tp_trucknzimp + 58
57 END

58
IF NOW > 12 MONTH

@ Bepalen van de maximale stackgrootte van alle terms @

END

END

END

@ Bepalen van de minimale stackgrootte van alle terms @

END

END

END

WAIT 10 MINUTES

REPEAT FROM createtrucknz
Module

Truckshmod
createtrucksh:

@ Aankomst trucks per 10 minuten in shanghai @

@ Aankomst treinen per 10 minuten in shanghai @

IF NOW ≥ 12 MONTH
tp_truckshexp ← tp_truckshexp + 19
END

IF sh_truck_st OF shanghaitem ≥ 19
sh_truck_st OF shanghaitem ← sh_truck_st OF shanghaitem − 19
IF NOW ≥ 12 MONTH
tp_truckshimp ← tp_truckshimp + 19
END
END

IF NOW ≥ 12 MONTH
tp_trainsheexp ← tp_trainsheexp + 43
END

IF sh_rail_st OF shanghaitem ≥ 38
sh_rail_st OF shanghaitem ← sh_rail_st OF shanghaitem − 38
IF NOW ≥ 12 MONTH
tp_trainshimp ← tp_trainshimp + 38
END
END

IF NOW ≥ 12 MONTH

@ Bijhouden van de maximale stackgrootte van alle terms @

END

END

END

END

TRUCKSHMOD - page 2

63 END
66 END
67
68 @---------------------------------------------------------------@
69 @ Blijhouden van de minimale stackgrootte van alle terms @
70 @---------------------------------------------------------------@
73 END
76 END
79 END
82 END
85 END
88 END
89
90 WAIT 10 MINUTES
91
92 REPEAT FROM createtrucksh
Module

Nzshuttlemod
nzshutscail:
@--------------------------@
@Eerste beelden afdrukken van de terminal op Nanhui Zui@
@--------------------------@
(actermshutnz - 1)
WHILE nzfoundshut = 0
    WHILE actermshutnz < nr_term_nz
        IF nz_shut_occq OF term_nz[actermshutnz] < nz_shut_q OF term_nz[actermshutnz]
            @Eerste beelden afdrukken van de terminal op Nanhui Zui@
        END
        IF actermshutnz = 1
            FOR nzst-1 TO 3
                IF nz_term_st[nzst] OF term_nz[actermshutnz] > biggestnzst
                    biggestnzsterrnr = actermshutnz
                    biggestnzstnr = nzst
                    biggestnzst = nz_term_st[nzst] OF term_nz[actermshutnz]
                END
            END
            IF actermshutnz = 2
                FOR nzst-4 TO 6
                    IF nz_term_st[nzst] OF term_nz[actermshutnz] > biggestnzst
                        biggestnzsterrnr = actermshutnz
                        biggestnzstnr = nzst
                        biggestnzst = nz_term_st[nzst] OF term_nz[actermshutnz]
                    END
                END
            END
            actermshutnz = actermshutnz + 1
        END
        IF biggestnzstnr = 0
            biggestnzsterrnr = 0
            biggestnzstnr = 0
            actermshutnz = 1
            WAIT 10 MINUTES
            wt_nzshutnzanc = wt_nzshutnzanc + 10
        END
    END
GOTO donel
END
IF biggestnzstnr > 0
    nzfoundshut = 1
    actermshutnz = biggestnzsterrnr
    actstshutnz = biggestnzstnr
    actermnzshtys = biggestnzstnr
        act_nzshut_l_exp = maxnzshutcont
        GOTO donel
    END
    IF act_nzshut_l_exp = 0
        act_nzshut_l_exp = nz_term_st[actstshutnz] OF term_nz[actermshut:]
        nz_term_st[actstshutnz] OF term_nz[actermshutnz] = 0
        GOTO donel
    END
END
donel:
biggestnzsterrnr = 0
biggestnzstnr = 0
biggestnzst = 0
63 nz_shut_occq OF term_nz[acttermshutnz] = nz_shut_occq OF term_nz[acttermshutnz] ·
64 WAIT 30 MINUTES @Voor het varen naar de berth@
65 @--------------------@
66 @ lossen van de (volle) nzshut op Nanhui Zui @
67 @--------------------@
68 WAIT (act_nzshut_l_imp)/(2(nz_shut_cranes OF term_nz[acttermshutnz])*(nz_shut_cranes
69 nz_truck_st OF term_nz[acttermshutnz] = nz_truck_st OF term_nz[acttermshutnz] +
70 IF NOW ≥ 12 MONTH
71 tp_nz OF term_nz[acttermshutnz] = tp_nz OF term_nz[acttermshutnz] + act_nzshut
72 END
73 act_nzshut_l_imp = 0
74
75 IF NOW ≥ 12 MONTH
76 @ Blijhouden van de maximale stackgrootte van alle terms @
77 @--------------------@
78 IF nz_truck_st OF term_nz[acttermshutnz] > max_nz_truck_st OF term_nz[actterm
79 max_nz_truck_st OF term_nz[acttermshutnz] = nz_truck_st OF term_nz[actter
80 END
81 @ Blijhouden van de minimale stackgrootte van alle terms @
82 @--------------------@
83 IF nz_truck_st OF term_nz[acttermshutnz] < min_nz_truck_st OF term_nz[actterm
84 min_nz_truck_st OF term_nz[acttermshutnz] = nz_truck_st OF term_nz[actter
85 END
86
87 @--------------------@
88 @ laden van de nzshuttle op Nanhui Zui @
89 @--------------------@
90 WAIT ((act_nzshut_l_exp)/(2(nz_shut_cranes OF term_nz[acttermshutnz]))*(nz_shut_cra
91
92 WHILE act_nzshut_l_exp < maxnzshutcont
93 IF nz_term_st[actstshutnz] OF term_nz[acttermshutnz] ≤ 0
94 WAIT 10 MINUTES
95 wt_nzshutnzq OF THIS nzshut = wt_nzshutnzq OF THIS nzshut + 10
96 END
97 IF nz_term_st[actstshutnz] OF term_nz[acttermshutnz] > 0
98 IF nz_term_st[actstshutnz] OF term_nz[acttermshutnz] ≥ (maxnzshutcont -
99 nz_term_st[actstshutnz] OF term_nz[acttermshutnz] = nz_term_st[actst:
100 WAIT ((maxnzshutcont-act_nzshut_l_exp)/(2(nz_shut_cranes OF term_nz[act
101 act_nzshut_l_exp = maxnzshutcont
102 END
103 IF act_nzshut_l_exp = maxnzshutcont & nz_term_st[actstshutnz] OF term_nz
104 act_nzshut_l_exp = act_nzshut_l_exp + nz_term_st[actstshutnz] OF term
105 nz_term_st[actstshutnz] OF term_nz[acttermshutnz] = 0
106 WAIT ((nz_term_st[actstshutnz] OF term_nz[acttermshutnz])/(2(nz_shut
107 END
108
109 WAIT 30 MINUTES @Time for the vessel to sail away@
110 nz_shut_occq OF term_nz[acttermshutnz] = nz_shut_occq OF term_nz[acttermshutnz]
111 @--------------------@
112 @ Blijhouden van de Nanhui Zui doorvoer en de wachttijden @
113 @--------------------@
125 IF NOW > 12 MONTH
126    tp_nz OF term_nz[acttermshutnz] + tp_nz OF term_nz[acttermshutnz] + act_nzhut
127    tp_nzshutexp + tp_nzshutexp + act_nzhut - exp
128
129    narrivalnz OF term_nz[acttermshutnz] - narrivalnz OF term_nz[acttermshutnz]
130    twt_nzshutnz OF term_nz[acttermshutnz] - twt_nzshutnz OF term_nz[acttermshutnz]
131    avgwt_nzshutnz OF term_nz[acttermshutnz] - (twt_nzshutnz OF term_nz[acttermshutnz]
132    STORE wt_nzshutnzo IN w_time_nzq OF term_nz[acttermshutnz]
133 END
134
135 wt_nzshutnzanc + 0
136 wt_nzshutnzo + 0
137 acttermshutnz + 0
138 nzfoundshut + 0
139
140 @-----------------------------------------------------------@
141 @ Varen naar Yangshan @
142 @-----------------------------------------------------------@
143 WAIT (dist_NZ/YS/mnspeed_nzshut) HOURS
144
145 @-----------------------------------------------------------@
146 @Bepalen van de beschikbaarheid van de term op Yangshan @
147 @-----------------------------------------------------------@
149    WAIT 10 MINUTES
150    wt_nzshutysanc + wt_nzshutysanc + 10
151 END
152
154 WAIT 30 MINUTES @voor varen naar de berth@
155
156 @-----------------------------------------------------------@
157 @ lossen van de shuttle op Yangshan @
158 @-----------------------------------------------------------@
159 WAIT (act_nzhut_l_exp/((ys_shut_nz_cranes OF term_ys[acttermnzshtys]) * (ys_shut_nz
160 am_ys_shut_nz OF term_ys[acttermnzshtys] + am_ys_shut_nz OF term_ys[acttermnzshtys])
161
162 IF acttermnzshtys = 1
165 IF am_ys_shut_nz OF term_ys[acttermnzshtys] MODULO(100) = 0
168 END
169 @-----------------------------------------------------------@
170 GOTO further1
171
172 END
173 IF acttermnzshtys = 2
176 IF am_ys_shut_nz OF term_ys[acttermnzshtys] MODULO(100) = 0
179 END
180 GOTO further1
181
182 END
183 IF acttermnzshtys = 3
NZSHUTTLEMOD - page 4

188  IF am ys_shut_nz OF term ys[acttermznzshutys] MODULO(100) = 0
192  END
193  GOTO further1
194 END
195
196  acttermznzshutys = 4
199  IF am ys_shut_nz OF term ys[acttermznzshutys] MODULO(100) = 0
202  END
203  GOTO further1
204  acttermznzshutys = 5
208  IF am ys_shut_nz OF term ys[acttermznzshutys] MODULO(100) = 0
212  act nzshut_1_exp = act nzshut_1_exp + 99
213  END
214  GOTO further1
215 END
216  acttermznzshutys = 6
221  IF am ys_shut_nz OF term ys[acttermznzshutys] MODULO(100) = 0
226  END
227 END
228
229 further1:
230  act nzshut_1_exp = 0
231  act term znzshutys = 0
232
233 IF NOW > 12 MONTH
234  0 ------------------------------@
235  0 Bijhouden van de maximale stackgrootte van alle terms @
236  0 ------------------------------@
239  END
242  END
245  END
248  END
END
END
END

---------------------------
@ Bijhouden van de minimale stackgrootte van alle terms
---------------------------
END
END
END
END

---------------------------
@ laden van de shuttle op Yangshan
---------------------------
repeat:
IF ys_shut_nz_st OF term_y[dacstermnnzshutys] > 0
@ shuttle laden tot max capaciteit als er genoeg cs zijn
END

---------------------------
@ shuttle laden met alle cs in stack aangezien er niet genoeg cs zijn voor een max
END

301
302
303
304
305
306
307
308
309
310
END

313 done3:

315 WAIT 30 MINUTES @voor deberthing@

316 ys_shut_nz_occq OF term_ys[acttermnzshutys] = ys_shut_nz_occq OF term_ys[actterm]

318 STORE acttermnzshutys OF THIS nzshut IN usedystermznz OF THIS nzshut

@ Blijhouden van de doorvoer en de wachttijden op Yangshan @

323 IF NOW ≥ 12 MONTH

324 tp_nzshutimp = tp_nzshutimp + act_nzshut_l_imp

326 nrnzarrivalys OF term_ys[acttermnzshutys] = nrnzarrivalys OF term_ys[actterm]

327 twt_nzshutys OF term_ys[acttermnzshutys] = twt_nzshutys OF term_ys[actterm]

328 avgwt_nzshutys OF term_ys[acttermnzshutys] = (twt_nzshutys OF term_ys[actterm]

END

331 wt_nzshutysanc = 0

334 @ Varen naar Nanhui Zui @

336 WAIT (dist_NZ_YS/mnspeed_nzshut) HOURS

337 nztripcount = nztripcount + 1

339 REPEAT FROM nzshutsail

@ Aanmaken van de shuttles @

344 createnonzshuts:

345 FOR shutcreatenz = 1 TO nr_shut_nz

346 act_nzshut_l_imp OF mznzshut[shutcreatenz] = 480

347 ACTIVATE mznzshut[shutcreatenz] FROM nzshutsail

348 WAIT 0.5 HOURS

350 TERMINATE
Module

Shuttlemod
1 shshutsail:
2 @-----------------------------------@
3 @keuze voor een stack op Shanghai @
4 @-----------------------------------@
5 WHILE biggestshstrn = 0
6 @Eerst alle stacks af voor bepaling grootste stack@
7 @-----------------------------------@
8 FOR shst=1 TO nr_term_yys
9 IF sh_st_term(shst) > biggestshst
10    biggestshstrn ← shst
11    biggestshst ← sh_st_term(shst)
12 END
13 IF biggestshstrn = 0
14    biggestshstrn ← 0
15    biggestshst ← 0
16 WAIT 10 MINUTES
17 GOTO done1
18 END
19 IF biggestshstrn > 0
20    actshshutsh ← biggestshstrn
21    acttermshshutys ← biggestshstrn
22 IF sh_st_term[actshshutsh] ≥ maxshshutcont
23      act_shshut_l_exp ← maxshshutcont
25 END
26 GOTO done1
27 IF act_shshut_l_exp = 0
28      act_shshut_l_exp ← sh_st_term[actshshutsh]
29      sh_st_term[actshshutsh] ← 0
30 END
31 END
32 done1:
33 END
34 END
35
36 biggestshstrn ← 0
37 biggestshst ← 0
38 WAIT 30 MINUTES @Voor het varen naar de berth@
39 @-----------------------------------@
40 @ lossen van de (volle) shshut op Shanghai @
41 @-----------------------------------@
42 WAIT ((act_shshut_l_imp)/(sh_shut_cranea)*(sh_shut_cranea))) HOURS
43 sh_truck_st ← sh_truck_st + 0.3333 * act_shshut_l_imp
44 sh_rail_st ← sh_rail_st + 0.6667 * act_shshut_l_imp
45 IF NOW ≥ 12 MONTH
46      tp_sh ← tp_sh + act_shshut_l_imp
47 END
48 act_shshut_l_imp ← 0
49 IF NOW ≥ 12 MONTH
50 @-----------------------------------@
51 @ Bijhouden van de maximale stackgrootte van alle terms @
52 @-----------------------------------@
53 IF sh_truck_st > max_sh_truck_st
54      max_sh_truck_st ← sh_truck_st
55 END
```plaintext
IF sh_rail_st > max_sh_rail_st
  max_sh_rail_st = sh_rail_st
END

@--------------------------------------------------------@
@ Bijhouden van de minimale stackgrootte van alle terms@
@--------------------------------------------------------@
IF sh_truck_st < min_sh_truck_st
  min_sh_truck_st = sh_truck_st
END

IF sh_rail_st < min_sh_rail_st
  min_sh_rail_st = sh_rail_st
END

@--------------------------------------------------------@
@ laden van de SHshuttle op Shanghai@
@--------------------------------------------------------@
WAIT (act_shshut_1_exp/((sh_shut_cranes)*(sh_shut_cranes))) HOURS

WHILE act_shshut_1_exp < maxshshutcont
  IF sh_term_st[actstshshut] ≤ 0
    WAIT 10 MINUTES
  END
  IF sh_term_st[actstshshut] > 0
    IF sh_term_st[actstshshut] ≥ (maxshshutcont - act_shshut_1_exp)
      sh_term_st[actstshshut] = sh_term_st[actstshshut] - (maxshshutcont -
      WAIT ((maxshshutcont - act_shshut_1_exp)/((sh_shut_cranes)*(sh_shut_cranes)))
      act_shshut_1_exp = maxshshutcont
    END
    IF act_shshut_1_exp = maxshshutcont & sh_term_st[actstshshut] < (maxshshutcont -
      act_shshut_1_exp + sh_term_st[actstshshut])
      sh_term_st[actstshshut] = 0
      WAIT ((sh_term_st[actstshshut])/((sh_shut_cranes)*(sh_shut_cranes)))
    END
  END
END

IF NOW ≥ 12 MONTH
  tp_sh = tp_sh + act_shshut_1_exp
  tp_shshutexp = tp_shshutexp + act_shshut_1_exp
END

WAIT 30 MINUTES @voor het wegvaren van de berth@

Varen naar Yangshan @
WAIT (dist_sh_YS/mnspeed_shshut) HOURS

@--------------------------------------------------------@
@ Bepalen van de beschikbaarheid van de term op Yangshan@
@--------------------------------------------------------@
WHILE ys_shut_sh_occq OF term_ys[acttermshshutys] ≥ ys_shut_sh_q OF term_ys[actt-
  wt_shshutysanc = wt_shshutysanc + 10
END

ys_shut_sh_occq OF term_ys[acttermshshutys] = ys_shut_sh_occq OF term_ys[actte-
WAIT 30 MINUTES @voor varen naar de berth@
```
SHSHUTTLEMOD - page 3

125 @----------------------------------------@
126 @ lossen de de shuttle op Yangshan @
127 @----------------------------------------@
128 WAIT (act_shshut_1_exp/(ys_shut_sh_cranes OF term_ys[acttermshshutys]) * (ys_shi
129 am_ys_shut_sh OF term_ys[acttermshshutys] - am_ys_shut_sh OF term_ys[acttei
130 131 IF acttermshshutys = 1
134 IF am_ys_shut_sh OF term_ys[acttermshshutys] MODULO(100) = 0
137 END
138 GOTO further1
139 END
140 IF acttermshshutys = 2
144 IF am_ys_shut_sh OF term_ys[acttermshshutys] MODULO(100) = 0
148 END
149 GOTO further1
150 END
151 IF acttermshshutys = 3
155 IF am_ys_shut_sh OF term_ys[acttermshshutys] MODULO(100) = 0
159 END
160 GOTO further1
161 END
162 IF acttermshshutys = 4
165 IF am_ys_shut_sh OF term_ys[acttermshshutys] MODULO(100) = 0
168 END
169 GOTO further1
170 END
171 IF acttermshshutys = 5
175 IF am_ys_shut_sh OF term_ys[acttermshshutys] MODULO(100) = 0
179 act_shshut_1_exp = act_shshut_1_exp + 99
180 END
181 GOTO further1
182 END
183 IF acttermshshutys = 6
186
SHSHUTTLEMOD - page 4

189 IF am_y[shut_sh OF term_y[acttermshshyts] MODULO(100) = 0
194 END
195 END
196
197 further1:
198 act_shshut_1_exp = 0
199
200 IF NOW > 12 MONTH
201 @---------------------------------------------------------------------@
202 @ Bijhouden van de maximale stackgrootte van alle terms @
203 @---------------------------------------------------------------------@
204 IF ys_ocean_st[1] OF term_y[acttermshshyts] > max_y[ys_ocean_st[1]] (2
205 max_y[ys_ocean_st[1]] OF term_y[acttermshshyts] = ys_ocean_st[1] (2
206 END
209 END
212 END
215 END
216
219 END
222 END
225 END
226 @---------------------------------------------------------------------@
228 @ Bijhouden van de minimale stackgrootte van alle terms @
229 @---------------------------------------------------------------------@
231 min_y[ys_ocean_st[1]] OF term_y[acttermshshyts] = ys_ocean_st[1] (2
232 END
235 END
236 IF acttermshshyts = 3 & ys_ocean_st[2] OF term_y[acttermshshyts] < mi:
238 END
239 IF acttermshshyts = 6 & ys_ocean_st[2] OF term_y[acttermshshyts] < mi:
241 END
244 END
247 END

IF ys_shut_sh_st OF term_yss[acttermshshutys] > 0
@ shuttle laden tot max capaciteit als er genoeg cs zijn

IF ys_shut_sh_st OF term_yss[acttermshshutys] ≥ (maxshshutcont - act_shshut_l)
y_shut_sh_st OF term_yss[acttermshshutys] = ys_shut_sh_st OF term_yss[acttermshshutys] = (maxshshutcont - act_shshut_l)
WAIT ((maxshshutcont - act_shshut_l) imp) / ((ys_shut_sh_cranes OF term_yss[acttermshshutys] = act_shshut_l) imp 
maxshshutcont
GOTO done3

IF ys_shut_sh_st OF term_yss[acttermshshutys] < maxshshutcont & ys_shut_sh_st
act_shshut_l imp act_shshut_l imp = ys_shut_sh_st OF term_yss[acttermshshutys] ≤ 0
WAIT ((ys_shut_sh_st OF term_yss[acttermshshutys]) / (ys_shut_sh_cranes OF term_yss[acttermshshutys]) > 0 & act_shshut_l imp = maxshshutcont
GOTO repeater

END

STORE acttermshshutys OF THIS shshut IN usedystermssh OF THIS shshut

Bijhouden van de doorvoer en de wachttijden op Yangshan

IF NOW ≥ 12 MONTH
tp_shshutimp = tp_shshutimp + act_shshut_l

ysfoundshutsh = 0
wt_shshutysanc = 0
acttermshshutys = 0

WAIT (dist_sh_yss/mnspeed_shshut) HOURS
shtripcount = shtripcount + 1
REPEAT FROM shshutsail
Aanmaken van de shuttles
createshshuts:
311 FOR shutcreatesh = 1 TO nr_shut_sh
312    act_shshut_[j] imp OF mshshut[shutcreatesh] = 480
313    ACTIVATE mshshut[shutcreatesh] FROM shshutsail
314    WAIT 0.5 HOURS
315 END
316 TERMINATE
Module

Storemod
storedata:

WAIT 4 HOURS

k = k + 1

time = 4*k

CONVERT time TO timer[k] FIELDLNGTH 10

Bijhouden van alle wachtijden

FOR 1-1 TO nr_term_nz
  CONVERT avgwt_nzshutnz OF term_nz[1] TO avgwtnz[k,1] FIELDLNGTH 10 DECIMAL
END

FOR 1-1 TO nr_term_ys
  STORE avg_oceanall OF term_ys[1] IN w_time_o OF term_ys[1]
  STORE avg_ssall OF term_ys[1] IN w_time_ss OF term_ys[1]
END

Bijhouden van de stacks

Nanhui Zui & Shanghai

FOR 1-1 TO nr_term_ys
END

FOR 1-1 TO 3
END

FOR 1-4 TO 6
END

FOR 1-1 TO nr_term_ys
  CONVERT sh_term_st[1] TO stsh[k,1] FIELDLNGTH 10
END

CONVERT sh_truck_st TO stsh[k,7] FIELDLNGTH 10
CONVERT sh_rail_st TO stsh[k,8] FIELDLNGTH 10
CONVERT nz_truck_st OF term_nz[1] TO stnz[k,7] FIELDLNGTH 10

Yangshan

FOR 1-1 TO nr_term_ys
  IF l=2
END
IF l=3
END
IF l=6
END

END
IF l=5
END
IF l=6
END


END

@--------------------------------------------------------@
@ Bijhouden van de gemiddelde interarrival tijden en capaciteiten van river oct
@--------------------------------------------------------@

CONVERT avg_o_cap TO avgdata[k,1] FIELLENGTH 6
CONVERT avg_o_intarr TO avgdata[k,2] FIELLENGTH 6 DECIMALS 2
CONVERT avg_ss_cap TO avgdata[k,3] FIELLENGTH 6
CONVERT avg_ss_intarr TO avgdata[k,4] FIELLENGTH 6 DECIMALS 2
CONVERT avg_river_cap TO avgdata[k,5] FIELLENGTH 6
CONVERT avg_river_intarr TO avgdata[k,6] FIELLENGTH 6 DECIMALS 2

REPEAT FROM storedata
Module

Justifier
WAIT 1440 MINUTES

@ Nanhui zu Justifier


IF NOW ≥ 12 MONTH


END

@ Shanghai Justifier


IF NOW ≥ 12 MONTH
tp[sh] + tp[sh] + 636 + 553

END

REPEAT FROM top
Module

Countermod
COUNTERMOD - page 1

1 count:
2 WAIT 12 MONTH
3 FOR z=1 TO 6
4  \hspace{1em} ocin OF term ys[z]
5  \hspace{1em} ocount OF term ys[z]
6  \hspace{1em} oceancountin OF term ys[z]
7  \hspace{1em} oceancountout OF term ys[z]
8  \hspace{1em} sscountin OF term ys[z]
9  \hspace{1em} sscountout OF term ys[z]
10 \hspace{1em} sscountin OF term ys[z]
11 \hspace{1em} sscountout OF term ys[z]
12 END
13 TERMINATE
Module

Controlbox
@ ask user for configuration data @
@----------------------------------------------------@
control - NEW WINDOW CALLED "Control"
SPECIFY control ORIGIN(0,550) UNITS(5,5) @Elke unit op de as bestaat uit 5 pixel
b_ok - NEW WOB
JOIN b_ok TO control
n - _wob_button(b_ok,0,5,10,4,15,1,100,"OK")
@---------------------------AMOUNT OF SHUTTLES------------------------@
@ Amount of shuttles Sailing between Nanhui Zui and Yangshan @
prm_amnzhut - NEW WOB
n - _wob_prompt(prm_amnzhut,0,110,1,"Amount of Shuttles sailing between Yangshan")
JOIN prm_amnzhut TO control

16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
prm_amnzhut - NEW WOB
str_amnzhut - NEW WOB
n - _wob_prompt(prm_amnzhut,10,105,1,"NZ Shuttles")
str_amnzhut - NEW WOB
n - _wob_string(str_amnzhut,25,105,5,0,15,"53",3)
JOIN prm_amnzhut TO control
JOIN str_amnzhut TO control
JOIN str_amnzhut TO control

@ Amount of shuttles Sailing between Shanghai and Yangshan @
prm_amnshut - NEW WOB
str_amnshut - NEW WOB
n - _wob_prompt(prm_amnshut,10,100,1,"SH Shuttles")
str_amnshut - NEW WOB
n - _wob_string(str_amnshut,25,100,5,0,15,"26",3)
JOIN prm_amnshut TO control
JOIN str_amnshut TO control
JOIN str_amnshut TO control

@--------------------NANHUI ZUI PROPERTIES--------------------------@
prm_nanhui - NEW WOB
n - _wob_prompt(prm_nanhui,0,85,1,"NANHUI ZUI")
JOIN prm_nanhui TO control

@ Amount of terminals at Nanhui Zui @
prm_amtermnz - NEW WOB
str_amtermnz - NEW WOB
n - _wob_prompt(prm_amtermnz,0,80,1,"Amount of NZ terminals")
str_amtermnz - NEW WOB
n - _wob_string(str_amtermnz,25,80,5,0,15,"2",2)
JOIN prm_amtermnz TO control
JOIN str_amtermnz TO control
JOIN str_amtermnz TO control

FOR i-1 TO 2
prm_termmnrz[i] - NEW WOB
END

n - _wob_prompt(prm_termmnrz[1],35,75,1,"TERM 1")
JOIN prm_termmnrz[1] TO control
n - _wob_prompt(prm_termmnrz[2],45,75,1,"TERM 2")
JOIN prm_termmnrz[2] TO control

prm_amnqz - NEW WOB
n - _wob_prompt(prm_amnqz,10,70,1,"shuttle quays")
JOIN prm_amnqz TO control

@ Amount of Shuttle quays at Nanhui Zui @
FOR i-1 TO 2
str_amnqz[i] - NEW WOB
n - _wob_string(str_amnqz[i],25 + 10*i),70,5,0,15,"12",2
JOIN str_amnqz[i] TO control
END
63 @----------------YANGSHAN PROPERTIES-----------------
64 prm_ys - NEW WOB
65 n = _wob_prompt(prm_ys,0,55,1,"YANGSHAN ARCHIPELAGO")
66 JOIN prm_ys TO control
67
68 @Amount of terminals at Yangshan@
69 prm_amtermys = NEW WOB
70 JOIN prm_amtermys TO control
71 str_amtermys = NEW WOB
72 n = _wob_prompt(prm_amtermys,0,50,1,"Amount of terminals")
73 n = _wob_string(str_amtermys,25,50,5,0,15,"6",2)
74 JOIN prm_amtermys TO control
75 JOIN str_amtermys TO control
76
77 FOR i=1 TO 6
78   prm_termnrys[i] - NEW WOB
79 END
80
81 n = _wob_prompt(prm_termnrys[1],35,45,1,"TERM 1")
82 JOIN prm_termnrys[1] TO control
83 n = _wob_prompt(prm_termnrys[2],45,45,1,"TERM 2")
84 JOIN prm_termnrys[2] TO control
85 n = _wob_prompt(prm_termnrys[3],55,45,1,"TERM 3")
86 JOIN prm_termnrys[3] TO control
87 n = _wob_prompt(prm_termnrys[4],65,45,1,"TERM 4")
88 JOIN prm_termnrys[4] TO control
89 n = _wob_prompt(prm_termnrys[5],75,45,1,"TERM 5")
90 JOIN prm_termnrys[5] TO control
91 n = _wob_prompt(prm_termnrys[6],85,45,1,"TERM 6")
92 JOIN prm_termnrys[6] TO control
93
94 @Amount of NZ shuttle quays at Yangshan@
95 prm_amnzqys = NEW WOB
96 n = _wob_prompt(prm_amnzqys,10,40,1,"NZ Shuttle berths")
97 JOIN prm_amnzqys TO control
98
99 FOR i=1 TO 6
100   str_amnzqys[i] - NEW WOB
101      n = _wob_string(str_amnzqys[i],(25 + 10*i),40,5,0,15,"5",2)
102     JOIN str_amnzqys[i] TO control
103 END
104
105 @Amount of river quays at Yangshan@
106 prm_amriverq = NEW WOB
107 n = _wob_prompt(prm_amriverq,10,35,1,"RIVER berths")
108 JOIN prm_amriverq TO control
109
110 FOR i=1 TO 6
111     str_amriverq[i] - NEW WOB
112        n = _wob_string(str_amriverq[i],(25 + 10*i),35,5,0,15,"8",2)
113     JOIN str_amriverq[i] TO control
114 END
115
116 @Amount of SH shuttle quays at Yangshan@
117 prm_amshqys = NEW WOB
118 n = _wob_prompt(prm_amshqys,10,30,1,"SH Shuttle berths")
119 JOIN prm_amshqys TO control
120
121 FOR i=1 TO 6
122     str_amshqys[i] - NEW WOB
123        n = _wob_string(str_amshqys[i],(25 + 10*i),30,5,0,15,"2",2)
124     JOIN str_amshqys[i] TO control
CONTROLBOX - page 3

END

@Amount of Ocean quays at Yangshan@
prm_amoceaq ← NEW WOB
n ← _wob_prompt(prm_amoceaq,10,25,1,"OCEAN berths")
JOIN prm_amoceaq TO control

FOR i ← 1 TO 6
str_amoceaq[i] ← NEW WOB
n ← _wob_string(str_amoceaq[i],(25 + 10*i),25,5,0,15,"4",2)
JOIN str_amoceaq[i] TO control
END

@Amount of Short Sea quays at Yangshan@
prm_amssq ← NEW WOB
n ← _wob_prompt(prm_amssq,10,20,1,"Short Sea berths")
JOIN prm_amssq TO control

FOR i ← 1 TO 6
str_amssq[i] ← NEW WOB
n ← _wob_string(str_amssq[i],(25 + 10*i),20,5,0,15,"5",2)
JOIN str_amssq[i] TO control
END

---------SIMULATION TIME---------

@Simulatietijd in maanden@
prm_simtime ← NEW WOB
str_simtime ← NEW WOB
n ← _wob_string(str_simtime,0,10,10,0,15,"48",4)
JOIN prm_simtime TO control

JOIN str_simtime TO control

SHOW control AT(10,10) SIZE(550,580)

n ← _window_response(control,n=0)  @Zorgt voor activering van windowtje@

-----------AMOUNT OF SHUTTLES--------

n ← _wob_string_value(str_amnznshut,<char>)
nr_shut_nz ← char

n ← _wob_string_value(str_amshshut,<char>)
nr_shut_sh ← char

-----------NANHUI ZUI PROPERTIES--------

n ← _wob_string_value(str_amtermnz,<char>)
nr_term_nz ← char

n ← _wob_string_value(str_amnqz[1],<char>)
nr_nz_shut_q[1] ← char

n ← _wob_string_value(str_amnqz[2],<char>)
nr_nz_shut_q[2] ← char

-----------YANGSHAN PROPERTIES--------

n ← _wob_string_value(str_amtermys,<char>)
nr_term_y <char>

FOR i ← 1 TO 6
n ← _wob_string_value(str_amnqys[i],<char>)
nr_nzshutys_q[i] ← char
END
187 FOR i-1 TO 6
188 n = _wob_string_value(str_amriverq[i],<char>)
189 nr_river_q[i] = char
190 END
191
192 FOR i-1 TO 6
193 n = _wob_string_value(str_amshqys[i],<char>)
194 nr_shshutys_q[i] = char
195 END
196
197 FOR i-1 TO 6
198 n = _wob_string_value(str_amoeanq[i],<char>)
199 nr_ocean_q[i] = char
200 END
201
202 FOR i-1 TO 6
203 n = _wob_string_value(str_amssq[i],<char>)
204 nr_ss_q[i] = char
205 END
206
207 @-----------------SIMULATION TIME-----------------@
208 n = _wob_string_value(str_simtime,<char>)
209 simtime = char
210
211 RETURN
Module

Outputmod
@-----------------------------------------------------------------------------------------------------------@
@ Bijhouden van annual throughput van de terminal en van de haven @
@-----------------------------------------------------------------------------------------------------------@
FOR i-1 TO nr_term_ys
END

FOR i-1 TO nr_term_nz
  @ totannutps[i] = totannutps[i] + tp ys[1] OF term_ys[i] @Totale doorvoer
  @ totannutps[i] = totannutps[i] + tp ys[2] OF term_ys[i] @Totale doorvoer
  @ totannutps[i] = totannutps[i] + tp ys[3] OF term_ys[i] @Totale doorvoer
  @ totannutps[i] = totannutps[i] + tp ys[4] OF term_ys[i] @Totale doorvoer
  totannutps[i] = (totannutps[i] + annu tp nz[1] OF term_ys[i]) (12/(simtime-12)) @Gemiddelde
END

@ tp sh * (12/(simtime-12)) @
FOR i-1 TO nr_shut_nz
  @ tottanutps[nzimp] = tottanutps[nzimp] + (tp nzshutimp OF mnzshut[i]) @
  @ tottanutps[nzexp] = tottanutps[nzexp] + (tp nzshutexp OF mnzshut[i]) @
END

FOR i-1 TO nr_shut_sh
  @ tottanutps[nzimp] = tottanutps[nzimp] + (tp shshutimp OF mshshut[i]) @
  @ tottanutps[nzexp] = tottanutps[nzexp] + (tp shshutexp OF mshshut[i]) @
END

@ (12/(simtime-12)) @
FOR i-1 TO nr_term_ys
  @ tp ttruckimp = tp ttruckimp * (12/(simtime-12)) @
  @ tp ttruckimp = tp ttruckimp * (12/(simtime-12)) @
  @ tp ttruckimp = tp ttruckimp * (12/(simtime-12)) @
  @ tp ttruckimp = tp ttruckimp * (12/(simtime-12)) @
  @ tp ttruckimp = tp ttruckimp * (12/(simtime-12)) @
END

@ (12/(simtime-12)) @
FOR i-1 TO nr_term_nz
  @ tp oexp = tp oexp * (12/(simtime-12)) @
  @ tp oimp = tp oimp * (12/(simtime-12)) @
  @ tp oimp = tp oimp * (12/(simtime-12)) @
  @ tp o = tp o * (12/(simtime-12)) @
  @ tp o = tp o * (12/(simtime-12)) @
END

@ (12/(simtime-12)) @
FOR i-1 TO nr_term_ys
  @ tp ssimp = tp ssimp * (12/(simtime-12)) @
  @ tp ssimp = tp ssimp * (12/(simtime-12)) @
  @ tp ssimp = tp ssimp * (12/(simtime-12)) @
  @ tp ssimp = tp ssimp * (12/(simtime-12)) @
  @ tp ssimp = tp ssimp * (12/(simtime-12)) @
END

@ (12/(simtime-12)) @
FOR i-1 TO nr_term_ys
  @ tp ss = tp ss * (12/(simtime-12)) @
  @ tp ss = tp ss * (12/(simtime-12)) @
  @ tp ss = tp ss * (12/(simtime-12)) @
  @ tp ss = tp ss * (12/(simtime-12)) @
  @ tp ss = tp ss * (12/(simtime-12)) @
END

@ (12/(simtime-12)) @
FOR i-1 TO nr_term_ys
  @ tp riverimp = tp riverimp * (12/(simtime-12)) @
  @ tp riverimp = tp riverimp * (12/(simtime-12)) @
  @ tp riverimp = tp riverimp * (12/(simtime-12)) @
  @ tp riverimp = tp riverimp * (12/(simtime-12)) @
  @ tp riverimp = tp riverimp * (12/(simtime-12)) @
END

@ (12/(simtime-12)) @
FOR i-1 TO nr_term_ys
  @ (import_o OF term_ys[i]) = (import_o OF term_ys[i]) * (12/(simtime)) @
  @ (import ss OF term_ys[i]) = (import ss OF term_ys[i]) * (12/(simtime)) @
  @ CONV import_o OF term_ys[i] TO termimport[i] OF term_ys[i] FIELDLENGTH 8 @
  @ CONV import ss OF term_ys[i] TO termimport[i] OF term_ys[i] FIELDLENGTH 8 @
  @ export_o OF term_ys[i] = ((export_o OF term_ys[i]) * (12/(simtime)) @
END
export_ss[1] = ((export_ss[1]*12/simtime)
END

@ Converteren van gegevens voor het wegschrijven in text files

@ Datastreams declareren

general ← NEW DATASTREAM
nzstacksout ← NEW DATASTREAM
wtoutnz ← NEW DATASTREAM
avgvalues ← NEW DATASTREAM
FOR i-1 TO nr_term_yys
    ysstacksout[i] ← NEW DATASTREAM
    wtoutys[i] ← NEW DATASTREAM
    indiviwts[i] ← NEW DATASTREAM
END

@ Filenames aan deze datastreams koppelen

ATTACH "nzshstks.txt" TO nzstacksout
ATTACH "ysstcks1.txt" TO ysstacksout[1]
ATTACH "ysstcks2.txt" TO ysstacksout[2]
ATTACH "ysstcks3.txt" TO ysstacksout[3]
ATTACH "ysstcks4.txt" TO ysstacksout[4]
ATTACH "ysstcks5.txt" TO ysstacksout[5]
ATTACH "ysstcks6.txt" TO ysstacksout[6]
ATTACH "wtoutystempl.txt" TO wtoutys[1]
ATTACH "wtoutystem2.txt" TO wtoutys[2]
ATTACH "wtoutystem3.txt" TO wtoutys[3]
ATTACH "wtoutystem4.txt" TO wtoutys[4]
ATTACH "wtoutystem5.txt" TO wtoutys[5]
ATTACH "wtoutystem6.txt" TO wtoutys[6]
ATTACH wtoutnzterms.txt TO wtoutnz
ATTACH "indiviwts1.txt" TO indiviwts[1]
ATTACH "indiviwts2.txt" TO indiviwts[2]
ATTACH "indiviwts3.txt" TO indiviwts[3]
ATTACH "indiviwts4.txt" TO indiviwts[4]
ATTACH "indiviwts5.txt" TO indiviwts[5]
ATTACH "indiviwts6.txt" TO indiviwts[6]
ATTACH "general.txt" TO general
ATTACH "avgvalues.txt" TO avgvalues

@ Datastreams vullen met gegevens

@ General properties

CONVERT nr_shut_nz TO inputstr[1,1] FIELDLENGTH 3
CONVERT nr_shut_sh TO inputstr[1,2] FIELDLENGTH 3
CONVERT nr_term_nz TO inputstr[2,1] FIELDLENGTH 3
CONVERT nr_nz_shut_d[1] TO inputstr[3,1] FIELDLENGTH 3
CONVERT nr_term_yys TO inputstr[4,1] FIELDLENGTH 3
FOR i-1 TO nr_term_yys
    CONVERT nr_ocean_d[i] TO inputstr[5,1] FIELDLENGTH 3
    CONVERT nr_ss_q[i] TO inputstr[6,1] FIELDLENGTH 3
    CONVERT nr_nzshuths_q[i] TO inputstr[7,1] FIELDLENGTH 3
    CONVERT nr_river_d[i] TO inputstr[8,1] FIELDLENGTH 3
    CONVERT nr_shshuths_q[i] TO inputstr[9,1] FIELDLENGTH 3

END

127 CONVERT tottptruckznimp TO totannuptstr[1] FIELDLONGTH 8
128 CONVERT tottptruckznexp TO totannuptstr[2] FIELDLONGTH 8
129 CONVERT tottptruckshimp TO totannuptstr[3] FIELDLONGTH 8
130 CONVERT tottptrucksheexp TO totannuptstr[4] FIELDLONGTH 8
131 CONVERT tottptrainshimp TO totannuptstr[5] FIELDLONGTH 8
132 CONVERT tottptrainsheexp TO totannuptstr[6] FIELDLONGTH 8
133
134 CONVERT totannuptpnz TO totannuptstr[7] FIELDLONGTH 8
135 CONVERT totannuptsh TO totannuptstr[8] FIELDLONGTH 8

136 CONVERT totannuptshunznimp TO totannuptstr[10] FIELDLONGTH 8
137 CONVERT totannuptshunznexp TO totannuptstr[11] FIELDLONGTH 8
138 CONVERT totannuptshunshimp TO totannuptstr[12] FIELDLONGTH 8
139 CONVERT totannuptshunsheexp TO totannuptstr[13] FIELDLONGTH 8
140 CONVERT totannuptpoexp TO totannuptstr[14] FIELDLONGTH 8
141 CONVERT totannuptpoom TO totannuptstr[15] FIELDLONGTH 8
142 CONVERT totannuptpotrans TO totannuptstr[16] FIELDLONGTH 8
143 CONVERT totannuptpo TO totannuptstr[17] FIELDLONGTH 8
144 CONVERT totannuptps TO totannuptstr[18] FIELDLONGTH 8
145 CONVERT totannuptpssimp TO totannuptstr[19] FIELDLONGTH 8
146 CONVERT totannuptpss TO totannuptstr[20] FIELDLONGTH 8
147 CONVERT totannuptpstrans TO totannuptstr[21] FIELDLONGTH 8
148 CONVERT totannuptps TO totannuptstr[22] FIELDLONGTH 8
149 CONVERT totannuptpriverimp TO totannuptstr[23] FIELDLONGTH 8
150 CONVVERT totannuptpriverexp TO totannuptstr[24] FIELDLONGTH 8

151
152 FOR i-1 TO nr_term_y
153 CONVERT tp_y[1] OF term_y[1] TO annuptperstr[i,1] FIELDLONGTH 8 @Doorvoel
158 END

159
160 CONVERT totannuptyp[1] TO annuptperstr[7,1] FIELDLONGTH 8 @Gemidde
161 CONVERT totannuptyp[2] TO annuptperstr[7,2] FIELDLONGTH 8
162 CONVERT totannuptyp[3] TO annuptperstr[7,3] FIELDLONGTH 8

165
166 FOR j-1 TO 3
168 END
169 FOR j-1 TO 3
171 END

172

175
176 FOR j-1 TO nr_term_y
177 CONVERT max_sh_term_st[j] TO maxstacksh[j] FIELDLONGTH :
178 END
179 CONVERT max_sh_truck_st TO maxstacksh[7] FIELDLONGTH :
180 CONVERT max_sh_rail_st TO maxstacksh[8] FIELDLONGTH :

181
182 FOR i-1 TO nr_term_y
CONVERT max ys shut sh st OF term ys[i] TO maxstackys [7] OF term ys[i] F:
CONVERT i
END

@ Converten van de minimale stackwaarden @

FOR j-1 TO 3
END

FOR j-4 TO 6
END


FOR j-1 TO nr term ys
CONVERT min sh term st[j] TO minstacksh[j] FIELDLONGTH :
END

CONVERT min sh truck st TO minstacksh[7] FIELDLONGTH :
CONVERT min sh rail st TO minstacksh[8] FIELDLONGTH :

FOR i-1 TO nr term ys
CONVERT i
END

@------------------------------------------@

@ Converteren van het aantal schepen dat op iedere ter is aangekomen gedurende

FOR i-1 TO nr term ys
CONVERT oceancountin OF term ys[i] TO shipcountin[i,1] FIELDLONGTH :
CONVERT sscountin OF term ys[i] TO shipcountin[i,2] FIELDLONGTH :
CONVERT rivercountin OF term ys[i] TO shipcountin[i,3] FIELDLONGTH :
CONVERT nrznarrivalys OF term ys[i] TO shipcountin[i,4] FIELDLONGTH :
CONVERT nrssharrivalys OF term ys[i] TO shipcountin[i,5] FIELDLONGTH :
END

@------------------------------------------@

@ Converteren van het aantal schepen dat op iedere ter is vertrokken gedurende

FOR i-1 TO nr term ys
CONVERT oceancountout OF term ys[i] TO shipcountout[i,1] FIELDLONGTH :
CONVERT sscountout OF term ys[i] TO shipcountout[i,2] FIELDLONGTH :
CONVERT rivercountout OF term ys[i] TO shipcountout[i,3] FIELDLONGTH :
CONVERT nrznarrivalys OF term ys[i] TO shipcountout[i,4] FIELDLONGTH :
CONVERT nrssharrivalys OF term ys[i] TO shipcountout[i,5] FIELDLONGTH :
END

@------------------------------------------@
CONVERT ssin OF term_ys[i] TO countin[i,2] FIELDDLENGTH 6
CONVERT riin OF term_ys[i] TO countin[i,3] FIELDDLENGTH 6

@--------------------------------------------------------------------------@
@Converting the number of ships that have been shipped from each term per 1 year@
@--------------------------------------------------------------------------@
FOR i=1 TO nr_term_ys
    CONVERT ocout OF term_ys[i] TO countout[i,1] FIELDDLENGTH 6
    CONVERT ssout OF term_ys[i] TO countout[i,2] FIELDDLENGTH 6
    CONVERT riout OF term_ys[i] TO countout[i,3] FIELDDLENGTH 6
END
Module

Filewritemod
OPEN general FOR OUTPUT
WRITE "Amount of NZ shuts "; inputstr[1,1] TO general WITH IMAGE a;
WRITE "Amount of SH shuts "; inputstr[1,2] TO general WITH IMAGE a;
WRITE "Amount of NZ terms "; inputstr[2,1] TO general WITH IMAGE a;
WRITE "TERM 1"," TERM 2";
WRITE "NZ quays "; inputstr[3,1]; inputstr[3,2] TO general WITH IMAGE a;
WRITE "NZ shuttles "; inputstr[4,1] TO general WITH IMAGE a;
WRITE "OCEAN quays "; inputstr[5,1]; inputstr[5,2]; inputstr[5,3] TO general;
WRITE "TERM 1"," TERM 2"," TERM 3"," TERM 4"," TERM 5"," TERM 6";
WRITE "NZ shuttles exp "; inputstr[6,1]; inputstr[6,2]; inputstr[6,3]; inputstr[6,4];
WRITE "Nzshut quays "; inputstr[7,1]; inputstr[7,2]; inputstr[7,3];
WRITE "River quays "; inputstr[8,1]; inputstr[8,2]; inputstr[8,3];
WRITE "Shshut quays "; inputstr[9,1]; inputstr[9,2]; inputstr[9,3];
WRITE "Total annual throughput of terminals: ";
WRITE "Nanhui Zui "; totnutptstr[7] TO general WITH IMAGE a;
WRITE "Shanghai "; totnutptstr[8] TO general WITH IMAGE a;
WRITE "Yangshan ";
WRITE "Yangshan Total ";
FOR i-1 TO nr_term_y
WRITE "Terminal "; maxstackys[8] OF term_y[i]; annutpterstr[i,1]; annutpterstr[i,2];
END
WRITE "Transport volumes of the individual service groups: ";
WRITE "NZ trucksimp "; totnutptstr[1] TO general WITH IMAGE a;
WRITE "NZ trucksexp "; totnutptstr[2] TO general WITH IMAGE a;
WRITE "SH Trucksimp "; totnutptstr[3] TO general WITH IMAGE a;
WRITE "SH Trucksexp "; totnutptstr[4] TO general WITH IMAGE a;
WRITE "SH Trainsimp "; totnutptstr[5] TO general WITH IMAGE a;
WRITE "SH Trainsexp "; totnutptstr[6] TO general WITH IMAGE a;
WRITE "NZ shuttlesimp "; totnutptstr[10] TO general WITH IMAGE a;
WRITE "NZ shuttlesexp "; totnutptstr[11] TO general WITH IMAGE a;
WRITE "SH shuttlesimp "; totnutptstr[12] TO general WITH IMAGE a;
WRITE "SH shuttlesexp "; totnutptstr[13] TO general WITH IMAGE a;
WRITE "Ocean Trans "; totnutptstr[16] TO general WITH IMAGE a;
WRITE "Ocean Imp "; totnutptstr[15] TO general WITH IMAGE a;
WRITE "Ocean Exp "; totnutptstr[14] TO general WITH IMAGE a;
WRITE "Ocean "; totnutptstr[17] TO general WITH IMAGE a;
WRITE "Shortsea Trans "; totnutptstr[20] TO general WITH IMAGE a;
WRITE "Shortsea Imp "; totnutptstr[19] TO general WITH IMAGE a;
WRITE "Shortsea Exp "; totnutptstr[18] TO general WITH IMAGE a;
WRITE "River Imp "; totnutptstr[22] TO general WITH IMAGE a;
WRITE "River Exp "; totnutptstr[23] TO general WITH IMAGE a;
WRITE "Import throughput per Yangshan terminal: ";
WRITE "Ocean ";
WRITE "Short ";
FOR i-1 TO nr_term_y
END
WRITE "export throughput per Yangshan terminal (incl. transhipment):" TO general WITH IMAGE a(5)x(2)a(15)x(1)a(1)x(2)A.
FOR i-1 TO nr_term_ys
END

WRITE "MAXIMUM stacksizes of terminals:" TO general WITH IMAGE a(
WRITE "Nanhui Zui terminal 1:" TO general WITH IMAGE a(
WRITE "Nanhui Zui terminal 2:" TO general WITH IMAGE a(
WRITE "Shanghai terminal:" TO general WITH IMAGE a(
WRITE "Shuttle ":"maxstacksh[1];maxstacksh[2];maxstacksh[3]
WRITE "Rail ":"maxstacksh[7] TO general WITH IMAGE a(
WRITE "Truck ":"maxstacksh[8] TO general WITH IMAGE a(
WRITE "Yangshan terminals" TO general WITH IMAGE a(18)
WRITE "Ocean 1";"Ocean 2";"Short 1";"Short 2";" River";"NZ Shut";"SH Sl
FOR i-1 TO nr_term_ys
END
WRITE "MINIMUM stacksizes of terminals:" TO general WITH IMAGE a(
WRITE "Nanhui Zui terminal 1:" TO general WITH IMAGE a(
WRITE "Nanhui Zui terminal 2:" TO general WITH IMAGE a(
WRITE "Shanghai terminal:" TO general WITH IMAGE a(
WRITE "Shuttle ":"minstacksh[1];minstacksh[2];minstacksh[3]
WRITE "Rail ":"minstacksh[7] TO general WITH IMAGE a(
WRITE "Truck ":"minstacksh[8] TO general WITH IMAGE a(
WRITE "Yangshan terminals" TO general WITH IMAGE a(18)
WRITE "Ocean 1";"Ocean 2";"Short 1";"Short 2";" River";"NZ Shut";"SH Sl
FOR i-1 TO nr_term_ys
END

@ Schrijven van de wacht tijden @
WRITE "Waiting times at the Yangshan terminals" TO general WITH IMAGE a(40) |
FOR j=1 TO nr_term_y$s
 FOR i=1 TO 5
 WRITE ";";"Ocean ";"ShortSea";"River ";"NZ Shuts";"SH Shuts" |
 WRITE ";";"Terminal ";maxstackys[8] OF term_y$s[1];timer[j*4320];avg
 END
END

@ Schrijven van het aantal aankomsten na 1 jaar
@
WRITE " amount of arr at Yangshan 1 year" TO general WITH IMAGE a(40) |
WRITE "";";"Ocean ";"ShortSea";"River ";"NZ Shuts";"SH Shuts" |
 WRITE TO general WITH IMAGE a(30) |
FOR l=1 TO 6
 WRITE @;"Terminal ";maxstackys[8] OF term_y$s[1];countin[l,1];countin[ |
END

WRITE @;"Schrijven van het aantal vertrekken na 1 jaar@ |
WRITE "amount of dep at Yangshan 1 year" TO general WITH IMAGE a(40) |
WRITE "";";"Ocean ";"ShortSea";"River ";"NZ Shuts";"SH Shuts" |
 WRITE TO general WITH IMAGE a(30) |
FOR l=1 TO 6
 WRITE @;"Terminal ";maxstackys[8] OF term_y$s[1];countout[l,1];countout[ |
END

WRITE @;"Schrijven van het aantal vertrekken" |
WRITE " amount of ARRIVALS at Yangshan" TO general WITH IMAGE a(30) |
WRITE "";";"Ocean ";"ShortSea";"River ";"NZ Shuts";"SH Shuts" |
 WRITE TO general WITH IMAGE a(30) |
FOR l=1 TO nr_term_y$s
 WRITE @;"Terminal ";maxstackys[8] OF term_y$s[1];shipcountin[l,1];ship
END

WRITE @;"Schrijven van het aantal vertrekken" |
WRITE " amount of DEPARTURES at Yangshan" TO general WITH IMAGE a(35) |
WRITE "";";"Ocean ";"ShortSea";"River ";"NZ Shuts";"SH Shuts" |
 WRITE TO general WITH IMAGE a(35) |
FOR l=1 TO nr_term_y$s
 WRITE @;"Terminal ";maxstackys[8] OF term_y$s[1];shipcountout[l,1];ship
END

WRITE " To general WITH IMAGE a(1)X(1)|| | | | | | |
CLOSE general

@ Nanhai Zui & Shanghai stacks
@
CONVERT totannutpsh TO annutpstrsh FIELDLENGTH 8
OPEN nzstacksout FOR OUTPUT
WRITE "Development of stacks at the satellite terminals" TO nzstacksout
WRITE "Annual throughput terminal 1:";annutpstrnz OF term.nz[1] TO nzstacksout
WRITE "Annual throughput terminal 2:";annutpstrnz OF term.nz[2] TO nzstacksout
WRITE "Annual throughput Shanghai ":;annutpstrsh TO nzsta
WRITE ";;NZTerminal1","NZTerminal2","SHTerminal" TO nzstacksout WITH IMAGE A:
WRITE ";;TERM 1"," TERM 2"," TERM 3","Truckst"," TERM 4"," TERM 5"," TERM
FOR 1-1 TO 21600
WRITE timer[i];stnz[i,1];stnz[i,2];stnz[i,3];stnz[i,7];stnz[i,11];stnz[i,12]
END
WRITE "" TO nzstacksout WITH IMAGE A(1)X(1)///////////
CLOSE nzstacksout

@ Yangshan stacks
OPEN yststacksout[1] FOR OUTPUT
CONVERT 1 TO termcount[2] FIELDELENGTH 2
WRITE "Annual throughput":;annutptermstr[1,1] TO yststacksout[1] WITH #
WRITE "Year 1 ";;annutptermstr[1,2] TO yststacksout[1] WITH #
WRITE "Year 2 ";;annutptermstr[1,3] TO yststacksout[1] WITH #
WRITE "Year 3 ";;annutptermstr[1,4] TO yststacksout[1] WITH #
WRITE "Year 4 ";;annutptermstr[1,5] TO yststacksout[1] WITH #
WRITE "Average":;annutptermstr[1,6] TO yststacksout[1] WITH #
WRITE "Time ";;"Ocean 1";"Ocean 2";"Short 1";"Short 2";"River ";"NZ S
FOR 1-1 TO 21600
WRITE timer[i];stys[i,1] OF term ys[i];stys[i,2] OF term ys[i];stys[i,3]
END
WRITE "" TO yststacksout[1] WITH IMAGE A(1)X(1)///////////
CLOSE yststacksout[1]
END

@ Alle wachttijden van Yangshan
OPEN wtoutys[1] FOR OUTPUT
WRITE "Development of waiting times at terminal ":;maxstackys[8] OF term ys[i]
WRITE ";;Ocean ";;"Short Sea";"River ";"NZ Shuts";"SH Shuts" TO w
FOR 1-1 TO 21600
WRITE timer[i];avgwtchar[i,1] OF term ys[i];avgwtchar[i,2] OF term ys[i]
END
WRITE "" TO wtoutys[1] WITH IMAGE A(1)X(1)///////////
CLOSE wtoutys[1]
END

@ Alle wachttijden van Nanhui Zui
OPEN wtoutnz FOR OUTPUT
WRITE "Development of waiting times at the NZ Terminal" TO wtoutnz WITH IMAGE A(
WRITE ";;Term 1"," Term 2" TO wtoutnz WITH IMAGE A(8)X(2)A(8)X(2)A(8)
FOR 1-1 TO 21600
WRITE timer[i];avgwtnz[i,1];avgwtnz[i,2] TO wtoutnz WITH IMAGE A(8)X(2)A(8)X
END
WRITE "" TO wtoutnz WITH IMAGE A(1)X(1)///////////
CLOSE wtoutnz

@ Alle individuele wachttijden van Yangshan
OPEN indiviwtys[7] FOR OUTPUT
WRITE "Individual waiting times per vessel type at terminal ":;maxstackys[8] (i
WRITE ";;River ";;"Short ";;"Ocean " TO indiviwtys[7] WITH IMAGE A(7)X(4)A(7)
FOR 1-1 TO 30000
WRITE httchar[i,3] OF term ys[i];htchar[i,2] OF term ys[i];htchar[i,1] OF
END
WRITE "" TO indiviwtys[1] WITH IMAGE A(1)X(1)!!!!!!!!!
CLOSE indiviwtys[1]
END

@------------------------------------------------------------------------------------@
@ Schrijven van de gemiddelde waarden van scheeps eigenschappen @
@------------------------------------------------------------------------------------@
OPEN avgvalues FOR OUTPUT
WRITE "Development of the average values of the inter arrival times and capacity
WRITE "";"" Ocean "";"" Shortsea "";""
WRITE "Time";"Capacity";"Inter arrival";"Capacity";"Inter arrival";"Capacity"
FOR i-1 TO 21600
WRITE timer[i];avgdata[i,1];avgdata[i,2];avgdata[i,3];avgdata[i,4];avgdata[i
END
WRITE "" TO avgvalues WITH IMAGE A(1)X(1)!!!!!!!!!
CLOSE avgvalues
RETURN