Development of a Container Transshipment Port on Ihavandhippolhu Atoll, Maldives

Master of Science Thesis Niek van der Sluijs

Final report: 12 February 2004

Confidential (See inner page)

Hydronamic Engineering Department BV
Royal Boskalis Westminster NV

TU Delft
Delft University of Technology
Faculty of Civil Engineering and Geosciences
Development of a Container Transshipment Port on Ihavandhippolhu Atoll, Maldives

Master of Science Thesis Niek van der Sluijs

Final Report

Supervisors:

Delft University of Technology:
Prof. ir. H. Ligteringen
Ir. R. Groenveld
Ir. B.A. Pielage

Hydronamic/ Royal Boskalis Westminster nv:
Ir. G.H. van Raalte

This report is confidential; it is neither allowed to copy or publish information from this report nor to lend this report without the absolute permission of the client. This restriction is valid until February 1st 2004. After this date publicity is permitted, unless the client agreed new restrictions with the Delft University of Technology. The client is Boskalis/ Hydronamic Engineering Department, G.H. van Raalte, Rosmolenweg 20, 3350 AA, Papendrecht.

Hydronamic Engineering Department BV
Royal Boskalis Westminster NV

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Ihavandhippolhu Atoll Transshipment Port

Preface

This report is a result of a graduation thesis. This thesis is the final part of Civil Engineering, which is a Master of Science study at the Delft University of Technology. When Hydronamic, the engineering department of Royal Boskalis Westminster nv, was asked to do research on the port development on the Maldives, they offered me the opportunity to do this research. After nine months of work at their office the research is finished and can be used to graduate at the University.

During my Master in Civil Engineering I specialised in hydraulics and more specific in port planning and construction. The variety of the aspects that influence port design interested me the most. To combine these aspects and to design a technically and economically feasible port was a big challenge for me. After the technical design and the feasibility a detailed design on the terminal transport is carried out.

The first main reason for writing this report is to convince the Delft University of Technology that I am able to use the acquired knowledge and to report this in a clear and logical way. Second, this report provides the answer to Hydronamic whether the construction of a transshipment port is feasible. Due to the limited data and time, the latter is not yet proven. However, this report can be used as a framework for further research on port development possibilities on the Maldives.

During this study there were some people, who I would like to thank for their help and support. First of all, the members of my graduation committee of the Delft University of Technology: prof. ir. H. Ligteringen, ir. R. Groenveld, ir. B.A. Pielage (Faculty for Mechanical Engineering) and my daily supervisor from Hydronamic: ir. G.H. van Raalte. Furthermore, I would like to thank the employees of Hydronamic for the good working environment and especially ir. D.N. Klazinga and ir. A. de Groot for helping me with questions and for providing data. Finally, I would like to thank Royal Boskalis Westminster nv for making their facilities available.

After nine months I look back to a very interesting period where I learned more on port development and where I gained new related interests.

Niek van der Sluijs
Papendrecht, January 2004
Executive Summary

Ihavandhipholhu is located on the most northern Atoll of the Maldives. There are two advantages of its location that are the reasons for this study on a container transshipment port. The first is the short distance to the main East-West shipping routes. Second, the central position in the Indian Ocean implies short feeder distances (see Figure 2). The exploitation of a transshipment port can generate more income for the Maldives besides the income from tourism.

One of the problems for a new port would be the competition in the Indian Ocean; Colombo is expanding its port after congestion and Salalah is a new port that expands rapidly. To survive in this competitive environment, the new port has to perform well. This means efficient and fast cargo handling and low tariffs compared to the competitors. Especially the tariffs can be kept low, because the investment costs are expected to be quite low as well. The port is situated on a deep water atoll but protected against incoming offshore waves; a breakwater is probably not required and dredging costs can be limited.

The main objective of this study is to investigate the technical and economical feasibility of a container transshipment port on Ihavandhipholhu Atoll on the Maldives.

A study in 1998 has forecasted a throughput of 1,000,000 TEU/year in 2010 for a transshipment port on a southern atoll. An economic study on the competitiveness and on recent changes in container transport has to show if this throughput is still reasonable. First, the competition has increased, since 1998 Salalah is a new competitor and Colombo is expanding. However, if sailing distances are considered, Ihavandhipholhu is very favourably located. Possible target markets are Eastern Africa and Western India. Second, the global and regional container port demand is still growing fast and in the future still a lot of capacity is needed. The share of transshipment increases as well. The main conclusion is that 1,000,000 TEU/year in 2010 is still reasonable; however Ihavandhipholhu has to distinguish itself by a high efficiency and low tariffs. With the recent trends in vessel sizes the new port has to be capable of receiving the Suezmax type of vessel that will be sailing by 2010. Construction of the port will be in 2005 and 2006, after that the port can be operational in 2007.

For designing the port lay-out, data on waves and soil is necessary. This data determines together with the economic forecasts, the dimensions of the port and its components. The Maldives has two monsoon seasons; the southwest monsoon from May to October brings the strongest wind and rains, the northwest monsoon from November to April is rather dry with very little wind. The prevailing wind and wave direction is west to southwest and the swell direction is most of the time from the south. The currents and morphological system do not play an important role.

With different distributions in relay and feeding transshipment the number of berths and quay length can be determined. Two berths for mainline vessels (Super-Post Panamax), where one berth is also usable for feeder vessels (2nd generation) and another feeder berth are required. This corresponds with a quay length of 1020 m. The berths are sufficiently deep and two mainline berths can serve the Suezmax vessel in the future.

The most important other components are the entrance channel and the terminal. The entrance channel has to be 2.2 km long without bends for tugs to tow up; 314 m wide for a safe one-way channel and the depth has to be 20.5 m for receiving Suezmax vessels. The terminal requires 46 ha for cargo handling and stacking.

On Ihavandhipholhu Atoll there are three major groups of islands that are suitable for the location of the port. In total eight rough sketches for the terminal and entrance channel situation are made. These sketches are evaluated on the distance to the main shipping routes, the hydraulic conditions and the construction possibilities. This evaluation results in three different locations for further analysis.

To make some distinction between the designs and because the downtime of the port is very important, some measures are taken in each design. The two designs that are located on the east of the atoll are exposed to western wave impact. The first design (Pd1) gets an indented berth as well as a little breakwater, the second design (Pd2) is protected with a long breakwater and the last design...
Preliminary design 3 is the preferred option according to the selection criteria. However, this design is not feasible, because its IRR is lower than 15%. Both the demand on the IRR of 15% and the prospected IRR of 12.2% are questionable. First, the demand is set according to a general standard in project engineering, but possible investors can have lower demand to participate. Second, the IRR can be prospected better by specifying the operational costs.
Ihavandhippolhu Atoll Transshipment Port

The port is considered to be not feasible on base of the demand of 15%, but due to the assumptions, this feasibility is questionable. In addition to the lay-out calculations in this report a more detailed study is done on the terminal lay-out and the required equipment. This detailed study has to prove the correctness of the assumption on the investment costs of the terminal.

Four concepts are considered and compared:

1. Straddle carriers (SC) for terminal and stacking transport.
2. A multi trailer system (MTS) for terminal transport and reach stackers (RS) for stacking.
3. A trailer system (TS) for terminal transport and rubber tyred gantry (RTG) cranes for stacking.
4. A fully automated concept with automated guided vehicles (AGV) for terminal transport and rail mounted gantry (RMG) cranes for stacking.

In each concept the stacks are situated perpendicular to the quay. Dependent on the required width the possible number of stacks is determined. There are two important parameters for the stacks. The first is the storage capacity, which has to be sufficient. The second is the total productivity of the stacks that has to be higher than the total productivity of the quay cranes (QC). When the number of stacks and the dimensions as length, width and height are determined, the required terminal area can be calculated.

For the terminal transport system, the queuing theories are applied. With applying the theories a system is made where the transport vehicles are the clients that have to wait in the queue to be served by a server, in this case the QC and the stacks. The minimum required number of clients can be determined in order to have a sufficiently utilised server.

Concept 3, where RTG operate the stacks and a trailer system fulfils the terminal transport, turns out to be the preferable concept. Due to high inaccuracies in the determination of the investment costs, the final decision is made on basis of the environment and employment. This concept requires less area and sand and offers more employment for the local population than other concepts. However estimation on the investment costs of the terminal was as high, so this concept does not improve the feasibility.

The main conclusion after this study is that there are opportunities for transshipment port developments on the Ihavandhippolhu, due to its favourable location. But the preferable design for the port is, based on the assumptions made in this report, not economically feasible. Besides, technical feasibility is likely but not yet proven because of a lack of data on the soil and the hydraulic conditions.

Most recommendations concern further research on economical aspects like, location in the transport network, costs versus throughput and research on the operational costs and IRR. On the technical feasibility it is recommended to do more research on site to obtain sufficient data.

A remark has to be made on the environment. The Maldives consists of a lot of reef. On the whole world reef is threatened with extinction. A good appreciation of the value of the reef and the possibilities for construction are required to continue this project. In this report very little attention is paid to the environment and it is recommended that if further studies on this subject are done, the environment is considered as well.
# Table of Contents

PREFACE ......................................................................................................................... IV

EXECUTIVE SUMMARY .................................................................................................... V

TABLE OF CONTENTS ........................................................................................................ VIII

GLOSSARY OF TERMS ......................................................................................................... XIII

LIST OF SYMBOLS ............................................................................................................ XV

1 INTRODUCTION ............................................................................................................. 1
   1.1 PROJECT RATIONALE ............................................................................................... 1
   1.2 PROJECT SCOPE ....................................................................................................... 1
   1.3 PROJECT HISTORY .................................................................................................... 1
   1.4 THE MALDIVES ........................................................................................................ 2
      1.4.1 Geography .......................................................................................................... 2
      1.4.2 Formation .......................................................................................................... 4
      1.4.3 Reefs ................................................................................................................. 5
   1.5 PROBLEM ANALYSIS .............................................................................................. 6
      1.5.1 Problem description ........................................................................................... 6
      1.5.2 Objective ............................................................................................................ 7
      1.5.3 Project phasing and readers guideline ............................................................... 7
   1.6 POINTS OF ATTENTION ......................................................................................... 9
   1.7 ASSUMPTIONS ........................................................................................................ 10

2 COMPETITIVENESS OF IHAHANDHIPPOLHU AND CONTAINER THROUGHPUT ........ 11
   2.1 INTRODUCTION ...................................................................................................... 11
      2.1.1 Competitiveness ............................................................................................... 11
      2.1.2 Throughput ...................................................................................................... 11
      2.1.3 Objective ........................................................................................................... 12
   2.2 SAILING DISTANCES AND COMPETITORS ......................................................... 12
      2.2.1 Criteria ............................................................................................................. 12
      2.2.2 Economic regions ............................................................................................ 14
      2.2.3 Competitors for Ihavandhippolhu Port ........................................................... 15
      2.2.4 Possible target markets .................................................................................... 16
   2.3 COMPETING PORTS AND THEIR SPECIFICATIONS ............................................ 16
      2.3.1 World container throughput forecast ............................................................... 16
      2.3.2 Middle East and Indian Subcontinent Forecasts ............................................... 17
      2.3.3 Port: Salalah ..................................................................................................... 18
      2.3.4 Port: Colombo ................................................................................................... 19
   2.4 HITHADHOO PORT CAPACITY FORECAST BY FISB AND RECENT EVENTS ...... 20
      2.4.1 FISB Forecast .................................................................................................. 21
      2.4.2 Recent events and aspects of container transport ............................................. 21
   2.5 REQUIREMENTS FOR IHAHANDHIPPOLHU ...................................................... 22
      2.5.1 Ihavandhippolhu Port capacity forecast ........................................................ 22
      2.5.2 Design vessel ................................................................................................... 23
   2.6 CONCLUSIONS AND DEMANDS ON THE IHAHANDHIPPOLHU PORT .......... 24
   2.7 RECOMMENDATIONS ........................................................................................... 25

3 DESIGNS ....................................................................................................................... 26
   3.1 DATA COLLECTION ................................................................................................. 26
      3.1.1 Wind ................................................................................................................ 26
      3.1.2 Waves .............................................................................................................. 27
      3.1.3 Tides ............................................................................................................... 32
      3.1.4 Currents .......................................................................................................... 33
3.1.5 Geophysical .......................................................................................... 33
3.1.6 Extreme episodic events ..................................................................... 33
3.1.7 Sea level rise ......................................................................................... 34
3.2 DIMENSIONS PORT COMPONENTS ......................................................... 34
3.2.1 Terminal ................................................................. 34
3.2.2 Berths and quay length ................................................................. 36
3.2.3 Hydraulic infrastructure ................................................................. 41
3.2.4 Possible locations ............................................................................... 45
3.3 DESIGNS ................................................................................................ 45
3.3.1 List of requirements .......................................................................... 45
3.3.2 Designs and evaluation .................................................................... 46
3.3.3 Possible concepts .............................................................................. 47
3.4 PRELIMINARY DESIGNS ..................................................................... 48
3.5 CONCLUSIONS .................................................................................... 51
3.6 RECOMMENDATIONS .......................................................................... 51

4  PRELIMINARY DESIGN EVALUATION .................................................................. 52

4.1 EVALUATION APPROACH ..................................................................... 52
4.2 IMPLEMENTATION OF THE SIMPLE ADDITIVE WEIGHTING (SAW) METHOD .......................................................... 52
4.2.1 Description ....................................................................................... 52
4.2.2 Criteria ............................................................................................. 52
4.2.3 Weighting method ........................................................................... 54
4.2.4 Stakeholders ..................................................................................... 54
4.2.5 Scores ............................................................................................... 55
4.2.6 Weighted scores ............................................................................. 57
4.2.7 Sensitivity .......................................................................................... 58
4.2.8 Comments on this method .............................................................. 60
4.3 COST-BENEFIT ANALYSIS .................................................................. 60
4.3.1 Port elements and costs .................................................................. 60
4.3.2 Construction phasing ...................................................................... 63
4.3.3 Operational costs ............................................................................ 63
4.3.4 Revenues .......................................................................................... 64
4.3.5 Finance .............................................................................................. 65
4.4 SELECTION PREFERRED DESIGN.......................................................... 66
4.5 CONCLUSIONS ..................................................................................... 67
4.6 RECOMMENDATIONS ............................................................................ 67

5  TERMINAL DESIGN .................................................................................... 68

5.1 INTRODUCTION ..................................................................................... 68
5.1.1 Starting points for the terminal design ........................................... 68
5.1.2 Terminal process and explanation ................................................. 70
5.1.3 Terminal handling equipment ....................................................... 72
5.1.4 Concepts .......................................................................................... 75
5.2 COSTS INFRASTRUCTURE .................................................................. 75
5.3 CONCEPT 1: STRADDET CARRIERS ...................................................... 76
5.3.1 Stacks concept 1 ............................................................................... 77
5.3.2 Productivity of the stacks concept 1 .............................................. 78
5.3.3 Queuing theories concept 1 ............................................................ 80
5.3.4 Terminal area concept 1 ................................................................. 83
5.3.5 Investment costs concept 1 ............................................................. 83
5.4 CONCEPT 2: MULTI TRAILER SYSTEM (MTS) WITH REACH STACKERS (RS) ...................................................... 83
5.4.1 Stacks concept 2 ............................................................................... 84
5.4.2 Productivity of the stacks concept 2 .............................................. 85
5.4.3 Queuing theories concept 2 ............................................................ 86
5.4.4 Terminal area concept 2 ................................................................. 88
5.4.5 Investment costs concept 2 ............................................................. 89
5.5 CONCEPT 3: TRAILER SYSTEM (TS) WITH RUBBER TYRED GANTRY CRANES (RTG) .................................................. 89
5.5.1 Stacks concept 3 ............................................................................... 89
5.5.2 Productivity of the stacks concept 3 .............................................. 90
5.5.3 Queuing theories concept 3 ............................................................ 91
List of figures:

FIGURE 1: THREE PRELIMINARY DESIGNS .................................................................................. VI
FIGURE 2: THE MALDIVES ON THE WORLD MAP .................................................................. 2
FIGURE 3: THE GEOGRAPHY OF THE MALDIVES AND IHAVANDHIPPOLU ATOLL ............. 3
FIGURE 4: BATHYMETRIC MAP OF IHAVANDHIPPOLU ......................................................... 4
FIGURE 5: FORMATION OF AN ATOLL ....................................................................................... 5
FIGURE 7: ONE OF THE INHABITANTS OF THE REEF ............................................................. 6
FIGURE 8: WORK/ DESIGN METHOD ......................................................................................... 8
FIGURE 9: MAJOR PORTS AND IMPORT/ EXPORT MARKETS .................................................... 14
FIGURE 10: WORLD CONTAINER PORT DEMAND .................................................................. 17
FIGURE 11: INDIAN OCEAN CONTAINER PORT DEMAND ..................................................... 18
FIGURE 12: UTILISATION SALalah AND ADen (CUMULATED) .................................................. 19
FIGURE 13: UTILISATION PORT OF COLOMBO ................................................................... 20
FIGURE 14: HITHADOO PORT: TRAFFIC FORECAST .............................................................. 21
FIGURE 15: THE OOCL SHENZHEN ......................................................................................... 24
FIGURE 16: SEASONALITY OF WIND SPEED .......................................................................... 27
FIGURE 17: WIND SPEED AND DIRECTION .......................................................................... 27
FIGURE 18: LOGNORMAL DISTRIBUTION FUNCTION OF THE WAVE DATA ............................. 28
FIGURE 19: SIGNIFICANT WAVE HEIGHT ............................................................................... 29
FIGURE 20: SWELL HEIGHT ..................................................................................................... 30
FIGURE 21: DIRECTIONS OF SWELL ........................................................................................ 30
FIGURE 22: PENETRATION FROM EASTERN DIRECTIONS ..................................................... 32
FIGURE 23: TIDE AT IHAVANDHOO ......................................................................................... 32
FIGURE 24: SEA LEVEL RISE ACCORDING TO IPCC ................................................................. 34
FIGURE 25: STACKING AREA WITH RTG CRANE .................................................................... 35
FIGURE 26: THE PORT’S THROUGHPUT .................................................................................... 36
FIGURE 27: PARAMETERS DETERMINING THE CHANNEL DEPTH ......................................... 42
FIGURE 28: COMPONENTS DETERMINING THE CHANNEL WIDTH .......................................... 43
FIGURE 29: ANGLE OF ENTRANCE CHANNEL WITH THE WAVES ........................................ 45
FIGURE 30: PD1 Uligamu ......................................................................................................... 49
FIGURE 31: PD2 Mulhadhoo Design ......................................................................................... 50
FIGURE 32: PD3 Huvaratupi Design ......................................................................................... 51
FIGURE 33: PROSPECTED GROWTH IN THROUGHPUT ............................................................ 63
FIGURE 34: OPERATIONAL COSTS (TOTAL AND PER TEU) ..................................................... 64
FIGURE 35: CASH FLOW, NPV AND IRR OF PD3 ................................................................... 66
FIGURE 36: PROCESSES AT A CONTAINER TERMINAL ............................................................ 70
FIGURE 37: GENERAL TERMINAL LAY-OUT ......................................................................... 72
FIGURE 38: STRADDLE CARRIER (SC) .................................................................................... 73
FIGURE 39: MULTI TRAILER SYSTEM (MTS) .......................................................................... 73
FIGURE 40: REACH STACKER AND MTS ............................................................................... 74
FIGURE 41: RUBBER TYRED GANTRY CRANES (RTGs) ............................................................. 74
FIGURE 42: AGVs LINED UP FOR AN AUTOMATED RMG ..................................................... 75
FIGURE 43: PROFILE OF THE TERMINAL CONSTRUCTION ..................................................... 76
FIGURE 44: CONCEPT 1: STRADDLE CARRIERS .................................................................. 77
FIGURE 45: NUMBER OF RESHUFFLES DEPENDENT ON THE STACKING HEIGHT ............... 79
FIGURE 46: DETERMINATION OF TRAVELLING DISTANCES .................................................. 80
FIGURE 47: QUEUE-DELAY SYSTEM ....................................................................................... 81
FIGURE 48: CONCEPT 2 .......................................................................................................... 84
FIGURE 49: QUEUE-DELAY SYSTEM CONCEPT 2 .................................................................. 86
FIGURE 50: CONCEPT 3 .......................................................................................................... 89
FIGURE 51: CONCEPT 4 .......................................................................................................... 93
List of Tables:

<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Table 1</td>
<td>Performances of the designs on the different criteria</td>
<td>V1</td>
</tr>
<tr>
<td>Table 2</td>
<td>Target markets and favourably located ports</td>
<td>16</td>
</tr>
<tr>
<td>Table 3</td>
<td>World container port demand growth forecast</td>
<td>17</td>
</tr>
<tr>
<td>Table 4</td>
<td>Indian Ocean container port demand forecast</td>
<td>18</td>
</tr>
<tr>
<td>Table 5</td>
<td>Different sources for the expected Suezmax dimensions</td>
<td>23</td>
</tr>
<tr>
<td>Table 6</td>
<td>Distribution of wind speed</td>
<td>27</td>
</tr>
<tr>
<td>Table 7</td>
<td>Wave induced inside atoll</td>
<td>30</td>
</tr>
<tr>
<td>Table 8</td>
<td>Different sea levels</td>
<td>33</td>
</tr>
<tr>
<td>Table 9</td>
<td>Different vessel distributions</td>
<td>37</td>
</tr>
<tr>
<td>Table 10</td>
<td>Required number of berths</td>
<td>39</td>
</tr>
<tr>
<td>Table 11</td>
<td>Comparison of quay lengths</td>
<td>41</td>
</tr>
<tr>
<td>Table 12</td>
<td>Channel width determination</td>
<td>43</td>
</tr>
<tr>
<td>Table 13</td>
<td>Design evaluation</td>
<td>47</td>
</tr>
<tr>
<td>Table 14</td>
<td>Weighting of criteria by different stakeholders</td>
<td>55</td>
</tr>
<tr>
<td>Table 15</td>
<td>Explanation of scores</td>
<td>55</td>
</tr>
<tr>
<td>Table 16</td>
<td>Scores of the different options</td>
<td>57</td>
</tr>
<tr>
<td>Table 17</td>
<td>Total scores</td>
<td>58</td>
</tr>
<tr>
<td>Table 18</td>
<td>Scores without downtime measures</td>
<td>59</td>
</tr>
<tr>
<td>Table 19</td>
<td>Total scores without downtime measures</td>
<td>59</td>
</tr>
<tr>
<td>Table 20</td>
<td>Costs of the facilities</td>
<td>61</td>
</tr>
<tr>
<td>Table 21</td>
<td>Cost estimation</td>
<td>62</td>
</tr>
<tr>
<td>Table 22</td>
<td>Operational costs</td>
<td>63</td>
</tr>
<tr>
<td>Table 23</td>
<td>Port charges in different ports</td>
<td>64</td>
</tr>
<tr>
<td>Table 24</td>
<td>Comparison of preliminary designs</td>
<td>66</td>
</tr>
<tr>
<td>Table 25</td>
<td>Comparison of preliminary designs without downtime measures</td>
<td>67</td>
</tr>
<tr>
<td>Table 26</td>
<td>Vessel distribution</td>
<td>69</td>
</tr>
<tr>
<td>Table 27</td>
<td>Costs of the civil works of the terminal</td>
<td>76</td>
</tr>
<tr>
<td>Table 28</td>
<td>Distribution of the cycle time and its aspects</td>
<td>82</td>
</tr>
<tr>
<td>Table 29</td>
<td>Investment costs concept 1</td>
<td>83</td>
</tr>
<tr>
<td>Table 30</td>
<td>Investment costs concept 2</td>
<td>89</td>
</tr>
<tr>
<td>Table 31</td>
<td>Investment costs concept 3</td>
<td>92</td>
</tr>
<tr>
<td>Table 32</td>
<td>Investment costs concept 4</td>
<td>96</td>
</tr>
<tr>
<td>Table 33</td>
<td>Comparison of the 4 concepts</td>
<td>96</td>
</tr>
<tr>
<td>Table 34</td>
<td>Comparison of terminal costs on two estimations</td>
<td>97</td>
</tr>
</tbody>
</table>
Glossary of Terms

This list gives the explanation of terms that are frequently used in this report, for some terms the [4] is used as a reference.

AGV: Automated Guided Vehicle, terminal transport vehicle that is unmanned and guided by electronic systems in the terminal.

Anchorage: Area where waiting ships can anchor, before entering the entrance channel.

Apron: Area between the quay and the stacking yards, the quay crane loads/unloads the container on the terminal transport system on the apron.

Atoll: Ring of islands formed from sediment deposits of a submerging volcano.

Beam: The width of a vessel at its broadest point.

Berth: Mooring place on the quay for one vessel, which can be loaded and unloaded.

Breakwater: Construction in the sea that protects the port against incoming waves and currents.

(to) Bunker: Supply of the vessels with diesel oil, water and food.

Buoy: A floating marker or navigational device, the colours and shapes designate channels or obstructions.

Cargo: Goods, merchandise or commodities of every description which may be carried aboard a vessel.

Carrier: A transport vehicle or vessel for cargo.

Cash flow: Sum of all the expenses and income during one year.

CBA Cost Benefit Analysis, method to compare the costs and the benefits of a project.

Chassis: A trailer frame with wheels for carrying a container on the terminal.

Container: A rectangular metal box used to transport cargo between two or more modes of transit. (See also TEU)

Current: A flow of water in a definite direction.

Cyclone: A tropical storm with wind speeds of 74 miles per hour or greater.

Downtime: Time that a certain item/component can not fulfil its primary functions.

Draft: The vertical distance from the waterline to the lowest part of the vessel.

Dwell time: Time that the container is stored in the yards

Feedering transshipment: Transshipment between mainline and feeder vessels and vice versa.

Fetch: Long strip of water where the wind generates waves.

Free zone: A secure zone or area in a port designated for duty-free entry of foreign goods or components.

GDP: Gross Domestic Product, measure for the country its productivity.

Hinterland: An area where import/export takes place close to the considered port, so this port can fulfil the transshipment.

Interlining: A shipping line connecting many ports in a row, in each port containers are loaded and unloaded.

Intra-terminal: Within the terminal.

IRR: Internal Rate of Return, prospected return on invested capital.
<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jetty</td>
<td>A pier or structure into the water that functions as a mooring place for vessels.</td>
</tr>
<tr>
<td>Latitude/ Longitude</td>
<td>Latitude lines (parallels) circle the earth parallel to the equator and locate a point's distance north or south of the equator. Longitude lines (meridians) radiate from the North to the South Pole and locate a point's distance to the prime meridian.</td>
</tr>
<tr>
<td>MCE</td>
<td>Multi Criteria Evaluation, method to evaluate more options on certain criteria.</td>
</tr>
<tr>
<td>MTS</td>
<td>Multi Trailer System, a truck with trailers used for terminal transport.</td>
</tr>
<tr>
<td>NPV</td>
<td>Net Present Value, present value of cash flow in the future.</td>
</tr>
<tr>
<td>Offshore</td>
<td>Sea outside the atoll.</td>
</tr>
<tr>
<td>Parcel size</td>
<td>Volume of containers (TEU) that is loaded or unloaded by a vessel.</td>
</tr>
<tr>
<td>Pilot</td>
<td>A navigator who is expert at navigating in a particular port. In most ports vessels are required to have or hire licensed pilots before entering or leaving the port.</td>
</tr>
<tr>
<td>Portainer</td>
<td>Type of quay crane.</td>
</tr>
<tr>
<td>QC</td>
<td>Quay Crane, device that unloads/ loads the container from the vessel to the terminal transport.</td>
</tr>
<tr>
<td>Quay</td>
<td>Interface between land and water with ship berthing possibilities.</td>
</tr>
<tr>
<td>Reefer</td>
<td>Refrigerated container.</td>
</tr>
<tr>
<td>Relay transshipment</td>
<td>Transshipment between mainline vessels.</td>
</tr>
<tr>
<td>Revenues</td>
<td>Earnings from the port activities, like cargo handling, towing, etc.</td>
</tr>
<tr>
<td>RS</td>
<td>Reach Stacker, type of intra-terminal transport, mostly serving the stacks.</td>
</tr>
<tr>
<td>RMG</td>
<td>Rail Mounted Gantry, stacking equipment driving on rails that can be automated.</td>
</tr>
<tr>
<td>RTG</td>
<td>Rubber Tyred Gantry, stacking equipment driving on rubber tyres.</td>
</tr>
<tr>
<td>SC</td>
<td>Straddle Carrier, type of intra-terminal transport.</td>
</tr>
<tr>
<td>Ship</td>
<td>A general term for a large seagoing vessel of considerable size.</td>
</tr>
<tr>
<td>Slot</td>
<td>Place where one container can be stored in the stack.</td>
</tr>
<tr>
<td>Spreader</td>
<td>A steel beam that is used to displace containers horizontally.</td>
</tr>
<tr>
<td>Stack/ stacking yard</td>
<td>Area to store containers, i.e. a number of slots, served by one gantry crane.</td>
</tr>
<tr>
<td>(to) Stack/ unstack</td>
<td>Put in/ remove from stack.</td>
</tr>
<tr>
<td>Stakeholder</td>
<td>Party that has special interest in the project to obtain advantages or to cope with negative influences.</td>
</tr>
<tr>
<td>Stevedore</td>
<td>A company or person that loads or unloads the vessels.</td>
</tr>
<tr>
<td>Suezmax</td>
<td>Generation of vessels where the width is limited by the Suez Canal passage</td>
</tr>
<tr>
<td>Superstructure</td>
<td>All terminal handling equipment</td>
</tr>
<tr>
<td>(Super-) Post Panamax</td>
<td>Generation of vessels that are too wide to pass the Panama Canal</td>
</tr>
<tr>
<td>Swell</td>
<td>Waves that travel faster (longer wave length) than the wind and the wind generated waves.</td>
</tr>
<tr>
<td>Target market</td>
<td>Market (geographical area) for which the port has possibilities to fulfil a hub port function.</td>
</tr>
</tbody>
</table>
Ihavandhippolhu Atoll Transshipment Port

Terminal: Place where cargo changes between transport modes combined with storage facilities.

Terminal chassis: Trucks and trailers on the terminal to transport containers on the terminal.

TEU: Twenty feet Equivalent Unit, standard container size 20 feet long, 8 feet wide and 8.6 feet high.

THC: Terminal Handling Charges, costs for a customer for terminal handling mostly in $/TEU.

Transshipment: Transfer of cargo between different deep-sea transport modes as mainline vessels and feeders.

Throughput: Sum of handled cargo volumes inbound and outbound.

Vessel: Watercraft of every description meant for transporting people or cargo from place to place on navigable waters.

List of Symbols

This list gives all the symbols and their definition used in this report. The subscripts used are stated in italic. Explanation of the terms can be found in the former section.

A = Required storage area for containers including in lanes and apron [m$^2$]
a = width apron [m]
B = Beam of a vessel [m]
b = width lanes on terminal [m]
C = Number of containers
   $i$ = of the port (total throughput of the port)
   $v$ = on a vessel (average parcel size)
   $vf$ = on a feeder vessel (parcel size of a feeder vessel)
   $vr$ = on a relay vessel (parcel size of a mainline vessel)

$C_t$ = Storage capacity of the port [TEU]

D = Draft of a vessel [m]
d = Authorised channel level (under CD) [m]
d = Travelling distance for terminal transport system [m]
F = Average required area per container [m$^2$]
F = Share of feeder transshipment in throughput ($C_t$) [-]
f = Frequency of storms [year$^{-1}$]
f = TEU/FEU-ratio [-]
f = Factor for irregularity in terminal storage capacity = $v^2$ [-]
h = Average height of the stack during full storage [TEU]
c = height of one container [m/TEU]
s = height stack ($h * h_c$) [m]
I = Investment costs [$]
IRR = Internal Rate of Return [$]
L = Length of the stack [TEU]
c = length of one container (1 TEU) [m/TEU]
s = length of the stack ($l * l_c$) [m]
LOA = Length Over All (length of the vessel) [m]
L_q = Quay length [m]
m = Safety margin for depth channel [m]
m_i = Acceptable occupancy rate of the berth [-]
N = Number [-]
b = berths [-]
c = cranes per berth [-]
s = stacks [-]
v = vessel calls [year^{-1}]
vl = feeder vessel calls [year^{-1}]
vr = relay vessel calls [year^{-1}]

NPV = Net Present Value [$]
n = Number of decision criteria [-]
n = N/N_QC = number of servers per QC = 4 [-]
P = Admissible chance of failure [-]
p = Productivity [moves/hour]
c = gross crane productivity [-]
R = Share of relay transshipment in throughput (C_i) [-]
r = Average stacking height/ nominal stacking height [-]
r = Ship motion due to wave response [m]
r = Discount rate [%]
r_i = Ranking score for the i^{th} criterion [-]
r = Number of reshuffles [-]
s = Squat [m]
s = Safety margin between stacks [m]
T = Technical design lifetime [year]
T_m = Acceptable waiting time [% of X]
T = Cycle time of terminal equipment [s]
g = time of spreader to grab the container
ga = travel time for the gantry
se = time for SC to travel over the stack without load
sl = time for SC to travel over the stack with load
p = total time to pick the container from the stack
d = time needed to drop the container on a vehicle
r = time needed for reshuffling moves
te = time needed to travel loaded
tl = time needed to travel loaded
m = time for manoeuvring of RS
t = travel time for the trolley

T = Time required to tie up for tugs [s]
t_d = Dwell time [day]
u = Current velocity [m/s]
u = utilisation of terminal handling equipment [-]
v = Speed (velocity) [m/s]
ga = travel speed of a gantry
e = travel speed SC empty
eff = vessel speed with proper rudder control
he = hoisting speed empty
hl = hoisting speed loaded
Ihavandhippolhu Atoll Transshipment Port

\( l \) = travel speed SC loaded
\( \text{min} \) = minimum entrance speed of vessel
\( s \) = travel speed SC over the stack
\( t \) = travel speed of a trolley

\( W \) = Width entrance channel [m]
\( BM \) = basic manoeuvrability
\( B \) = bank clearance
\( i \) = additional safety factors

\( W \) = Waiting time in units of service time [-]
\( w_i \) = Normalised weight for the \( i^{th} \) criterion [-]

\( w \) = Width of one stack [TEU]
\( c \) = width of one container (1 TEU) [m/TEU]
\( s \) = width of the stack \( (w \times w_c) \) [m]
\( t \) = width of the trolley [m]

\( X \) = Service time of a vessel [hour]

\( \alpha \) = Angle of cross current with channel axis [°]
\( \varphi \) = Drift angle of ship [°]
\( \mu \) = Average
\( s \) = service time [s]
\( a \) = inter-arrival time [s]

\( \sigma \) = Standard deviation

\( \nu_a \) = \( 1/k \) = Variability of \( E_a \) distribution of inter arrival times
\( \nu_s \) = \( 1/m \) = Variability of \( E_s \) distribution of service times

\( \psi \) = Berth utilisation [-]

Subscripts used for T (cycle time), N (number) and W (waiting time):

- \( QC \) = Quay Crane
- \( SC \) = Straddle Carrier
- \( RS \) = Reach stacker
- \( MTS \) = Multi Trailer System
- \( RTG \) = Rubber Tyred Gantry
- \( TS \) = Trailer System
- \( AGV \) = Automated Guided Vehicle
- \( RMG \) = Rail Mounted Gantry
1 Introduction

1.1 Project rationale

In the past 30 years the Maldives have achieved good economical developments [2]. In the 90s the average growth was 7.4%. A major part of the growth is due to the development of the tourism and related sectors. The tourism sector accounts for 31.9% of the Gross Domestic Product (GDP) and the transport sector for 14.2%, which is second highest. The population growth is small, but is expected to be much higher in the future. This can result in higher unemployment rates. The tourism has a lot of influence on other parts of the economy. Events like September 11th 2001 and the Iraqi war in 2003 affects tourism all over the world, the Maldives included. Downturns in tourism can have spill-over effects on other sectors of the Maldives economy. A more diverse composition of the economy and the GDP can give the government of the Maldives the ability to cope with downturns in specific sectors. The location of the Maldives near the main Europe-Asia routes gives the country the possibility to perform better in the transport sector and the country can generate more income from this sector.

1.2 Project scope

General expectations among economists on the global container traffic market are that there is still an estimated increase of 100% in the next 10 years. Logistical aspects like transshipment – both interlining and feeding – are responsible for the main part of this increase. Two reasons make the Maldives a favourable transshipment location: near the main Europe-Asia routes and centrally located in the Indian Ocean to feeder the Indian Subcontinent, the Middle East and East Africa. (see Figure 2) A port construction can anticipate on the regional container port demand. The Maldives has no natural hinterland, so the port’s throughput will be only transshipment. There are some difficulties, as the port has to compete with other ports and sailing distances can be a little bit longer. A feasibility study can tell if a port can help the Maldives with their objectives to diversify their income.

1.3 Project history

In the past few years a number of studies on the development of a new container port on the Maldives were completed.

In July 1998 consultants of the Port of Marseilles completed a study [12] on container trade forecasts and the development of a new container port at Addoo Atoll, Maldives. This study was presented to the Foreign Investment Services Bureau of the Maldives, but was only focused on the development of a port on the southern part of the Maldives.

Hydronamic, the in-house engineering department of Royal Boskalis Westminster, has performed some studies as a result on the 1998 study. These studies are more based on physical planning and construction. The first study was also concerning the Addoo Atoll. This Atoll is located in the south of the Maldives. The second study was regarding two northern atolls [15], because they are much more attractive due to shorter sailing distances. This difference of sailing distance is about 500 miles.

This study is succeeding the second study concerning the northern atolls. A short summary of the contents of the report [15] is given. After short studies on container trade and boundary conditions two designs were made, one on the Ihavandhippolhu Atoll and one on the North Thiladhunmathee Atoll. Both designs include entrance channel design, terminal design, jetty construction and costs. The conclusion is that the Ihavandhippolhu design is the best option, because of more favourable nautical conditions.

This coming study will proceed with the location of the port on the Ihavandhippolhu Atoll and its economical and technical feasibility. Hereby is the focus on the efficiency and the costs. After an economic study with some resulting requirements, the port and its components are dimensioned. After that a number of designs are made. Different locations, with their different characteristics on the Atoll
are considered. At least three different preliminary designs are made. After evaluating the designs a detailed calculation on a particular subject is carried out.

1.4 The Maldives

1.4.1 Geography

The Republic of the Maldives is located in the centre of the Indian Ocean south west of India and stretches 860 km from latitude 7º6’35”N, crossing the equator to 0º42’24”S. The Longitude is between 72º32’19”E and 73º46’13”E. The chain of islands consists of about 26 geographic atolls, which are grouped in 20 administrative atolls. Ihavandhippolhu, some 420 kilometres north of the equator, is the most northern atoll and is located near the most important east/west shipping route. (See Figure 2) [15]

Figure 2: The Maldives on the world map

Ihavandhippolhu Atoll consists of about 24 islands or islets, mostly small with the largest barely 1.5 miles long. (See Figure 3) In this figure, reef is represented by the colour green. Water depths are ranging between 35 and 50 on the eastern half of the atoll and the water depth on the western part is ranging between 20 and 35 meters. Huvarafushi is the main island, with a population of around 3000.
Figure 2 shows that the port has to compete with ports like Colombo in Sri Lanka and Salalah in Oman. The location of the Maldives is favourable with respect to the feeding of containers to the Indian-Subcontinent and East Africa. The figure also shows some travelling distances. Recent studies [14] show that the travelling time is longer when calling at the Ihavandhippolhu Port, but the target is to compensate this with shorter service time and modern facilities.

Geographical information:
Ihavandhippolhu Atoll, Main island: Ihavandhoo Island (6° 57’ N, 72° 56’ E)
1.4.2 Formation

About 150 million years ago the plate containing the Indian continent started migrating from Africa and Madagascar towards the Laurasia supercontinent. A substratum hotspot in the neighborhood of the Reunion Island created volcanoes in the thinner part of the plate; this hotspot perforated a strip, which now forms the Laksadweep-Maldives-Chagos Archipelago. The plate tectonics move away the volcanoes from the hotspot and source of magma, resulting in relict volcanoes. [4]

The general belief about the formation of an atoll is that after the eruptive stage of a volcano (post-caldera stage) it starts to erode and sinks into the sea. On the sides coralline sediment starts to accumulate and this forms the Atoll. [1]
The Maldives officially consist of 26 atolls with over 1,900 small islands. The total surface is 298 km$^2$. The islands are very flat and the average altitude is 2 m above average level. In April 1987 tidal floods inundated one third of Malé Island. The sea level rise due to the global warming is important; because of the low altitude a small rise can flood a big part of the surface. In section 3.1.7 the expectations on the sea level rise are discussed.

Some other risks are the destruction of coral reef and coastal erosion by sea attack or human intervention, the lack of fresh water because of mixing with salt water and pollution because of the lack of space to put sewage.

1.4.3 Reefs

85% of the world’s reefs are potentially threatened by human activity [6]. Most important threats are coastal development and destructive fishing practices. According to the study see Figure 6, the majority of the Maldives’ reefs total around 9,000 km$^2$ is under low potential threat. This means that in the operational phase of the port, the threat has to stay low.

Ports of a large size form a high risk within a radius of 20 kilometers and a medium risk within 50 kilometers. The definitions of high and low risks are not given clearly by this study. Threats concerning the construction of the port are: dredging and the use of reef for land reclamation. Important threats related to shipping are discharges, spills, and groundings.
The biodiversity of the Maldives almost only consists of its marine ecosystem, because of its isolated location in the Indian Ocean [17]. The islands have a wide variety of mangrove species. They also house many species of seabirds, including five sub-species that are identified as endemic.

The marine life is very rich, more than 1,200 species of reef fish, 250 species of hermatypic corals and 285 species of algae have been identified.

1.5 Problem analysis

1.5.1 Problem description

In this project there is not a specific problem, but more of an opportunity. Section 1.1 tells about the one-sided income of the Maldives. The previous section shows the central location. Constructing a port if feasible would be a perfect opportunity to generate more income sources, besides tourism. However the port has to compete with Salalah and Colombo.

Besides, because of the deep water in the Atoll, the vessels can have a safe approach to the calm water, before tugs tow up. It is possible that no expensive breakwaters are needed and the required dredging works are limited. These two aspects are limiting the construction costs, so tariffs can be kept low.
One of the possible disadvantages is the isolated location of the Maldives and the small size of the islands.

1.5.2 Objective

The target of this thesis is to come up with an economically and technically feasible design for a port on the Ihavandhippolhu Atoll that can be used by Hydronamic to continue to the next phase, the detailed design. This study on the feasibility and the design of the Ihavandhippolhu Port includes the following items:

- Container port demand indication with a forecast for this port, a small analysis of competing ports and their expected expansions.
- Create a few different designs, dependent on different locations on the atoll.
- Evaluations of the designs using MCE (Multi Criteria Evaluation) resulting in a preferred option. A financial CBA (Cost Benefit Analysis) is combined with this MCE to determine the best quality-price ratio.
- Establish different concepts to operate the terminal and select the concept with the lowest investment costs.

In order to create a good competitive port it is important to focus on the efficiency and the low tariffs during this study.

1.5.3 Project phasing and readers guideline

In this report five different phases can be distinguished. The first is the initiation that consists of the introduction to the whole project in chapter 1 and an estimation of the throughput in chapter 2. The formulation of the problem and the objective are the most important aspects of the introduction besides the general information on the Maldives. In chapter 2 a forecast is made based on a former study. Recent changes and an overview of the competitors can give an indication if this forecast is still valid.

The second phase is the port design in chapter 3. After collection of the data in section 3.1 the different port components are dimensioned in section 3.2. The most important components are the terminal, entrance channel and the basin. Due to the restricted areas three possible groups of islands are suitable for construction. From eight options in section 3.3 three preliminary designs (Pd1 to Pd3) are selected with a short MCE in section 3.4.

In chapter 4 the final selection is made. This selection is based on two models an MCE and a CBA. From these models two selection criteria are deducted: the Quality/Cost-ratio and the IRR (Internal Rate of Return). The preferred design on the base of these criteria will be the final design.

In the fourth phase or chapter 5 one of the port its components is designed in more detail. In this case is chosen for the terminal lay-out. In sections 5.3 to 5.6 four different concepts are developed. The design that implies the lowest in investment costs is implemented in the port lay-out in section 5.7.

After each phase conclusions are drawn and recommendations are made, these conclusions and recommendations are summarised in phase five consisting of chapter 6 conclusions and 7 recommendations.
Figure 8: Work/design method

Chapter 1: Introduction

Chapter 2: Estimation of throughput → Conclusions

Section 3.1: Data collection

Section 3.2: Dimensioning port components

Section 3.3: Generating designs

- Design 1
- Design 2
- Design ...
- Design 8

Section 3.4: Pre-selection

- Pd 1
- Pd 2
- Pd 3 → Conclusions

Chapter 4: Selection with MCE and CBA → Final design → Conclusions

Chapter 5: Terminal lay-out

- Concept 1
- Concept 2
- Concept 3
- Concept 4

- Selection best concept on investment costs

- Implementation concept on final design → Conclusions

Chapter 6: Conclusions/Recommendations

CBA: Costs Benefits Analysis
MCE: Multi Criteria Evaluation
1.6 Points of attention

During the design, special attention has to be drawn on the following aspects:

**Economical**
- The port has to be feasible: the Net Present Value (NPV) has to be positive and the Internal Rate of Return (IRR) has to be higher than 15%.
- The design capacity resulting from section 2.5.1 is the initial capacity; possibilities for future expansions have to be present.
- The port has to be competitive with other ports and at least not lose cargo to other ports, cooperation can be possible.

**Environmental**
- Impact on the flora and fauna has to be minimised during construction as well as during operation. When significant damage is inevitable, compensating measures have to be considered. Waste disposal and other forms of pollution (warm cooling-water can bleach the coral) by mooring ships have to be minimised or mitigated.
- The port has to be able to adapt on the expected sea level rise and its negative influences, like the disappearance of a part of the Maldives.
- The damage due to extreme episodic events must be minimised.
- Fresh water production facilities, because of lack of fresh water on the Maldives, have to be constructed.

**Legal**
- The designed port has to comply with local laws, concerning housing and farming of the population.
- Restrictions concerning protected coral reef have to be considered.
- Safety zones have to be created around fuel tanks or hazardous cargo.
- Safety measures as escape routes, fire stations or tools to clean pollution are important.

**Logistic**
- The port has to be designed to handle containerised cargo; there is very little need for other types of cargo.
- The port and terminal have to be operational for the whole year for 24h/day
- The port has to accommodate all the necessary facilities like (reefer) storage, fuel facilities and small wharf facilities.
- Waiting times can only be a fraction of service times, quay length has to be sufficient and the entrance channel wide and deep enough.
- Fast cargo handling is essential, so capable and dedicated personnel are needed.

**Hydraulic**
- Especially on the low altitude islands of the Maldives sea level rise should be taken into account.
- Interference of the port in currents and tides can cause different conditions elsewhere on the Atoll.
- Morphology effects like sedimentation or erosion have to be minimised or reversed.
- Loading and unloading may never be interrupted by wave penetration in the harbour basin.
- Wave penetration should not limit the operations of the tugs.

**Navigational**
- The water depth in the basin must be sufficient for the largest ship.
- The dimensions of the entrance channel have to be optimised to have a safe approach without delay.
- Turning basins and curves in the channel have to be sufficiently wide to create safe passages.
- Mooring facilities have to be present in case of downtime.
- Guiding systems in case of limited visibility are necessary.

**Constructional**
On the landside there is limited space to construct a port.
There is limited sand available in the area to create new land.
Stones for construction of a quay wall or a breakwater are not available.

Social
- Welfare of the local population has to increase after completion of the port; harmed people have to be compensated.
- The population is dependent on the fishery and farming, disadvantage due to loss of land or sea has to be compensated with other income.

1.7 Assumptions

The following is assumed in this report, with between brackets the section in which the assumption is made.

Economic
- Technical lifetime 50 years (benchmark) but the feasibility is calculated for an initial period of 25 years (3.1.2)
- Chance of failure in this lifetime is 10% (3.1.2)
- Shorter sailing distance result in a shift of traffic to the Maldives, while other factors like quality and service time remain constant. (2.2)

Environmental
- Prohibited to construct on coral reefs or heads (3.2.4)
- No morphological changes due to the limited currents and sand.

Logistic
- For the berth calculations a simple distribution of Super Post Panamax vessels (parcel size of 4000 TEU) and feeder vessels (1000 TEU) is used (3.2.2)
- In 2010 the berths have to be capable of serving a Suezmax vessel (2.5.2)
- 5 cranes are serving a Super-Post Panamax vessel (3.2.2)
- Additional area of 50% for service buildings, dry-docking, free zone, etc. (3.2.1)
- Waiting times 5% for mainline vessels and 10% for feeder ships (3.2.2)

Hydraulic
- Currents due to tides are between 0 and 0.5 m/s (3.1.4)
- To calculate wave penetration the wave direction is assumed to come from the same direction as the wind (3.1.2)
- No downtime due to tides is accepted (3.2.3)
- Acceptable downtime of the entrance of vessels due to limiting tug operations due to wave penetrations is less than 1% (3.1.2)

Navigational
- Entrance channel one lane (3.2.3)
- Sloping embankment of entrance channel (3.2.3)
2 Competitiveness of Ihavandhippolhu and container throughput

In this chapter the annual container throughput for the port on Ihavandhippolhu is forecasted on the base of a former study and the competitiveness of Ihavandhippolhu with respect to Colombo and Salalah.

Section 2.1 gives an introduction with the followed procedure to come to the forecast. A comparison of possible competitors and target markets for Ihavandhippolhu is given in section 2.2. The characteristics of the two remaining competitors and their expansion are more specified in section 2.3. Compared with the global and regional throughput forecasts the required remaining port expansions in the area can be determined. Ihavandhippolhu can fulfil a part of the remaining capacity needs in the region. In section 2.4 the former study is discussed. In section 2.5 the forecast for Ihavandhippolhu is made and the required demands on the port are given.

2.1 Introduction

This introduction gives a short explanation of the criteria for the competitiveness of Ihavandhippolhu. Besides the method to forecast the throughput and the objective of this chapter are given.

2.1.1 Competitiveness

Competition is the main threat for a new port on the Ihavandhippolhu Atoll, when competing ports remain (or become) more attractive to the customers, the port on the Maldives will not attract throughput.

The attractiveness of a port is dependent on:
- Service efficiency: time needed to tranship the cargo.
- Tariffs: cost per TEU to tranship the cargo.
- Sailing times: related to the sailing distances, the distance per TEU has to be minimised.

On the criteria for an attractive port, there is one important shortcoming for Ihavandhippolhu:
- The Maldives do not form a natural hinterland; the ports throughput is only transshipment traffic. Other ports have advantages on this point, because when also serving a natural hinterland, a part of the cargo is already close to its destination. So it is expected that the sailing times are of negative influence on the competitiveness of Ihavandhippolhu.

In order to create a good competitive position for Ihavandhippolhu in the Indian Ocean container market, the port has to focus on the remaining criteria:
- Efficiency: this can be realised in several ways and their combination; a dedicated and experienced terminal operator with good personnel, an innovative construction like two-sided unloading and the construction of extra components to limit the downtime
- Tariffs: if construction costs are limited, the tariffs can be kept low and the port can still earn enough to repay its investments. Prices of labour and taxes are considered to be the same in all ports.

In this chapter several short studies are combined to give a qualitative indication if the port can realise its needed competitiveness. Because sailing times and distances can not be influenced, the focus is on the efficiency and the tariffs.

Dependent on the competitiveness the throughput and the requirements can be determined.

2.1.2 Throughput

The forecast for the throughput of the Ihavandhippolhu transshipment port is based on a former study on a transshipment port at Hithadhoo, made by the Foreign Investigations Services Bureau (FISB) [12]. There are three major differences that have to be concerned: the former study is outdated, there
are new competitors and the atoll now considered is located on a 500 nautical miles distance of Hithadhoo.

In this chapter two comparisons with competing ports are made to determine the difference between the two situations. The first is on the sailing distances and the second on the specifications of the ports. These two studies have to outline the differences and show if there are major reasons to deviate from the former initial capacity, which was set on 1,000,000 TEU [12]. The throughput is related to the competitiveness.

2.1.3 Objective

Main objective for this forecast:
Give a qualitative indication of the competitiveness. The combination of this indication and the study on the recent events (or changes in the market) can result in a deviation from the FISB report that set the initial capacity on 1,000,000 TEU.

The main questions in this forecast are:
- What is the location like with respect to other ports: is Ihavandhippolhu centrally located and are there possible import/ export markets that can be fedded through Ihavandhippolhu?
- Are there any competitors and what are the specifications and prospected utilisations?
- Is the world and regional container transport still rising as much as in 1998, the time the FISB study was performed?
- What are the most recent trends in vessel size?

It has to be outlined clearly that:
- The shipping network is too complex to calculate the new traffic flows.
- Information on ports is sometimes taken from the website of the port itself, which can be misleading or not complete for competitive reasons.
- Lower costs are not always responding in higher throughput.
- The FISB report is based on forecasts that are of course always insecure.

2.2 Sailing distances and competitors

The sailing distances between different hub ports and import/ export markets give an indication of the favourable locations of the different port. The ports that are as favourably located as Ihavandhippolhu are concerned as competitors.

2.2.1 Criteria

The sailing distances are used to define the regions for which the port on the Ihavandhippolhu Atoll can fulfil the transshipment. Assumed is that shorter distance will result in a shift of traffic to the new port. The following criteria decide on whether ports are competing with Ihavandhippolhu or not: distance to the major shipping lines and distance to the target markets.

In Appendix I the table with the sailing distances is given. Most of this data is determined with the Fairplay Database [11]; this database uses the distance along the shipping routes. Islands of Ihavandhippolhu and Salalah and Tuticorin are not included in the database. The lengths of the shipping routes between these ports and the rest of the ports are determined with the (N-E) co-ordinates. In some cases more points are necessary to come closer to the realistic sailing route. This is less accurate than the data from the Fairplay database.

Distance to target markets
The target markets are the import/ export areas around the Indian Ocean. In section 2.2.2 there is a broader description of the ports and throughput in these markets. If distances are the same between two ports and a target market, they can be considered as competitors on this market.

The sum of the distances between the ports in the region show, which port is centrally located in the Indian Ocean. A weighted model with the use of volumes gives the most favourable position, which is not necessarily centrally located. Unfortunately, because of the complexity of the system and the lack
of information provided by the ports or the shipping lines, it is too difficult to distinguish all the different volumes between the ports.

The import/export demand is supposed to be the highest for the Middle East and West Side of India. With the resulting transport volume to this region, Salalah is supposed to be a competitor of Ihavandhippolhu in spite of its less central position. Jebel Ali is located in the Arabian Gulf – one of the biggest import/export markets – this port gets a lot of direct calls from which the rest of the area is feedered. The port is no major competitor of Ihavandhippolhu. Colombo and Tuticorin are located near Ihavandhippolhu and have the same target markets for their feedering and are strong competitors on this aspect.

Most ports in the Indian Ocean also serve a natural hinterland. Ihavandhippolhu has no hinterland, but is more central located. However, because of the lack of experience with pure transshipment ports, this is considered to be a shortcoming for Ihavandhippolhu.

**Distance to the main shipping routes**

The distance to the main shipping routes is important, because the mainline vessels can stop over without long sailing times. Ports can play an important role in relay transshipment between east-west lines as well.

The big mainline vessels on the Europe - East Asia line have to stop at hub ports from which the different areas around the Indian Ocean can be feedered. Port Klang and Tanjung Pelepas in Malaysia are considered to be direct competitors for Singapore; these ports are the starting points for the E-W routes. A major part of the East Side of India and Bangladesh is served from these ports. These ports are further considered to play a different role than a port on the Ihavandhippolhu Atoll and hence are no direct competitors. Jawaharlal Nehru is too far from the main shipping lines and this port has a limited transshipment function, the main part is import/export for the Indian Sub continent.
2.2.2 Economic regions

In this section the port surrounding the Indian Ocean and target (import/export) markets are analysed. For each region and the most important ports some economic backgrounds and expansion possibilities are given. The information is mainly obtained from [19].

The Middle East
The largest share of container port demand is taken by the Middle East countries; around 64% in 2002.

The Red Sea:
In the Red Sea range, Jeddah on the West Side of Saudi-Arabia is the most dominant port and is the gateway to the whole Red Sea. The port serves the rest of the ports; those ports are considered to have no transshipment. The total throughput is just over 1.6m TEU. The region has no transshipment function; so all traffic can be described as domestic traffic.

There are some new terminal developments in the region, like El Sokhna in Egypt, but none with high transshipment targets. The estimated port demand in 2015 is 4m TEU in a favourable situation. Even in the future no major hubs but only regional hubs are expected. Stopovers for interlining are likely. The ports in this region are not considered as competing ports for a new port on the Ihavandhippolhu Atoll.

Arabian Sea and the Gulf of Aden:
In this region there are two emerging hub ports, Aden and Mina Raysut. Both ports are relatively new. Especially Mina Raysut, near to Salalah in Oman and now called Salalah, has targets to expand rapidly in the next 10 years. Both ports have a high transshipment and they are serving the Middle East, Indian Subcontinent and East Africa. The port in Djibouti is added as well to the total throughput for this region, which now is around 2m TEU.
**Arabian Gulf:**
The ports in the United Arab Emirates dominate the Arabian Gulf container market. These ports are responsible for almost all the feeding of the Gulf countries. However these ports are too far from the major shipping lines and the new hubs in the Arabian Sea like Salalah and Aden will take over their feeding function. The main ports are Khor Fakkan and ports in Dubai (Jebel Ali). The total container throughput of all the countries in the region is over 6m TEUs.

**Indian Subcontinent and Sri Lanka:**

**Indian Subcontinent:**
Container traffic on the Indian Subcontinent almost entirely consists of Import/Export traffic. Most of the containers are first transshipped at Colombo, Singapore, Salalah or Dubai. In the last years, Jawaharlal Nehru has got some direct services and there are more interlining services linking Tuticorin to Singapore, Port Klang, Colombo and Jeddah. Ihavandhippolhu, which is located near Colombo, is ideal to transship containers destined for the Indian Subcontinent. India needs in total 3.3m TEU, Pakistan close to 1m and Bangladesh around 0.5m.

**Sri Lanka:**
After a big increase in the period 1995-2000 the throughput of the Port of Colombo did not increase further in the last two years and is now around 1.7m TEU. The total transshipment is almost 70%; the port handles a quarter of the West Coast container trade and 10% of the East Coast trade. Singapore and the Malaysian ports handle the major part of the East Coast bound traffic. For a description of the Port of Colombo see section 2.3.4.

**South-east Asia:**

**Singapore:**
As one of the biggest hub-ports in the world, it is difficult to get good data on all the traffic flows. For this study it is only important to know the share of transshipment and which part is going to the regions that can be served by the Port on the Ihavandhippolhu Atoll as well. This contestable hinterland is the Indian East Coast, now almost totally feedered by Singapore. From the 16m TEU handled, over 80% is transshipment. The last 5 years the throughput did not increase much. Due to competition with Tanjung Pelepas – Maersk Sealand and Evergreen transferred their transshipment traffic - the throughput even declined in 2001.

**Malaysia:**
Malaysia is becoming a major competitor for Singapore. Port Klang naturally only serving its inland, now also acts as a hub for the Indian Subcontinent. Transshipment is around 50% and because of expansion plans the port has to be considered as a major player in the Indian Ocean. Tanjung Pelepas is a new port and since the beginning attracting a lot of transshipment. Within 3 years the throughput climbed to 2.7m TEU, with a transshipment rate of 74%. In the next decades the port has plans to expand up to 10m TEU. Forecasts by OSC for container throughput in Malaysia are not specified per port. It is assumed that Port Klang and Tanjung Pelepas are responsible for the total transshipment in Malaysia with a certain distribution over both ports. To complete the throughput of both ports the rest is subscribed to import/export.

**East and South Africa**
In this region there are no competitors for the new Port on Ihavandhippolhu. The region only has import/export traffic. Durban is the main port in South Africa and serves up to Mozambique. The countries more northern, like Tanzania and Kenya, are assumed to be served by Salalah or Colombo. The import/export needs for East Africa is 1m TEU and will be 2.5m by 2015.

### 2.2.3 Competitors for Ihavandhippolhu Port

From the sailing distance and the analysis of the major import/ export markets, a qualitative score can be given to the ports, i.e. competitor and non-competitor. The score is a little bit black and white; there is always some competition between ports. However, due to the limited availability of data and the complexity of the system it is impossible to quantify this competition.
An overview of the ports and their location characteristics, which determine the competitiveness with the new Ihavandhippolhu Port:

Competitors:
- Salalah: located near the Middle East – which has the biggest import/export market in the examined area – but located further from the other areas.
- Colombo: located nearby Ihavandhippolhu, sailing distances almost the same.

Non-competitors:
- Tuticorin: idem as Colombo, but throughput is small and no expansion plans in the future (so not yet considered as a competitor)
- Jebel Ali, in the Middle East and too far from the main shipping lines, this port is supposed to have direct calls from which the Middle East is feedered.
- Jawaharlal Nehru, load centre for the West Side of India and too far from the shipping routes.
- Port Klang, only competing on feeding the East Side of India, this side does not receive much traffic. Furthermore this port is located too far from the other hinterland regions (target markets).
- Tanjung Pelepas, idem.

2.2.4 Possible target markets

In Appendix I a table is given with the distances between the different ports. There are 7 possible hub ports in the region, from Salalah to Tanjung Pelepas that can compete with Ihavandhippolhu (Huvarafushi). 4 ports have a comparable distance to the main shipping routes; e.g. 8322 miles for Colombo to 8439 miles for Ihavandhippolhu. For the distances to the target markets there are three competitors (see last column). A combination of these two gives a confirmation of the qualitative analysis of section 2.2.3.

In that appendix, two examples are included, to show a port its favourability as a hub for a certain target market compared with other ports. Example 1 shows that Ihavandhippolhu (Huvarafushi) is favourably located for traffic to West India compared to Salalah. For every import/export market (hinterland region) the most favourably located port for transshipment is given:

<table>
<thead>
<tr>
<th>Target (import/export) markets</th>
<th>Favourably Located port</th>
<th>Semi-favourably Located port</th>
<th>Not favourably Located port</th>
</tr>
</thead>
<tbody>
<tr>
<td>Middle East</td>
<td>Salalah</td>
<td>Ihavandhippolhu</td>
<td>Colombo</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Salalah</td>
</tr>
<tr>
<td>West India</td>
<td>Ihavandhippolhu</td>
<td>Colombo</td>
<td>Salalah</td>
</tr>
<tr>
<td>East India</td>
<td>Colombo</td>
<td>Ihavandhippolhu</td>
<td>Salalah</td>
</tr>
<tr>
<td>East Africa</td>
<td>Ihavandhippolhu / Salalah</td>
<td>Colombo</td>
<td></td>
</tr>
</tbody>
</table>

Conclusions:
- Analysis of the sailing distances result in two major competitors: Salalah and Colombo.
- The effects of the absence of natural hinterland are not clear, but this is not considered as a major shortcoming.

2.3 Competing ports and their specifications

The two remaining competing ports Colombo and Salalah are discussed in this section. A comparison of the regional capacity needs in the future and the expansion plans of the two competitors can give an indication of possibilities for Ihavandhippolhu.

2.3.1 World container throughput forecast

Ocean Shipping Consultants Ltd. has two forecast scenarios. The scenarios are dependent on the US economy, the political and economical stability in different regions (especially the Middle East en East
Ihavandhippolhu Atoll Transshipment Port

Asia) and macro-economic factors as mentioned in [19] under globalisation. All the optimistic scenarios form case I with the high growth and case II represents the lower growth scenarios.

With the most recent developments in the Middle East and the loosening of trade barriers the growth is expected for this region to be more on the higher scenario. For the rest of the world, with the ongoing stagnation of the economy, it is recommended to follow Case II.

Table 3: World container port demand growth forecast

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>East Asia</td>
<td>32</td>
<td>63</td>
<td>106</td>
<td>160</td>
<td>205</td>
<td>226</td>
<td>260</td>
<td>300</td>
</tr>
<tr>
<td>Americas</td>
<td>22</td>
<td>32</td>
<td>49</td>
<td>65</td>
<td>79</td>
<td>88</td>
<td>100</td>
<td>120</td>
</tr>
<tr>
<td>Europe/ Mediterranean</td>
<td>23</td>
<td>34</td>
<td>55</td>
<td>75</td>
<td>93</td>
<td>101</td>
<td>120</td>
<td>130</td>
</tr>
<tr>
<td>Others</td>
<td>9</td>
<td>15</td>
<td>24</td>
<td>35</td>
<td>46</td>
<td>50</td>
<td>60</td>
<td>80</td>
</tr>
<tr>
<td>World</td>
<td>86</td>
<td>144</td>
<td>234</td>
<td>335</td>
<td>423</td>
<td>465</td>
<td>540</td>
<td>630</td>
</tr>
<tr>
<td>World Transshipment</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>55</td>
<td>82</td>
<td>103</td>
<td>115</td>
<td>130</td>
<td>155</td>
<td></td>
</tr>
</tbody>
</table>

| Others are: Middle East/Indian Subcontinent, Sub-Saharan Africa, and Australasia/Oceania. |

It can be concluded from Figure 10 that in all markets the container port demand will keep expanding over the next years. In East Asia the demand is larger than average and in the Americas the growth is a little bit slower. In the market “others” it is predicted that the Middle East and Indian Subcontinent (ME/IS) generate the most rapid expansion.

2.3.2 Middle East and Indian Subcontinent Forecasts

The Middle East and Indian Subcontinent (ME/IS) is a part of region “others”. First the outlook for the whole area “others” is given and then the part of ME/IS.
In the next years the demand for throughput in the region is rising, however the throughput consists of transshipment and import/export. Nowadays the capacity available is almost occupied, so extra capacity will be needed in the future. A part of this capacity will be used to anticipate on the growth in the transshipment. From this part of growth, when Ihavandhipholhu has a superior level of quality and lower costs, it can take a share.

In the next two sections the characteristics of the competitors for Ihavandhipholhu, Salalah and Colombo, are described. With this closer look, the specific targets for Ihavandhipholhu to reach the efficiency become clear.

### 2.3.3 Port: Salalah

On the south coast of Oman a new container port is developed. The first phase was completed in 1998 and has crossed the 1m TEU mark within two years after that. The port is deeper than ports in the Arabian Gulf and has shorter sailing distances. The Salalah port is supposed to take over the feeder function for the Arabian Gulf.

**Strengths [7]:**
- Salalah is ideally located at the main shipping routes, which lead through the Red Sea.
- Oman has a stable government and the country has a strong economy, due to privatisation there is a good business climate.
- New port with super-post Panamax facilities.

**Present facilities [6]:**
- Total area 550,000sq meters 54 hectares land developed.
Ihavandhippolhu Atoll Transshipment Port

- 1236 meter of quay wall
- 16 meter harbour depth 16.5 meter approach channel
- 500 m turning circle
- 9 super post Panamax gantry container cranes (IHI)

Forecasts/ developments [19]:
The port authorities of the Salalah port envisaged the development over a period of 20 years, in Figure 12 a shorter period is shown. The Port of Aden has some expansions as well, but they are small compared to Salalah.

![Forecasts Gulf of Aden/ Arabian Sea](image)

**Figure 12: Utilisation Salalah and Aden (cumulated)**

2.3.4 Port: Colombo

Colombo, the capital of Sri Lanka, is located at the main NW Europe - SE Asia shipping routes. This port is the main competitor for The Ihavandhippolhu Port. The total throughput in 2001 was 1,7m TEU [8]. The transshipment share of the total throughput is 67%. The efficiency has gone up from 35 moves/hour/ship to 65 – 90 moves/hour/ship. The Colombo Port has a capacity to handle 2.4m TEUs. Jaye Container Terminal is able to handle 1.9m TEUs and the South Asia Gateway Terminal (operated by P&O) its capacity is the remaining 0.5m TEU.

- Container berths with a total length 1,292m of quay wall.
- Feeder berths with a quay wall of together 350m long.
- 12.0 – 15.0 m dredged depth.
- 14 Container cranes (Panamax and Super-post Panamax).
- 44,120 TEU dry container-stacking capacity with 1,548 reefer container stacking.

Forecasts/ Developments [2]:
The Port of Colombo is fully aware of the world container market and the rising demand in the region. Both by expanding the existing port and constructing a new terminal at Hambantota, the Port Authority hopes to keep playing a leading role in South Asia. In 2003, the capacity of both existing terminals is expanded to 3.4m TEU.

In 2006-2007 the first phase of the additional 3.4m TEU capacity is ready. In the end 12 new berths with a depth of 17m (capable of handling the Malaccamax type of carriers, which are expected to be launched in 2015-2020) are constructed.
Ihavandhippolhu Atoll Transshipment Port

To show that efficiency plays an important role in competing with other ports, the following article is included.

**Conclusions for Ihavandhippolhu:**
- **Throughput:** as well the global as the regional throughput is rising. The share of transshipment in the Indian Ocean stays the same.
- **Efficiency:** both ports, Salalah and Colombo, have expansion plans for the next years, but when comparing with the increase in demand, which is bigger than the capacity, the utilisation will rise. This means that efficiency will decrease. If Ihavandhippolhu has a superior efficiency, the port will attract throughput to the Maldives.
- **Tariffs:** because of the lack of knowledge on the specifications of both ports (Salalah and Colombo) and the type of financing, it is not possible to draw conclusions on their construction cost and their charged tariffs. However, it would make sense that a port in the deep and sheltered Atoll would be less expensive, so a port on the Ihavandhippolhu Atoll could be competitive because of lower tariffs.

**2.4 Hithadhoo Port capacity forecast by FISB and recent events**

The former forecast by FISB in 1998 for Hithadhoo is given in this section as well as a summary of the recent events. When the recent events do not influence the forecast made in 1998 and when
Ihavandhipholhu can compete with Colombo and Salalah, then there are no major reasons to divert from this former forecast.

2.4.1 FISB Forecast

The FISB (Foreign Investigations Services Bureau) estimated a market share for Hithadhoo transshipment port in [12]. They first started with defining different levels of service quality in the new port. Dependent on the quality, the port was able to take a certain share in feedering the Indian Subcontinent. The only competitor considered is Colombo, because the Port of Salalah was still under construction. When Hithadhoo offers superior quality it will of course take more traffic from Colombo, than when offering minimal quality.

Partly based on the OSC report [17, 1998 version] the FISB made two future scenarios, one with high traffic growth and limited competition and one with low traffic growth and two competing ports. Two different qualities and two scenarios result in four forecasts (see Figure 14). In each forecast the Hithadhoo container traffic is the sum of the volume in interlining and feedering.

![Hithadhoo port: traffic forecast](image)

Figure 14: Hithadhoo port: traffic forecast

Estimations vary between 570,000 TEU and 1,400,000 TEU.

The FISB sets the mean hypothesis on 1,000,000 TEU in 2010.

Remarks on this estimation:
- The Indian Subcontinent is only considered as a hinterland region, while the Ihavandhipholhu Port is favourably located to transship container traffic for the African East Coast as well. This is just a small part and will affect the actual design volume only positively.
- The study forecasts the expected market shares resulting from the quality of service and the privileged position, but no direct relation between market share (throughput) and quality of service is given.

2.4.2 Recent events and aspects of container transport

Section 2.4.2 from World Container Outlook 2015 of OSC ltd. [19].

Globalisation

In the recent decades figures on world output (global equivalent of GDP) and on the container port demand show a more or less continuous growth, with a constant more rapid growth of container port demand. Globalisation of production is expected to develop even further in the future. Besides the
growth in trade, increasing containerisation and transshipment are also responsible for the more rapid growth of container transport. There are some threats that can limit the growth of container port demand, but according to OSC they are not expected to happen in the near future. The most important are, demand saturation, trade imbalances, elasticity between world output and container port demand and at last regionalisation, the end of globalisation.

Transshipment and increasing vessel size
There are two important logistic aspects that are on the base of the increase in transshipment:

Hub-and-spoke (feeder): Most shipping lines start to co-operate with each other by forming alliances. Ship sizes still continue to grow and designs of ships of 12,000-13,000 TEU are underway. In the future the alliances will operate these ships between big regional hub ports that are centrally located in a certain region. From these ports smaller ports in the region are feedered. This development asks for expansion of some existing ports with deeper basins and for more small ports that can be feedered.

Relay transshipment (mainline to mainline vessel): This is the exchange of containers between two or more mainline services. For example, ships on East-West services exchange cargo with ships on the North-South services.

Stevedoring and terminal operating
Some major changes took place in the management of stevedoring and terminal operating. Most of the changes have resulted in faster container handling and control over the logistic chain by shipping lines.

- Port operators have expanded through acquisitions or by merging. The 4 largest operators handle about 60% of the containers in the world. [30]
- Some shipping lines own and operate their own terminals, better integration of the shipping and stevedoring is a result.

2.5 Requirements for Ihavandhippolhu

2.5.1 Ihavandhippolhu Port capacity forecast

Requirements on the Ihavandhippolhu port:
Analyses of different ports and the target markets on the distances show that the privileged position of Ihavandhippolhu is negligible compared with Salalah and Colombo. Colombo and Salalah are the main competitors. Besides the absence of natural hinterland can even be a shortcoming. The port has to be a strong competitor to Salalah and Colombo in order to survive their expansions.

Competitiveness can be reached by the following aspects:

- Superiority of quality: the port has to be more efficient, this means faster cargo handling, shorter waiting times and limited downtime. The utilisation in Figure 12 and Figure 13 show that there is still need for more capacity in the region. In 2015 there are high utilisations (above 80%). Traffic will shift to Ihavandhippolhu.
- Low tariffs: the expected less expensive construction can result in lower tariffs than Colombo and Salalah. Costs of labour and taxes have to be considered in further studies.

Forecast Ihavandhippolhu
There are two main criteria that determine the difference with the former study:

- Competitiveness: as told above, the competitiveness of the port is expected to be strong; this means, the higher scenarios with superior quality from section 2.4.1 can be followed.
- The study is from 1998; recent developments have to be taken into account for Ihavandhippolhu. Besides the port of Ihavandhippolhu is more favourably located than Hithadhoo, approximately 500 miles to the north.

The following aspects show that the recent developments are not making much difference with the current situation:
Recent developments in the world economics do not have influence on the global and local container transport. The container port demand still shows the in 1998 expected growth. (See section 2.3.1 and 2.3.2)

- The concepts of interlining and feedering are still growing. Transshipment grows faster than the global container traffic.
- Salalah showed, two years after completion of the port, already a throughput of 1m TEU. This port is cheap and fast, so this can be a good example for a new port on the Ihavandhippolhu Atoll. But on the other side a very big competitor.
- The Port of Colombo has reduced its service problems, but still is limited by its depth. The port has new plans for a deeper port, see section 2.3.4.

On the basis of the limited differences with Hithadhoo in 1998 and with a superior quality, an initial capacity of 1.3m TEU would be expected (see Figure 14) for Ihavandhippolhu. However with the expansions of the competitors kept in mind, an initial capacity of 1m TEU in 2010 is a good estimation.

For the years after 2010 a yearly growth of 7% of the regional container port demand is expected [19]. In 2015 another 0.5m TEU capacity is constructed and again in 2020. For the feasibility study in chapter 4 with a lifetime of 25 years, the throughput of the port rises to 2.7m TEU.

### 2.5.2 Design vessel

Vessel sizes are developing rapidly the last decade. In 1996 the Regina Maersk was the largest container ship with a capacity of 6,000 TEU. Nowadays, it is the OOCL Shenzhen with a capacity of 8,063 TEU. Already container vessels of 10,000 TEU have been ordered and will be sailing by the end of 2004. The Suezmax container vessel with 12,000 TEU is expected to be operational by 2010 and the Malacca-max of 18,000 TEU by 2020.

The Port on the Ihavandhipholhu Atoll is supposed to be a main transshipment hub. In order to keep competing with other hubs it is important to be able to receive the mainline vessels. If a port adapts faster on a change in vessel size it will have an advantage compared to its competitors. The Initial phase of the Ihavandhipholhu Port has to be designed to receive the Suezmax ships. The ports of Salalah and Colombo have plans as well to built terminals that are able to serve these types of ships.

The Suezmax container vessel is not yet constructed. Some designs have been made, but there are only speculations about the dimensions. A comparison of several sources will result in the expected, length, beam and draft.

In Appendix II the scantling details of some container vessels are plotted versus the capacity. The data is obtained from the Fairplay Database [11]. In total 1980 vessels with a capacity of more than 1,500 are analysed. A part of these vessels are still on order, including the 10,000 TEU. When the data is plotted on a logarithmic scale the trend lines give a good indication of the expected dimensions of the future Suezmax vessel.

A comparison of some references and the results from Appendix II determines the design characteristics of the Suezmax type, which will call at Ihavandhipholhu. Wijnolst [28] designs the ship with limitations in breadth and draught based on the Suez Canal. Chalmers and Easterbrook [7] consider the depth of other major hub ports as a restriction. Table 5 shows that there are differences between expectations of the dimensions.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length OA (m)</td>
<td>440</td>
<td>400</td>
<td>400</td>
<td>400</td>
</tr>
<tr>
<td>Beam (m)</td>
<td>54</td>
<td>50</td>
<td>57</td>
<td>57</td>
</tr>
<tr>
<td>Draft (m)</td>
<td>15</td>
<td>17</td>
<td>15</td>
<td>17</td>
</tr>
<tr>
<td>DWT</td>
<td>150,000</td>
<td>158,000</td>
<td>140,000</td>
<td></td>
</tr>
</tbody>
</table>
Notes about the vessel dimensions:
Draft: The depth of the harbour channel is easy to change by dredging when needed. On the contrary bringing the port on this depth at the start of construction may be cheaper. However, the change of a quay construction to a deeper basin can be very costly.
Beam: The beam depends on the outreach of the container cranes; at the moment an outreach of 18 containers across is now the maximum. The Suezmax designs goes up to 22 across. It can be expensive to replace the cranes at the moment the Suezmax is operational. The feasibility study must determine the crane size. For the dimensions of the waterways the 57 m beam is used to be on the safe side.

In the next chapters the following vessels are used to design the port layouts:
- Suezmax: cap = 12,000 TEU, LOA = 400m, B = 57m, D = 17m.
- Super Post Panamax: cap = 6000-8000 TEU, LOA = 320m, B = 42.8m, D = 14m.
- 2nd generation feeding vessel: cap = 1500 TEU, LOA = 200m, B = 30m, D = 11.5m.

From: [www.oocl.com](http://www.oocl.com)

<table>
<thead>
<tr>
<th></th>
<th>GRT</th>
<th>NRT</th>
</tr>
</thead>
<tbody>
<tr>
<td>L.O.A. (meters)</td>
<td>322.971</td>
<td>55204</td>
</tr>
<tr>
<td>L.B.P. (meters)</td>
<td>308</td>
<td></td>
</tr>
<tr>
<td>B. MLD (meters)</td>
<td>42.80</td>
<td></td>
</tr>
<tr>
<td>D. MLD (meters)</td>
<td>24.60</td>
<td></td>
</tr>
<tr>
<td>DWT (M/T)</td>
<td>99518.3</td>
<td></td>
</tr>
<tr>
<td>DWT (L/T)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Summer Draft (meters)</td>
<td>14.528</td>
<td></td>
</tr>
<tr>
<td>Summer Displacement (M/T)</td>
<td>133843.6</td>
<td></td>
</tr>
<tr>
<td>Air Draft from Base Line</td>
<td>61.50</td>
<td>meters above B.L.</td>
</tr>
<tr>
<td>Light Weight (M/T)</td>
<td>34325.3</td>
<td></td>
</tr>
<tr>
<td>TEUs</td>
<td>8063</td>
<td></td>
</tr>
</tbody>
</table>

Figure 15: The OOCL Shenzhen

### 2.6 Conclusions and demands on the Ihavandhippolhu Port

From the previous sections the following can be concluded:
- The Port on the Ihavandhippolhu Atoll fulfils the economic needs (need for container handling facilities) in the near future, but as Colombo and Salalah have expansion plans as well, the port has to prove its competence. That means the port has to be attractive on a combination of the following aspects: port dues, sailing distances and cargo handling.
- The initial design throughput of the port is 1,000,000 TEU. The actual capacity is dependent on the number of berths and cranes and their productivity. In order to keep competing, possibilities to expand have to be included in the design. When to expand and how much, has to be determined in a later stage.
- The design vessel is the Suezmax with a capacity of 12,000 TEU. Dimensions are still a bit variable depending on the technical and financial conditions, but they are around 400 * 54 * 17 (Length * Beam * Draft in meters). (Section 2.5.2)
- The main reason to construct this port is its proximity to the main shipping lines. The same counts for Salalah and Colombo. These are the main competitors. Other ports are located too far from the shipping lines or the import/ export markets. The main target markets for Ihavandhippolhu Port are: West India and East Africa.
- The port has to assure superior quality of service to compete, this means very short waiting times, fast cargo handling and low costs. The quantification of these aspects is done in the next chapters of this report.
2.7 Recommendations

There are some disadvantages of the study made in this section, due to the limited time and the centre of gravity of this report that is in chapter 3 and 5. The following can be recommended to improve this economic forecast:

- Competitiveness in this chapter is only related to the distances to the main shipping lines and import/export markets, a good relation between distances and time or costs is necessary to point out the real advantages of Ihavandhippolhu.
- The comparison in Appendix I does not make a difference between cargo volumes from East or West. A weighted model with volumes included can result in other privileged locations in order to serve certain import/export markets. A logistic model can be applied to simulate the cargo flows with the addition of Ihavandhippolhu as a new transport node.
- Predictions on the expansions of the existing ports are never certain. Port Authorities keep their plans confidential. Inside information has to be acquired to know the specifications on other port expansions.
3 Designs

In this chapter the designs are made, that can fulfill on the economic requirements of the port while taking the local conditions into account. During the design it is important to keep the points of attention from section 1.6 in consideration. In the first section 3.1 the data on the hydraulic conditions is collected, i.e. data on waves, tides, etc. This data is used to design the different components of the port, like the berths or the entrance channel in section 3.2.

Because of the fact that not all data is collected, assumptions have to be made; an overview of all the assumptions is shown in section 1.7. After this a list of requirements is presented, which is used to make a certain number of designs.

The 8 designs are included in Appendix VII. A short evaluation is performed to reduce the number of designs in section 3.3. The most important criteria are the downtime during (un)loading, the availability of sand and the distance to the main shipping routes.

In the end of this chapter in section 3.4, three preliminary designs are made, two designs have extra measures against downtime; one uses the two-sided unloading principle and the other a breakwater. In the next chapter a detailed evaluation of these designs is carried out.

3.1 Data collection

The data collection is important to dimension the components of the port. Wind (3.1.1) and waves (3.1.2) are important for the manoeuvrability of the ships and the required width of the entrance channel. The tides (3.1.3) have influence on the downtime of the entrance channel. Waves also influence the situation and protection of the harbour basin. Besides, some more important data on geophysical aspects, episodic events and sea-level rise is given.

3.1.1 Wind

The climate of the Maldives is determined by two monsoons, the southwest monsoon from May to October and the northeast monsoon from November till April. The southwest monsoon brings some wind and rain, on the contrary the other monsoon period is dry and with very little wind.

Wind data is collected from www.wavEClim@te.nl (Argoss [9]), this data is based on satellite passes. All the data is concerning an area with the following characteristics:

Centre of area: 7° 00'N, 72° 50'E
Size of area: 100x100 km

Figure 16 shows the seasonality of the wind speed, the red line is the average and the orange area gives the 5% and 95% under and upper bound. This is based on 11299 samples from 969 satellite passes.
More important for the downtime for manoeuvring in the entrance channel is the wind direction. With the wind direction the direction of the waves can be determined (see section 3.1.2). In Table 6 and Figure 17 the wind speed and directions and the relative time of occurrence are shown.

Table 6: Distribution of wind speed

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>NE</th>
<th>E</th>
<th>SE</th>
<th>S</th>
<th>SW</th>
<th>W</th>
<th>NW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-4 m/s</td>
<td>5%</td>
<td>4%</td>
<td>4%</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>5%</td>
<td>32%</td>
</tr>
<tr>
<td>4-8 m/s</td>
<td>9%</td>
<td>4%</td>
<td>4%</td>
<td>1%</td>
<td>1%</td>
<td>8%</td>
<td>22%</td>
<td>9%</td>
</tr>
<tr>
<td>8-12 m/s</td>
<td>14%</td>
<td>8%</td>
<td>8%</td>
<td>4%</td>
<td>5%</td>
<td>14%</td>
<td>33%</td>
<td>14%</td>
</tr>
</tbody>
</table>

The most occurring wind direction is W and WSW with wind speeds up to 12 m/s, 6 Beaufort, stronger winds hardly occur in this region.

3.1.2 Waves

There is acceptable downtime of the port due to normal waves and downtime of the port due extreme conditions like the failure of structures, e.g. a breakwater. The wave data from the Argoss site is concerning the offshore waves. These are waves generated outside the atoll. Offshore waves consist of a regular spectrum and swell, which are waves generated before and travelling faster than the present wind conditions.
Offshore waves:

Data on the wave height and their direction is not sufficient, only 242 samples. There is more data on the wave height and its seasonality; this data will be used to find the wave distribution. The following is assumed: if the strongest winds come from W to WSW, the biggest waves are also coming from this direction.

The best probability density function is found with the program BestFit, this program gives the best matching distributions according to the Kolmogorov-Smirnov and Chi-Square tests. The input existed of 34187 samples; the result was a Gamma distribution, however the lognormal function fits as well and is more practical to use. (For the results see Appendix III) The lognormal can be transformed to a normal distribution \[ \text{lognormal} \rightarrow \text{normal} \] The equation and the characteristics are as follows:

\[
 f_X (X) = \frac{1}{X \sigma \sqrt{2\pi}} e^{-\frac{1}{2} \left( \frac{\ln(X-\mu)}{\sigma} \right)^2} 
\]

(3.1)

In which \( X \) is a lognormal distribution and \( Y = \ln(X) \) is a normal distribution. With the following mean and standard deviation:

\[
 \sigma_Y = \ln \left( 1 + \left( \frac{\sigma_X}{\mu_X} \right)^2 \right) = \sqrt{\ln \left( 1 + \left( \frac{0.75}{1.37} \right)^2 \right)} = 0.512 
\]

\[
 \mu_Y = \ln \left( \mu_X - \frac{1}{2} \sigma_X^2 \right) = \ln \left( 1.37 - \frac{1}{2} \cdot 0.75^2 \right) = 0.085 
\]

(3.2)

The maximum downtime for ships in the entrance channel is assumed to be 1\% of the year. So 99\% of the year the waves have to be lower than this design wave height. \( P(X<X) \) has to be bigger than 0.99 and \( 1-P(X<X) \) has to be smaller than 0.01:

\[
 F_X (X) = 1 - \Phi_N \left( \frac{\ln(X) - \mu_Y}{\sigma_Y} \right) \leq 0.01 
\]

\[
 \frac{\ln(X) - \mu_Y}{\sigma_Y} \geq 2.326 \quad \ln(X) = 2.326 \cdot 0.512 + 0.085 = 1.27 
\]

\[ X \geq 3.57 \text{m} \]

(3.3)

The cumulative distribution function in Figure 18 shows roughly the same value:

![Comparison of Input Distribution and Lognormal(1.37,0.75)](image)

Figure 18: Lognormal distribution function of the wave data

The design wave for the manoeuvrability in the entrance channel has to be higher than 3.57, i.e. 1\% of the time waves are higher, the breakwaters have to be designed or located in a way that less than 1\% in time the design vessels are not able to enter the port.
Design wave height

Other components of the port like the armour on the breakwater have to be determined on another design wave height, the significant wave height. This height is the average of the highest one-third of the wave spectrum. Figure 19 deduced from [9], shows the frequency of the wave height for a period of three hours.

The significant wave height, on which the port is designed, depends on the lifetime and the admissible chance of failure. With the equation of Poisson the significant wave height can be calculated.

\[ P = 1 - \exp(-fT) \]
\[ f = \frac{1}{T} \ln(1 - P) \]  

(3.4)

In which:
\[ P \] = admissible chance of failure [-]
\[ f \] = frequency of storm [1/year]
\[ T \] = design lifetime [year]

The lifetime for this port is 50 years and the assumed chance of failure of 10% is:

\[ f = \frac{1}{50} \ln(1 - 0.1) = 0.0021 \]

The significant wave height may occur only once in 500 years. Figure 19 shows that this height is 6.0m.

Swell

The most important data on the swell, as wave height and prevailing direction, is shown in Figure 19 and Figure 21. Swell can be important; because of its longer amplitude it can induce unwanted resonances or currents in the harbour basin.
Local conditions on Atoll

The former calculations only concerned the offshore waves. The Atoll is considered to be a shelter. Only from the east side waves can penetrate, but inside the Atoll the wind can also generate waves. The significant wave height $H_s$ and period $T_s$ are depending on the fetch and the wind velocity. The relation is given in [8, p.3-41]

<table>
<thead>
<tr>
<th>Direction</th>
<th>Location</th>
<th>Wind Speed (m/s)</th>
<th>Fetch (km)</th>
<th>$H_s$ (m)</th>
<th>$T_s$ (s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>Ihavandhoo/ Huvarafushi</td>
<td>13-14</td>
<td>14.8</td>
<td>1.3</td>
<td>3.3</td>
</tr>
<tr>
<td>NE</td>
<td>Ihavandhoo/ Huvarafushi</td>
<td>7-8</td>
<td>11.1</td>
<td>0.6</td>
<td>2.5</td>
</tr>
<tr>
<td>E</td>
<td>Ehavandhoo/ Huvarafushi</td>
<td>Penetration from deep sea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SE</td>
<td>Thuraakunu/ Uligamu</td>
<td>Penetration from deep sea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>Thuraakunu/ Uligamu</td>
<td>10-11</td>
<td>14.8</td>
<td>1.0</td>
<td>3.1</td>
</tr>
<tr>
<td>SW</td>
<td>Uligamu/ Mulhadhoo</td>
<td>13-14</td>
<td>11.0</td>
<td>1.2</td>
<td>3.1</td>
</tr>
<tr>
<td>W</td>
<td>Mulhadhoo/ Uligamu</td>
<td>15-16</td>
<td>13.0</td>
<td>1.5</td>
<td>3.6</td>
</tr>
<tr>
<td>NW</td>
<td>Mulhadhoo</td>
<td>13-14</td>
<td>14.8</td>
<td>1.3</td>
<td>3.3</td>
</tr>
</tbody>
</table>

There is no sufficient data on waves and their directions. Assumed is that the waves come from the east, when the wind direction is east. There are more samples on the wind speed related to the wave
height. The data gives for each wind speed a spectrum of waves. Accumulation of these spectra times the percentage of time that this wind speed comes from the direction E and SE gives the curve in Figure 22.
3.1.3 Tides

The tide consists of numerous driving forces. The most important are the M and S forces, caused by the gravitational forces of the moon and sun. The Admiralty charts and publications [1] give four harmonic constants, two semidiurnal $M_2$, $S_2$ and two diurnal $K_1$, $O_1$. The last two take into account (amongst others) the inclination of the equatorial plane with respect to the plane of the moon’s orbit. These constant form a function with certain phase and amplitude around $Z_0$. With the help of the program Tidepred it is possible to predict the tides.

$Z_0 = $ Mean Level $= 0.68m$
$M_2 = 0.24m \, 338^\circ$
$S_2 = 0.11m \, 037^\circ$
$K_1 = 0.18m \, 063^\circ$
$O_1 = 0.09m \, 051^\circ$

In Figure 23 the prediction of the period 16 July to 14 August 2000 is given. The period of 29 days is long enough to show all the periods of the different harmonic constants.
This chart results in the next table:

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Explanation</th>
<th>Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>CD</td>
<td>Chart Datum</td>
<td>0.0</td>
</tr>
<tr>
<td>MSL</td>
<td>Mean Sea Level</td>
<td>CD + 0.68 m</td>
</tr>
<tr>
<td>MHHW</td>
<td>Mean Higher High Water</td>
<td>CD + 1.2 m</td>
</tr>
<tr>
<td>MLHW</td>
<td>Mean Lower High Water</td>
<td>CD + 0.8 m</td>
</tr>
<tr>
<td>MHLW</td>
<td>Mean Higher Low Water</td>
<td>CD + 0.6 m</td>
</tr>
<tr>
<td>MLLW</td>
<td>Mean Lower Low Water</td>
<td>CD + 0.15 m</td>
</tr>
</tbody>
</table>

3.1.4 Currents

There is currently no information about currents available. Assumed is that currents due to tides are between 0 and 0.5 m/s.

3.1.5 Geophysical

Most of the atolls are formed from reefal limestone and unconsolidated carbonate sediment. [5] The top layer is a mixture of sand and organic material. Below that there is compressed sand or sandstone. The subsoil has a poor water retaining capacity.

The submerged parts of the atolls consist of more coral with some sand (indicated on the admiraltry maps with Co.S) and the much deeper centre part of the atoll possesses more sand than coral (S.Co).

Boskalis Dolman BV performed a soil investigation at Fuah Mulaka for a harbour project. Specifications on the soil are included in Appendix IV. Due to the same formation history of the atolls they can be compared and the soil profile from Appendix IV is considered to be applicable for Ihavandhippolhu as well.

The subsoil mostly consisting of hard and loose coral rock mixed with coral sand is considered to be strong enough to found the port. Sand for land reclamation can be found in the inner part of the Atoll.

3.1.6 Extreme episodic events

According to Maniku [16] there have been several occasional extreme events in the past. It is impossible to give these events a certain probability of occurrence and to predict the impact. The historic events are mentioned here, but these events do not influence the design process.

Hurricanes:
Several cyclone driven storms are reported; about 18 islands from the northern atolls were abandoned after being devastated. The most recent storm was on 30th of May 1991 when the maximum wind speed reached 90 kts/hour and 4,081 houses in 13 atolls were damaged. Former storms were in 1955, 1821 and before.

In Appendix V data on the hurricane tracks is included. Most hurricane tracks have been between 15 and 25° latitude so Ihavandhippolhu is not in a risky zone. In the picture in the appendix the tracks passing the square between 5 and 10° latitude and 70 and 75° longitude have been drawn. The density of tracks outside this square is much higher but this does not become clear in the picture.

Over the last 50 years (1952 to 2002) only 23 tracks have crossed the square with total storm duration of 4100 hour, this means a probability of 0.82% per year. This probability of occurrence looks important; however several remarks can be made:
- The duration of 4100 hours is the sum of the all the lifetime of the storms so the actual time that the storm affects the considered area is much smaller, this results in a smaller probability.
- The categorisation according to Saffir-Simpson shows that only a small amount of time (less than 0.1%) the storms are categorised as cyclones and the track plot shows that this only occurred on a great distance of Ihavandhippolhu.
- The area is 300 x 300 miles, the highest wind speeds occur in the eye of the storm that is often significant smaller.
Other extreme episodic events:
- A very localised storm event (freak storm) hit the Bolifushi Island in 2000. It lasted 12 hours and caused about US$ 1.2m worth of damages.
- Floods: Inundations due to heavy rainfall or high waves. Especially strong tidal waves during high spring tide have caused floods. In 1987 extreme damage to the capital Malé was reported resulting from a tidal flood.

### 3.1.7 Sea level rise

The Maldives are vulnerable to sea level rise, because of the low altitude of the islands. The Intergovernmental Panel on Climate Change [3] developed some scenarios on the sea level rise. The scenarios are developed with the use of some models, information on these models is not at hand, but the foundation is on the gas emissions (primarily CO$_2$) and the global warming.

![Figure 24: Sea level rise according to IPCC](image)

The port is developed for a lifetime of 50 years, so in 2055 the sea level rise according to the most pessimistic scenario is 0.35m (from Figure 24). The question is, if this sea level is also valid for the Maldives, aspects like change in tides and different location on the world, also play part. In [17] a table is included also based on the IPCC scenarios but valid for the Maldives. This table gives a high scenario in 2050 with a sea level rise of 39.7 cm.

### 3.2 Dimensions port components

In this section the components of the port are dimensioned. The components can be divided in the terminal and berths and the hydraulic infrastructure as the entrance channel and basin.

#### 3.2.1 Terminal

The area needed for the container terminal can be calculated with equation 3.5. One of the most important factors is the dwell time. This is the average time a container is stored on the terminal.
Normally ports also handle import and export containers. The throughput of the Ihavandhippolhu Port only consists of transshipment traffic. Relay transshipment has a very short dwell time; large numbers of containers (parcel size is high) are unloaded and loaded between mainline vessels. Containers for feeding can have a longer dwell time. In [25] an average dwell time of 5-7 days is considered to be reasonable. For the calculations of the Ihavandhippolhu Port a dwell time of 5 days is applied.

![Figure 25: Stacking area with RTG crane](image)

The availability of land for building the terminal on one of the Ihavandhippolhu Islands is an important limitation. The stacking height with the use of gantry cranes is nowadays 3-4 high. With RTG's a height of 4-5 containers can be reached. In that case advanced logistic systems must avoid expensive moves to get the containers from the bottom of the stack. For this design with a stacking height of 4 containers, the area needed included with lanes is 20m² per TEU. Parameter \( r \), the stacking ratio, reflects a logistic problem; the higher the stacking the greater the risk of making more reshuffling moves. For this terminal \( r \) is set on 0.8 [5].

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

(3.5)

In which:
- \( A \) = required area [m²]
- \( C_i \) = number of container movements a year [TEU]
- \( t_d \) = average dwell time [days]
- \( F \) = required area per TEU including lanes [m²]
- \( r \) = ratio average stacking height / nominal stacking height [-]
- \( m_i \) = acceptable occupancy rate [-]

\[
A = \frac{1,000,000 \cdot 5 \cdot 20}{365 \cdot 0.8 \cdot 0.75} = 460,000m²
\]

(3.6)

In [25] a benchmark is set on 20,000 TEU/hectare/year with even a 50% increase for large terminals. For the Ihavandhippolhu terminal with a capacity of 1,000,000 TEU it would be 50 hectare.

An additional area of 50% is assumed for the terminal area for customs, dry-docking and repairs, bunkering terminal, industrial/ duty free zone and offices. Total area needed is 46 ha for the container terminal and 23 ha for other services.

Colombo: 45.5 ha for 1.7m TEU is 27 ha/mTEU (excl. facilities like bunkering, offices, etc.)
Salalah: 54 ha total for 1.2m TEU is 45 ha/mTEU (excl. facilities like bunkering, offices, etc.)

Two remarks can be made to the differences in the areas. First, Colombo is an old port, with limited space to expand. In this port longer services times and higher cargo handling costs are the result of more container movements on the stacking area. Second, Salalah is a new port with enough space. Furthermore, more space gives the port more opportunities to increase the throughput. The terminal, that has the same area per TEU as Salalah, can compete with Colombo on cargo handling.
3.2.2 Berths and quay length

According to the competitiveness of the port the waiting times have to be minimal. Nowadays, accepted waiting times are 5% for the Post-Panamax vessels and 10% for the feedering ships. The number of berths determines the waiting time; the more berths, the shorter the waiting times.

To determine the quay length, the number of berths must be determined first, this number is dependent from the accepted waiting times and the berth productivity. The crane productivity is the most important factor in the berth productivity; see also the article in section 2.3.4. The operational time of the port is 24 hours.

Number of berths \( (N_b) \)

For the determination of the number of berths, the throughput has to be divided in relay and feedering transshipment. Both types of transshipment differ on the number of ships that have to call for the same share of throughput. In case of feedering traffic the segmentation of the cargo is smaller. The feedering vessels \( (N_{vf2}) \) arrive at a higher frequency and need more, but smaller berths. Figure 26 shows the different traffic flows. The throughput of relay transshipment is the number of vessels times the amount of containers that is loaded times 2 (loading and unloading). The throughput of feedering transshipment is the same, only there is differentiation in vessel types.

During the next section case 2 is taken as an example for the different calculations.

![Figure 26: The port's throughput](image)
\[C_i = RC_i + FC_i \quad (R + F = 100\%)\]
\[RC_i = 2C_{vr}N_{vr}\]
\[FC_i = 2(C_{vf1}N_{vf1} + C_{vf2}N_{vf2}) \quad \text{with} \quad C_{vf1}N_{vf1} = C_{vf2}N_{vf2}\]

In which:
- \(C_i\) = total throughput of the port [TEU]
- \(R\) = share of relay transshipment in throughput [%]
- \(F\) = share of feedering transshipment in throughput [%]
- \(C_{vr}\) = parcel size of relay mainline vessel [TEU]
- \(N_v\) = number of vessel calls [\(\cdot\)]

The subscripts \(r\) and \(f\) correspond to relay and feedering

Four cases are distinguished; the difference is the share of relay transshipment in the total throughput. The mainline vessels are Super Post Panamax ships with a total capacity of 6000 to 8000 TEU. Assumed is that in case of relay transshipment 3000 TEU is transhipped (the parcel size) and in case of mainline vessel to feeder the parcel size is 4000 TEU and after segmentation (4 times) 1000 TEU. In case 4 the part of the Super Post Panamax ships are replaced by Suezmax ships

Case 2, with the use of equation 3.7:

\[C_i = RC_i + FC_i = 1,000,000\]
\[RC_i = 0.25 \cdot 1,000,000 = 250,000 = 2C_{vr}N_{vr}\]
\[N_{vr} = \frac{250,000}{2 \cdot 3000} = 42\]
\[FC_i = 0.75 \cdot 1,000,000 = 750,000 = 2(C_{vf1}N_{vf1} + C_{vf2}N_{vf2})\]
\[N_{vf1} = \frac{375,000}{2 \cdot 4000} = 47\]
\[N_{vf2} = \frac{375,000}{2 \cdot 1000} = 188\]

Table 9: Different vessel distributions

<table>
<thead>
<tr>
<th></th>
<th>Case 1 (0% Relay)</th>
<th>Case 2 (25% relay)</th>
<th>Case 3 (50% Relay)</th>
<th>Case 4 (Suezmax)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Throughput</td>
<td>N</td>
<td>Throughput</td>
<td>N</td>
<td>Throughput</td>
</tr>
<tr>
<td>Mainline vessel relay (3000 TEU)</td>
<td>250,000</td>
<td>42</td>
<td>500,000</td>
<td>83</td>
</tr>
<tr>
<td>Mainline vessel feedering (4000 TEU)</td>
<td>500,000</td>
<td>63</td>
<td>375,000</td>
<td>47</td>
</tr>
<tr>
<td>Feeder (1000 TEU)</td>
<td>500,000</td>
<td>250</td>
<td>375,000</td>
<td>188</td>
</tr>
<tr>
<td>Mainline vessel Suezmax (6000 TEU)</td>
<td>1,000,000</td>
<td>750,000</td>
<td>1,000,000</td>
<td>1,000,000</td>
</tr>
</tbody>
</table>

1. Used model

With the queuing theory explained in [13], one can determine the number of berths. A queuing model with a Kendall notation of \(E_2/E_2/n\) is used. In this model the arrival and service rate have an Erlang probability distribution. The table in Appendix VI-1 gives the waiting times in units of the average service time.
2. Service time

A Super-post Panamax ship can be served by 6 cranes, in this calculation 5 cranes are used and an occupation during (un)loading of 100%. The terminal and the cranes are operational for 24 hours a day. The crane productivity is nowadays, when specialised companies run the terminal, around 40 moves/hour [25]. The TEU factor is the ratio between twenty and forty feet containers, this factor is always between 1 and 2, a good approximation is 1.5 [14].

In Appendix VI the calculations for each case are given.

The service time for a Super Post Panamax vessel in case 2 is:

\[
\frac{1}{\mu} = \frac{C_v}{p_c \cdot f \cdot N_c} \cdot 2.1 = \frac{3528}{40 \cdot 1.5 \cdot 5} \cdot 2.1 = 24.7
\]

In which:
- \(\mu\) = service rate (1/\(\mu\) = service time [hours])
- \(C_v\) = average parcel size [TEU]
- \(p_c\) = gross production per crane [moves/hour]
- \(f\) = TEU factor [-]
- \(N_c\) = number of cranes per berth [-]
- \(2.1\) = factor for loading unloading and additional time for administrative paperwork

3. Berth utilisation

The utilisation can be calculated by dividing the number of ships and their service time by the total time and number of berths, in case 2 with 1 berth:

\[
\Psi = \frac{1}{\mu N_v} = \frac{24.7 \cdot 89}{365 \cdot 24 \cdot N_b} = 0.25
\]

In which:
- \(\Psi\) = berth utilisation [-]
- \(T_m\) = waiting time [%]
- \(N_b\) = number of berths [-]
- \(N_v\) = vessel calls a year [-]

4. Acceptable waiting time

The acceptable waiting times for shipping companies are 5% for the Super Post Panamax and 10% for the feeder vessels.

\[\Psi = 0.25 \Rightarrow (\text{Appendix VI-3}) \ T_m = 0.5 \ast (0.1310-0.0604) + 0.0604 = 0.0957\]

\(T_m = 9.57\%\), this is not acceptable! The number of berths has to be increased, in Appendix VI-3 the calculations of case 2 with respectively 1 and 2 Super Post Panamax berths are given.

In Table 10 the results are given of the berth calculations for each case. In each case two berths fulfil the requirements for each type of ship; two Super Post Panamax berths and two Feeder berths.
Table 10: Required number of berths

<table>
<thead>
<tr>
<th>Case 1 (0%)</th>
<th>SP Panamax</th>
<th>Feeder</th>
<th>Case 2 (25%)</th>
<th>SP Panamax</th>
<th>Feeder</th>
<th>Case 3 (50%)</th>
<th>SP Panamax</th>
<th>Feeder</th>
<th>Case 4</th>
<th>Suez max</th>
<th>Feeder</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. berths</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Utilisation</td>
<td>0.20</td>
<td>0.80</td>
<td>0.25</td>
<td>0.60</td>
<td>0.30</td>
<td>0.40</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waiting times</td>
<td>6.04</td>
<td>186.53</td>
<td>9.36</td>
<td>63.55</td>
<td>13.10</td>
<td>23.55</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. berths</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilisation</td>
<td>0.10</td>
<td>0.40</td>
<td>0.125</td>
<td>0.30</td>
<td>0.15</td>
<td>0.20</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Waiting times</td>
<td>0.06</td>
<td>5.76</td>
<td>0.21</td>
<td>2.35</td>
<td>0.35</td>
<td>0.65</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>No. berths</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Utilisation</td>
<td>0.095</td>
<td>0.406</td>
<td>0.400</td>
<td>0.227</td>
<td>0.323</td>
<td>0.300</td>
<td>0.213</td>
<td>0.200</td>
<td>0.200</td>
<td>6.96</td>
<td>0.65</td>
</tr>
<tr>
<td>Waiting times</td>
<td>0.06</td>
<td>5.68</td>
<td>0.21</td>
<td>2.70</td>
<td>0.35</td>
<td>1.17</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

5. Exchangeable berths

Table 10 shows that 2 berths for each type of vessel is sufficient. If each SP Panamax berth will serve feeders as well during the time that there are no mainline vessels, the quay length can be reduced. For this situation some assumptions are made:

- The mainline vessel gets right of way to be served at the SP Panamax berths and feeder vessels have to move and wait to continue (un)loading.
- Time to move the feeder vessels between berths is neglected and not included in the service time.

There are 3 berths: berth 1 and 2 are SP Panamax berths that also serve feeder vessels and berths 3 is a feeder berth.

For case 2:

If there is 1 SP Panamax berth: Appendix VI-3 shows that there is a waiting time 9.36% with a berth utilisation of 25%. With only one berth a second mainline vessel has to wait. The time a vessel is waiting in units of a year is 9.36 * 25 = 2.34%. With two SP-Panamax berths, the vessel which is waiting can use the extra berth during this time. Feeder vessels can use both SP Panamax berths when they are not occupied besides their own berth. When a mainline vessel calls, they have to move and wait to give priority to the mainline vessel.

In case 2 with 1 SP Panamax berth: \( T_m = 9.36\% \) and ? (SP Panamax) = 25%

The second SP Panamax berth is occupied with a mainline vessel for \( \text{equation 3.9} \):

\[
\Psi = \frac{T_m \cdot 1}{365 \cdot 24} = 2.35\%
\]

In case 2 with 2 SP Panamax berths: \( T_m = 0.21\% \) and ? (SP Panamax 1) = 25% - 2.35% = 22.65% and ? (SP Panamax 2) = 2.35%. In other words, 22.65% of the time one mainline vessel is served and 2.35% two mainline vessels are served. In fact the utilisation will spread over the two berths equally, because the mainline vessels are not moved. The 2.35% only shows the extra waiting time for feeders due to the presence of mainline vessels.

With these two low utilisations, the 2 SP Panamax berths can serve enough feeder vessels and are assumed to function as 1 extra Feeder berth as well. The waiting times of the feeders are:

In case 2 with 1 feeder berth: \( T_m = 63.06\% \) and ? (Feeder) = 60%.
When considered as 2 feeder berths: \( T_m = 2.35\% \) and ? (Feeder) = 30%. (Note: the outcome of \( T_m \) (Feeder) and ? (SP Panamax 2) on 2.35% is a coincidence)
However, half of the number of feeder vessels that are berthing at the Super Post Panamax berths (with an utilisation of 30%) get a 2.35% extra waiting time. The total average waiting time is than:

\[ 2.35 + 0.3 \times 0.50 \times 2.35 = 2.70\% \]

Conclusions:

- Two SP Panamax berths and 1 feeder berth are sufficient in all cases to serve the vessels with acceptable waiting times. When no mainline vessels are present the SP Panamax berths also serve feeder vessels.
- Two Super-post Panamax berths in a row can in the future function as one Suezmax berth. There is still much space then to berth 2 smaller feeder vessels. However waiting times become too high in this case and port expansions are needed in the near future after that.

In the designs in the next sections the 3 berths are included. See also the section of the quay length calculations.

For further more detailed calculations on the number of berths, the following is recommended:

- Make a comparison of costs of waiting, smaller throughput and anchorages versus the costs of berths and cranes.
- Use a simulation model with more types of vessels, downtime due to hydraulic conditions and traffic aspects.

Because of the exchangeability of the berth, all quay cranes are considered to have a productivity of 40 moves/hour. Number of quay cranes is \( 2 \times 5 + 1 \times 2 = 12 \).

Quay length

The quay length can be determined with:

\[
L_q = 1.1 \cdot N_b \cdot (\text{LOA} + 15) + 15 \quad (3.10)
\]

In which:

- \( L_q \) = quay length [m]
- \( N_b \) = number of berths [-]
- \( \text{LOA} \) = Length Over All [m]

Super-post Panamax, \( \text{LOA} \) is 320m:

\[ L_q = 1.1 \cdot (320 + 15) + 15 = 384 \text{ m}. \]

Feeder, \( \text{LOA} = 200 \):

\[ L_q = 1.1 \cdot (200 + 15) + 15 = 252 \text{ m}. \]

Total: \( 2 \times 384 + 252 = 1,020 \text{ m}. \)

The total length of the quay is 1,020 m. The throughput per meter quay is then 980 TEU. A benchmark in port planning is 1,000 TEU/m. Colombo is an old port with longer service and waiting times, so the berth utilisation is high as well. In Salalah the service time is short, so the berth occupancy is low and the waiting times are short. Some figures on western ports are included in [25], most of the European ports have productivities between 600 and 900 TEU/m.
Table 11: Comparison of quay lengths

<table>
<thead>
<tr>
<th>Throughput (TEU)</th>
<th>Quay length (m)</th>
<th>TEU/m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>1,000,000</td>
<td>1,000</td>
</tr>
<tr>
<td>Ihavandhippolhu</td>
<td>1,000,000</td>
<td>1,020</td>
</tr>
<tr>
<td>Colombo</td>
<td>1,700,000</td>
<td>1,642</td>
</tr>
<tr>
<td>Salalah</td>
<td>1,200,000</td>
<td>1,236</td>
</tr>
<tr>
<td>Hong Kong HIT [25]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Antwerp [25]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Quay height**

The quay height strongly depends on the land level. If the terminal is constructed in the same level the use of material can be minimised and there are no height differences. If the land level is too high or low the quay height is determined by the wave impact and the permitted downtime of the terminal caused by wave overtopping.

On the Ihavandhippolhu Atoll the average land level is 2 m above MSL, the quay height however compared to CD will be:
- CD = 0 m.
- Tides (Table 8) between CD +0.6 m and CD +1.2 m
- Waves elevation 0.5 m.
- Sea level rise 0.4 m.
- 1.5 m to prevent the terminal against overtopping

Quay height = CD + 1.2 + 0.5 + 0.4 + 1.5 = CD + 3.6m

This is 1.6m above average land level.

**3.2.3 Hydraulic infrastructure**

The characteristics of the design ship:

- LOA = Length Over All = 400m
- B = Beam = 57m
- D = Draft = 17m

**Depth entrance channel [14]**

In this case, when assumed that no downtime due to tides is accepted (the depth is probably all ready sufficient), the design channel depth is:

\[ d = D + s_{max} + r + m \]  \hspace{1cm} (3.11)

In which:
- d = authorised channel level [m]
- D = draft design ship [m]
- r = ship motion due to wave response [m]
- s = squat [m]
- m = remaining safety margin [m]
All the parameters in this equation can be estimated on the basis of experience. \( s_{\text{max}} \) is 0.5m and \( r = \frac{H_s}{2} \), for \( H_s \) use the 1% downtime wave height, calculated on 3.57. \( m \) depends on the type of soil, for hard soil or rock \( m = 1.0 \) m. The total depth is:

\[
\begin{align*}
\text{Depth} & = 17 + 0.5 + \frac{3.57}{2} + 1.0 = 20.3 \approx 20.5
\end{align*}
\]

**Channel width**

On the base of on average less than one call a day, one can assume that a one-way channel is sufficient. PIANC [21] gives the next equation to determine the width of a one-way entrance channel:

\[
W = W_{BM} + \sum W_i + 2W_B
\]  

\[ (3.12) \]
Ihavandhippolhu Atoll Transshipment Port

Figure 28: Components determining the channel width

In which:
- $W$ = design width of channel [m]
- $W_{BM}$ = basic manoeuvrability [m] if $d < 1.25D = 1.7B$
- $W_B$ = bank clearance [m]
- $W_i$ = sum of additional factors:

<table>
<thead>
<tr>
<th>Component</th>
<th>Cond.</th>
<th>Width</th>
<th>Explanation</th>
<th>Add.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prevailing crosswinds:</td>
<td>15-33 kts</td>
<td>0.4B</td>
<td>The minimum wind speed for addition is 15 kts, which is 7.5 m/s. Figure 16 shows in the months June and July higher wind speeds. 10 m/s corresponds with 20 kts.</td>
<td>0.4B</td>
</tr>
<tr>
<td></td>
<td>33-48 kts</td>
<td>0.8B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevailing Cross current</td>
<td>0.2-0.5 kts</td>
<td>0.2B</td>
<td>There is no data available on the currents an assumption of 0.5 m/s is made in section 3.1.4. That is 1.0 kts.</td>
<td>0.7B</td>
</tr>
<tr>
<td></td>
<td>0.5-1.5 kts</td>
<td>0.7B</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>1.5-2.0 kts</td>
<td>1.0B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevailing long current</td>
<td>1.5-3.0 kts</td>
<td>0.1B</td>
<td>Do not occur, see assumption in section 3.1.4.</td>
<td>0.7B</td>
</tr>
<tr>
<td></td>
<td>&gt; 3.0 kts</td>
<td>0.2B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Prevailing wave height</td>
<td>1-3 m</td>
<td>1.0 B</td>
<td>Inside the atoll waves do not exceed 3m, outside the atoll they do, so different width are needed.</td>
<td>1.0B</td>
</tr>
<tr>
<td></td>
<td>&gt; 3 m</td>
<td>2.2 B</td>
<td></td>
<td>2.2B</td>
</tr>
<tr>
<td>Aids to navigation</td>
<td>VTS</td>
<td>0</td>
<td>Because of the new port, the best systems for aids to navigation are used.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Good</td>
<td>0.1B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Seabed characteristics</td>
<td>Soft</td>
<td>0.1B</td>
<td>The soil consists of coral and lime/sandstone.</td>
<td>0.2B</td>
</tr>
<tr>
<td></td>
<td>Hard</td>
<td>0.2B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cargo hazard</td>
<td>Medium</td>
<td>0.5B</td>
<td>Cargo hazard is medium; no oil or chemical tankers will call at this port.</td>
<td>0.5B</td>
</tr>
<tr>
<td></td>
<td>High</td>
<td>1.0B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The total additional width $W_i$</td>
<td>Inside atoll</td>
<td></td>
<td>Inside atoll</td>
<td>2.8B</td>
</tr>
<tr>
<td></td>
<td>Outside atoll</td>
<td></td>
<td></td>
<td>4.0B</td>
</tr>
<tr>
<td>Bank Clearance</td>
<td>Sloping</td>
<td>0.5B</td>
<td>It depends on the dredgability of the material, assumed is a sloping embankment</td>
<td>0.5B</td>
</tr>
<tr>
<td></td>
<td>Steep</td>
<td>1.0B</td>
<td></td>
<td></td>
</tr>
<tr>
<td>The total width of the entrance channel</td>
<td>Inside atoll</td>
<td>Inside atoll</td>
<td>Inside atoll</td>
<td>5.5B</td>
</tr>
<tr>
<td></td>
<td>Outside atoll</td>
<td>Outside atoll</td>
<td>Outside atoll</td>
<td>6.7B</td>
</tr>
</tbody>
</table>

The channel width varies from $6.7B = 382$ m outside the atoll to $5.5B = 314$ m inside the atoll, to have a safe entrance channel without significant downtime. The major difference is found in the bigger waves outside the atoll, waves perpendicular to the sailing direction have a big influence on the width.
**Length and alignment of the entrance channel**

The length of the entrance channel is determined by the next parameters:

- Entrance speed of the ship; the vessel should have appropriate speed to keep proper rudder control. This is 4 kts, when dealing with cross or long currents the minimum speed will be higher, the following relations can be used:

  **Cross current:**
  \[ v_{\text{eff}} = 4(u \sin \alpha) \]  
  (3.13)

  **Long current:**
  \[ v_{\text{eff}} = v_{\text{min}} \cos \varphi + u \cos \alpha \]  
  (3.14)

In which:

- \( v_{\text{eff}} \) = speed with proper rudder control \([\text{m/s}]\)
- \( u \) = current speed \([\text{m/s}]\)
- \( \alpha \) = angle of cross current with channel axis = 90°
- \( f \) = drift angle of ship = 0°

The currents were assumed on 0.5 m/s or 1 knot. The required speed \( v_{\text{eff}} \) is as a result of the long currents 5 kts.

- Required time to tie up and manoeuvre it in position; tug boats need a certain time to tie up, under normal conditions this time is 10 minutes. The maximum speed is 5 to 6 kts. The maximum wave height is 1.5 m.

For all the locations the height of the waves (H) generated by the winds in the atoll are 1.5 m or less (see Table 7). For the Mulhadhoo location the used wind speed does not occur more than 1% of the time. So for all the locations on the atoll, except for the places where off shore waves can penetrate, the conditions for tugs are adequate to tie up. Inside the atoll no breakwaters to protect the entrance channel are needed. On the other hand the use of breakwaters to protect the harbour basin against penetration for loading and unloading has to be reviewed.

Outside the atoll the \( H_s = 1.5 \) m is exceeded around 50% of the time. Breakwaters are needed to reduce the waves. The wave height which occurs only 1% of the time is \( H_s = 3.57 \) m. The breakwater has to reduce all waves smaller than 3.57 m to a maximum of 1.5 m.

The length of the entrance channel for towage is:

\[ L = \frac{v_{\text{eff}} \cdot 1.852}{3.6} \cdot t = \frac{5 \cdot 1.852}{3.6} \cdot 10 \cdot 60 = 1543 \approx 1600 \text{ m}. \]  
(3.15)

In which:

- \( L \) = length required for tugs to tie up
- \( t \) = time required to tie up

- Actual stopping length: the vessel gives astern power when the tugboats can control the course and the vessel can stop in 1.5L from 5 kts.

\[ 1.5 \cdot L = 1.5 \cdot 400 = 600 \text{ m}. \]  
(3.16)

The total length of the entrance channel is 1600 + 600 = 2,200 m.

Outside the atoll the entrance channel has to be protected with a breakwater. When a breakwater is applied, several extra demands concerning the navigation have to be regarded. For the manouevrability it is recommended to locate the entrance channel under a small angle with the incoming waves (see Figure 29) and no bends are allowed in the alignment.
Turning and port basins

The entrance channel ends in a turning basin, from where tugboats tow the ships to their berths. The minimum diameter $D > 2L \sim 800m$.

The width of the port basin should be 4 to 5B +100 m. In case of a long basin (> 1,000m) it is desirable that ships have to turn, the width has to be $L + B + 50$ m. In the designs a port basin width of between 350 m and 500 m is used.

3.2.4 Possible locations

There are two conditions that limit the locations for the several options:

Conditions on the limited space for construction and the limited sand availability. The port has to be constructed in shallow water connected to one of the islands land. A port constructed on a new built island is considered as no option, due to limited availability of sand.

Reef protection: the red areas are prohibited to construct a port, because of the numerous coral heads. For this condition no official resources are consulted.

There are 3 main groups of islands:
1. Uligamu
2. Mulhadhoo
3. Huvarafushi and Ihavandhoo

In Appendix VII-1 a map is included with the prohibited areas and the incoming waves.

3.3 Designs

3.3.1 List of requirements

Port

The port is a transshipment hub for the Indian Ocean with the following specifications:

- The throughput in 2010 is 1m TEU, from the first operational year the increase is linear to this 1m TEU. After 2010 the throughput increases with 7% a year.
- The technical lifetime is 50 years, for the feasibility the first 25 operational years are considered. By that time the throughput is 2.7m TEU.
- The first phase of the terminal, calculated in section 3.2.2, and the quay length is more than sufficient for 1m TEU. The port is expanded to twice the initial size in two phases after 5 years.
and 10 years of the first completion. Due to the economies of scale, the port’s capacity will be sufficient to meet the 2.7m TEU in 20 years after the start.

- For the feasibility and the repayment of the investments an IRR of more than 15% is required.

**Terminal**

Only the initial part is considered, the second and third phases have together the same dimensions as the first part.

- In order to meet the required efficiency the terminal has to be operational 24h/day and the downtime has to be limited. An experienced terminal operator has to be found to exploit the terminal. A crane productivity of 40 moves/hour is desirable.

- The accepted waiting times are 5% of the service time, this results in one feeder berths of 252m and 2 Super-Post Panamax berths of 384m. The total quay length is 1020m. If the berths and cranes are exchangeable, the length is sufficient and the quay will be adapted to future growth in throughput.

- The terminal surface contains 46ha for cargo handling and stacking. An additional area of 50% (23ha) for dry-docking/repair, industrial/free zone, hotel and bunkering refinery is needed as well.

- The quay height is not flush with land level but determined by the hydraulic conditions and is 3.5m above CD.

**Hydraulic infrastructure**

Most of the dimensions are determined with the PIANC guidelines for safe navigation [21], the dimensions and characteristics of the infrastructure are:

- The entrance channel is a one way with a width outside the atoll of 384m and inside 314m. The length is 2200m, dependent on the wave height the channel has to be protected by breakwaters. The depth is 20.5m sufficient for the future Suezmax type of vessels.

- Curves have to be avoided as much as possible, the turning circle has a radius of at least 800m. The basin width is dependent on the lay out of the terminal. There is enough deep water (not too deep) to locate a good mooring spot.

- Guiding systems are not important in this phase.

### 3.3.2 Designs and evaluation

In section 3.2.4 the possible locations are given. There are three main groups of islands with enough space for construction and several entrance channels, which are deep and wide enough for safe navigation. The designs shown in Appendix VII are the most likely combinations of location and channel alignment. The designs fulfil the most logistic, constructional and navigational demands.

**Designs (Appendix VII-2 and 3):**

1a Uligamu: On the west side of the island the terminal will be constructed. The quays are affected by the waves in the atoll from the west, which is also the prevailing wind direction. Because the vessels come from the north the approach channel is located in the Thuraakunu Kandu, the first part of the channel is exposed to offshore waves.

1b Thuraakunu: This is the smallest island and on its south side the terminal is constructed. The entrance channel is through the Vagaaru Kandu, this inlet is for a big part exposed to offshore waves as well.

1c Uligamu: This second Uligamu option only differs from the first on the location of the entrance channel, the Uligamu Kandu is because of its more eastern location on the atoll better protected against incoming offshore waves.

2a: Gaamathikuhudhoo: On the big shallow reef around this island a terminal does not need much construction material. However the winds coming from the west create a big wave set up, so probably the harbour basin has to be protected. The entrance channel directs to Mulhadhoo Kandu, where the wave impact is limited.

2b Mulhadhoo: This option is located a little more to the south on Mulhadhoo Island; the entrance channel is through the Mulhadhoo Kandu.
Ihavandhippolhu Atoll Transshipment Port

3a Huvahandhoo: Located a little bit south of Huvarafushi, this option has an approach channel more exposed to wave impact through the Huvahandhoo channel.

3b Ihavandhoo: The terminal constructed on the east side is protected well against wave impact. The entrance channel is directed to the east as well as to Mulhadhoo Kandu. Approach from the west is difficult because of the wave impact and curves in the channel. The island itself is a little bit small and expansion possibilities can become a problem.

3c Huvarafushi: On the east side of this island the terminal is constructed with the advantage that eastern wave impact is limited. The entrance channel through the Huvahandhoo Kandu is protected by the islands and approach from the east through the Mulhadhoo Kandu is possible as well. This island is heavily populated.

The layouts of the designs are almost similar. To reduce the number of designs, an evaluation is carried out. After this evaluation a more detailed design of each remaining option is presented and some additional possibilities are included. The designs are evaluated on the following three criteria:

- Distance to main shipping routes: 20%.
  Costs for extra sailing time by the vessels result in an extra barrier to call at the Ihavandhippolhu Atoll, this will limit the revenues. Or the other way around, lower costs for vessels, can give the port authority more motives to increase port dues.
- Hydraulic conditions and possibilities to protect with breakwaters: 50%.
  The costs of the breakwater are dependent on the length and the depth. For some of the options this will result in a considerable amount of the construction costs.
- Construction possibilities and sand availability: 30%.
  When the port is constructed in shallow water, less sand is required and more dredging works have to be performed. In deep water a lot of sand is required and for the entrance channel one needs less dredging works; sand for the quay construction has to be acquired from elsewhere. It is clear that this can be a large cost item.

<table>
<thead>
<tr>
<th></th>
<th>W.f.</th>
<th>1a</th>
<th>1b</th>
<th>1c</th>
<th>2a</th>
<th>2b</th>
<th>3a</th>
<th>3b</th>
<th>3c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance</td>
<td>0.2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Hydraulic</td>
<td>0.5</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Construction</td>
<td>0.3</td>
<td>3</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>1.0</td>
<td>2.5</td>
<td>1.9</td>
<td>2.5</td>
<td>2.0</td>
<td>1.5</td>
<td>1.6</td>
<td>1.8</td>
<td>2.6</td>
</tr>
</tbody>
</table>

In the Table 13 there are three options that score significant higher. These three options are 1a, 1c and 3c. However, 1a and 1c are in the outlines almost the same concepts. To select 3 different designs 1a and 1c are combined and the third design is 2a. In the next sections the following designs are specified: 1a/1c, 2a and 3c. The names of the different options are Pd1 Uligamu, Pd2 Mulhadhoo (actual construction on Gaamathikulhudhoo) and Pd3 Huvarafushi design. Pd stands for preliminary design.

### 3.3.3 Possible concepts

The next possibilities are examined to create some extra difference in the three designs. In this case three possibilities are given to deal with the downtime in loading and unloading due to the wave agitation:

- An indented berth has limited wave penetration.
- The use of a breakwater reduces the penetration.
- The possibility to allow more downtime.

It depends on the type of vessel and the response of this vessel to the waves, what the limiting wave heights are. In general, a significant wave height of not more than 0.5m is allowed. A more detailed study of the wave penetration and ship motions and with which measure these motions can be limited has to be carried out. When the measures and downtime are quantified correctly a good comparison between different possibilities can be made.
In the designs some measures are used to limit the downtime, this results in three different concept designs.

**Indented berth and two-sided loading and unloading**

One of the worlds most modern terminals in Amsterdam has a whole new principle of cargo handling. Two sided loading and unloading can improve the productivity up to 300 moves/hour/ship. In Amsterdam the indented berth has 9 Super Post Panamax cranes, which will serve future Suezmax vessels of 22 containers across.

Advantages:
- Fast cargo handling.
- Less ship motions by penetrating waves.

Disadvantages:
- Difficult construction; extra protection of bed to withstand currents during mooring.
- Longer quay wall, than for conventional berths.

**Breakwaters**

To limit the wave penetration into the harbour basin, breakwaters can be constructed. Simple calculations for the remaining penetration can be carried out with the Cornu spiral or with the use of computer models extensive calculations can be done.

### 3.4 Preliminary designs

The different points of view towards wave penetration of the former section results in 3 preliminary designs (see also Appendix VII):

**Pd1: Uligamu design**

Because of the prevailing winds coming from the west and southwest, the wave load on the quays in the Uligamu design can limit the cargo handling operations. The downtime when a conventional berth was constructed would exceed the acceptable downtime of 1%. Indented berths can reduce the wave agitation because the waves in this case only enter on the bow of the ship, which causes pitching motion but will not affect the unloading/loading process.

**Berths:**
Indented berth: 430 m * 65 m, the berth is capable of serving Suezmax vessels with a maximum of 8 to 10 cranes. The conventional berths are protected with a breakwater against wave penetration with a length of $L = 700$ m. This is enough for one feeder berth and one exchangeable berth. The space between the breakwater and the berth is 350m for tugs and manoeuvring.

**Terminals:**
There are two terminals: one of 300 * 700 m and one of 400 * 700 m.

**Entrance channel:**
Inside the atoll the tugs have no operational downtime due to hydraulic conditions; the entrance channel is located in an arbitrary way.
Mulhadhoo and Gaamathikulhudhoo are also located on the east side of the Atoll and are thus exposed to incoming waves from the west. In this design the harbour basin is protected by a breakwater. Because of the bigger shallow area, the breakwater can be constructed less expensive than when it is constructed in the deeper parts of the atoll. The port is exposed to swell coming from the south. This event has to be studied in more detail when this design is preferable.

**Berths:**
The berths are constructed in a row and have the calculated length of 1064 m.

**Terminals:**
The terminals are divided over the berths and are 470 m wide.

**Entrance channel:**
There are no specific remarks about the entrance channel.
Fd3: Huvarafushi design

The location of this design is in the sheltered area of Huvarafushi island. There is hardly any wave penetration from the east. In this design the quay is not protected and a little extra downtime is accepted. Space for expansion in this design is at hand.

**Berths:**
The berths are constructed in one long quay, with the advantages mentioned by option 2.

**Terminals:**
Layout the same as in option 2, the terminal is constructed along the whole quay and is 470 meters wide.

**Entrance channel:**
The Huvahandhoo Kandu is exposed to wave penetration from the prevailing wind / wave direction. The channel is assumed to have enough space for the vessels to enter at a speed at which the vessel is still manoeuvrable. After entering the atoll, the tugs can serve the vessels. In this option the construction of an entrance channel to the east is possible, because the depth is sufficient.
3.5 Conclusions

The available data is sufficient to calculate the dimensions for a preliminary design. As a result there are three different concept designs that fulfil most important demands. The three designs can be appraised in the next chapter.

3.6 Recommendations

There are some recommendations to improve the designs and limit the assumptions:
- More varied berth calculations, with different type of vessels and exchangeability of berths. With the use of simulation models downtime studies can be made that also include wave conditions and entrance channel downtime.
- There is a big lack on wave data, especially on penetrating waves into the atoll. This lack causes too much insecurity. Better wave data has to be acquired.
- More soil characteristics are necessary. In the first place the type of dredged material is not known. The strength of the material can be an important condition to locate the port. In the second place choice of the quay wall construction has to be based when it is a weight construction or drilled when sheet piles are used.
4 Preliminary design evaluation

In this chapter the three preliminary designs from chapter 3 are evaluated. In section 4.1 the approach is explained. The MCE is made in section 4.2 and the CBA in section 4.3. These two methods result in two decision criteria that are used in section 4.4 to compare the designs and to make the selection of the preferred design. In this section the same comparison is made if downtime measures where not taken to see if the measures are a good investment and improve quality.

4.1 Evaluation approach

There are two tools that are used in this chapter to evaluate the three preliminary designs that resulted from chapter 3:

- The Multi Criteria Evaluation (MCE): this is a non-economic based model. With this model it is possible to determine the quality of engineering projects. In Appendix VIII different MCE methods are explained. For each method the advantages and disadvantages are enumerated; the Simple Additive Weighting method is the best method, however there are not many differences. To see the usefulness of the downtime measures, the MCE is repeated on the designs without the measures.

- The Cost-Benefit Analysis (CBA): this is an economic model where the costs and benefits are compared. This method takes the time aspect for each cash flow into account. This means that the present value of the cash flows has to be positive.

From these two studies the two decision criteria can be defined:

- Quality/Cost-ratio (Q/C-ratio) (section 4.2): a non-economic based model is used to quantify the quality. This quality can then be compared with the costs. It is important to separate the costs from the criteria used to determine the quality. The costs are determined in the CBA. **The higher the Q/C-ratio the more attractive the considered design.** This decision criterion is made to fulfill the wishes of certain stakeholders and non-investors.

- Internal Rate of Return (IRR) (section 4.3.5): this is a decision criterion for the attractiveness to invest in the port. A good Q/C-ratio will not mean that the port is feasible. Each investor has a Required Rate of Return (RRR) if the IRR is higher than their RRR, investments are likely. In cases the IRR is too low, institutes as the World Bank can help to finance. The RRR is assumed to be 15%. **The design with the highest IRR is the most preferable design.**

4.2 Implementation of the Simple Additive Weighting (SAW) method

The most suitable evaluation method is the SAW. The method is explained and compared with other criteria in Appendix VIII.

4.2.1 Description

This technique shortly consists of comparing the different designs on certain criteria, where each criterion has a certain importance. First a set of main criteria is determined and each main criterion is again divided in some sub-criteria. By ranking the importance of the criteria, the weights can be determined.

There are various sensitivity tests, in this case different stakeholders and their policies or wishes are defined. For each stakeholder this can be reflected in the weight distribution among the criteria.

The three preliminary designs are appraised on the criteria with a score. When the scores are multiplied with the weights of the criteria and summated, the preferable design according to a stakeholder is determined by the highest total score. Each stakeholder has a preferred design. The design that is preferred by most of the stakeholders will be the design with the highest quality.

4.2.2 Criteria
The criteria used in the SAW are divided in 4 main criteria, each with its sub-criteria. An explanation of the 4 main criteria and a short description of the sub-criteria are given. Each design option will be assessed on each criterion, with a score between 0 and 1. Weights are applied to make a distinction between the importance of the criteria with respect to certain points of view. The highest summated value, gives an indication on the overall performance or quality of the port.

It is important to separate the costs from the criteria to avoid double-counting. However there are some criteria like construction that determine the cost for a big part but also are of influence on the quality.

**Competitiveness / operational:**
For the port the survival in the competitive environment with Salalah and Colombo is important. This competitiveness consists of:
- Service time: the service time is also important, a shorter service time means time saving for customers and a more appealing port.
- Downtime/ waiting time: related to quay length and the berth occupation, waiting times have to be minimal.
- Reliability: a stable government and no strikes in the port give the port a good name, convenience and a quick transaction of administrations can be classed under this criterion as well.

**Environment:**
Because the port will be constructed on an atoll that is protected with reef, which is very vulnerable, extra awareness has to be present or created:
- Affection of coral: loss of coral due to port construction (cutting for the entrance channel, area of reclaimed land), affection by turbid water due to dredging and water temperature rise due to intensive shipping.
- Loss of land and flora: the inhabitants are depending on the farming and the land has an extra function as drinking water storage, loss of land can endanger people’s income. Loss of flora can also affect the water retaining capacity.
- Liveability of the people: the noise and visibility are important, but also the fishing requirements as clean and quiet water.

**Nautical aspects and safety:**
Safety regulations are one of the country’s responsibilities, but differences in designs can in spite of regulations result in big differences for the safety.
- Nautical Safety and manoeuvrability: wave penetration through on of the channels, limits the manoeuvrability. Bends in the entrance channel, small turning circles or rock partitions in the neighbourhood are limiting safety.
- Quay length and exchangeability of quays: for the flexibility and the limitation of downtime, exchange of cranes between berths and a uniform depth are important factors.
- Sailing time: the eight degree channel is north of the Ihavandhippolhu Atoll; a 10 mile distance between options corresponds with a 30 minute time loss.
- Downtime entrance channel: time-taking manoeuvres or towing can obstruct other traffic and increase downtime.

**Constructional:**
- Expansion possibilities: the port is expected to expand, at least in order to stay competing with other expanding ports.
- Construction methodology and equipment: this aspect is related to the costs, but risks for delay due to difficult construction methods do not appear in a cost calculation, in a NPV they occur due to the discount rate. Possibilities to phase the construction are advantages for an option.
- Construction time: the lesser the construction time the earlier the port operates, and a shorter construction time limits also the inconvenience for the inhabitants.
4.2.3 Weighting method

To reduce the subjectivity of obtaining weights to criteria, a method is used (see Appendix IX). This method involves a ranking from which the weights are deducted. First the main criteria are ranked from a certain point of view. In this case the Port Authority positions the nautical safety and competitiveness on rank ‘1’. Constructional aspects are ranked after that on ‘2’ and the port authority does care less about the environment, so this main criteria is ranked on ‘3’.

The two main criteria competitiveness and safety are occupying place 1 and 2, so their rank score $r_i$ is $(1+2)/2 = 1.5$. The constructional aspects get score 0.50 and the environment the score 0.75. With the next equation from [26] the normalised weight can be calculated, for the competitiveness this will be:

$$w_i = \frac{n - r_i + 1}{\sum_{i=1}^{n} (n - r_i + 1)} = \frac{4 - 1.5 + 1}{10} = 0.35$$  \hfill (4.1)

where:

- $w_i$ = normalised weight for the $i^{th}$ criterion
- $r_i$ = ranking score for the $i^{th}$ criterion
- $n$ = number of decision criteria.

The normalised weights for the main criteria are determined. The same process is repeated for each sub-criterion of a main criterion, the normalised weight for each sub-criterion has to be multiplied with the weight for the main criterion to obtain with which weight this sub-criterion contributes to the overall score of the design. The weight of the tariffs, see also Appendix IX-1, is $0.35 * 0.35 = 0.123$.

4.2.4 Stakeholders

To evaluate the port some stakeholders and their different points of view are considered. Four parties that are involved with the port, in the constructional or operational phase, have their different distribution of the weights among the four main criteria. For example an environmental group would prefer a safe and clean port in contrast to the shipping company, which is focussed on time saving and costs. More parties can be considered, like investors, but they are more interested in the financial appraisal that is treated in section 4.3. The quality of the port on performance and construction is evaluated.

**Port Authority:**

The port authority is responsible for the operations of the port, which are determining the competitiveness, and for the nautical safety. During the operational time of the port the Authority would be more caring about these aspects than about the environment or the construction.

**Government Maldives:**

In this case it is assumed that the government of the Maldives is promoting the interests of their inhabitants and the quality of life. The environment criterion is ranked on the first place. Of course the government is also benefiting from the port by extra income and employment but that is considered to be the same for each option and resulting from the CBA. Nautical aspects and safety are the second concern of the Maldives. Competitiveness is off course important as well to generate income but not of concern to the government.

**Environmental groups:**

The priority of the environmental groups is on the first place off course the environment, but at a second place the safety, with respect to accidents and disasters, is very important. The construction can harm or disturb the ecology and is a little bit important as well. The competitiveness is of no importance for these groups and thus ranked on the last place.

**Shipping company:**

The shipping companies are the only clients of the port. Besides the location; the low tariffs and short service times are important aspects to choose for a port as transhipment hub. Competitiveness will be
the most important main criterion from a shipping company's view. A good competing port attracts traffic and has to most chance to succeed. Safe port approach and limited downtime are also valuable; accidents besmirch the company’s name and the risk on loss of cargo and the ship as asset result in financial loss. The construction and environmental aspects are criteria that are of less importance for the pure financial appraisal of the port by the shipping company.

**Equal**

As an extra evaluation the weights of the sub-criteria are kept equal.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Port Authority</th>
<th>Government of the Maldives</th>
<th>Environmental groups</th>
<th>Shipping Company</th>
<th>Equal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competitiveness / Operational</td>
<td>0.350</td>
<td>0.200</td>
<td>0.100</td>
<td>0.400</td>
<td>0.231</td>
</tr>
<tr>
<td>Service time</td>
<td>0.175</td>
<td>0.083</td>
<td>0.033</td>
<td>0.200</td>
<td>0.077</td>
</tr>
<tr>
<td>Waiting time</td>
<td>0.088</td>
<td>0.083</td>
<td>0.033</td>
<td>0.133</td>
<td>0.077</td>
</tr>
<tr>
<td>Reliability</td>
<td>0.088</td>
<td>0.033</td>
<td>0.033</td>
<td>0.067</td>
<td>0.077</td>
</tr>
<tr>
<td>Environment</td>
<td>0.100</td>
<td>0.400</td>
<td>0.400</td>
<td>0.100</td>
<td>0.231</td>
</tr>
<tr>
<td>Affection of coral</td>
<td>0.033</td>
<td>0.133</td>
<td>0.167</td>
<td>0.033</td>
<td>0.077</td>
</tr>
<tr>
<td>Loss of land and flora</td>
<td>0.017</td>
<td>0.067</td>
<td>0.167</td>
<td>0.033</td>
<td>0.077</td>
</tr>
<tr>
<td>Liveability of the people</td>
<td>0.050</td>
<td>0.200</td>
<td>0.067</td>
<td>0.033</td>
<td>0.077</td>
</tr>
<tr>
<td>Nautical aspects and safety</td>
<td>0.350</td>
<td>0.300</td>
<td>0.300</td>
<td>0.300</td>
<td>0.308</td>
</tr>
<tr>
<td>Nautical safety and manoeuvrability</td>
<td>0.140</td>
<td>0.120</td>
<td>0.120</td>
<td>0.105</td>
<td>0.077</td>
</tr>
<tr>
<td>Quay length and exchangeability of quays</td>
<td>0.105</td>
<td>0.030</td>
<td>0.060</td>
<td>0.030</td>
<td>0.077</td>
</tr>
<tr>
<td>Sailing time</td>
<td>0.053</td>
<td>0.075</td>
<td>0.060</td>
<td>0.105</td>
<td>0.077</td>
</tr>
<tr>
<td>Downtime entrance channel</td>
<td>0.053</td>
<td>0.075</td>
<td>0.060</td>
<td>0.060</td>
<td>0.077</td>
</tr>
<tr>
<td>Constructional</td>
<td>0.200</td>
<td>0.100</td>
<td>0.200</td>
<td>0.200</td>
<td>0.231</td>
</tr>
<tr>
<td>Expansion possibilities</td>
<td>0.100</td>
<td>0.050</td>
<td>0.033</td>
<td>0.143</td>
<td>0.077</td>
</tr>
<tr>
<td>Construction methodology</td>
<td>0.033</td>
<td>0.025</td>
<td>0.083</td>
<td>0.029</td>
<td>0.077</td>
</tr>
<tr>
<td>Construction time</td>
<td>0.067</td>
<td>0.025</td>
<td>0.083</td>
<td>0.029</td>
<td>0.077</td>
</tr>
<tr>
<td>Total</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
<td>1,000</td>
</tr>
</tbody>
</table>

**4.2.5 Scores**

The lay-outs get scores on each criterion from 0 to 1. To explain the scores and induce the transparency, Table 15 gives the assessments aspects of the scores.

<table>
<thead>
<tr>
<th>Score</th>
<th>Impact (I)</th>
<th>Safety (S)</th>
<th>Time (T)</th>
<th>Advantage (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00</td>
<td>Severe</td>
<td>Unsafe (irresponsible design)</td>
<td>Longest</td>
<td>Major disadvantage</td>
</tr>
<tr>
<td>0.25</td>
<td>Major</td>
<td>High risks</td>
<td>Long</td>
<td>Disadvantage</td>
</tr>
<tr>
<td>0.50</td>
<td>Moderate</td>
<td>Normal risks</td>
<td>Normal</td>
<td>No</td>
</tr>
<tr>
<td>0.75</td>
<td>Minor</td>
<td>Low risks</td>
<td>Short</td>
<td>Advantage</td>
</tr>
<tr>
<td>1.00</td>
<td>Negligible</td>
<td>Safe</td>
<td>Shortest</td>
<td>Major advantage</td>
</tr>
</tbody>
</table>

**Service time**

This criterion is assessed off course on the aspect time. In design 1 two-sided unloading is used with an indented berth, so more cranes can serve the vessel. Service times are shorter than in designs 2 and 3 with conventional berths. Because of the specialised terminal operator, service times are short for all designs. 2 and 3 get a score 0.50 and 1 gets a 1.00.

**Waiting time / downtime**

Is also assessed on the aspect time. Waiting time is considered to be the same for each design, because the berth length is sufficient in each design (calculated in section 3.2.2). The downtime is dependent on the wave penetration into the harbour basin. Design 2 is protected with a breakwater.
and has limited downtime (score 1.00) and the others get a score 0.50. Design 1 is exposed to western wave impact, but limited by an indented berth and a small breakwater, and design 3 is exposed by eastern wave impact, which is less than western wave impact.

Reliability
Reliability which is difficult to measure or to forecast is assessed on the aspect advantage. A bigger reliability results in a bigger advantage for that option. Factors determining reliability are: good authority, quick transaction of administration, etc. Due to the small differences, the reliability is considered to be the same for each port (score 0.50).

Affection of coral
This criterion is assessed on impact. Design 1 and 2 are located on islands that are all around protected with reef. It remains important to protect this reef because of the world-wide disappearance of reefs and its ecology. At the Huvarafushi design the coral is less extensive so the impact will be less than in other options. Design 3 gets score 0.50 and design 1 and 2 a score 0.00.

Loss of land and flora
Also assessed on impact. There is no difference in the required area for the terminal between the three cases and the impact will be the same (all score 0.50).

Liveability of the people
This criterion is assessed as the impact on peoples life. Design 3 is planned on the heaviest populated island, and will have a severe impact on the people that live there (score 0.00). Visibility, smell and loss of farming land and fishing water are the heaviest impacts. Design 2 is planned on an uninhabited small piece of land on a distance of Mulhadhoo, this will have minor impact (score 0.75). Design 1 receives a score of 0.50 for moderate impact.

Nautical safety and manoeuvrability
All designs are relatively safe; there are no currents and there is limited wave penetration. The entrance channel of design 1 needs a bend and is exposed to waves from the east (score 0.75). The channel of design 3 begins in Huvahandhoo Kandu that is exposed to offshore waves (score 0.50). Design 2 gets a 1.00.

Quay length and the exchangeability
Assessed on advantage. All the designs are assessed equally, because there are no major differences. The quay length is calculated before, in the end design 1 has a slightly longer quay but the exchangeability is limited. (All score 0.50)

Sailing time
The eight degree channel is on the northern side, so Uligamu (Pd1) which is located most northern scores 0.75, Mulhadhoo (Pd2) scores 0.50 and Huvarafushi (Pd3) scores 0.25.

Downtime entrance channel
On the short run the entrance channel is for all the designs wide enough. On the long run all designs have enough space for a two-way entrance channel. Due to the sufficient depth and the small tide amplitude there is no tide table. The downtime of the entrance channels is in all three cases limited, score 1.00.

Expansion possibilities
Expansion possibilities are off course an advantage. Design 1 has no space for expansions, score 0.00. Design two has, but on a habited island, score 0.50 and design 3 has space but needs a lot of sand for construction, score 0.75.

Construction methodology
The construction methodology is also assessed on the aspect advantage. For all the designs it is possible to construct the ports in several phases. The methodologies of design 1 and 2 with respectively the indented berth and the breakwater are significantly more difficult (score 0.25) than design 3, which gets a score of 0.75.
Construction time
The construction time is for the designs with the more difficult components, design 1 and 2, is longer than for design 3, which can be very short. So design 3 gets a 1.00 and the other two designs a 0.50.

Table 16: Scores of the different options

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Assessed on:</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Competitiveness / Operational</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service time</td>
<td>T</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Waiting time / Downtime</td>
<td>T</td>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Reliability / convenience</td>
<td>A</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affection of coral</td>
<td>I</td>
<td>0.00</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Loss of land and flora</td>
<td>I</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Liveability of the people</td>
<td>I</td>
<td>0.50</td>
<td>0.75</td>
<td>0.00</td>
</tr>
<tr>
<td><strong>Nautical aspects and safety</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nautical safety and manoeuvrability</td>
<td>S</td>
<td>0.75</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>Quay length and exchangeability of quays</td>
<td>A</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>Sailing time</td>
<td>T</td>
<td>0.75</td>
<td>0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>Downtime entrance channel</td>
<td>T</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td><strong>Constructional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expansion possibilities</td>
<td>A</td>
<td>0.00</td>
<td>0.50</td>
<td>0.75</td>
</tr>
<tr>
<td>Construction methodology</td>
<td>A</td>
<td>0.25</td>
<td>0.25</td>
<td>0.75</td>
</tr>
<tr>
<td>Construction time</td>
<td>T</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
</tr>
</tbody>
</table>

The following notes can be made on the criteria and their scores:
- Due to the design conditions and the calculations in section 4 there are very limited differences on certain criteria.
- The housing of the employees is not considered, a good spot will be chosen and vessels can transport the people.
- Differences in labour or the allocation of labour for the three different designs is not considered, in all three cases the amount of labour for the local people is the same. Educated personnel will be found and employed by the different operators.

4.2.6 Weighted scores

In Appendix X the scores of the designs are multiplied by the different weights of the stakeholders. The overall scores of the designs for each stakeholder are shown in Table 17. By averaging the scores, the preferences of the stakeholders diminish. By concluding that Pd2 is preferred 3 times compared to Pd3 which is preferred only 1 time (Pd1 and Pd3 score equal on one stakeholder), Pd2 can be chosen as the design with the highest quality.
In section 4.4 this table is discussed further in combination with the sensitivity and the cost calculation.

### 4.2.7 Sensitivity

In section 3.3.3 there are three measures proposed to deal with the downtime. In Pd1 an indented berth is constructed and in Pd2 a breakwater, while in Pd3 the extra downtime is accepted. The main reason was to improve the quality and competitiveness through a more efficient port.

To see the sensitivity of these measures, the process is repeated without the measures. The construction of the port will be the same in all three designs; a long quay wall of 1060 m. The choice made upon this evaluation is now only location choice, instead of a concept choice.

Both Pd1 and Pd2 score equal on more criteria in this case with Pd3 (see Table 18), because there are less differences between the designs. For the competitiveness the service time is equal, but Pd1 and Pd2 have a longer downtime compared to Pd3 due to western wave impact. Pd2 scores a 0.00 and Pd1 a 0.50, Pd3 gets a 1.00 to make a better distinction. The reliability/ convenience decrease a bit in Pd1 and Pd2; downtime is not satisfying even when prices are low. For the environmental impact nothing will change. The nautical safety is a little bit less in Pd2 due to the disappearance of the breakwater, score 0.75 instead of 1.00. Except for the expansion possibilities, the other constructional criteria get an equal score as well.

Changes due to the removal of the downtime measures are given in the table in bold figures.

#### Table 17: Total scores

<table>
<thead>
<tr>
<th></th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Authority</td>
<td>0.587</td>
<td>0.606</td>
<td>0.555</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Government Maldives</td>
<td>0.530</td>
<td>0.671</td>
<td>0.525</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Environmental Groups</td>
<td>0.471</td>
<td>0.511</td>
<td>0.553</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Shipping Company</td>
<td>0.587</td>
<td>0.617</td>
<td>0.544</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>Equal Weights</td>
<td>0.519</td>
<td>0.558</td>
<td>0.558</td>
<td>2</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0.539</td>
<td>0.593</td>
<td>0.547</td>
<td>2,2</td>
<td>1,2</td>
<td>2,2</td>
</tr>
</tbody>
</table>
Table 18: Scores without downtime measures

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Assessed on:</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Competitiveness / Operational</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Service time</td>
<td>T</td>
<td>0,50</td>
<td>0,50</td>
<td>0,50</td>
</tr>
<tr>
<td>Waiting time / Downtime</td>
<td>T</td>
<td>0,50</td>
<td><strong>0,00</strong></td>
<td>1,00</td>
</tr>
<tr>
<td>Reliability / convenience</td>
<td>A</td>
<td>0,25</td>
<td>0,25</td>
<td>0,50</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Affection of coral</td>
<td>I</td>
<td>0,00</td>
<td>0,00</td>
<td>0,50</td>
</tr>
<tr>
<td>Loss of land and flora</td>
<td>I</td>
<td>0,50</td>
<td>0,50</td>
<td>0,50</td>
</tr>
<tr>
<td>Liveability of the people</td>
<td>I</td>
<td>0,50</td>
<td>0,75</td>
<td>0,00</td>
</tr>
<tr>
<td><strong>Nautical aspects and safety</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nautical safety and manoeuvrability</td>
<td>S</td>
<td><strong>0,75</strong></td>
<td>0,75</td>
<td>0,50</td>
</tr>
<tr>
<td>Quay length and exchangeability of quays</td>
<td>A</td>
<td>0,50</td>
<td>0,50</td>
<td>0,50</td>
</tr>
<tr>
<td>Sailing time</td>
<td>T</td>
<td>0,75</td>
<td>0,50</td>
<td>0,25</td>
</tr>
<tr>
<td>Downtime entrance channel</td>
<td>T</td>
<td>1,00</td>
<td>1,00</td>
<td>1,00</td>
</tr>
<tr>
<td><strong>Constructional</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expansion possibilities</td>
<td>A</td>
<td>0,00</td>
<td>0,50</td>
<td>0,75</td>
</tr>
<tr>
<td>Construction methodology</td>
<td>A</td>
<td><strong>0,75</strong></td>
<td><strong>0,75</strong></td>
<td>0,75</td>
</tr>
<tr>
<td>Construction time</td>
<td>T</td>
<td><strong>1,00</strong></td>
<td><strong>1,00</strong></td>
<td><strong>1,00</strong></td>
</tr>
</tbody>
</table>

When the scores are multiplied with the weights of the stakeholders the scores of the designs can be compared again (see Table 19). For this sensitivity calculation the tables are not included in Appendix X. Preliminary design 3 (Pd3) is for 3 stakeholders the preferred design and is also preferred when the weights are divided equally.

Table 19: Total scores without downtime measures

<table>
<thead>
<tr>
<th></th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port Authority</td>
<td>0,528</td>
<td>0,533</td>
<td>0,599</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Government Maldives</td>
<td>0,505</td>
<td>0,579</td>
<td>0,569</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Environmental Groups</td>
<td>0,529</td>
<td>0,531</td>
<td>0,569</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Shipping Company</td>
<td>0,499</td>
<td>0,486</td>
<td>0,611</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Equal Weights</td>
<td>0,538</td>
<td>0,538</td>
<td>0,596</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>0,520</td>
<td>0,533</td>
<td>0,589</td>
<td><strong>2,6</strong></td>
<td><strong>2,0</strong></td>
<td><strong>1,2</strong></td>
</tr>
</tbody>
</table>

The score of Pd3 increases, despite that nothing changed for this option. The reason for this is that the designs are compared with each other on a criterion. So when one design gets a worse score, another design can get a better score.

From the decreased quality of Pd1 and Pd2 it can be concluded that the measures improve the port, especially from the shipping company's point of view. Because they are the client they prefer an efficient port with low tariffs. These are the main criteria for a competitive port. However as said before, the port has to be feasible as well in case these measures are taken.

Conclusion
The best preliminary design, with the highest quality, is Pd2 Mulhadhoo with a breakwater as a protection against wave penetration. If the measures appear not feasible and will not be taken, the design with the highest quality is Pd3 Huvarafushi.

The Q/C-ratio will be determined at the end of this chapter, when the costs are calculated.
4.2.8 Comments on this method

There are a few comments on this method:

- The subjectivity of the method: the weights and the scores are determined by one individual, a single person can never be objective. The weights of the stakeholders can be obtained from the stakeholders themselves. To create objective scores several studies or simulations have to be done to quantify the real impact of each criterion.

- A reference is missing: some scores on a criterion are compared with each other. However, for the service time, is that time long or short compared to other ports? This method will never give a good reflection of the quality. Only of the best qualitative options between these three designs. For some criteria it is easy to determine by comparing it with a 0-option (the option where no construction is built). In case of environmental impact the 0-option scores 1.00 and the other designs score probably 0.00.

4.3 Cost-Benefit Analysis

The costs benefits analysis is used to determine the investment costs to calculate the Q/C-ratio. Besides, the method gives an insight in the feasibility of the project.

4.3.1 Port elements and costs

Entrance channel

The cost of the entrance channel depends for a big part on the removed volume and type of material. The costs often are given in dollars per cubic meter ($/m³), in this price the most aspects, like distance to disposal site and type of material, are included. This unit price has to be multiplied with the removed volume. Costs for mobilisation and demobilisation of the equipment are added to the dredging costs. For the total costs of the entrance channel the shipping aids as buoys and lights have to be added as well.

Coral rock/ sandstone with a point load of 15 MPa can be dredged with a cutter.

Exchange rate October 27th 2003: € 1.00 = US$ 1.18

Cutter €10/m³ = US$ 11.80
Trailer € 4/m³ = US$ 4.72

The mobilisation and demobilisation costs for a Cutter Suction Dredger (CSD) from Singapore are € 2 million and for a Trailing Suction Hopper Dredger (TSHD) € 1 million. Converted into US$ it would be US$ 3.54 million.

Pd3 Huvarafushi design is taken as an example in the next sections.

For the entrance channel a high spot of 136,000 m³ has to be removed. The costs are:

136,000 * 11.8 + 3,540,000 = US$ 5,144,800 + US$ 5,000,000 = US$ 10.14 million

In Pd2 the turning basin is located near the harbour basin. As the harbour is protected with a breakwater that is constructed on reef, the turning and harbour basin have to be deepened from around CD to -19 m. This results in about 10 million m³ more for the turning basin, which costs about US$ 120 million. The costs to deepen the harbour basin are added under the component basin, later in this section.

In Pd3 and Pd1 the entrance channel is located in deep water and no dredging works are required.

Quay wall

There are different types of quay wall. The most preferable one depends on the soil characteristics. A short explanation is given:

- Weight constructions: Caisson, L-wall. There are no construction possibilities for caissons or prefab concrete elements. A construction site has to be built or the elements have to be transported, which is difficult and expensive due to their size.
- Sheet piles with friction plates in fill: metal (H-profile) sheets, concrete shields. The soil is consisting of hard/loose coral rock, it is impossible to drill a metal sheet in rock. A concrete sheet can be made, but this can only be made on land or shallow water. A metal sheet is possible to construct from waterside if landside equipment is not available, the quay still needs a prefab concrete deck.

- Open berth structure: this type is proposed in [15] and as an advantage there is less sand required in the fill, however the construction is more expensive due to the concrete poles and armour stones on the slope under the structure. For this quay again a concrete deck is needed.

The soil is considered to be loose enough to construct the sheet piles. The cost of this type of construction is 30,000 US$/m. The length of the wall needed in design 1 is longer than in the other designs due to the indented berth and the different terminal lay-out, see Appendix VII-4

The quay wall costs in Pd3:
30,000 US$ * 1,020 = US$ 30.6 million.

Due to the different lay-out, Pd2 requires more length of the quay wall. The costs for the quay wall result than

**Basin**

The costs of a breakwater depend on the depth of the water, the construction height and the required stone size. In both designs (Pd1 and Pd2) the breakwater is constructed on the shallow reef. A good cost estimation for a breakwater is 15,000 US$/m.

The extra costs for the indented berth are estimated at US$ 30 million.

The costs of the basin of Pd3 are:
1,822,000 m$^3$ * 11.80 US$ = US$ 21.50 million.

As said before, Pd2 requires more dredging works to deepen the basin, this volume is 20,000,000 m$^3$. If the terminal is constructed on the edge of the island, the dredging costs decrease but the costs for the breakwater increase rapidly, as the depth of the inner atoll increases as well. This extra volume costs about US$ 220 million more. The breakwater is around US$ 20 million.

**Terminal:**

The dredged material from the entrance channel can be used to fill the terminal area, with the use of shore pumping from the cutter. The costs are included in the price of 11.8 US$/m$^3$ that is used in the costs of deepening the entrance channel. However for design 3 extra fill materials is necessary. On the atoll sand is available as well. A Trailing Suction Hopper Dredger (TSHD) can obtain the sand for 4.72 US$/m^3$.

In [15] an amount of 105,000 US$/m quay is used as a price for the terminal that lies behind. In this price the surfacing of the area and the superstructure is included. For all three designs a unit price of 105,000 US$/m is used. This results in a terminal of US$ 111.72 million.

The costs of the terminal in Pd3 are:
(5,376,000 - 1,337,000) * 4.72 + 111.72 = US$ 130.78 million.

**Facilities**

In all three designs the same facilities are required, the costs per item are in Table 20:

<table>
<thead>
<tr>
<th>Facility</th>
<th>Costs (million US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hotel/ offices</td>
<td>10</td>
</tr>
<tr>
<td>Small craft harbour</td>
<td>12</td>
</tr>
<tr>
<td>Dry-docking/ ship repair</td>
<td>20</td>
</tr>
<tr>
<td>Bunkering terminal/ jetty</td>
<td>15</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td><strong>57</strong></td>
</tr>
</tbody>
</table>

61
In Table 21 the total project cost estimations for the three designs are shown. Procurement consists of the parts of the port that are acquired at suppliers, in all designs these are the shipping aids and the terminal superstructure.

Contingencies are added as a percentage of the total costs. The risks on extra costs or extension of construction are quantified, the contingencies have to exceed this amount, the remaining amount is considered as profit for the contractor.

Table 21: Cost estimation

<table>
<thead>
<tr>
<th>Cost Estimation</th>
<th>Fd1</th>
<th>Fd2</th>
<th>Fd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preliminary studies</td>
<td>2,000,000</td>
<td>2,000,000</td>
<td>2,000,000</td>
</tr>
<tr>
<td>Entrance channel</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Material: hard/ loose coral rock, mixed with sand (US$/m³)</td>
<td>0.00</td>
<td>11.80</td>
<td>11.80</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>0</td>
<td>10,374,000</td>
<td>136,000</td>
</tr>
<tr>
<td>(De)mobilisation (m US$)</td>
<td>0</td>
<td>3,540,000</td>
<td>3,540,000</td>
</tr>
<tr>
<td>Total dredging (m US$)</td>
<td>0</td>
<td>125,953,200</td>
<td>5,144,800</td>
</tr>
<tr>
<td>Shipping aids (buoys/ lights) (US$)</td>
<td>5,000,000</td>
<td>5,000,000</td>
<td>5,000,000</td>
</tr>
<tr>
<td><strong>Total costs entrance channel</strong></td>
<td>5,000,000</td>
<td>130,953,200</td>
<td>10,144,800</td>
</tr>
<tr>
<td>Quay wall</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Required depth (m)</td>
<td>-19</td>
<td>-19</td>
<td>-19</td>
</tr>
<tr>
<td>Type of construction ($/m)</td>
<td>Piled Sheets</td>
<td>Piled Sheets</td>
<td>Piled Sheets</td>
</tr>
<tr>
<td>Length of construction (m)</td>
<td>1.400</td>
<td>1.020</td>
<td>1.020</td>
</tr>
<tr>
<td>Rate (US$/m)</td>
<td>30,000</td>
<td>30,000</td>
<td>30,000</td>
</tr>
<tr>
<td><strong>Total costs quay wall</strong></td>
<td>42,000,000</td>
<td>30,600,000</td>
<td>30,600,000</td>
</tr>
<tr>
<td>Basins</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rate: hard/ loose coral rock, mixed with sand (US$/m³)</td>
<td>11.80</td>
<td>11.80</td>
<td>11.80</td>
</tr>
<tr>
<td>(De)mobilisation (m US$)</td>
<td>3,540,000</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Volume (m³)</td>
<td>3,100,801</td>
<td>20,000,000</td>
<td>1,822,000</td>
</tr>
<tr>
<td>Indented berth</td>
<td>30,000,000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Breakwater</td>
<td>15,750,000</td>
<td>21,210,000</td>
<td></td>
</tr>
<tr>
<td><strong>Total costs basin</strong></td>
<td>70,129,452</td>
<td>257,210,000</td>
<td>21,499,600</td>
</tr>
<tr>
<td>Terminal</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fill volume (m³)</td>
<td>1,750,000</td>
<td>2,415,000</td>
<td>5,376,000</td>
</tr>
<tr>
<td>Volume from entrance channel (m³)</td>
<td>1,960,000</td>
<td>2,415,000</td>
<td>1,337,000</td>
</tr>
<tr>
<td>Required volume (m³)</td>
<td>0</td>
<td>0</td>
<td>4,039,000</td>
</tr>
<tr>
<td>Rate (US$/m³)</td>
<td></td>
<td>4.72</td>
<td></td>
</tr>
<tr>
<td>Total reclamation (US$)</td>
<td>0</td>
<td>0</td>
<td>19,064,080</td>
</tr>
<tr>
<td>Surfacing, cranes and equipment (US$)</td>
<td>111,720,000</td>
<td>111,720,000</td>
<td>111,720,000</td>
</tr>
<tr>
<td><strong>Total costs terminal</strong></td>
<td>111,720,000</td>
<td>111,720,000</td>
<td>130,784,080</td>
</tr>
<tr>
<td>Facilities</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Buildings (offices, hotel)</td>
<td>10,000,000</td>
<td>10,000,000</td>
<td>10,000,000</td>
</tr>
<tr>
<td>Small craft harbour</td>
<td>12,000,000</td>
<td>12,000,000</td>
<td>12,000,000</td>
</tr>
<tr>
<td>Dry-docking ship repair</td>
<td>20,000,000</td>
<td>20,000,000</td>
<td>20,000,000</td>
</tr>
<tr>
<td>Bunkering jetty / terminal</td>
<td>15,000,000</td>
<td>15,000,000</td>
<td>15,000,000</td>
</tr>
<tr>
<td><strong>Total costs facilities</strong></td>
<td>57,000,000</td>
<td>57,000,000</td>
<td>57,000,000</td>
</tr>
<tr>
<td>SUBTOTAL</td>
<td>285,849,452</td>
<td>587,483,200</td>
<td>250,028,480</td>
</tr>
<tr>
<td>Civil works</td>
<td>169,129,452</td>
<td>470,763,200</td>
<td>133,308,480</td>
</tr>
<tr>
<td>Procurement and design</td>
<td>116,720,000</td>
<td>116,720,000</td>
<td>116,720,000</td>
</tr>
<tr>
<td><strong>Contingencies (20% of SUBTOTAL)</strong></td>
<td>57,169,890</td>
<td>117,496,640</td>
<td>50,005,696</td>
</tr>
<tr>
<td><strong>TOTAL (US$)</strong></td>
<td>343,019,342</td>
<td>704,979,840</td>
<td>300,034,176</td>
</tr>
</tbody>
</table>
4.3.2 Construction phasing

The total construction time is estimated on three years for preliminary designs 1 and 2 and two years for preliminary design 3 (Pd3).

Pd3 is taken as an example in the next sections. The construction costs are equally divided over the two construction years. So that in the beginning of each construction year; the half of the total construction cost has to be acquired. The construction years are 2005 and 2006, in the end of year 2004 (year 0) the first part is acquired, which will then be available in 2005 to finance the construction. In the end of 2005 the last half is acquired to finance the costs in 2006. If the construction takes 3 years the initial costs will be financed in 3 parts.

The cost calculation is only pointed on the first phase of the construction calculated in section 3.2.2. Dependent on the growth in the throughput the port is enlarged up to 2 times its initial size. In the first five years the throughput increases linearly to 1m TEU (section 2.5.1), after that time it will increase with a certain percentage per year. Ocean Shipping Consultants [19] foresees an increase till 2015 of 7% per year.

When this percentage is smaller than 4% no expansion is considered in its 20 year lifetime, when between 4% and 5.5% one expansion will be constructed 10 years after the first operational year. The size and costs of this expansion are half the size and costs of the initial phase. When the growth factor is above 7% the port is expanded after 5 years to 1.5 and after 10 years further to 2.0 times its initial size. The quay length in that case is 2500 m; due to economies of scale this longer quay will be capable of handling up to 3.5 to 4m TEU.

4.3.3 Operational costs

The operational costs consist of costs of labour, taxes and costs of equipment as cranes, tugs and pilots. For a transshipment port for the Caribbean on Puerto Rico the following operational costs are known:

<table>
<thead>
<tr>
<th>Throughput (TEU)</th>
<th>Operational costs (million US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>300,000</td>
<td>26.7</td>
</tr>
<tr>
<td>600,000</td>
<td>39.9</td>
</tr>
<tr>
<td>1,500,000</td>
<td>64.4</td>
</tr>
<tr>
<td>2,700,000</td>
<td>79.2</td>
</tr>
</tbody>
</table>

In Figure 34 the total operational costs and, with the use of a prospected throughput of 7% from Figure 33, the operational costs per TEU are plotted.
Ihavandhippolhu Atoll Transshipment Port

Maintenance
Yearly US$ 2 million maintenance is assumed for the least expensive design (Pd3) and US$ 3 million for the other designs (Pd2 and 3). Maintenance is enclosing: painting, repairing of superstructure and dredging works.

4.3.4 Revenues

The port revenues are equal to the port charges; these are the costs that a customer has to pay for each port operation. There are no taxes that the port has to pay to the government.

The terminal handling charges (THC) are the main revenues from the port operations, the other port revenues are derived from, among others, towing and piloting. The THC are different for import/ export or transshipment traffic in some ports. Due to the non-transparency of the charges in other ports it is hard to compare and determine the possible port charges in Ihavandhippolhu. Table 23 gives some THC or total charges (in US$/TEU) from other ports, the average can be used as a reference for the port of Ihavandhippolhu. The THC in most ports are around 80% of the total port charges, so in the table the THC is multiplied by 1.25.

<table>
<thead>
<tr>
<th>Table 23: Port charges in different ports</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port</td>
</tr>
<tr>
<td>Puerto Rico Transshipment Port (total charges)</td>
</tr>
<tr>
<td>Salalah [7] (Total charges = 1.25*110 (THC))</td>
</tr>
<tr>
<td>Colombo [8] (Total charges = 1.25*115 (THC))</td>
</tr>
<tr>
<td>Port Economics [27] (total charges) (€ 100)</td>
</tr>
<tr>
<td>Average/ benchmark</td>
</tr>
</tbody>
</table>

There are special requirements on the port in order to attract traffic and survive in the competition with Salalah and Colombo (see section 2.1.1). The combination of high efficiency and low tariffs are important. However, measures to improve the efficiency can cause higher tariffs needed to repay the investments.

For the three preliminary designs the first revenue in (US$/TEU) is set on US$ 100, the design is feasible when the IRR is above 15%. In section 4.4 the port revenues are varied to see which revenues are required for each design to meet the IRR demand.

In order to be competitive, the port its revenues, which are in this case all the costs for a customer to call at Ihavandhippolhu, may not exceed 100 US$/TEU.
4.3.5 Finance

As a measure of the value of the design, the cost and the benefits are compared, if the benefits are higher than the costs, the project is at least repaying itself. However the cash flows in the future are not worth as much as cash flows in the present. The Net Present Value (NPV) is calculated with a discount rate according to the following equation:

\[ NPV = \sum_{t=0}^{i} I \cdot \left(1 + r\right)^{t_{0}-t_{i}} \tag{4.2} \]

Where:
NPV = Net Present Value [US$]
r = discount rate [%]
t0 = year 0 (end of 2004)
ti = year i

The Internal Rate of Return (IRR) is the discount rate at which the NPV is 0.

\[ NPV = \sum_{t=0}^{i} I \cdot \left(1 + IRR\right)^{t_{0}-t_{i}} = 0 \tag{4.3} \]

Where:
IRR = Internal Rate of Return [%]

The following aspects are included in the discount rate or IRR:
- Currency inflation: due to the increase in prices, the value of money earned in the present is relatively more worth than money earned in the future.
- Price of getting money: what is the interest rate on loans or is the money available.
- Interest rate: if money is available and the interest rate is higher than the rate of return, saving money on the bank or repaying debts can be more preferable than investing in projects.
- Income risks: the risks on lower revenue.

For the NPV calculations a discount rate of 8% is used. In case of Pd3, with a prospected throughput increase of 7% a year the NPV and IRR are shown in Figure 35. With this growth in throughput, there are two more investments needed to expand, the cash flows in 2011 and 2016 are negative. The IRR shows strange negative values due to these interim investments. The NPV is 0 in 2023; the project has repaid the investments within this period. The IRR figure shows indeed a value of 8% in 2023.

When the IRR is used as a decision criterion, it can be concluded that it is too low. The minimum required IRR (the RRR for investors) after 25 years operational time is 15%.
4.4 Selection preferred design

The focus on the efficiency and the feasibility of the port is very important in this section. The efficiency is appraised in the quality. However this quality has a price, the extra investments required to achieve this quality can not be repaid. This results in a non-feasible port. In Appendix XI the results are shown and in Table 24 a summary is given. The best preliminary design and thus the final design is:

- Quality/Costs-ratio: best option is Pd3.
- Internal Rate of Return: Pd3 has the highest return, but not sufficient to meet the required 15%.

Conclusion: Pd3 Huvarafushi is the best preliminary design.

<table>
<thead>
<tr>
<th>Table 24 : Comparison of Preliminary designs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pd1</td>
</tr>
<tr>
<td>Quality</td>
</tr>
<tr>
<td>Costs (million US$)</td>
</tr>
<tr>
<td>Q/C-ratio</td>
</tr>
<tr>
<td>NPV (8%) (million US$)</td>
</tr>
<tr>
<td>IRR (%) when tariffs are US$ 100/TEU</td>
</tr>
<tr>
<td>Tariffs (so IRR will be 15%) (US$/TEU)</td>
</tr>
</tbody>
</table>

If the IRR is too low some measures can be considered:
- Reduction of costs: cheaper material, smaller terminal/ quay. Beware that the required quality or efficiency is still met.
- Rise of THC: when the port is operational and has some customers, the THC can be increased slowly.
- The Government of the Maldives can lend money on a cheaper rate than private investors. The Required Rate of Return (RRR) for the government is lower than that for other investors. If the government invests and does not ask for a high share of the profit, the RRR for other investors can be lower than 15%. Governments can do this when the project is benefiting their population as well, by e.g. employment or better transport.
- The same as on former point counts for other investors as multilateral banks or development banks.

In Table 25 the values of the criteria without the downtime measures are shown. The most important changes are:
- The construction costs and NPV and IRR are considered to be equal in all designs.
- However quality decreased without downtime measures, but costs decreased more rapidly. Both together make the Q/C-ratio increase.
- Pd3 is still the best option.
### 4.5 Conclusions

The following conclusion can be drawn:

- The best design is Pd3 Huvarafushi, its Q/C-ratio is the highest and its NPV and IRR are also the highest compared to design Pd1 and Pd2. This design is going into detailed design. Under the recommendations in the next section some possibilities to make a better decision are presented.
- The port is not feasible when the tariffs are 100 US$/TEU. The IRR is too low to attract investors. For Pd2 the NPV is negative and thus the IRR is even smaller than the discount rate. In order to increase the IRR, the tariffs have to be raised. Because of the importance of the competitiveness of the port, there is limited space for an increase. However it is possible to increase the IRR in other ways (see section 4.4).
- The SAW method is a good method to evaluate the designs from different stakeholders their point of view, however the mechanical character of obtaining weights is disputable. An important question is: ‘do criteria as the service time get the importance, they need for competitive demands?’ Furthermore, the subjectivity of the scores and the lack of a reference for the scores are problems of this method.
- For customers of the port the service time/tariff ratio is important, if this was included in the MCE, with the risen tariffs, the quality would decrease. The price the customers want to pay for a shorter service time by e.g. an indented berth is not known. A good appraisal of the effects of the downtime measures is not possible in this way.
- The downtime measures increase the quality, but are that costly, that the Q/C-ratio decreases. The measures should not have been considered in the first place.

### 4.6 Recommendations

The following recommendations can be made:

- As said before in the recommendations in section 3.6 more research has to be carried out on aspects like downtime, soil characteristics, etc. With this data a better design can be made and as a result the costs for the CBA are better estimated and the criteria in the SAW are better appraised.
- A specification of the RRR of the possible investors has to be done. A good estimation is 15%, but if the RRR is smaller and lower than the IRR, the project can be feasible.
- A better market study is necessary to see the service time, tariffs and throughput relation. This relation is important, the competitiveness and feasibility strongly depend on this relation.
- The pricing of side-effects on the environment or the population can give a good comparison, however pricing methods are extensive and subjective.
- Better specifications of the operational costs for the specific preliminary designs. What is the minimum required workforce, what are their wages and how many taxes do the operating companies have to pay?
- With the use of different non-economic models the subjectivity can be decreased. When the outcome is the same with different models, it is clear which one is the preferred design.
5 Terminal design

5.1 Introduction

In section 3.2 the main dimensions of the components of the port like the hydraulic infrastructure and terminal are determined. In section 4.5 the main conclusion is that the demand on the internal rate of return of 15% is not obtained. In this chapter the terminal is designed in more detail. To find the optimum situation by varying several terminal parameters the terminal transport process has to be simulated. However, in this case, due to the limited time simulation is not possible. In this chapter for several concepts only the investment costs are determined. Operational costs which depend on labour costs are not considered. The costs of investments of superstructure and civil works have to be minimised. When the costs are lower than in Table 21 the IRR can rise and feasibility can be achieved. The overall port performance is assumed to be equal, as it is determined by the starting points. These starting points are the result of the demands on the port in the former sections. In the end of this chapter an overview is given for all concepts and the best concept is implemented in the port.

Objective
Generate different concepts of intra-terminal transport systems with the given performance of the quay. Design the lay-outs and evaluate the costs of the superstructure and civil works and determine the concept with the lowest investment costs.

In the former sections and especially in section 3.2.2 some assumptions are made for the number of ships, parcel sizes and the productivity and number of cranes. These assumptions result in the starting points for the terminal in section 5.1.1; the terminal may not limit the port productivity.

In section 5.1.2 the different transport processes on the terminal are explained. Each process can be performed with several types of vehicles. If rational combinations of the vehicles for each process are made, it results in four comparable concepts in section 5.1.4. A short explanation of the terminal handling equipment is given before.

Because each concept requires a certain area, the costs of the infrastructure have to be determined as well. In all concepts the quay length will remain the same. The costs consist of the land fill and the surfacing of the terminal and are given in $/m². In section 5.2 the cost items are summed.

Sections 5.3 to 5.6 give the calculations for each concept. The approach for each concept is the same. Dependent on the quay length the possible number of stacks perpendicular to the quay is determined. And resulting from the number of stacks, the stacks have a certain length and height. The length determines the required terminal area. Each stack is served by a certain transport vehicle. The productivity of these vehicles also depends on the length and the height. The productivity of the vehicles is compared with the port productivity. With queuing theories the required number of vehicles is calculated. For each design the investment costs and the costs of the infrastructure can be determined.

In section 0 the concepts are compared with each other and the best concept is selected to be further implemented in the port lay-out.

5.1.1 Starting points for the terminal design

Ihavandhippolhu is a transshipment port without a hinterland so no dedicated import/ export stacks are required. There will be stacks for hazardous cargo and reefers necessary. However, these two areas are not considered in the next concepts. But are assumed to be the same in each concept and each (hazardous or reefer) is 10% of the total area required.

Furthermore, this chapter continues on case I from section 3.2.2 where no share for relay transshipment is assumed. The vessel distribution and the berth characteristics like cranes and productivity are shown in Table 26.
In section 3.2.2 with queuing theories the quay length and the number of berths are determined. In the service time of the vessels the mooring time and the time of loading and unloading is included. The number of berths follow from the accepted waiting times by the shipping companies. In the calculation in this section the irregular arrival of the vessels is taken into account. In order not to increase the waiting times, the berths have to be operational simultaneously with the productivity assumed in section 3.2.2.

Resulting starting points from section 3.2.2:
- \( L_q = \text{Length quay} = 1020 \text{ m} \)
- \( N_b = \text{Number of berths} = 3 \)
- \( N_c = \text{Number of Quay Cranes (QC)} = 12 \)
- \( p_c = \text{Gross crane productivity} = 40 \text{ moves/hour} \)
- \( t_d = \text{Dwell time} = 5 \text{ days} \)

Productivities
From the assumptions above one can determine the required overall productivity of the port.

\[
p = N_c \cdot p_c = 480
\]

(5.1)

This productivity is given in moves/hour. The most important demand is that the intra-terminal transport and the stacking transport achieve at least the same productivity.

For each vehicle in each concept the cycle times are determined. The cycle time consists of a certain number of aspects that can be simply added according the next equation:

\[
T = \sum_{i=1}^{n} T_i
\]

(5.2)

In which:
- \( T = \text{cycle time [s]} \)
- \( T_i = \text{i^{th} aspect of the cycle time [s]} \)

The productivity is then 3600/T and has to be higher than the port productivity:

\[
N \cdot \frac{3600}{T} > 480
\]

(5.3)

In which:
- \( N = \text{Number of vehicles} \)

However, equation 5.3 gives the minimum required productivity. This relation is valid when the utilisation is 100% and when there are no irregularities. In fact, cycle times and arrival times from the QC vary; this variation causes irregularities and thus waiting times and queues. Queuing theories are applied for each concept to determine the required number of vehicles with the minimisation of the waiting times for the QCs. These queuing theories are explained in section 5.3.3.
Storage capacity
The storage capacity depends for the main part on the dwell time. This is the average time a container is stored on the terminal. With equation 5.4 the required storage capacity can be determined. With the number of berth the irregularity in the inter-arrival of the vessels is taken into account with the use of queuing theories. It is not possible to determine the storage capacity with a continuation on the calculation of the vessel arrival irregularity. Instead a factor is assumed for this irregularity. A factor \( f \) of \( v^2 \) is a good approximation.

\[
C_t = \frac{C_i \cdot t_d \cdot f}{365} \quad (5.4)
\]

In which:
- \( C_i \) = Port capacity = 1,000,000 TEU/year
- \( t_d \) = dwell time = 5 days
- \( f \) = factor for irregularity = \( v^2 \)

Results in a storage capacity:
- \( C_t \) = Terminal capacity = 19,373 TEU

This storage capacity has to be achieved with a certain number of stacks \( (N_s) \) with a height, width and length. However, concluded from practical experience it is not possible to have a fully occupied terminal. In case the terminal capacity \( (C_t) \) of 19,373 is reached, the average stacking height \( (h) \) is still \( 0.8 \times h_{\text{max}} \). This means that if the required 19,373 containers have to be stored, the actual number of slots is \((1/0.8)\) higher. This extra space in the stacks is used for reshuffling the containers.

\[
N_s \cdot w \cdot h \cdot l > 19,373 \quad (5.5)
\]

In which:
- \( N_s \) = Number of stacks
- \( w \) = width of one stack [TEU]
- \( h \) = height of one stack [TEU]
- \( l \) = length of one stack [TEU]

5.1.2 Terminal process and explanation
This section gives a short explanation of the processes that take place on the terminal. Figure 36 gives the sequence of the processes from when a vessel arrives until it leaves again. The arrival of the ships is explained as well in section 3.2.2. After arrival, the containers are unloaded and transported to the stacks. In the stacks they are stored till they are picked to be loaded on another ship.

![Figure 36: Processes at a container terminal](image)
Arrival
When a vessel arrives it chooses the quay as explained in section 3.2.2. The arrivals during the year show a certain irregularity that is approached with an arrival distribution of the vessels. Before the ship arrives an unload plan is made. This plan tells which containers should be unloaded and what their characteristics (like destination, weight and category) are.

Loading and unloading
The loading and unloading takes place at the quay. The quay consists of a number of berths, with for each berth a number of cranes. The berths have to be operational at the same time in order not to increase the waiting times.

The QCs (Quay Cranes) are manned, because automation still has practical problems with exact positioning. The cranes are mounted on rails and are exchangeable when berths are connected. Super-Post Panamax cranes are necessary to operate on the biggest mainline vessels with a capacity up to 12,000 TEU. The cranes take the container from the ship’s hold or deck and put them on the apron or on a terminal transport system. When a vessel is loaded the process is reversed and the QC picks the container from the terminal transport system to place it somewhere in the ships hold.

Terminal transport
If the containers are placed on the apron, a reach stacker (RS) or a straddle carrier (SC) can pick them up. However a RS is seldom used for terminal transport on large terminals. A SC is used for transport as well as for stacking. When a multi trailer system (MTS) or automated guided vehicles (AGV) are used the QC has to place the containers on the chassis. An AGV is unmanned and capable of transporting one container along a predefined path.

For each different type of terminal transport, the cycle time is almost the same. It consists of receiving a container from the QC, travelling to the stacks and waiting for the stacking vehicle to pick the container. After that it travels back to wait for the new container, delivered by the quay crane.

Stack
The stack is the place where the containers are stored. There are two possible ways: on a chassis, so that every container is individually accessible or piled up. In the last case it is possible that some reshuffles have to be made if a specific container has to be loaded.

A stack consists most of the times of a block of containers, a driving lane for the handling equipment and a transfer point to load the terminal transport system. Dependent on the handling equipment used, the blocks have a certain height, length and width; together with the specifications of the handling equipment these factors determine the productivity. An optimum can be found between the costs of the handling equipment and the area needed.
5.1.3 Terminal handling equipment

Each process explained in the former section can be operated by a type of vehicle. The available types of handling equipment are stated below. After this the concepts can be developed.

**Unloading and loading of the ship**

- **Quay Crane (QC):** The QC normally determine the productivity of the port, because the berth occupancy follows from the accepted waiting times. The dimensions of the QC are determined by the design vessel; the largest vessel that has to be served at the port. The height and reach are the most important dimensions. The productivity of these cranes is high (40 moves/hour) and the waiting times of the QC for terminal transport have to be minimised. The cranes are rail mounted along the quay.

**Intra-terminal transport system**

- **Automated Guided Vehicles (AGV):** The use of a fully automated terminal is a new concept. The vehicles are unmanned and are guided through an electronic system in the terminal surface. The automation has to improve the regularity (reliability) in the service and the flexibility of the vehicles between the quays and the stacks. Initial investment costs are high but due to the unmanned vehicles the operation costs are lower.

- **Straddle carriers (SC):** These are vehicles that are able to do both terminal transport and stacking. As shown in the figure the vehicle drives over a long stack to pick a container. However in case of long stacks the productivity will decrease because driving over the stacks needs to be secure, which results in long travelling times. The stacking density is limited because of the width of the stack of one container and the driving spaces needed on both sides of it. At the QC the SC can drop the container on the apron and the QC can pick it up; the SC continues its cycle. This improves the productivity and reduces the waiting times. A disadvantage is its height; the QC construction must have enough height clearance to allow the straddle carrier to drive underneath.
• Trailer System (TS) or Multi Trailer Systems (MTS): Both systems consist of a lorry, which trails a number of trailers. In the first case only one and in the last off course more than one. It is possible that the containers can be piled up two-high on the trailer. Advantages of a MTS is the more continuous unloading/ loading by the QC or stack transport, but probably more trailers are needed compared with a single trailer system, but less lorry to trail them.

Stacking area

• Straddle Carriers (SC)

See intra-terminal transport.

• Reach Stackers (RS)

The reach stacker has a lifting device on a long arm; this makes it possible to operate on a 3-deep and 5-high container stack (dependent on the load of the containers) on both sides of its driving lane. The reach stacker requires a wide driving lane, as it has to move 40 feet containers perpendicular to its driving direction. Besides the driving space a lane to load the terminal transport system is preferable, because the RSs are not very suitable for travelling long distances. Compared to SCs or RTGs the productivity of stacking is high and the reach stackers are flexible; more reach stackers on one lane is possible. A reach stacker can easily load a MTS.
• Rubber Tyred Gantry cranes (RTG)

RTGs mostly operate on stacks between 4 to 8 containers wide and 3 to 5 high. A driving lane is needed for the terminal chassis. Extra height is required to lift the container over the stack. The trolley with the spreader moves the container to the chassis lane and places the container at the terminal chassis. RTGs are more flexible than RMG because more RTGs are exchangeable between stacks.

• Rail Mounted Gantry cranes (RMG)

RMGs are moving along rails and can serve stacks up to 12 wide and 6 high, the lanes for the terminal chassis are situated on both sides. If a RMG is used on a fully automated terminal the stacks will be smaller. Because of the practical experienced with automated terminals is limited and the maximum dimensions of the stacks used on other terminals are maximum 8 wide and 3 high. In these concepts when automation is applied the vehicles are lined up on one of the ends of the stack.
5.1.4 Concepts

In the section above, four types of handling equipment for the stacks are discussed. From these four types 4 different concepts are made. The most likely combinations of this stacking equipment with the terminal transport system are found. This is resulting in the following concepts that are elaborated in sections 5.3 to 5.6.

- Straddle carriers (SC) for terminal transport and stacking
- MTS for terminal transport and reach stackers for the stacking
- TS for terminal transport and RTGs for the stacking
- Fully automated: AGVs for terminal transport and RMG for stacking

5.2 Costs infrastructure

Construction methodology: After the land fill and the surfacing of it, a geo textile is put on the sand to divide the forces of the next rubble layer and to prevent both layers from mixing. The rubble layer is compressed. A layer of coarse sand is made as a base for the concrete plates; this layer has to be levelled securely. The concrete bricks can be shipped from India or Sri Lanka. The bricks of 0.12m thick are the top layer on which the superstructure has to operate.

On the sides a kerb is made in mortar and after that the connection with the quay construction is constructed. On the terminal drains have to be present and a sewer system is constructed in the land fill. Rails are constructed on concrete beams that are based on piles as a foundation. In Table 27 10% extra costs are calculated for these extra aspects.
Table 27: Costs of the civil works of the terminal

<table>
<thead>
<tr>
<th>Layer</th>
<th>Unit price</th>
<th>Thick (m)</th>
<th>$/m²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Placing the plates</td>
<td>7.3 $/m²</td>
<td></td>
<td>7.3</td>
</tr>
<tr>
<td>Concrete bricks</td>
<td>14.4 $/m²</td>
<td>0.12</td>
<td>14.4</td>
</tr>
<tr>
<td>Levelling</td>
<td>2.4 $/m²</td>
<td></td>
<td>2.4</td>
</tr>
<tr>
<td>Coarse sand</td>
<td>4.72 $/m²</td>
<td>0.10</td>
<td>0.472</td>
</tr>
<tr>
<td>Compress</td>
<td>1.2 $/m²</td>
<td></td>
<td>1.2</td>
</tr>
<tr>
<td>Rubble (2,0 ton/m³)</td>
<td>12 $/ton</td>
<td>0.50</td>
<td>12</td>
</tr>
<tr>
<td>Geo textile 300 g/m²</td>
<td>1.8 $/m²</td>
<td></td>
<td>1.8</td>
</tr>
<tr>
<td>Land fill</td>
<td>4.72 $/m²</td>
<td>4.00</td>
<td>18.88</td>
</tr>
<tr>
<td>10% cables, drainage, etc.</td>
<td></td>
<td></td>
<td>5.85</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td></td>
<td></td>
<td><strong>64.32 $/m²</strong></td>
</tr>
</tbody>
</table>

5.3 Concept 1: Straddle carriers

When the quay crane unloads the vessel it leaves the container on the quay. A straddle carrier as shown in Figure 38 picks the container and drives to the stacks. Because of the lifting height of the straddle carrier it can drive over a row of containers to stack the container. The capacity of a straddle carrier depends on the length and the height of the row, as the width of a row is only one container.

For concept 1, one over three (1 over 3) straddle carriers are chosen. Quay cranes must have a high clearance if the container is dropped on the apron between the rails, with a QC with a back reach this problem does not occur.
5.3.1 Stacks concept 1

Width of the stack

The number of stacks depends on the quay length ($L_q$) and the width of one stack ($w_s$). The stacks are situated perpendicular to the quay. This width of one stack is the width of one container (TEU) and extra space for the straddle carrier and either space for safety.

To minimise the required stacking area, it is not possible to pick a container from two adjoining stacks at the same time. In all concepts the required width for a stack can be approached by equation 5.6:

$$w_s = w_c + w_{SC} + s$$  \hspace{1cm} (5.6)

In which:
- $w_c = \text{width container} = 2.44$ m
- $w_{SC} = \text{width SC} = \frac{4.94 - 2.44}{2} = 1.25$ m
- $s = \text{safety margin} = 1.0$ m

Then:
- $w_s = \text{width stack} = 4.69$ m

Number of stacks

On both sides of the terminal an extra space with the width of an apron is made and in the middle an extra lane is necessary for special transport on the terminal, the number of stacks perpendicular to the quay is then:

$$N_s = \frac{L_q - 2 \cdot a - b}{w_s}$$  \hspace{1cm} (5.7)

In which:
- $L_q = \text{quay length} = 1020$ m
- $a = \text{width apron} = 50$ m
- $b = \text{width lane} = 30$ m
- $w_s = \text{width one stack} = 4.69$ m
Then:
\[ N_s = \text{number of stacks} = 190 \]

**Length of the stack**

In the former section the number of stacks and the stacking height and width are determined. To meet the required storage capacity, the stack has to have a certain length in TEU.

\[ l = \frac{C_t}{N_s \cdot w \cdot h} \]  
(see 5.5)

In which:
- \( C_t \) = storage capacity of the terminal = 19,373 TEU
- \( w \) = width stack = 1 TEU
- \( h \) = average stacking height = 0.8 \( h_{\text{max}} \) = 2.4 TEU

Then:
- \( l \) = length of stack = 43 TEU
- \( l_c \) = length container = 6.1 + extra = 6.4 m
- \( l_s \) = length stack = 43 \( \times 6.4 \) = 275 m

The stacks are in this case 275 m long. A SC has to drive all the way over the stack, this operation is a big aspect in the cycle time. If a lane is considered to divide the stacks into two, the time needed to travel over the stack decreases more than the increase in the time to travel by road.

Then:
- \( l \) = length of stack = 22 TEU
- \( l_c \) = length container = 6.1 + extra = 6.4 m
- \( l_s \) = length stack = 22 \( \times 6.4 \) = 141 m

### 5.3.2 Productivity of the stacks concept 1

**Number of reshuffles**:

The number of reshuffles depends on the stacking height. If a container has to be loaded, first the containers on the top of the stack have to be removed. It is assumed, due to the relation between the average stacking height and the maximum stacking height that a top container gets a new position in the stack and does not have to be placed back on its initial position.

When a vessel is unloaded, with random stacking all the containers are stacked at a chosen position by the drivers of the terminal equipment. However the load plan of a vessel has fixed sequence. It is possible that a required container is on the bottom of the stack. With a stacking height of 3 TEU the chances that a container has to be picked from a pile is 1/3. But for the bottom container 2 reshuffles are needed, for the middle 1 reshuffle and for the top container noreshuffles. The average number of reshuffles per loaded container can be calculated with equation 5.8:

<table>
<thead>
<tr>
<th>Stacking height</th>
<th>Reshuffles</th>
<th>Chance</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>0</td>
<td>1/3</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1/3</td>
<td>1/3</td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>1/3</td>
<td>2/3</td>
</tr>
</tbody>
</table>

Total: 1
Ihavandhippolhu Atoll Transhipment Port

\[ r = \sum_{i=1}^{n} \frac{1}{n} \cdot (i - 1) = \frac{1}{2} \cdot n - \frac{1}{2} \] (5.8)

\[ r \quad = \text{average number of reshuffles per container [moves]} \]
\[ n \quad = \text{maximum stacking height [TEU]} \]

Stacking strategy
In Figure 45 equation 5.8 is shown for random stacking as well as for a more favourable situation when for a certain stacking strategy is applied. When a strategy is applied it is assumed that the number of reshuffles is reduced with 50% [10], so equation 5.8 is multiplied with 0.5. With the big parcel sizes in this transshipment port it is possible to find a good strategy for example by sorting them by destination, so in all the concepts the relation with the stacking strategy in Figure 45 is used.

![Number of reshuffles](image)

Figure 45: Number of reshuffles dependent on the stacking height

When using the average stacking height of 2.4. Equation 5.8 gives the number of reshuffles \( r \):

\[ r = 0.5 \cdot \left( \frac{1}{2} \cdot 2.4 - \frac{1}{2} \right) = 0.35 \] (see 5.8)

Cycle time
The cycle of one straddle carrier consists of the following actions: drive over the stack without container (se = stack empty) to get the wanted container (p = pick), but first some reshuffles have to be made (r = reshuffle) with the loaded container the SC has to drive over the stack again (sl = stack loaded) and continue its way to the quay crane (tl = travel loaded) to drop (d = drop) the container at the apron, finally it has to travel back to a new stack (te = travel empty). The total cycle time is then:

\[ T_{SC} = T_{se} + T_r + T_p + T_{sl} + T_{te} + T_d + T_r \]
\[ T_{se} = T_{sl} = 0.5 \cdot \frac{1}{v_s} \]
\[ T_r = r \cdot (T_p + T_d) = 2 \cdot r \cdot T_p \] (see 5.2)
\[ T_p = T_{d} = \frac{h_s}{v_h} + T_g \]
\[ T_{sl} = \frac{d}{v_i} \]
\[ T_{te} = \frac{d}{v_e} \]

In which:
\[ d = \text{distance [m]} \quad = 0.417 \cdot L_q + l_s = 0.417 \cdot 1020 + 0.5 \cdot 141 = 496 \text{ m} \text{ (see Figure 46)} \]
\[ v_i = \text{speed loaded [m/s]} \quad = 7.22 \text{ m/s} \text{ [ref: in Appendix XII]} \]
\[ v_e = \text{speed empty [m/s]} \quad = 8.33 \text{ m/s} \]
\[ v_h = \text{speed hoist [m/s]} \quad = 0.36 \text{ m/s} \]
\[ v_s = \text{speed stack [m/s]} \quad = 3.9 \text{ m/s} \]
Ihavandhippolhu Atoll Transshipment Port

\[ h_s = \text{height stacks [m]} = 2.60 \times 3 + 1 = 9 \text{ m} \]
\[ T_g = \text{time grab [s]} = 20 \text{ s} \]
\[ r = \text{number of reshuffles} = 0.35 \text{ (see Figure 45 for average stacking height 2.4)} \]
\[ l = \text{length stack [m]} = 141 \text{ m} \]

In which the distance (d) is a function of the quay length and the stack length. This function is the same for each concept. However in some concepts the stack length is not taken into account, because for example with the use of AGV in concept 4, the AGV line up at the head of the stack. In case of straddle carrier the length of the stacks is considered as a separate aspect with a slower travelling speed and

\[
D = \frac{1}{2} L_q + \frac{1}{2} l_s \\
D = \frac{1}{4} L_q + \frac{1}{2} l_s \\
D = \frac{1}{2} L_q + \frac{1}{2} l_s
\]

Stacking area

Figure 46: Determination of travelling distances

The resulting average distance is:

\[
\bar{D} = \frac{2 \cdot \frac{1}{2} + \frac{1}{4}}{3} \cdot L_q + \frac{1}{2} l_s = 0.417 \cdot L_q + 0.5 \cdot l_s \quad (5.9)
\]

Then:

\[ T_{se} + T_{sl} = \text{time stack} = 2 \times (0.5 \times 141 / 3.9) = 36 \text{ s} \]
\[ T_{p}, T_{d} = \text{time pick, drop} = 8.80 / 0.36 + 20 = 44 \text{ s} \]
\[ T_r = \text{time reshuffle} = 0.35 \times 2 \times 44.44 = 31 \text{ s} \]
\[ T_{tl} = \text{time travel loaded} = 425 / 7.22 = 69 \text{ s} \]
\[ T_{te} = \text{time travel empty} = 425 / 8.33 = 60 \text{ s} \]
\[ T_{SC} = \text{cycle time SC} = 284 \text{ s} \]
\[ p_{SC} = \text{productivity SC} = 3600 / 284 = 13 \text{ moves/hour} \]

5.3.3 Queuing theories concept 1

In the first place the average cycle time of a SC is estimated. With this cycle time the resulting productivity and the required number of SCs can be calculated. However, due to the irregularity in the different aspects of the cycle time the average cycle time has a certain deviation, this deviation causes waiting times for the QC. With the queuing theories the required number of vehicles can be determined in order to limit these waiting times.

A general queuing model is represented in Figure 47:
One important simplification is made:
The productivity of the QC is converted into inter arrival times, but the productivity is affected by the waiting times, because the QC is not able to pick a new container from the vessel. This means that there is no actual queue. But if the process is divided in a generator of containers with an inter arrival time and a queue. The average waiting time which is calculated in that situation, can be added to the inter arrival times. The inter arrival times increase and relative waiting time decreases. When accepting only small waiting times, this effect is negligible. On the other hand if inter arrival times increase with the productivity has to increase as well to meet the required 40 moves/hour.

Arrival time
The QCs have a productivity of 40 moves/hour. The arrival-interval time is 90 s. A standard deviation of 30 s is assumed, this depends on the location of the container on the vessel and the hoisting times of the QC. The nearest container on the deck takes a shorter time than a container on the bottom of the hold.

The productivity of the QC may not be affected too much by long queues or the absence of terminal transport. In general for these concepts a reduction in productivity of the QC of 10% is allowed. However, a SC is able to pick up the container from the quay. The operations of the QC do not have to wait for the terminal transport and are thus not affected. In concept 1 the average waiting time in units of the inter-arrival time of the QC for a container on the quay may not exceed 25%.

Service time
All time aspects are assumed to be normal distributed. Where $\mu$ is the average, which equals the sum of all calculated time aspects $T_i$. The standard deviation $\sigma$ is $0.5 \times \mu$. Both the assumption on the normal distribution as the assumption on the standard deviation are not verifiable. However, the assumptions make the calculation and thus the continuation possible. Otherwise, application of the queuing theories is not possible. In that case a direct assumption on the number of equipment had to be made, which is even more inaccurate.

These normal distributions can be combined into one normal distribution with the next equation:

$$\sum_{i=0}^{n} N(\mu_i, \sigma_i) = N(\mu = \mu_1 + \mu_2 + ... + \mu_n, \sigma = \sqrt{\sigma_1^2 + \sigma_2^2 + ... + \sigma_n^2}) \quad (5.10)$$

$\mu$ = mean value [s]
$s$ = standard deviation [s]
Table 28: Distribution of the cycle time and its aspects

<table>
<thead>
<tr>
<th>Time aspect</th>
<th>Max</th>
<th>Min</th>
<th>μ</th>
<th>s</th>
<th>s^2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ts</td>
<td>54.31</td>
<td>18.10</td>
<td>36.21</td>
<td>9.05</td>
<td>81.93</td>
</tr>
<tr>
<td>Tp</td>
<td>66.67</td>
<td>22.22</td>
<td>44.44</td>
<td>11.11</td>
<td>123.46</td>
</tr>
<tr>
<td>Td</td>
<td>66.67</td>
<td>22.22</td>
<td>44.44</td>
<td>11.11</td>
<td>123.46</td>
</tr>
<tr>
<td>Tte</td>
<td>118.98</td>
<td>0.00</td>
<td>59.49</td>
<td>29.74</td>
<td>884.73</td>
</tr>
<tr>
<td>Ttl</td>
<td>137.28</td>
<td>0.00</td>
<td>68.64</td>
<td>34.32</td>
<td>1177.89</td>
</tr>
<tr>
<td>Tr</td>
<td>62.22</td>
<td>0.00</td>
<td>31.11</td>
<td>15.56</td>
<td>241.98</td>
</tr>
<tr>
<td>Tsc</td>
<td>506.12</td>
<td>62.55</td>
<td>284.34</td>
<td>51.32</td>
<td>1111.91</td>
</tr>
</tbody>
</table>

\[ T_{SC} = N(284, 51) \]
\[ T_{QC} = N(90, 30) \]

Queuing system [13]
The waiting times and the utilisation in this system can be approached with an \( E_k/E_m/n \) system, where \( E \) stands for an Erlang distribution. The actual distributions are unknown, but this system divides the range of the distribution in a fixed number of phases (\( k \)), each with its own negative exponential distribution. If \( k = 1 \) the distribution has one phase and is then of course negative exponential, if \( k > 10 \) the Erlang random variable is approximately normally distributed and if \( k \to \infty \) it approaches a constant value of \( 1/\mu \).

\[ W_n = (1 - \nu_a) \cdot \nu_s \cdot W_n(0, 1, u) + \nu_a \cdot (1 - \nu_s) \cdot W_n(1, 0, u) + \nu_a \cdot \nu_s \cdot W_n(1, 1, u) \quad (5.11) \]

\[ \nu_a = \frac{1}{k} = \left( \frac{\sigma_a}{\mu_a} \right)^2 = \left( \frac{30}{90} \right)^2 = 0.111 \quad k = 9 \quad (5.12) \]

\[ \nu_s = \frac{1}{m} = \left( \frac{\sigma_s}{\mu_s} \right)^2 = \left( \frac{51}{284} \right)^2 = 0.032 \quad m = 31 \]

\[ u = \frac{\mu_s}{\mu_a} \cdot n = \frac{284}{90 \cdot 4} = 0.79 \quad (5.13) \]

Equation 5.11 when \( u = 0.8 \) (see Appendix XIII):

\[ W(0.1, 0.8) = 0.2725 \]
\[ W(1, 0.8) = 0.3860 \]
\[ W(1, 1, 0.8) = 0.7455 \]

\[ W_n = (1 - 0.111) \cdot 0.032 \cdot 0.273 + (1 - 0.032) \cdot 0.111 \cdot 0.386 + 0.111 \cdot 0.032 \cdot 0.746 = 0.052 \]

When \( u = 0.7 \):

\[ W(0.1, 0.7) = 0.1020 \]
\[ W(1, 0.7) = 0.1897 \]
\[ W(1, 1, 0.7) = 0.3572 \]
\[ W_a = (1 - 0.111) \cdot 0.032 \cdot 0.102 + (1 - 0.032) \cdot 0.111 \cdot 0.190 + 0.111 \cdot 0.032 \cdot 0.357 = 0.024 \]

Linear interpolation of the utilisation gives a waiting time of 4.9\% in units of the service time (the cycle time of a SC). This means that each container arriving from the QC has to wait \( 4.9 \times 284 / 90 = 16\% \) of the inter arrival time.

Normally, the number of servers (SCs) has to be increased to get the required 10\% and as a result the utilisation decreases while the waiting times decrease as well. However, a SC can pick the container from the ground, where it has been placed by the QC. There is enough space to put two containers on the apron. In that case the QC can continue with unloading the vessel. The productivity of the quay crane is not affected when only 4 SCs per crane are used.

\[ N_{SC} = \text{Number of Straddle Carriers} = 48 \]

5.3.4 Terminal area concept 1

The terminal area consists of first the apron where the quay cranes serve the vessels and the straddle carriers can pick up the containers and second a driving lane. The two rows of stacks are separated by one lane and the land side of the terminal also has one lane.

\[ A = L_q \cdot (2 \cdot l_s + a + 3 \cdot b) \]

\[ l_s = l_c \cdot l \]  

(5.14)

In which:

- \( l_c \) = length container = 6.1 + extra = 6.4 m
- \( l_s \) = length stack = 6.4 \times 22 = 141 m
- \( a \) = apron = 50 m
- \( b \) = lane = 30 m

Then:

\[ A = \text{terminal area} = 430,032 \, m^2 = 43 \, \text{ha}. \]

5.3.5 Investment costs concept 1

The sum of the investment costs of the vehicles and the infrastructure gives a total of US$126 million.

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit costs</th>
<th>Units</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs terminal area</td>
<td>$64,32</td>
<td>430,032</td>
<td>$27,659,658</td>
</tr>
<tr>
<td>Costs Straddle Carrier</td>
<td>$550,000</td>
<td>48</td>
<td>$26,400,000</td>
</tr>
<tr>
<td>Costs Quay Crane</td>
<td>$6,000,000</td>
<td>12</td>
<td>$72,000,000</td>
</tr>
<tr>
<td>Total costs (US$)</td>
<td></td>
<td></td>
<td>$126,059,658</td>
</tr>
</tbody>
</table>

The investment costs of the quay wall are not included.

5.4 Concept 2: Multi trailer system (MTS) with reach stackers (RS)

In this concept the stacks are served by reach stackers. These vehicles load a trailer system on a lane between the stacks. The trailer system drives to the quay crane. The quay cranes can continue loading/unloading as the trailer systems queue up on the apron. After the MTS is unloaded, it has to drive around the stacks to line up for new containers that have to be loaded by the RSs.
5.4.1 Stacks concept 2

Width of stacks
The reach stackers can serve a stack of 3 wide and 4 high but on both sides of its driving lane. So a stack of 6 wide and the lane is considered as one stack in this case. The space of the RS for manoeuvring with a 40 feet container is $12.60m + 2m = 14.60m$ and the width of a lane for the MTS is another 4m. The space between the stacks is 18.60m.

$$w_s = w_c + w_{RS} + s + w_{MTS}$$

(see 5.6)

In which:
- $w_{RS}$ = width required for manoeuvring of the reach stacker = 12.60m
- $s$ = safety margin = 2m
- $w_c = $ width containers = $6 * 2.44 + 5 * 30 = 16.14m$
- $w_{MTS}$ = lane for MTS = 4 m

Then:
- $w_s = $ width stack = 35 m

Number of stacks
With the same equation as in the former concept, the number of stacks can be determined; however because of the wide lanes between the stacks no additional lanes are needed.

$$N_s = \frac{L_q - 2 \cdot a}{w_s}$$

(see 5.7)

$N_s = $ number of stacks = 26

Length of stacks
To fulfil the demand on the required storage capacity equation 5.4 can be used; the length has to be 35 TEU or 224m.
In which:
\[ C_t = \text{storage capacity of the terminal} = 19,373 \text{ TEU} \]
\[ w = \text{width stack} = 6 \text{ TEU} \]
\[ h = \text{average stacking height} = 0.8 \times h_{\text{max}} = 3.2 \text{ TEU} \]

Then:
\[ l = \text{length of stack} = 39 \text{ TEU} \]
\[ l_c = \text{length container} = 6.1 + \text{extra} = 6.4 \]
\[ l_s = \text{length stack} = 39 \times 6.4 = 250 \text{ m} \]

5.4.2 Productivity of the stacks concept 2

Cycle time:
The cycle time for a reach stacker depends on the time needed to pick up the container and drop it on the MTS, in between the RS has to manoeuvre. For reshuffling the same equation with the stacking height from section 5.3.2 will be used, however more reshuffles are necessary because the containers on the pile in front of a required container have to be moved first. The average number of reshuffles per loaded container when using a 3 wide stack turns out to be linear with the stacking height. That means if the stack is 4 high and 3 wide, the average number of reshuffles per container is 4.

With 50% reduction due to the use of a stacking strategy:
\[ r = \text{number of reshuffles} = 0.5 \times h = 1.6 \]

\[ T_{\text{RS}} = T_m + T_p + T_d + T_r \]

\[ T_p = 0.5 \times \left( \frac{h_s}{v_{\text{he}}} + \frac{h_s}{v_{\text{hl}}} \right) + T_g \]

\[ T_r = r \times (T_p + T_d) \]

In which:
\[ v_{\text{he}} = \text{hoisting speed empty [m/s]} = 0.23 \text{ m/s} \]
\[ v_{\text{hl}} = \text{hoisting speed loaded [m/s]} = 0.40 \text{ m/s} \]
\[ h_s = \text{lifting height [m]} = 4 \times 2.60 + 1 = 11.40 \text{ m} \]
\[ T_g = \text{time grab} = 20 \text{ s} \]

Then:
\[ T_p = \text{time pick} = 0.5 \times (11.40 / 0.23 + 11.40 / 0.40) + 20 = 59 \text{ s} \]
\[ T_m = \text{time manoeuvering} = 60 \text{ s} \]
\[ T_d = \text{time drop} = 20 \text{ s} \]
\[ T_r = \text{time reshuffle} = 1.6 \times (59.3 + 20) = 127 \text{ s} \]
\[ T_{\text{RS}} = \text{cycle time RS} = 266 \text{ s} \]

\[ \rho_{\text{RS}} = \text{productivity RS} = 3600 / 266 = 14 \text{ moves/hour} \]

The total cycle time of a RS (\( T_{\text{RS}} \)) is 266 s. Most of this time is spent on reshuffling; this is one of the major shortcomings of the RS. The standard deviation is in the same way determined as in section 5.3.3 with a triangular distribution for the reshuffling and normal distribution for the other factors. With equation 5.10 in section 5.3.3 the new standard deviation is calculated.

The normal distribution is \( N(266, 67) \)
Cycle time MTS:
The cycle time of the Multi Trailer System ($T_{MTS}$) depends on the inter arrival times of both the QCs and the RSs and its travelling times loaded or empty between the stacks and the QCs.

\[
T_{MTS} = T_{te} + 4 \cdot T_{RS} + T_{tl} + 4 \cdot T_{QC} \quad \text{(see 5.2)}
\]

In which:
- $T_{te}$, $T_{tl}$ = time travel loaded/ empty (s) = \((0.417L_q + l_s) / 10 = 67\) s
- $T_{QC}$ = time QC = 90 s
- $T_{RS}$ = time RS = 266 s

Then:
- $T_{MTS}$ = cycle time MTS = 1560 s
- $p_{MTS}$ = productivity MTS = $4 \cdot 3600/1560 = 9 \text{ moves/hour}$

The normal distribution of the cycle time of the MTS is $N(1560, 154)$

5.4.3 Queuing theories concept 2

When applying the queuing theories on the MTS there are some difficulties:
- There are two queues in which the containers may not exceed the 10% waiting times (in units of the inter arrival time of the $T_{QC}$ and $T_{RS}$).
- The MTS transports parcels of 4 containers (4 moves in each cycle); due to this the standard deviations of the $T_{QC}$ and $T_{RS}$ become relatively smaller. Assumed is in this case that the 4 containers arrive on the same moment.

In this case, if the system is considered in the same way as in concept 1, where the QC generates the containers (clients) with the inter-arrival time and the SC are the servers with their cycle time as service time, there are occurring problems with the addition of the waiting times of the MTS to the cycle time of it. The MTS has to queue for the RS at the stack and for the QC at the quay. Both waiting times have to be added. In this concept the problem is approached from the other side, where the MTS is the client, which commutes between the QC and the RS, which are the servers.

Client: MTS
Server: RS (3) and QC (1)

In order not to decrease the productivity of the QC and the RS the servers must have a high utilisation. If the servers are not occupied, the crane cannot drop a container on the MTS and has to wait; this decreases the productivity of the QC. If the utilisation is 90%, it means that the crane is waiting for 10% and the productivity has to be 44 to meet the required gross production of $0.9 \cdot 44 = 40$ moves/hour.

The most important parameter is the number of MTS ($N_{MTS}$). It has to be sufficient in number to have a short inter-arrival time and thus a high utilisation of both servers.
The cycle times become:

\[ T_{QC} = 4 \times N(90, 30) = N(360, 60) \]
\[ T_{RS} = 4 \times N(266, 67) = N(1065, 134) \]
\[ T_{MTS} = N(1560, 154) \]

For this queue-delay system the \( E/k/n \) system is used. With the use of equations 5.11 to 5.13 the waiting times of the MTS at the QC can be calculated:

The inter-arrival time has to be calculated with the next equation:

\[ u = \frac{\mu_s}{\mu_a \cdot n} = \frac{360}{\mu_a \cdot 1} = 0.90 \]

(see 5.13)

\[ \mu_a = 400 \]

In which:
\( u \) = utilisation \( = 0.9 \)
\( \mu_s = \) service time of the QC \( = 360 \) s
\( n = \) number of servers \( = 1 \)

Then:
\( \mu_a = \) inter-arrival time of the MTS [s] \( = 400 \) s

\[ \nu_a = \frac{1}{k} \left( \frac{\sigma_a}{\mu_a} \right)^2 = \left( \frac{154}{400} \right)^2 = 0.148 \]

\[ k = 7 \]

(see 5.12)

\[ \nu_s = \frac{1}{m} \left( \frac{\sigma_s}{\mu_s} \right)^2 = \left( \frac{60}{360} \right)^2 = 0.032 \]

\[ m = 36 \]

In which:
\( \sigma_a \) = standard deviation of inter-arrival time of container \( = 60 \) s
\( \sigma_s \) = standard deviation of service time \( = 154 \) s

The waiting time in the queue for the QC is (see tables in Appendix XIII):

\[ W_a = (\nu_a, \nu_s, u) = (1 - \nu_a) \cdot \nu_s \cdot W_a(0,1,u) + \nu_a \cdot (1 - \nu_s) \cdot W_a(1,0,u) + \nu_a \cdot \nu_s \cdot W_a(1,1,u) \]
\[ W_{QC} = (1 - 0.148) \cdot 0.032 \cdot 9.0 + 0.148 \cdot (1 - 0.032) \cdot 4.5 + 0.148 \cdot 0.032 \cdot 3 = 76\% \]

(see 5.11)

In which:
\( W_{QC} \) = average waiting time as a % of the service time of the MTS at the QC \( = 76\% \)

The same can be done for the queue at the stacks:

\[ n = \) number of servers \( = 3 \]

\[ u = \frac{\mu_s}{\mu_a \cdot n} = \frac{1065}{\mu_a \cdot 3} = 0.90 \]

(see 5.13)

\[ \mu_a = 394 \]
\[ v_a = \frac{1}{k} = \left( \frac{\sigma_a}{\mu_a} \right)^2 = \left( \frac{154}{394} \right)^2 = 0.152 \quad k = 7 \]  
\[ v_s = \frac{1}{m} = \left( \frac{\sigma_s}{\mu_s} \right)^2 = \left( \frac{134}{1065} \right)^2 = 0.016 \quad m = 63 \]  
(see 5.12)  

\[ W_a = (v_a, v_s, u) = (1-v_u) \cdot v_s \cdot W_n (0,1,u) + v_u \cdot (1-v_s) \cdot W_n (0,0,u) + v_u \cdot v_s \cdot W_n (1,1,u) \]  
\[ W_{RS} = (1-0.152) \cdot 0.016 \cdot 2.724 + 0.152 \cdot (1-0.016) \cdot 1.289 + 0.152 \cdot 0.016 \cdot 1.211 = 22\% \]  
(5.11)  

In which:  
\[ W_{RS} = \text{average waiting time as a % of the service time of the MTS at the RS} = 22\% \]  
The waiting times have to be added to the cycle time. Together with the required inter-arrival times, the number of MTS can be determined.  
\[ T = T_{MTS} + W_{RS} \cdot T_{RS} + W_{QC} \cdot T_{SC} \]  
\[ T = 1560 + 0.76 \cdot 360 + 0.22 \cdot 1065 = 2096 \]  
(5.15)  
\[ N_{MTS} = \frac{T}{\mu_u} = \frac{2096}{400} = 5.24 = 6 \quad (MTS/QC) \]  
\[ N_{MTS} = 6 \cdot 12 = 72 \]  
(5.16)  

It can be concluded that there have to be 72 MTS.  
\[ N_{MTS} = 72 \]  

### 5.4.4 Terminal area concept 2

\[ A = L_q \cdot (l_s + a + 2 \cdot b) \]  
(see 5.14)  
\[ l_s = l_c \cdot l \]  

In which:  
\[ l_c = \text{length container} = 6.1 + \text{extra} = 6.4 \text{ m} \]  
\[ l_s = \text{length stack} = 6.4 \cdot 22 \text{ m} = 250 \text{ m} \]  
\[ a = \text{apron} = 50 \text{ m} \]  
\[ b = \text{lane} = 30 \text{ m} \]  

Then:  
\[ A = \text{terminal area} = 366,792 \text{ m}^2 \]
5.4.5 Investment costs concept 2

The sum of all investment costs is given in Table 30:

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit costs</th>
<th>Units</th>
<th>Costs (US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs terminal area</td>
<td>$44,32</td>
<td>366.792</td>
<td>$23,592,061</td>
</tr>
<tr>
<td>Costs Reach Stacker</td>
<td>$400,000</td>
<td>36</td>
<td>$14,400,000</td>
</tr>
<tr>
<td>Costs MTS</td>
<td>$360,000</td>
<td>72</td>
<td>$25,920,000</td>
</tr>
<tr>
<td>Costs Quay Crane</td>
<td>$6,000,000</td>
<td>12</td>
<td>$72,000,000</td>
</tr>
<tr>
<td><strong>Total costs (US$)</strong></td>
<td></td>
<td></td>
<td><strong>$135,912.061</strong></td>
</tr>
</tbody>
</table>

The investment costs of the quay wall are not included.

5.5 Concept 3: Trailer system (TS) with rubber tyred gantry cranes (RTG)

RTGs are manned gantries that drive over the stack. Besides the stack a driving lane is situated. A simple trailer system, one lorry and one trailer, drives along the stack over this lane and stops where the gantry is picking a container from the stack. The gantry can simply load the TS. After which the TS continues its way to the QC.

5.5.1 Stacks concept 3

Width of stacks
The Rubber Tyred Gantry (RTG) can serve a stack of 4 high and 8 wide, together with a chassis lane. The width of the RTG is 29.20 m if on both sides a safety margin of 1m is applied, the width of one stack is then 30.2 m. In the middle of the terminal an extra lane is preferable with width b.

\[ w_s = \text{width stack} = 30 \text{m} \]

Number of Stacks

\[ N_s = \frac{L_s - 2 \cdot a - b}{W_s} \quad \text{(see 5.7)} \]

\[ N_s = \text{number of stacks} = 29 \]
Length of stacks

The length of the stack has to be sufficient to meet the required storage capacity of around 20,000 TEU. With the following equation this length in TEU can be determined:

\[ l = \frac{C_t}{N_s \cdot w \cdot h} \]  

(see 5.5)

In which:

- \( C_t \) = Storage capacity of the terminal = 19,373 TEU
- \( w \) = width stack = 8 TEU
- \( h \) = average stacking height = 0.8 * \( h_{\text{max}} \) = 3.2 TEU

Then:

- \( l \) = length of stack = 27 TEU
- \( l_c \) = length container = 6.1 + extra = 6.4 m
- \( l_s \) = length stack = 27 * 6.4 = 173 m

5.5.2 Productivity of the stacks concept 3

Cycle time

The cycle of a RTG consists of the following aspects. First the gantry travels to the new required container (\( T_{ga} \)), to get this container first some reshuffles (\( r \)) have to be made, this takes time (\( T_r \)). The time to pick the container (\( T_p \)) depends on the hoisting speed, the time to grab the container and the stacking height. The average hoisting height is total height with a safety margin. The trolley moves the container to the chassis lane (\( T_t \)), where it drops the container on the trailer (\( T_d \)).

\[ T_{RTG} = T_{ga} + T_r + T_p + T_d \]

\[ T_p = 0.5 \left( \frac{h_s}{v_{hl}} + \frac{h_s}{v_{he}} \right) + T_g \]

\[ T_r = \frac{w_t}{v_t} \]

\[ T_{ga} = 0.25 \cdot l_s \cdot \frac{1}{v_{ga}} \]

\[ T_{RTG} = r \cdot 2 \cdot T_p \]  

(see 5.2)

In which:

- \( v_{ga} \) = speed gantry [m/s] = 2.17 m/s
- \( v_t \) = speed trolley [m/s] = 1.17 m/s
- \( v_{hl} \) = hoisting speed loaded [m/s] = 0.33 m/s
- \( v_{he} \) = hoisting speed empty [m/s] = 0.66 m/s
- \( h_s \) = height stacks [m] = 4 * 2.6 + 1 = 11.4 m
- \( T_g \) = time grab [s] = 20 s
- \( w_t \) = width trolley = 30 m
- \( r \) = number of reshuffles = 0.55 (see Figure 45 for average stacking height 3.2)
- \( l_s \) = length stack [m] = 173 m

Then:

\( T_{p}, T_d \) = Time pick = 0.5 * (11.4 / 0.33 + 11.4 / 0.66) + 20 = 62 s

\( T_r \) = time reshuffle = 0.55 * 2 * 61.8 = 34 s

\( T_{ga} \) = time gantry = 0.25 * 173 / 2.17 = 20 s

\( T_t \) = time trolley = 30.2 / 1.17 = 26 s

\( T_{RTG} \) = cycle time RTG = 204 s

\( p_{RTG} \) = productivity RTG = 3600 / 204 = 18 moves/hour

The normal distribution is \( N(204, 50) \)
Cycle time Trailer:
The four components of the trailer that determine the cycle are: the loading of a container at the QC, the unloading at the stacks by the RTG and two times the travelling in between.

\[ T_{TS} = T_{te} + T_{RTG} + T_t + T_{QC} \]  \hspace{1cm} \text{(see 5.2)}

In which:
- \( T_{te} \), \( T_{tl} \) = time travel loaded/ empty (s) = \( 0.417L_q + l_s \) / 10 = 60 s
- \( T_{QC} \) = time QC = 90 s
- \( T_d \) = time drop = 62 s

Then:
- \( T_{TS} \) = cycle time TS = 272 s
- \( \rho_{TS} \) = productivity TS = 3600 / 272 = 13

The normal distribution of the cycle time of the TS is \( N(272, 69) \)

5.5.3 Queuing theories concept 3

The same queue-delay system can be used as in Figure 49, where the TS commute between the QC and the RTG. And again the waiting times in both queues are added to the total cycle time of the TS in order to determine the required number of TS.

The cycle times become:
- \( T_{QC} \) = \( N(90, 30) \)
- \( T_{TS} \) = \( N(272, 69) \)
- \( T_{RTG} \) = \( N(204, 50) \)

With the use of equations 5.11 to 5.13:

For the queue at the QC:
- \( \mu_a = 90 / 0.9 = 100 \) s
- \( ?_a = 0.476 \)
- \( ?_s = 0.111 \)

One QC as server:
- \( W_{QC} = 255\% \) (equation 5.11)

For the queue at the RTG:
- \( \mu_a = 204 / 0.9 = 227 \) s
- \( ?_a = 0.093 \)
- \( ?_s = 0.060 \)

One RTG as server:
- \( W_{RTG} = 61\% \) (equation 5.11)

\[ T = 272 + 2.55 \cdot 90 + 0.61 \cdot 204 = 625 \] \hspace{1cm} \text{(see 5.15)}

\[ N_{TS} = \frac{T}{\mu_a} = \frac{625}{100} = 6.25 = 7 \cdot (TS/QC) \] \hspace{1cm} \text{(see 5.16)}

\( N_{TS} = 7 \cdot 12 = 84 \)

The required number of TS is 84.

\( N_{TS} = 84 \)
5.5.4 Terminal area concept 3

\[ A = L_q \cdot (l_s + a + 2 \cdot b) \]

\[ l_s = l_c \cdot l \]  

(see 5.14)

In which:
- \( l_c \) = length container = 6.1 + extra = 6.4 m
- \( l_s \) = length stack = 6.4 \* 27 = 173
- \( a \) = apron = 50 m
- \( b \) = lane = 30 m

Then:

\[ A = \text{terminal area} = 288,456 \text{ m}^2 \]

5.5.5 Investment costs concept 3

The total investment costs for this option are US$ 130 million.

Table 31: Investment costs concept 3

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit costs</th>
<th>Units</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs terminal area</td>
<td>$64,32</td>
<td>288,456</td>
<td>$18,553.490</td>
</tr>
<tr>
<td>Costs RTG</td>
<td>$1,000,000</td>
<td>29</td>
<td>$29,000.000</td>
</tr>
<tr>
<td>Costs TS</td>
<td>$120,000</td>
<td>84</td>
<td>$10,080.000</td>
</tr>
<tr>
<td>Costs Quay Crane</td>
<td>$6,000,000</td>
<td>12</td>
<td>$72,000.000</td>
</tr>
<tr>
<td><strong>Total costs (US$)</strong></td>
<td></td>
<td></td>
<td><strong>$129,633.490</strong></td>
</tr>
</tbody>
</table>

The investment costs of the quay wall are not included.
5.6 Concept 4: Automated guided vehicles (AGV) with rail mounted gantry cranes (RMG)

This concept is fully automated except for the QCs. The AGVs line up on the quay side of the stack. The RMG have to travel between the place, where the containers have to be picked and the quay side, where it drops the container on the AGV. The AGV are guided by an electronic system in the terminal surface. Exact positioning especially at the stacks is very important.

![Figure 51: Concept 4](image)

5.6.1 Stacks concept 4

Width of stacks
Nowadays the maximum stacking height and width used in case of automated RMGs is 3 high and 8 wide. The width of the stack is in this case 26m. An extra lane for emergency transport is preferable in the middle of the terminal.

\[ w_s = \text{width stack} = 26m \]

Number of stacks

\[ N_s = \frac{L_s - 2 \cdot a - b}{w_s} \]  
(see 5.7)

\[ N_s = \text{number of stacks} = 34 \]

Length of stacks
At the same way as in the former concepts the required length is calculated:

\[ l = \frac{C_t}{N_s \cdot w \cdot h} \]  
(see 5.5)

In which:

\[ C_t = \text{Storage capacity of the terminal} = 19,373 \text{ TEU} \]

\[ w = \text{width stack} = 8 \text{ TEU} \]

\[ h = \text{average stacking height} = 0.8 \cdot h_{\text{max}} = 2.4 \text{ TEU} \]
Ihavandhippolhu Atoll Transshipment Port

Then:

\[ l_s = \text{length of stack} = 30 \text{ TEU} \]
\[ l_c = \text{length container} = 6.1 + \text{extra} = 6.4 \text{ m} \]
\[ l_s = \text{length stack} = 30 \times 6.4 = 192 \text{ m} \]

5.6.2 Productivity of the stacks concept 4

Cycle time

The cycle is almost the same as for an RTG, but because the AGVs are lined up at the quay side of the stack, the travelling time of the gantry takes longer. The cycle consists of the grabbing of the container by the spreader, hoisting and moving of the trolley. The gantry has to travel to the quay side of the stack and the place the container on the AGV. At the end the gantry travels back to the next container.

\[
T_{RMG} = T_g + T_r + T_p + T_d
\]
\[
T_p = T_d = 0.5 \left( \frac{h_s}{v_{hi}} + \frac{h_s}{v_{he}} \right) + T_g
\]
\[
T_r = w_t / v_t \\
T_g = l_s / v_ga \\
T_r = r \cdot 2 \cdot T_p
\]

In which:

\[ v_{ga} = \text{speed gantry [m/s]} = 2.17 \text{ m/s (see Appendix XII)} \]
\[ v_t = \text{speed trolley [m/s]} = 1.17 \text{ m/s} \]
\[ v_{hi} = \text{hoisting speed loaded [m/s]} = 0.33 \text{ m/s} \]
\[ v_{he} = \text{hoisting speed empty [m/s]} = 0.66 \text{ m/s} \]
\[ h_s = \text{height stacks [m]} = 3 \times 2.6 + 1 = 8.8 \text{ m} \]
\[ T_g = \text{time grab [s]} = 20 \text{ s} \]
\[ w_t = \text{width trolley} = 26 \text{ m} \]
\[ r = \text{number of reshuffles} = 0.35 \text{ (see Figure 45 for average stacking height 2.4)} \]
\[ l_s = \text{length stack [m]} = 192 \text{ m} \]

Then:

\[ T_p, T_d = \text{Time pick} = 0.5 \times (8.8 / 0.33 + 8.8 / 0.66) + 20 = 40 \text{ s} \]
\[ T_r = \text{time reshuffle} = 0.35 \times 2 \times 40 = 28 \text{ s} \]
\[ T_{ga} = \text{time gantry} = 192 / 2.17 = 90 \text{ s} \]
\[ T_i = \text{time trolley} = 26.0 / 1.17 = 22 \text{ s} \]
\[ T_{RMG} = \text{cycle time RMG} = 218 \text{ s} \]
\[ P_{RMG} = \text{productivity RMG} = 3600 / 218 = 16 \text{ moves/hour} \]

The normal distribution is \(N(218, 55)\)

Cycle time AGV:

The four components of the AGV that determine the cycle are: the loading of a container at the QC, the unloading at the stacks by the RMG and two times the travelling in between.

\[
T_{AGV} = T_{te} + T_d + T_{tl} + T_{QC}
\]

In which:

\[ T_{te}, T_{tl} = \text{time travel loaded/ empty (s)} = 0.417L_q / 4 = 106 \text{ s} \]
\[ T_{QC} = \text{time QC} = 90 \text{ s} \]
\[ T_d = \text{time drop} = 40 \text{ s} \]
Then:
\[ T_{AGV} = \text{cycle time AGV} = 342 \text{ s} \]
\[ P_{AGV} = \text{productivity AGV} = \frac{3600}{342} = 11 \]

The normal distribution of the cycle time of the AGV is \( N(342, 59) \)

### 5.6.3 Queuing theories concept 4

As in sections 5.4.3 and 5.5.3 the same process is repeated:

The cycle times become:

- \( T_{QC} = N(90, 30) \)
- \( T_{AGV} = N(342, 59) \)
- \( T_{RMG} = N(218, 55) \)

With the use of equations 5.11 to 5.13:

**For the queue at the QC:**

\[ \mu_a = \frac{90}{0.9} = 100 \text{ s} \]
\[ \sigma_a = 0.348 \]
\[ \sigma_s = 0.111 \]

One QC as server:

\[ W_{QC} = 196\% \text{ (equation 5.11)} \]

**For the queue at the RMG:**

\[ \mu_a = \frac{218}{0.9} = 242 \text{ s} \]
\[ \sigma_a = 0.059 \]
\[ \sigma_s = 0.064 \]

One RMG as server:

\[ W_{RMG} = 46\% \text{ (equation 5.11)} \]

\[ T = 342 + 2.01 \cdot 90 + 0.26 \cdot 218 = 619 \]

\[ N_{AGV} = \frac{T}{\mu_a} = \frac{619}{100} = 6.25 = 7 \text{ (AGV / QC)} \]

\[ N_{AGV} = 7 \cdot 12 = 84 \]

The required number of AGV is 84.

### 5.6.4 Terminal area concept 4

\[ A = L_q \cdot (l_s + a + 2 \cdot b) \]

\[ l_s = l_c \cdot l \] \hspace{1cm} (5.14)

In which:

- \( l_c \) = length container = \( 6.1 + \text{extra} \) = 6.4 m
- \( l_s \) = length stack = \( 6.4 \cdot 30 \) = 192 m
- \( a \) = apron = 50 m
- \( b \) = lane = 30 m

Then:

\[ A = \text{terminal area} = 308,040 \text{ m}^2 \]
5.6.5 Investment costs concept 4

The investment costs for this concept are much higher compared to former concepts. This is likely because the equipment is very expensive. However, operational costs can be lower due less employment.

Table 32: Investment costs concept 4

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit costs</th>
<th>Units</th>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>Costs terminal area</td>
<td>$64.32</td>
<td>308.040</td>
<td>$19,813.133</td>
</tr>
<tr>
<td>Costs RMG</td>
<td>$2,000,000</td>
<td>34</td>
<td>$68,000.000</td>
</tr>
<tr>
<td>Costs AGV</td>
<td>$300,000</td>
<td>84</td>
<td>$25,200.000</td>
</tr>
<tr>
<td>Costs Quay Crane</td>
<td>$6,000,000</td>
<td>12</td>
<td>$72,000.000</td>
</tr>
<tr>
<td><strong>Total costs (US$)</strong></td>
<td></td>
<td></td>
<td><strong>$185,013.133</strong></td>
</tr>
</tbody>
</table>

*The investment costs of the quay wall are not included.*

5.7 Selection of the preferred concept

The tables from former sections are compared in Table 33. The main objective was to select the concept with the lowest investment costs. According to this criterion concept 1 would be the preferable option. However, during the calculations many assumptions were made. These assumptions result in a very high inaccuracy. The costs of the first 3 concepts are very close to each other. With this inaccuracy it is impossible to make unambiguous decision.

Due to this inaccuracy, the decision has to be made with the consideration of two more criteria. These criteria are the required terminal area and the number of manned equipment. The decision will be more qualitative instead of the quantitative decision only based on investment costs.

**Terminal area**

The Maldives, existing of small islands with low altitude, has a shortage of sand. Sand acquired with dredging activities in the middle of the atoll, can be very valuable. The smaller the terminal area, the more sand will remain for future port expansions or other land reclamation projects around the Maldives. Besides, with the prospected sea level rise and the low altitude, this sand can be used to protect the islands and the population. Concepts 3 and 4 have additional advantages because of this reason.

**Manned equipment and operational costs**

To make a good decision on the preferable concept, the operational costs have to be included to make an estimate on the NPV and IRR of the terminal investments and its operations. Unfortunately, it is hard to determine the operational costs, but the relation with the number of manned equipment is known; the higher the number the higher the operational costs and the lower the IRR. On this base concept 4 can be competitive with the other concepts. It is not possible the make a selection on this criterion. A remark can be made on the secondary benefits of extra employment; extra employment can have economic spill-over to other Maldivian industries.

Table 33: comparison of the 4 concepts

<table>
<thead>
<tr>
<th>Item</th>
<th>Concept 1 (SC)</th>
<th>Concept 2 (RS + MTS)</th>
<th>Concept 3 (RTG + TS)</th>
<th>Concept 4 (RMG + AGV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Investment Costs US$ million</td>
<td>126</td>
<td>136</td>
<td>130</td>
<td>185</td>
</tr>
<tr>
<td>Terminal Area (ha)</td>
<td>43</td>
<td>37</td>
<td>29</td>
<td>31</td>
</tr>
<tr>
<td>Number of manned equipment (e.g. N_{QC} + N_{MTS} + N_{RS})</td>
<td>60</td>
<td>120</td>
<td>125</td>
<td>12</td>
</tr>
</tbody>
</table>

*The investment costs of the quay wall are not included.*
The preferred concept is concept 3; this concept is implemented in the port in next section.

Evaluation of Automation:
When the operational costs are not determined, the automated concept is the least preferable option. But some remarks have to de made about this concept. Automated terminals are still developing and are in this first phase of development still coping with some difficulties. Automation is useful when the terminal process exist of rather standardized operations. However, the still complex system of operation requires expensive software and high-educated personnel for operating the system. Due to the reduction of the crafted personnel compared with a little increase in the high-educated, the operational costs decrease as well.

5.8 Implementation of concept 3

The most important question is if concept 3 makes a big difference in the costs estimation in section 4.3.1. In that section the costs are estimated on US$ 131 million. Where the costs for the civil works of the terminal area, except for the costs from the material acquired from the entrance channel, are estimated on US$ 19 million. The remaining part is investment costs for the terminal handling equipment, which is US$ 112 million.

When considering concept 3, the investment costs are US$ 130 million. However, the estimation from section 4.3.1 comes very close, there is a difference in the estimation of the superstructure; in concept 3 the surfacing of the area is considered as civil work and in section 4.3.1 the surfacing is part of the superstructure. In the first estimation the surfacing has to be added to the area costs. The estimation on the superstructure would be too low in that case.

<table>
<thead>
<tr>
<th>Estimation</th>
<th>Area</th>
<th>Item</th>
<th>Investment costs in (million US$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 4.3.1</td>
<td>46 ha</td>
<td>Area (land fill)</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superstructure (Incl. surfacing)</td>
<td>111</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total:</strong></td>
<td><strong>130</strong></td>
</tr>
<tr>
<td>Concept 3</td>
<td>29 ha</td>
<td>Area (Incl. surfacing)</td>
<td>19</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Superstructure</td>
<td>112</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total:</strong></td>
<td><strong>131</strong></td>
</tr>
</tbody>
</table>

The investment costs of the quay wall are not included.

The IRR and NPV do not change as the estimations do not differ between each other. When concept 3 is implemented in preliminary design 3 (Pd3), the IRR remains 12.2% and NPV remains US$ 285 million, when a growth of 7% is forecasted (see Figure 35 and Table 24).

Reefers and hazardous cargo facilities are considered to be included in the terminal area that is calculated in concept 3.

In Figure 32 and Appendix VII the port lay-out is given before the terminal design. This lay-out gives some areas for facilities that have to be present as well. In this section the facilities are a little more specified. These facilities are:
- Offices for the port authority, terminal management, pilots etc. The area is 2 ha and situated close to the terminal.
- Ship repair. A dry-docking would not be necessary at first place, so a ship repair will be sufficient. The area required is around 2 ha. The ship repair is located close to the terminal.
- Hotels and leisure facilities. These facilities accommodate employees and visitors. The accommodation is situated on the island near the village and 8 ha big.
- An oil bunkering terminal (2 ha) with a jetty is necessary to fuel the vessels. This terminal must be situated on a considerable distance from the village and the hotel.
- A small craft harbour where pilots, suppliers and other vessels can moor to enter the terminal and its facilities. These small craft berth are closely located to the terminal. And the land side occupies 2 ha of land.
In Appendix XIV some Autocad drawings are included. In the first the top view is presented, in this top view the dimensions of the components are shown. In the last three figures, some impressions are given of the port when looked through an aerial viewpoint.

### 5.9 Conclusions

From this chapter it can be concluded that:

- From the calculations in former sections it can be concluded that a good approximation of the investment costs can be made. However, the approximation is not accurate enough to make a decision between concepts that have about the same investment costs. The assessment of some second-order effects can be a decisive factor in that case. For Ihavandhippolhu Port the concept with the lowest investment costs is concept 1, but concept 3 is the most preferable concept. This concept has positive effects on the employment and the availability of sand for future plans of the Maldives.
- The actual investment costs of concept 3 are US$ 130 million. Compared to the rough estimation in section 4.3.1 this more detailed estimation does not differ. However, in the first calculation in section 4.3.1 the required terminal area is bigger and costs for the civil works are estimated lower. The costs for the terminal handling equipment are estimated quite correct.
- Because there is no decrease in the investment costs for the terminal area and superstructure, the IRR, calculated in section 4.3.5, will not change as well, the port is still not feasible.
- Implementation of concepts 3 in the port lay-out does not bring any difficulties.

### 5.10 Recommendations

The following recommendations have to be made:

- Simulation is preferable; this manual calculation is dependent on a lot of assumptions that result in high inaccuracies. When a simulation is made, the arrival irregularity of the vessels can be combined with the terminal transport and the storage capacity. A simulation model gives better insight in the productivity, occupancy of the storage area, number of reshuffles and the waiting times and downtime of all terminal handling equipment. With a model several parameters can be varied. The most interesting would be the application of a stacking strategy to reduce the reshuffling.
- Terminal transport vehicles are in this chapter considered to be dedicated to a particular QC or stack. In fact, the vehicles can commute between different stacks and QCs. The productivity can increase, however the complexity for the drivers increase as well, a good coordination is necessary in this case.
- Better research on the aspects of the cycle times of the terminal handling equipment can give a better approximation of the productivity.
- Better research on the possibilities of the automated terminal can be done. This terminal with rather standardised operations can be very suitable for automation.
- A study to the operational costs has to be performed, the operational costs are important to compare the NPVs (Net Present Values). This is necessary for a good choice of the preferable concept.
6 Conclusions

In this report on the development of a container transshipment port on Ihavandhippolhu Atoll on the Maldives a design is made with the constant awareness on the demands for competition with Colombo and Salalah. In the first section the conclusions about this competitiveness and the economical feasibility are drawn and in the last section the conclusions on the technical design and feasibility are drawn.

6.1 Conclusions on the competitiveness and economical feasibility:

- The location of Ihavandhippolhu Atoll for a transshipment port is favourable with respect to import/export markets as East-Africa and West-India. However competition is expected from Salalah and Colombo, who have natural hinterland and are as well located more or less favourable to these import/export markets.
- Colombo and Salalah have planned port expansions as well. Competitive factors that can distinguish Ihavandhippolhu from them are costs and efficiency. The investment costs can be low due to natural protection. The most important demands are an average crane productivity of 40 moves/hour during loading/unloading and short waiting times where the total port dues may not exceed US$100/TEU. For the feasibility the Internal Rate of Return (IRR) has to be higher than 15%.
- The total investment costs in the preferable design are US$ 300 million. For different throughput growth scenarios compared with port expansions the IRR is around 12.5%. This means that the port is not feasible.
- However, it can be concluded that during this study a lot of essential information is missing and not directly obtainable. This resulted in many assumptions also on the demands for competitiveness with Salalah and Colombo. (See chapter 7 recommendations).

Main conclusion: There are opportunities for the development of a transshipment port; however economical feasibility can not be reached with the assumptions made in this report. Further research on these assumptions is required to draw better founded conclusions.

6.2 Conclusions on the port design:

- The throughput is forecasted on 1,000,000 TEU in 2010. With different distributions of vessels it can be concluded that 2 mainline berths and one feeder berths are necessary, where one mainline berth can be used by feeder vessels as well. With this number of berths and the required crane productivity the service times and waiting times are short. Waiting times remain below 10% for feeder vessels and 5% for mainline vessels. The port is designed to serve the new Suezmax type of vessel in the future.
- There are 3 good preliminary designs developed that are technically feasible. Design 1 on Uligamu with two-sided unloading, design 2 on Mulhadhoo with a breakwater and design 3 without downtime measures. Preliminary design 2 (Pd2) has the highest quality, but the investment costs of the breakwater are too high. Design 3 has the best quality/costs-ratio and the highest IRR and is because of these two criteria the preferable design.
- The downtime measures taken in design 1 and 2 improve the quality of the port, but these measures increase the investment costs, so that the quality/costs-ratio is decreasing. However the real effect of downtime on the service and on the attraction of customers for the port is not clear.
- With the limited information on the hydraulic conditions it can be concluded that breakwaters are not necessary for port designs on the western part of the Atoll, with the quay exposed to eastern wave impact. If it appears that a breakwater is required, like in design 2, the result is that dredging or breakwater costs are too high and that the port is not feasible anymore.
- For terminal handling the concept of Rubber Tyred Gantiers (RTG) for stacking and a Trailer System (TS) for terminal transport is the preferable concept. The investment costs are US$
130 million, but due to assumptions there is still a big margin on this. Besides this concept requires the smallest terminal area and supplies the most employment for the Maldives.

Main conclusion:
Due to the shortcomings in the geotechnical and hydraulic data, the technical feasibility is not yet proven. (See recommendations)

The environment is not considered in this study and can be a major concern for the approval for the actual construction.
7 Recommendations

This study is the first step in the development of a transshipment port on Ihavandhippolhu. As said before the conclusions drawn are based on assumptions. The conclusions point out that the economical and technical feasibility is questionable. If one wishes to verify this study and continues the following can be recommended.

More research is necessary to give a good conclusion on the ports economical feasibility and technical feasibility. The conclusions have to be verified with the results from further research. In this chapter the required research is recommended again divided in research concerning the economical feasibility and the technical feasibility.

7.1 Recommendations concerning more detailed studies on:

- A good forecast is necessary to determine the demand to a port and the extra container handling capacity in this region. A logistic model with simulations of the cargo flows and the addition of Ihavandhippolhu as a transport node can be used to determine the real favourable position and the disadvantages of the absence of a natural hinterland.
- A good relation between the costs and service time and actual throughput. When new concepts are used as two-sided unloading and the use of ultra-modern quay cranes that are able to make up to 90 moves/hour, the investment costs and thus the port dues are inevitably higher. But the reduction in service time can be as considerable that shippers are willing to pay that price. A good insight in this price/service-ratio and a favourable location is preferable to make a good throughput estimation.
- Operational costs are assumed in this report; if more detailed studies are carried out, the number of employees, equipment and maintenance can be determined with these aspects the operational costs can be better estimated.
- Investigation among some possible investors if the IRR has to 15%. If e.g. the investors are willing to invest in a project with an IRR of 10%, the Ihavandhippolhu port is feasible.
- Better information on Salalah and Colombo to determine more exact requirements for Ihavandhippolhu is required, in this report the maximum port dues are estimated on 100 US$ and the average crane productivity on 40 moves/hour. Both assumptions are a bit arbitrary as clear figures on both other ports are not at hand.
- The disadvantages of a port on an island with minimal facilities are not clear. It is understandable that a port on the main land near a city has advantages from the presence of all kind of facilities. On Ihavandhippolhu the facilities for bunkering, water sewage and ship repair are still less flexible. And there is limited space to develop port related industries.

7.2 Recommendations on the port design.

- Extensive soil research has to be done on Ihavandhippolhu Atoll. The most important parameters are the foundation capacity for the quay wall, the volume of sand available for the reclamation and the compressive strength for cutting rock.
- The use of a hydraulic model gives better insight in the wave penetration and the downtime for the entrance channel and quay. With the results of this model the requirement for a breakwater can be determined.
- In order to complete the port the demands on the additional facilities, like ship repair and bunkering services have to be more specific. The planning and lay-out of these facilities can be combined with the terminal lay-out for a good impression of the area needed and the situation in the area.
- The terminal handling has to be simulated. This simulation is needed to determine the productivity and the required number of equipment in different situations.
- An extensive study to the quality of the reef and the possible threats due to port construction has to be done. This study can provide information for measures to limit the impact on the reef. A good quantification can give the value of the reef and the remaining measure that have to compensate inevitable loss.
List of references

2. Asian Development Bank, County Economic Review, the Maldives, October 2002
8. d’Angremond/ Bezuyen/ Van der Meulen e.a., Inleiding Waterbouwkunde, TU Delft, January 2003
11. Fairplay database
12. FISB, Hithadhoo transshipment port, 1998
15. Looij, J.J. van de, Port Development Huvarafushi Transshipment Port, Papendrecht 2002
17. Ministry of Home Affairs, Housing and Environment, First National Communication of Maldives to the UNFCCC, Maldives, 2001
22. PIANC, Criteria for Moored Ships in Harbors, Brussels 1995
Ihavandhippolhu Atoll Transshipment Port


27. Welters, Prof. Drs. H.W.H et al, Port Economics, Rotterdam, September 2002

28. Wijnolst, N et al., Malacca-Max, the ultimate container carrier, the Netherlands, 1999

29. Worldbank, Port Reform Toolkit, 2001


Websites:

1. Bishopmuseum.org/research/nwhi/geoact.shtml, last visited on July 16th 2003
2. Blonnet.com, Last visited at May 25th 2003
3. Ippc.ch, last visited on 31st of July 2003
5. Parahol.com/maldives/geography, last visited on August 1st 2003
6. Port-technology.com, last visited October 3rd 2003
7. Salalahport.com, Last visited at June 3rd 2003
8. Slpa.lk, Last visited at May 20th 2003
10. Weather.unisys.com/hurricane/indian_oc, last visited on October 29th 2003
Ihavandhippolhu Atoll Transshipment Port

Development of a Container Transshipment Port on Ihavandhippolhu Atoll, Maldives

Master of Science Thesis Niek van der Sluijs

Appendices

Supervisors:

Delft University of Technology:

Prof. ir. H. Ligteringen
Ir. R. Groenveld
Ir. B.A. Pielage

Hydronamic/ Royal Boskalis Westminster nv:

Ir. G.H. van Raalte

Hydronamic Engineering Department BV
Royal Boskalis Westminster NV

Delft University of Technology
Faculty of Civil Engineering and Geosciences
Ihavandhipholhu Atoll Transshipment Port

Table of Contents:

APPENDIX I : SAILING DISTANCES ........................................................................................................3
APPENDIX II : CONTAINER VESSEL SIZE VS. DIMENSIONS ..............................................................5
APPENDIX III : RESULTS OF BESTFIT ..................................................................................................7
APPENDIX IV : SOIL INVESTIGATION ..................................................................................................10
APPENDIX V : HURRICANES ...............................................................................................................12
APPENDIX VI : BERTH CALCULATIONS .............................................................................................15
APPENDIX VII : DESIGNS ..................................................................................................................21
APPENDIX VIII : MULTI CRITERIA EVALUATION MODELS ...............................................................28
APPENDIX IX : RANKING SYSTEM FOR OBTAINING WEIGHTS .........................................................33
APPENDIX X : SCORES OF THE PRELIMINARY DESIGNS .................................................................39
APPENDIX XI : FINANCIAL RESULTS ................................................................................................43
APPENDIX XII : SPECIFICATIONS OF TERMINAL EQUIPMENT ..........................................................47
APPENDIX XIII : TABLES QUEUING THEORIES ...............................................................................50
APPENDIX XIV : AUTOCAD DRAWINGS ............................................................................................51
Appendix I: Sailing distances

In section 2.2 a comparison of some ports on their distances to other ports is made. The sum of the figures in one column or a row is a measure for the allocation of that port.
**Ihavandhipholhu Atoll Transshipment Port**

**Description:**
A comparison is made of the sailing distances between main ports as R’dam and S’pore and the Indian Ocean hubs, as well as a comparison between the hubs and the import/export markets (Mombasa, Karachi, etc.).

**Appendix: I-1**

**Name:** sailing distances

**Section number:** 2.2

**Scale:**
Appendix II: Container vessel size vs. dimensions

Recent trends in container vessel size show that the capacity is increasing rapidly. In the chart in this appendix, the dimensions from the ships from the Fairplay database [11] are plotted and a trend line is added with a varying threshold. The upper and lower boundaries are displayed.
Description:
The vessel dimensions are plotted on logarithmic scale. The trend lines give an estimation of the development of the dimensions compared with the development of the capacity.

Appendix: II-1

Name: Vessel dimensions
Section number: 2.5.2
Scale:
Appendix III: Results of BestFit

BestFit is a statistical computer program to determine the best fitting curve for a certain distribution. The wave data obtained from Waveclimate is used as input (see section 3.1.2). The second page shows the result of the different tests (Chi-square and Kolmogorov-Smirnov) and the ranking of the different distributions, the first page shows the graphical comparison.
Ihavandhippolhu Atoll Transshipment Port

Comparison of Input Distribution and Erlang(4.00,0.34)

Comparison of Input Distribution and Lognormal(1.37,0.75)

Comparison of Input Distribution and Weibull(2.02,1.59)

Comparison of Input Distribution and Gamma(4.15,0.33)

Description:
Different functions were tested and compared with the program BestFit, the best comparing distributions are showed above.

Appendix: III-1
Name: Comparison BestFit curves
Section number: 3.1.2
Scale:
### Ihavandhippolhu Atoll Transshipment Port

Statistics for UNTITLED
- Minimum = 0.0
- Maximum = 10.0
- Mode = 1.3
- Mean = 1.354793
- Std Deviation = 0.665111
- Variance = 0.442372
- Skewness = 1.078909
- Kurtosis = 4.24645

Input Settings:
- Type of Fit: Full Optimization

Tests Run: Chi-Square

<table>
<thead>
<tr>
<th>Function</th>
<th>Chi-Square</th>
<th>K-S Test Rank</th>
<th>K-S Test Rank</th>
<th>A-D Test Rank</th>
<th>A-D Test Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gamma(4.15,0.33)</td>
<td>0.486775</td>
<td>1</td>
<td>0.064664</td>
<td>3</td>
<td>N/A</td>
</tr>
<tr>
<td>Erlang(4.00,0.34)</td>
<td>0.490799</td>
<td>2</td>
<td>0.064117</td>
<td>2</td>
<td>N/A</td>
</tr>
<tr>
<td>Weibull(2.02,1.59)</td>
<td>0.911167</td>
<td>3</td>
<td>0.122762</td>
<td>6</td>
<td>N/A</td>
</tr>
<tr>
<td>Logistic(1.24,0.37)</td>
<td>0.989954</td>
<td>4</td>
<td>0.078766</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>Lognormal2(0.22,0.64)</td>
<td>1.052248</td>
<td>5</td>
<td>0.083495</td>
<td>5</td>
<td>N/A</td>
</tr>
<tr>
<td>Binomial(10.00,8.12e-2)</td>
<td>2.383244</td>
<td>6</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>HyperGeo(31.00,10.00,3.13e+2)</td>
<td>2.46255</td>
<td>7</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Beta(1.37,8.28) * 10.00</td>
<td>2.538494</td>
<td>8</td>
<td>0.159873</td>
<td>8</td>
<td>N/A</td>
</tr>
<tr>
<td>Poisson(0.94)</td>
<td>2.573412</td>
<td>9</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Expon(1.35)</td>
<td>3.976696</td>
<td>10</td>
<td>0.274621</td>
<td>9</td>
<td>N/A</td>
</tr>
<tr>
<td>NegBin(1.00,0.42)</td>
<td>4.585326</td>
<td>11</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Chisq(1.00)</td>
<td>5.862452</td>
<td>12</td>
<td>1.137651</td>
<td>13</td>
<td>N/A</td>
</tr>
<tr>
<td>Geomet(0.42)</td>
<td>6.044439</td>
<td>13</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Erl(0.47)</td>
<td>7.353003</td>
<td>14</td>
<td>0.68976</td>
<td>11</td>
<td>N/A</td>
</tr>
<tr>
<td>Triang(0.00,0.60,10.00)</td>
<td>8.196603</td>
<td>15</td>
<td>0.532981</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>Lognormal(1.37,0.75)</td>
<td>9.235583</td>
<td>16</td>
<td>0.044599</td>
<td>1</td>
<td>N/A</td>
</tr>
<tr>
<td>Pareto(1.01,0.00)</td>
<td>4.62e+05</td>
<td>17</td>
<td>0.995495</td>
<td>12</td>
<td>N/A</td>
</tr>
<tr>
<td>Normal(1.35,0.67)</td>
<td>1.96E+08</td>
<td>18</td>
<td>0.126687</td>
<td>7</td>
<td>N/A</td>
</tr>
</tbody>
</table>

### Description:
Different tests of BestFit result in different rankings. The tests ran, their results and the rankings are showed in the table.

### Appendix: III-2
- Name: Rankings BestFit
- Section number: 3.1.2
- Scale:
Appendix IV: Soil investigation

Boskalis Dolman BV performed a soil research on another atoll of the Maldives named Fuah Mulaka. A total of 6 boreholes results in some overall characteristics for the soil. In this appendix a soil profile and the sieve curve are shown. The boreholes are not deep enough penetrated; to know construction possibilities in this port design characteristics up to CD -30m are acquired for foundation possibilities of the quay wall. The soil on Ihavandhippolhu however is assumed to be the same.
Ihavandhippolhu Atoll Transshipment Port

### Soil investigation Fuah Mulaka, Maldives

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latitude</td>
<td>0.15 N</td>
</tr>
<tr>
<td>Longitude</td>
<td>73.25 O</td>
</tr>
<tr>
<td>Samples</td>
<td>6</td>
</tr>
<tr>
<td>D10</td>
<td>312 µm</td>
</tr>
<tr>
<td>D50</td>
<td>500 µm</td>
</tr>
<tr>
<td>D60</td>
<td>550 µm</td>
</tr>
<tr>
<td>D90</td>
<td>779 µm</td>
</tr>
<tr>
<td>Point load</td>
<td>2.09 to 5.55 Mpa</td>
</tr>
<tr>
<td>Grain weight sand</td>
<td>2.722 kg/l</td>
</tr>
<tr>
<td>Permeability k</td>
<td>2.20E-03 m/s</td>
</tr>
</tbody>
</table>

### Average soil conditions

<table>
<thead>
<tr>
<th>Depth below sea bed level</th>
<th>Soil Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>-2</td>
<td>Hard coral rock</td>
</tr>
<tr>
<td>-4</td>
<td>Loose coral rock</td>
</tr>
<tr>
<td>-6</td>
<td>Coral sand/ loose coral rock with pieces of coral</td>
</tr>
<tr>
<td>-8</td>
<td></td>
</tr>
<tr>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>-12</td>
<td></td>
</tr>
<tr>
<td>-14</td>
<td></td>
</tr>
<tr>
<td>-16</td>
<td></td>
</tr>
</tbody>
</table>

### Grainsize distribution total sample

<table>
<thead>
<tr>
<th>Grainsize (µm)</th>
<th>% passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>20</td>
</tr>
<tr>
<td>20</td>
<td>40</td>
</tr>
<tr>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
</tr>
<tr>
<td>50</td>
<td>100</td>
</tr>
</tbody>
</table>

**Description:**
The average characteristics of the 6 boreholes are shown in the table. Other figures are an average soil profile and a sieve curve.

**Appendix:** IV-1

- **Name:** Geophysical conditions
- **Section number:** 3.1.5
- **Scale:**
Appendix V: Hurricanes

The data on the hurricanes is collected from a website [10]; this site has data on all track coordinates and wind speed of depressions since 1945. 23 Cyclones have been passing Ihavandhippolhu, but most of them still on a certain distance. In the figures the seasonality is shown and the classification of the cyclones, furthermore two track plots are included.
Description:
The hurricane tracks that passed the square between 5° and 10° Latitude and 70° and 75° Longitude in the last 50 years are counted and categorised according to the Saffir-Simpson Scale. In the first chart the seasonality of cyclones is expressed.

<table>
<thead>
<tr>
<th>Category</th>
<th>Wind speed (kts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tropical Depression</td>
<td>&lt;34</td>
</tr>
<tr>
<td>Tropical Storm</td>
<td>34-64</td>
</tr>
<tr>
<td>Cyclone1</td>
<td>64-83</td>
</tr>
<tr>
<td>Cyclone2</td>
<td>83-96</td>
</tr>
<tr>
<td>Cyclone3</td>
<td>96-113</td>
</tr>
<tr>
<td>Cyclone4</td>
<td>113-135</td>
</tr>
<tr>
<td>Cyclone5</td>
<td>&gt;135</td>
</tr>
<tr>
<td>Unknown</td>
<td>Before 1977 (no measurements)</td>
</tr>
</tbody>
</table>

Appendix: V-1

Name: Prob. and season. of Cyclones

Section number: 3.1.6

Scale:
**Description:**
The tracks are plotted. Note that there is a higher density along the 15-20° which is not displayed, because the tracks do not pass the square around Ihavandhippolhu. The distance between two degrees latitude is 60 miles. The distance of most tracks with Ihavandhippolhu is therefore still large.

**Appendix:** V-2

**Name:** Hurricane tracks

**Section number:** 3.1.6

**Scale:**
Appendix VI: Berth Calculations

In section 3.2.2 the quay length is determined with the queuing theory. For several distributions of relay and feeder ing transshipment and a future situation with Suezmax vessels, the minimal number of berths is calculated. The table with the waiting times according to an E2/E2/n model is included in this appendix. Furthermore the calculations of each case, as well for a situation with one berth as for the situation with the required number of berths, are included.
<table>
<thead>
<tr>
<th>Utilisation (u)</th>
<th>Number of servers (n)</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.1</td>
<td>0.0166</td>
<td>0.0006</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>0.2</td>
<td>0.0604</td>
<td>0.0065</td>
<td>0.0011</td>
<td>0.0002</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>0.3</td>
<td>0.1310</td>
<td>0.0235</td>
<td>0.0062</td>
<td>0.0019</td>
<td>0.0007</td>
<td>0.0002</td>
<td>0.0001</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td>0.4</td>
<td>0.2355</td>
<td>0.0576</td>
<td>0.0205</td>
<td>0.0085</td>
<td>0.0039</td>
<td>0.0019</td>
<td>0.0009</td>
<td>0.0005</td>
<td>0.0003</td>
<td>0.0001</td>
<td></td>
</tr>
<tr>
<td>0.5</td>
<td>0.3904</td>
<td>0.1181</td>
<td>0.0512</td>
<td>0.0532</td>
<td>0.0142</td>
<td>0.0082</td>
<td>0.0050</td>
<td>0.0031</td>
<td>0.0020</td>
<td>0.0013</td>
<td></td>
</tr>
<tr>
<td>0.6</td>
<td>0.6306</td>
<td>0.2222</td>
<td>0.1103</td>
<td>0.0639</td>
<td>0.0400</td>
<td>0.0265</td>
<td>0.0182</td>
<td>0.0128</td>
<td>0.0093</td>
<td>0.0069</td>
<td></td>
</tr>
<tr>
<td>0.7</td>
<td>1.0391</td>
<td>0.4125</td>
<td>0.2275</td>
<td>0.1441</td>
<td>0.0988</td>
<td>0.0712</td>
<td>0.0532</td>
<td>0.0407</td>
<td>0.0319</td>
<td>0.0258</td>
<td></td>
</tr>
<tr>
<td>0.8</td>
<td>1.8653</td>
<td>0.8300</td>
<td>0.4600</td>
<td>0.3300</td>
<td>0.2300</td>
<td>0.1900</td>
<td>0.1400</td>
<td>0.1200</td>
<td>0.0900</td>
<td>0.0900</td>
<td></td>
</tr>
<tr>
<td>0.9</td>
<td>4.3590</td>
<td>2.0000</td>
<td>1.2000</td>
<td>0.9200</td>
<td>0.6500</td>
<td>0.5700</td>
<td>0.4400</td>
<td>0.4000</td>
<td>0.3200</td>
<td>0.3000</td>
<td></td>
</tr>
</tbody>
</table>

**Description:**
This table gives the waiting times in units of the service time, when the number of berths and the utilisation are known.

**Appendix:** VI-1

**Name:** Waiting time table for E2/E2/n

**Section number:** 3.2.2

**Scale:**
**Ihavandhippolhu Atoll Transshipment Port**

### Case 1

1 **Used model:** E2/E2/n

2 **Service tijd (X):**

   - \( p \) Crane productivity: moves/hour
   - \( f \) TEU factor
   - Factor for loading/unloading and additional time

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>Cv</th>
<th>Nc</th>
<th>X (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainline vessel relay</td>
<td>0</td>
<td>3000</td>
<td>5</td>
<td>21.00</td>
</tr>
<tr>
<td>Mainline vessel feeder</td>
<td>63</td>
<td>4000</td>
<td>5</td>
<td>28.00</td>
</tr>
<tr>
<td>Average relay and feeder</td>
<td>63</td>
<td>4000</td>
<td>5</td>
<td>28.00</td>
</tr>
<tr>
<td>Feeders 2nd generation</td>
<td>250</td>
<td>1000</td>
<td>2</td>
<td>28.00</td>
</tr>
</tbody>
</table>

3 **Utilisation (?)**

   - Number of berths: 1
     - Super Post Panamax berth
     - Feeder berth
     - Berth utilisation (?): 0.201

4 **Acceptable waiting times**

   - The waiting times accepted by shipping companies are:
     
     - (in % of service time) 5% 10%
     
     With the given number of berths and utilisation, the table gives a waiting time of:
     
     - 6.04% 186.53%

3 **Utilisation (?)**

   - Number of berths: 2
     - Super Post Panamax berth
     - Feeder berth
     - Berth utilisation (?): 0.101 0.400

4 **Acceptable waiting times**

   - The waiting times accepted by shipping companies are:
     
     - (in % of service time) 5% 10%
     
     With the given number of berths and utilisation, the table gives a waiting time of:
     
     - 0.06% 5.76%

3 **Utilisation (?)**

   - Number of berths: 2
     - Super Post Panamax berth
     - Feeder berth
     - Berth utilisation (?): 0.101 0.799
     - Berth 1 0.095  Berth 2 0.006  Berth 2 0.400  Berth 3 0.400

4 **Acceptable waiting times**

   - The waiting times accepted by shipping companies are:
     
     - (in % of service time) 5% 5% 10%
     
     With the given number of berths and utilisation, the table gives a waiting time of:
     
     - 0.06% 5.88%

---

**Description:**

Case 1 assumes 0% relay transshipment. Calculations are shown for 1 berth per vessel type, 2 berths per vessel type and 3 berths with one combined berth. In the last situations the waiting times are sufficiently low.

**Appendix:** VI-2

**Name:** Waiting times case 1

**Section number:** 3.2.2

**Scale:**
### Case 2

*Used model:* E2/E2/n

#### Service tijd (X):

<table>
<thead>
<tr>
<th>p</th>
<th>Crane productivity moves/hour</th>
<th>40</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>f</td>
<td>TEU factor</td>
<td>1.5</td>
<td></td>
</tr>
</tbody>
</table>

*Factor for loading/unloading and additional time:* 2.1

#### Type | N | Cv | Nc | X (hour) |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>mainline vessel relay</td>
<td>Super Post Panamax</td>
<td>42</td>
<td>3000</td>
<td>5</td>
</tr>
<tr>
<td>mainline vessel feeder</td>
<td>Super Post Panamax</td>
<td>47</td>
<td>4000</td>
<td>5</td>
</tr>
<tr>
<td>Average relay and feeding</td>
<td>Super Post Panamax</td>
<td>89</td>
<td>3528</td>
<td>5</td>
</tr>
<tr>
<td>Feeders</td>
<td>2nd generation</td>
<td>188</td>
<td>1000</td>
<td>2</td>
</tr>
</tbody>
</table>

### 3 Utilisation (?)

<table>
<thead>
<tr>
<th>Number of berths:</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super Post Panamax berth</td>
<td>0.251</td>
<td></td>
</tr>
<tr>
<td>Feeder berth</td>
<td>0.601</td>
<td></td>
</tr>
</tbody>
</table>

#### Acceptable waiting times

- The waiting times accepted by shipping companies are:
  - (in % of service time): 5% 10%

  - With the given number of berths and utilisation, the table gives a waiting time of:
    - 9.36% 63.06%

---

### 3 Utilisation (?)

<table>
<thead>
<tr>
<th>Number of berths:</th>
<th>2</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super Post Panamax berth</td>
<td>0.125</td>
<td></td>
</tr>
<tr>
<td>Feeder berth</td>
<td>0.300</td>
<td></td>
</tr>
</tbody>
</table>

#### Acceptable waiting times

- The waiting times accepted by shipping companies are:
  - (in % of service time): 5% 10%

  - With the given number of berths and utilisation, the table gives a waiting time of:
    - 0.21% 2.35%

---

### 3 Utilisation (?)

<table>
<thead>
<tr>
<th>Number of berths:</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super Post Panamax berth</td>
<td>0.125</td>
<td></td>
</tr>
<tr>
<td>Feeder berth</td>
<td>0.601</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Berth 1</th>
<th>Berth 2</th>
<th>Berth 2</th>
<th>Berth 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.227</td>
<td>0.023</td>
<td>0.300</td>
<td>0.300</td>
</tr>
</tbody>
</table>

#### Acceptable waiting times

- The waiting times accepted by shipping companies are:
  - (in % of service time): 5% 5% 10%

  - With the given number of berths and utilisation, the table gives a waiting time of:
    - 0.21% 2.70%

---

**Description:**
Case 2 assumes 25% relay transshipment. Calculations are shown for 1 berth per vessel type, 2 berths per vessel type and 3 berths with one combined berth. In the last situations the waiting times are sufficiently low.

**Appendix:** VI-3

**Name:** Waiting times case 2

**Section number:** 3.2.2

**Scale:**
### Case 3

1. **Used model:** E2/E2/n

2. **Service tijd (X):**
   - p: Crane productivity (moves/hour) 40 25
   - f: TEU factor 1,5
   - Factor for loading/unloading and additional time 2,1

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>Cv</th>
<th>Nc</th>
<th>X (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mainline vessel relay</td>
<td>83</td>
<td>3000</td>
<td>5</td>
<td>21,00</td>
</tr>
<tr>
<td>mainline vessel feeding</td>
<td>31</td>
<td>4000</td>
<td>5</td>
<td>28,00</td>
</tr>
<tr>
<td>Average relay and feeding</td>
<td>114</td>
<td>3272</td>
<td>5</td>
<td>22,90</td>
</tr>
<tr>
<td>Feeders</td>
<td>2nd generation</td>
<td>125</td>
<td>1000</td>
<td>2</td>
</tr>
</tbody>
</table>

3. **Utilisation (?)**

<table>
<thead>
<tr>
<th>Number of berths:</th>
<th>1</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berth utilisation (?):</td>
<td>0,298</td>
<td>0,400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>Cv</th>
<th>Nc</th>
<th>X (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super Post Panamax berth</td>
<td>83</td>
<td>3000</td>
<td>5</td>
<td>21,00</td>
</tr>
<tr>
<td>Feeder berth</td>
<td>125</td>
<td>1000</td>
<td>2</td>
<td>28,00</td>
</tr>
</tbody>
</table>

4. **Acceptable waiting times**

<table>
<thead>
<tr>
<th>(in % of service time)</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>With the given number of berths and utilisation, the table gives a waiting time of:</td>
<td>13,10%</td>
<td>23,55%</td>
</tr>
</tbody>
</table>

3. **Utilisation (?)**

<table>
<thead>
<tr>
<th>Number of berths:</th>
<th>2</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berth utilisation (?):</td>
<td>0,199</td>
<td>0,266</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>Cv</th>
<th>Nc</th>
<th>X (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Super Post Panamax berth</td>
<td>83</td>
<td>3000</td>
<td>5</td>
<td>21,00</td>
</tr>
<tr>
<td>Feeder berth</td>
<td>125</td>
<td>1000</td>
<td>2</td>
<td>28,00</td>
</tr>
</tbody>
</table>

4. **Acceptable waiting times**

<table>
<thead>
<tr>
<th>(in % of service time)</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>With the given number of berths and utilisation, the table gives a waiting time of:</td>
<td>0,35%</td>
<td>0,65%</td>
</tr>
</tbody>
</table>

3. **Utilisation (?)**

<table>
<thead>
<tr>
<th>Number of berths:</th>
<th>2</th>
<th>1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berth utilisation (?):</td>
<td>0,149</td>
<td>0,400</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Berth 1</th>
<th>Berth 2</th>
<th>Berth 2</th>
<th>Berth 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,259</td>
<td>0,039</td>
<td>0,200</td>
<td>0,200</td>
</tr>
</tbody>
</table>

4. **Acceptable waiting times**

<table>
<thead>
<tr>
<th>(in % of service time)</th>
<th>5%</th>
<th>5%</th>
<th>10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>With the given number of berths and utilisation, the table gives a waiting time of:</td>
<td>0,35%</td>
<td>1,17%</td>
<td></td>
</tr>
</tbody>
</table>

**Description:**
Case 3 assumes 50% relay transshipment. Calculations are shown for 1 berth per vessel type, 2 berths per vessel type and 3 berths with one combined berth. In the last situations the waiting times are sufficiently low.

**Appendix:** VI-4

**Name:** Waiting times case 3

**Section number:** 3.2.2

**Scale:**
## Case 4

1. **Used model:** E2/E2/n

2. **Service tijd (X):**
   - **p**  - Crane productivity  - moves/hour  - 40  - 25
   - **f**  - TEU factor  - 1,5
   - Factor for loading/unloading and additional time  - 2,1

<table>
<thead>
<tr>
<th>Type</th>
<th>N</th>
<th>Cv</th>
<th>Nb</th>
<th>X (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>mainline vessel relay</td>
<td>Super Post Panamax</td>
<td>41</td>
<td>6000</td>
<td>7</td>
</tr>
<tr>
<td>mainline vessel feedering</td>
<td>Super Post Panamax</td>
<td>16</td>
<td>8000</td>
<td>7</td>
</tr>
<tr>
<td>Average relay and feedering</td>
<td>Super Post Panamax</td>
<td>57</td>
<td>6561</td>
<td>7</td>
</tr>
<tr>
<td>Feeders</td>
<td>2nd generation</td>
<td>125</td>
<td>1000</td>
<td>2</td>
</tr>
</tbody>
</table>

3. **Utilisation (?)**

<table>
<thead>
<tr>
<th>Number of berths:</th>
<th>1</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Berth utilisation (?)</td>
<td>0,213</td>
<td>0,200</td>
</tr>
</tbody>
</table>

4. **Acceptable waiting times**

   - The waiting times accepted by shipping companies are: (in % of service time)
     - 5%
     - 10%

   - With the given number of berths and utilisation, the table gives a waiting time of:
     - 6,04%
     - 0,65%

---

**Description:**

In case 4 the Super-Post Panamax vessels are replaced by the Suezmax type of vessels. Calculations are shown for 1 berth for Suezmax vessels and 2 berths for Feeder vessels. The parcel size increases and the number of ships decreases in this case.

**Appendix:** VI-5

**Name:** Waiting times case 4

**Section number:** 3.2.2

**Scale:**
Appendix VII: Designs

In this appendix a map of the area with the restricted areas and the different groups of island to construct a port on is given. In section 3.3 the 8 designs are made and evaluated, these designs and the 3 preliminary designs are included.
Description:
An overview of the restricted areas and the possible areas follow from this small map. Together with the wave loads the eight designs from VII-2 and VII-3 can be generated. The designs vary on location and entrance channel.

Appendix: VII-1
Name: Restricted areas
Section number: 3.3
Scale: 1 cm : 1 nm (nautical mile)
Description:
The first 4 different lay-outs that are used in the pre-selection in section are given.

Appendix: VII-2

Name: Designs 1a to 2a

Section number: 3.3

Scale: 1 : 100,000 cm / 1.6 cm : 1 nmile
Description:
The second 4 different lay-outs that are used in the pre-selection in section 3.3.2 are given.

Appendix: VII-3
Name: Designs 2b to 3c
Section number: 3.3
Scale: 1 : 100,000 cm / 1.6 cm : 1 n mile
Description:
This first preliminary design is located on Uligamu. To reduce the wave agitation, an indented berth and a short breakwater are constructed.

Appendix: VII-4
Name: Pd1: Uligamu option
Section number: 3.4
Scale: 3 : 100,000 cm
Description:
The second preliminary design is constructed on Mulhadhoo; a breakwater has to protect the vessels against wave agitation.

Appendix: VII-5
Name: Pd2: Mulhadhoo option
Section number: 3.4
Scale: 3 : 100,000 cm
Description:
The third preliminary design is located on Huvarafushi. An advantage is the possible approach from the east, which is not shown in the figure.

Appendix: VII-6
Name: Pd3: Huvarafushi option
Section number: 3.4
Scale: 3 : 100,000 cm
Appendix VIII: Multi Criteria Evaluation Models

From [26] several non-economic methods to appraise projects are explained in this appendix. All the methods have advantages and disadvantages that are listed as well. In section 4.1 the choice for the evaluation method is explained.
Simple non-compensatory methods

The methods are called ‘simple’ because there is no trading-off of the disadvantages on one criterion against the advantages on another. There is no process of decomposition and aggregation. These methods lead to less rational outcomes than the methods explained in the next sections. Examples of simple non-compensatory methods are: dominance, satisfying, sequential elimination and attitude-oriented methods.

Advantages:
- Very easy to carry out.

Disadvantages:
- No decomposition and thus no possibilities to evaluate the interactions between the different criteria.
- Not useful for complex engineering projects.

Simple Additive Weighting (SAW) Method

The SAW finds its basis in Multi Attribute Utility Theory (MAUT). This method uses U, which expresses the ‘utility’ function of a project option in terms of a number of criteria. With this U the absence or existence of preference between examined options can be determined. All separate utility functions for environment, economic, social and technical aspects, are combined within one multi attribute utility function. The dependence or independence of the criteria is important and the criteria have to be selected carefully to minimise interaction.

The SAW calculates an overall weighted score V, comparable with U. For each criterion the different measurement scales have to be normalised, these normalised ratings are multiplied by an importance weight. The overall weighted score \( V_i \) is then:

\[
V_i = \sum_{j=1}^{n} w_j r_{ij}
\]

In which:
- \( w_j \) = weight for criterion j
- \( r_{ij} \) = rating for option i on criterion j

A multiple-criterion problem is now reduced to a single dimension problem. When the construction costs and revenues are combined in a CBA as one criterion, it can be compared with the other criteria. All criteria scores can be based on their raw monetary value. The weight has to be based on their relative importance. By the simple multiplication the overall score is calculated. Again the different costs aspects have to be separated so that there is no interaction or double-counting.
Sensitivity testing to gauge the effect that incremental changes have on the preliminary result is possible. Increments in heavily weighted criteria can cause significant changes. Criteria involving high uncertainty and subjectivity are important as well.

Probabilistic additive weighting is an option, if one criterion has more possibilities with a probability of occurrence. The expected value has to be calculated. The variance is a measure of the dispersion around the expected value. The standard deviation is the square root of the variance. The distributions of the criteria have to be normalised and can in that case be aggregated, this results in a new expected value of the overall score with its own standard deviation.

It is important to assign weights to the decision criteria on a rational base. The most common way is to rank the criteria and calculate the weights with a translation equation. Other ways are: pair wise comparison, resistance to change grid, hierarchy of weights, multiple weighting systems and scoring systems for the criteria.

Checklists are a form of SAW, including the following methods:
- Environmental Evaluation System
- Sondheim’s Environmental Assessment Methodology
- Mongkol’s methodology

**Advantages:**
- Easy to perform and a quick, univocal decision-making
- Suitable for complex engineering projects
- Different weight distributions to reflect certain opinions
- Sensitivity analysis possible

**Disadvantages:**
- Subjectivity of weights and scores
- Mechanical character of decision-making

**Analytic Hierarchy Process (AHP)**

The method described by Saaty (1977) [26] is the most familiar AHP, this method provides a good methodology for modelling unstructured decision-making problems. It is based on defining a hierarchy, so the decision-problem can be broken down into individual elements. Then the functional interactions between the components and the impacts on the whole systems have to be determined. A pair wise comparison results in a matrix.

<table>
<thead>
<tr>
<th>Description:</th>
<th>Appendix: VIII-2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Name: Analytic Hierarchic Process</td>
<td></td>
</tr>
<tr>
<td>Section number: 4.1</td>
<td></td>
</tr>
<tr>
<td>Scale:</td>
<td></td>
</tr>
</tbody>
</table>
The Overall objective is divided in main criteria, which are again divided in sub-criteria. The weight of the sub-criteria comes from the pair wise judgements, first the main criteria (Cr1 and Cr2) are judged and normalised and then per main criterion the sub-criteria (Cr1,1 and Cr1,2) are judged and normalised. The exact normalisation process requires some iteration steps. Three matrices result in a 4x1 matrix (a weight for each sub-criteria).

Then each possible option (A1 or A2) is judged on each sub-criterion and is again normalised. The 4 matrices result in a 2x4 matrix. Multiplication of the 4x1 and the 2x4-matrix gives the overall weighted score V.

\[
\begin{bmatrix}
V_{A1} \\
V_{A2}
\end{bmatrix} = 
\begin{bmatrix}
r_{A1,Cr1,1} & \cdots & \cdots & r_{A1,Cr2,2} \\
\cdots & \cdots & \cdots & \cdots 
\end{bmatrix} \times 
\begin{bmatrix}
w_{Cr1,1} \\
w_{Cr1,2} \\
w_{Cr2,1} \\
w_{Cr2,2}
\end{bmatrix}
\]

Advantages:
- Useful in engineering problems where quantitative valuations do not exist.
- Pair wise comparison excludes subjectivity

Disadvantages:
- Extensive method with lot of calculations
- Mechanical character of decision-making

Description:

Name: Analytic Hierarchic Process
Section number: 4.1
Appendix: VIII-3
Scale:
Concordance Analysis Techniques

PROMETHEE I:
For a given pair of options, comparison of their relative performance takes place on each individual criterion. For the same or better performance a 1 is scored and for a worse performance a 0. A ranking of each option on the different criteria is needed. The weights are determined with the procedures outlined in by the SAW method. The concordance index $C_{a,b}$ for options a and b is the multiplication of the criterion concordance by its normalised weight.

A concordance matrix can be made, with each possible comparison. For an option the figures on its row, tell about the domination of this option above others. The figures in the column give an indication to what extend an option is dominated by others. Two rankings can be made, one on the sums of the row scores and one on the sums of the column scores. By subtracting both score the overall ranking can be made. The best scoring option is the preferred option.

\[
\begin{array}{ccc|c}
  & a & b & c & \text{sum} \\
 a & - & C_{a,b} & - & - \\
b & - & - & - & - \\
c & - & - & - & - \\
\text{sum} & - & - & - & - \\
\end{array}
\]

In which:
$C_{a,b} = \text{dominance of } a \text{ over } b$

Other Concordance Techniques:
ELECTRE I: uses a discordance index and determines the rankings with the use of a chosen threshold. More advanced methods of PROMETHEE and ELECTRE exist and are possible method to use when deciding to apply a concordance method to choose the preferred option.

Advantages:
- Suitable for a large number of project options
- Useful when project options are incomparable
- Possible to give a ranking without sufficient project information.

Disadvantages:
- Simple ranking of options, no relative ranking but only hierarchy
- Mechanical character of decision-making

Description: Concordance Techniques
Appendix: VIII-4
Name: Concordance Techniques
Section number: 4.1
Scale:
Appendix IX: Ranking system for obtaining weights

In section 4.2.3 the method for obtaining weights to criteria is explained. In this appendix the criteria are ranked for the different stakeholders and converted to a weight. The method is easy to carry out, but to reduce subjectivity, the calculations are shown.
# Ihavandhippolhu Atoll Transshipment Port

## Weights distribution model

### Port Authority

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1 Competitiveness / Operational</td>
<td>1</td>
<td>1,5</td>
<td>3,5</td>
<td>0,35</td>
</tr>
<tr>
<td>Cr2 Environment</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0,10</td>
</tr>
<tr>
<td>Cr3 Nautical aspects and safety</td>
<td>1</td>
<td>1,5</td>
<td>3,5</td>
<td>0,35</td>
</tr>
<tr>
<td>Cr4 Constructional</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>0,20</td>
</tr>
</tbody>
</table>

### Competitiveness / Operational

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1.1 Service time</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0,5</td>
</tr>
<tr>
<td>Cr1.2 Waiting time</td>
<td>2</td>
<td>2,5</td>
<td>1,5</td>
<td>0,25</td>
</tr>
<tr>
<td>Cr1.3 Reliability</td>
<td>2</td>
<td>2,5</td>
<td>1,5</td>
<td>0,25</td>
</tr>
</tbody>
</table>

### Environment

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr2.1 Affection of coral</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0,33</td>
</tr>
<tr>
<td>Cr2.2 Loss of land and flora</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0,17</td>
</tr>
<tr>
<td>Cr2.3 Liveability of the people</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0,50</td>
</tr>
</tbody>
</table>

### Nautical aspects and safety

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr3.1 Nautical safety and manoevrability</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>0,40</td>
</tr>
<tr>
<td>Cr3.2 Quay length and exchangeability of quays</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0,30</td>
</tr>
<tr>
<td>Cr3.3 Sailing time</td>
<td>3</td>
<td>3,5</td>
<td>1,5</td>
<td>0,15</td>
</tr>
<tr>
<td>Cr3.4 Downtime entrance channel</td>
<td>3</td>
<td>3,5</td>
<td>1,5</td>
<td>0,15</td>
</tr>
</tbody>
</table>

### Constructional

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr4.1 Expansion possibilities</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0,50</td>
</tr>
<tr>
<td>Cr4.2 Construction methodology</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0,17</td>
</tr>
<tr>
<td>Cr4.3 Construction time</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0,33</td>
</tr>
</tbody>
</table>

### Description:
The Port Authority cares about the performance of the port and this is mainly the competitiveness and safety.

### Appendix: IX-1

Name: Weights Port Authority

Section number: 4.2.3

Scale:
## Weights distribution model

### Government of Maldives

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1 Competitiveness / Operational</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td>Cr2 Environment</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>Cr3 Nautical aspects and safety</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>Cr4 Constructional</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>0.1</td>
</tr>
</tbody>
</table>

<p>| | | | | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>n-ri+1</td>
<td>wi</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

### Competitiveness / Operational

<table>
<thead>
<tr>
<th></th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1.1 Service time</td>
<td>1</td>
<td>1.5</td>
<td>2.5</td>
<td>0.41667 0.083</td>
</tr>
<tr>
<td>Cr1.2 Waiting time</td>
<td>1</td>
<td>1.5</td>
<td>2.5</td>
<td>0.41667 0.083</td>
</tr>
<tr>
<td>Cr1.3 Reliability</td>
<td>2</td>
<td>3</td>
<td>1</td>
<td>0.16667 0.033</td>
</tr>
</tbody>
</table>

### Environment

<table>
<thead>
<tr>
<th></th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr2.1 Affection of coral</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0.33 0.133</td>
</tr>
<tr>
<td>Cr2.2 Loss of land and flora</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0.17 0.067</td>
</tr>
<tr>
<td>Cr2.3 Liveability of the people</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0.50 0.200</td>
</tr>
</tbody>
</table>

### Nautical aspects and safety

<table>
<thead>
<tr>
<th></th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr3.1 Nautical safety and manoevability</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>0.40 0.120</td>
</tr>
<tr>
<td>Cr3.2 Quay length and exchangeability of quays</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0.10 0.030</td>
</tr>
<tr>
<td>Cr3.3 Sailing time</td>
<td>2</td>
<td>2.5</td>
<td>2.5</td>
<td>0.25 0.075</td>
</tr>
<tr>
<td>Cr3.4 Downtime entrance channel</td>
<td>2</td>
<td>2.5</td>
<td>2.5</td>
<td>0.25 0.075</td>
</tr>
</tbody>
</table>

### Constructional

<table>
<thead>
<tr>
<th></th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr4.1 Expansion possibilities</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0.50 0.050</td>
</tr>
<tr>
<td>Cr4.2 Construction methodology</td>
<td>2</td>
<td>2.5</td>
<td>1.5</td>
<td>0.25 0.025</td>
</tr>
<tr>
<td>Cr4.3 Construction time</td>
<td>2</td>
<td>2.5</td>
<td>1.5</td>
<td>0.25 0.025</td>
</tr>
</tbody>
</table>

### Description:

It is assumed that in this case the government of the Maldives is protecting its population and environment, and not acting as an investor and thus not caring about their income.

### Appendix: IX-2

Name: Weights Government Maldives

Section number: 4.2.4

Scale:
### Weights distribution model

#### Environmental Groups

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1 Competitiveness / Operational</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>0.1</td>
</tr>
<tr>
<td>Cr2 Environment</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>0.4</td>
</tr>
<tr>
<td>Cr3 Nautical aspects and safety</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0.3</td>
</tr>
<tr>
<td>Cr4 Constructional</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### Competitiveness / Operational

<table>
<thead>
<tr>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1.1 Service time</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cr1.2 Waiting time</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Cr1.3 Reliability</td>
<td>1</td>
<td>2</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr2.1 Affection of coral</td>
<td>1</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Cr2.2 Loss of land and flora</td>
<td>1</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Cr2.3 Liveability of the people</td>
<td>2</td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>

#### Environment

<table>
<thead>
<tr>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr3.1 Nautical safety and manoeuvrability</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>Cr3.2 Quay length and exchangeability of quays</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Cr3.3 Sailing time</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Cr3.4 Downtime entrance channel</td>
<td>2</td>
<td>3</td>
<td>2</td>
</tr>
</tbody>
</table>

#### Nautical aspects and safety

<table>
<thead>
<tr>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr4.1 Expansion possibilities</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Cr4.2 Construction methodology</td>
<td>1</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Cr4.3 Construction time</td>
<td>1</td>
<td>1.5</td>
<td>2.5</td>
</tr>
</tbody>
</table>

### Description:
Environmental groups obviously appraise the environmental criteria, like safety and affection of coral, the most important. They do not care about most other criteria.
## Weights distribution model

### Shipping company

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1 Competitiveness / Operational</td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>0,40</td>
</tr>
<tr>
<td>Cr2 Environment</td>
<td>4</td>
<td>4</td>
<td>1</td>
<td>0,10</td>
</tr>
<tr>
<td>Cr3 Nautical aspects and safety</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>0,30</td>
</tr>
<tr>
<td>Cr4 Constructional</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>0,20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

### Competitiveness / Operational

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr1.1 Service time</td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>0,50</td>
</tr>
<tr>
<td>Cr1.2 Waiting time</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>0,33</td>
</tr>
<tr>
<td>Cr1.3 Reliability</td>
<td>3</td>
<td>3</td>
<td>1</td>
<td>0,17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

### Environment

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr2.1 Affection of coral</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0,33</td>
</tr>
<tr>
<td>Cr2.2 Loss of land and flora</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0,33</td>
</tr>
<tr>
<td>Cr2.3 Liveability of the people</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>0,33</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>6</td>
</tr>
</tbody>
</table>

### Nautical aspects and safety

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr3.1 Nautical safety and manoeuvrability</td>
<td>1</td>
<td>1,5</td>
<td>3,5</td>
<td>0,35</td>
</tr>
<tr>
<td>Cr3.2 Quay length and exchangeability of quays</td>
<td>3</td>
<td>4</td>
<td>1</td>
<td>0,10</td>
</tr>
<tr>
<td>Cr3.3 Sailing time</td>
<td>1</td>
<td>1,5</td>
<td>3,5</td>
<td>0,35</td>
</tr>
<tr>
<td>Cr3.4 Downtime entrance channel</td>
<td>2</td>
<td>3</td>
<td>2</td>
<td>0,20</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

### Constructional

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Rank Position</th>
<th>Rank score (ri)</th>
<th>n-ri+1</th>
<th>wi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr4.1 Expansion possibilities</td>
<td>1</td>
<td>1,5</td>
<td>2,5</td>
<td>0,71</td>
</tr>
<tr>
<td>Cr4.2 Construction methodology</td>
<td>2</td>
<td>3,5</td>
<td>0,5</td>
<td>0,14</td>
</tr>
<tr>
<td>Cr4.3 Construction time</td>
<td>2</td>
<td>3,5</td>
<td>0,5</td>
<td>0,14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3,5</td>
</tr>
</tbody>
</table>

---

**Description:**
However they are a likely investor, the shipping company looks from the customer its point of view, in that case it is caring much about the service time, safety, waiting time and sailing time.

**Appendix: IX-4**

**Name:** Weights Shipping Company

**Section number:** 4.2.4

**Scale:**
### Weights distribution model

<table>
<thead>
<tr>
<th>Criteria</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environmental Groups</strong></td>
<td></td>
</tr>
<tr>
<td>Cr1 Competitiveness / Operational</td>
<td>0.231</td>
</tr>
<tr>
<td>Cr2 Environment</td>
<td>0.231</td>
</tr>
<tr>
<td>Cr3 Nautical aspects and safety</td>
<td>0.308</td>
</tr>
<tr>
<td>Cr4 Constructional</td>
<td>0.231</td>
</tr>
<tr>
<td></td>
<td>1.000</td>
</tr>
<tr>
<td><strong>Competitiveness / Operational</strong></td>
<td></td>
</tr>
<tr>
<td>Cr1.1 Service time</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr1.2 Waiting time</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr1.3 Reliability</td>
<td>0.231</td>
</tr>
<tr>
<td><strong>Environment</strong></td>
<td></td>
</tr>
<tr>
<td>Cr2.1 Affection of coral</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr2.2 Loss of land and flora</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr2.3 Liveability of the people</td>
<td>0.077</td>
</tr>
<tr>
<td><strong>Nautical aspects and safety</strong></td>
<td></td>
</tr>
<tr>
<td>Cr3.1 Nautical safety and manoeuvrability</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr3.2 Quay length and exchangeability of quays</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr3.3 Sailing time</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr3.4 Downtime entrance channel</td>
<td>0.077</td>
</tr>
<tr>
<td><strong>Constructional</strong></td>
<td></td>
</tr>
<tr>
<td>Cr4.1 Expansion possibilities</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr4.2 Construction methodology</td>
<td>0.077</td>
</tr>
<tr>
<td>Cr4.3 Construction time</td>
<td>0.231</td>
</tr>
</tbody>
</table>

**Description:**
As an extra evaluation possibility the weights are distributed equally.

**Appendix:** IX-5

**Name:** Equal weights

**Section number:** 4.2.4

**Scale:**
Appendix X: Scores of the preliminary designs

In section 4.2.5 the table with the scores of the different designs is shown. Together with the weights from Appendix IX the total weighted score can be calculated for each stakeholder. The comparison is again shown in section 4.2.6.
### Ihavandhippolhu Atoll Transshipment Port

<table>
<thead>
<tr>
<th>Port Authority</th>
<th>Score</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
<th>Score * weight</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.350</td>
<td>0.175</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>0.175</td>
<td>0.088</td>
<td>0.088</td>
<td>0.088</td>
</tr>
<tr>
<td></td>
<td>0.088</td>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
<td>0.044</td>
<td>0.088</td>
<td>0.044</td>
<td>0.044</td>
</tr>
<tr>
<td>0.003</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.017</td>
</tr>
<tr>
<td>0.017</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.008</td>
<td>0.028</td>
<td>0.008</td>
<td>0.008</td>
</tr>
<tr>
<td>0.050</td>
<td>0.50</td>
<td>0.75</td>
<td>0.00</td>
<td>0.00</td>
<td>0.025</td>
<td>0.038</td>
<td>0.004</td>
<td>0.000</td>
</tr>
<tr>
<td>0.140</td>
<td>0.75</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>0.105</td>
<td>0.140</td>
<td>0.070</td>
<td>0.070</td>
</tr>
<tr>
<td>0.053</td>
<td>0.75</td>
<td>0.50</td>
<td>0.25</td>
<td>0.50</td>
<td>0.053</td>
<td>0.026</td>
<td>0.013</td>
<td>0.013</td>
</tr>
<tr>
<td>0.053</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>0.053</td>
<td>0.053</td>
<td>0.053</td>
<td>0.053</td>
</tr>
<tr>
<td>0.100</td>
<td>0.00</td>
<td>0.50</td>
<td>0.75</td>
<td>0.00</td>
<td>0.00</td>
<td>0.050</td>
<td>0.075</td>
<td>0.075</td>
</tr>
<tr>
<td>0.033</td>
<td>0.25</td>
<td>0.25</td>
<td>0.75</td>
<td>0.50</td>
<td>0.008</td>
<td>0.008</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>0.067</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
<td>0.00</td>
<td>0.033</td>
<td>0.033</td>
<td>0.067</td>
<td>0.067</td>
</tr>
<tr>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.587</td>
<td>0.606</td>
<td>0.555</td>
<td>0.555</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Government</th>
<th>Score</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
<th>Score * weight</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.083</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.083</td>
<td>0.088</td>
<td>0.088</td>
<td>0.088</td>
</tr>
<tr>
<td>0.033</td>
<td>0.50</td>
<td>0.25</td>
<td>0.50</td>
<td>0.50</td>
<td>0.017</td>
<td>0.022</td>
<td>0.044</td>
<td>0.044</td>
</tr>
<tr>
<td>0.133</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.50</td>
<td>0.00</td>
<td>0.00</td>
<td>0.067</td>
<td>0.067</td>
</tr>
<tr>
<td>0.067</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.033</td>
<td>0.033</td>
<td>0.033</td>
<td>0.033</td>
</tr>
<tr>
<td>0.200</td>
<td>0.50</td>
<td>0.75</td>
<td>0.00</td>
<td>0.00</td>
<td>0.100</td>
<td>0.150</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>0.120</td>
<td>0.75</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
<td>0.090</td>
<td>0.120</td>
<td>0.060</td>
<td>0.060</td>
</tr>
<tr>
<td>0.030</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
</tr>
<tr>
<td>0.075</td>
<td>0.75</td>
<td>0.50</td>
<td>0.25</td>
<td>0.50</td>
<td>0.056</td>
<td>0.038</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>0.075</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
<td>0.50</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
<td>0.075</td>
</tr>
<tr>
<td>0.050</td>
<td>0.00</td>
<td>0.50</td>
<td>0.75</td>
<td>0.50</td>
<td>0.00</td>
<td>0.025</td>
<td>0.038</td>
<td>0.038</td>
</tr>
<tr>
<td>0.025</td>
<td>0.25</td>
<td>0.25</td>
<td>0.75</td>
<td>0.50</td>
<td>0.006</td>
<td>0.006</td>
<td>0.019</td>
<td>0.019</td>
</tr>
<tr>
<td>0.025</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
<td>0.00</td>
<td>0.013</td>
<td>0.013</td>
<td>0.025</td>
<td>0.025</td>
</tr>
<tr>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.530</td>
<td>0.671</td>
<td>0.525</td>
<td>0.525</td>
</tr>
</tbody>
</table>

**Description:**
For both the Port Authority and the Government Fd2 is the preferable design with respectively 0.606 and 0.671.

**Appendix:** X-1

**Name:** Scores

**Section number:** 4.2.5

**Scale:**
### Ihavandhippolhu Atoll Transshipment Port

#### Environmental groups

<table>
<thead>
<tr>
<th>Score</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.033</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.033</td>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.033</td>
<td>0.50</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>0.167</td>
<td>0.00</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.167</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.067</td>
<td>0.50</td>
<td>0.75</td>
<td>0.00</td>
</tr>
</tbody>
</table>

#### Score * weight

<table>
<thead>
<tr>
<th>Score * weight</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.033</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>0.017</td>
<td>0.033</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>0.017</td>
<td>0.008</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>0.083</td>
<td>0.083</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>0.033</td>
<td>0.002</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>0.090</td>
<td>0.120</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>0.030</td>
<td>0.030</td>
<td>0.030</td>
<td></td>
</tr>
<tr>
<td>0.045</td>
<td>0.080</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>0.000</td>
<td>0.017</td>
<td>0.025</td>
<td></td>
</tr>
<tr>
<td>0.021</td>
<td>0.021</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>0.042</td>
<td>0.042</td>
<td>0.083</td>
<td></td>
</tr>
<tr>
<td>0.471</td>
<td>0.511</td>
<td>0.553</td>
<td></td>
</tr>
</tbody>
</table>

#### Shipping Company

<table>
<thead>
<tr>
<th>Score</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.200</td>
<td>1.00</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.133</td>
<td>0.50</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.067</td>
<td>0.50</td>
<td>0.25</td>
<td>0.50</td>
</tr>
<tr>
<td>0.033</td>
<td>0.00</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.033</td>
<td>0.50</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>0.033</td>
<td>0.50</td>
<td>0.75</td>
<td>0.00</td>
</tr>
<tr>
<td>0.105</td>
<td>0.75</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.030</td>
<td>0.50</td>
<td>0.50</td>
<td>0.20</td>
</tr>
<tr>
<td>0.105</td>
<td>0.75</td>
<td>0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>0.060</td>
<td>1.00</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.143</td>
<td>0.00</td>
<td>0.50</td>
<td>0.75</td>
</tr>
<tr>
<td>0.029</td>
<td>0.25</td>
<td>0.25</td>
<td>0.75</td>
</tr>
<tr>
<td>0.029</td>
<td>0.50</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>1.000</td>
<td>0.587</td>
<td>0.617</td>
<td>0.544</td>
</tr>
</tbody>
</table>

#### Score * weight

<table>
<thead>
<tr>
<th>Score * weight</th>
<th>Pd1</th>
<th>Pd2</th>
<th>Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.200</td>
<td>0.100</td>
<td>0.100</td>
<td></td>
</tr>
<tr>
<td>0.067</td>
<td>0.133</td>
<td>0.067</td>
<td></td>
</tr>
<tr>
<td>0.033</td>
<td>0.017</td>
<td>0.033</td>
<td></td>
</tr>
<tr>
<td>0.000</td>
<td>0.000</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>0.017</td>
<td>0.017</td>
<td>0.017</td>
<td></td>
</tr>
<tr>
<td>0.017</td>
<td>0.025</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>0.079</td>
<td>0.105</td>
<td>0.053</td>
<td></td>
</tr>
<tr>
<td>0.015</td>
<td>0.015</td>
<td>0.015</td>
<td></td>
</tr>
<tr>
<td>0.079</td>
<td>0.053</td>
<td>0.026</td>
<td></td>
</tr>
<tr>
<td>0.060</td>
<td>0.060</td>
<td>0.060</td>
<td></td>
</tr>
<tr>
<td>0.000</td>
<td>0.071</td>
<td>0.107</td>
<td></td>
</tr>
<tr>
<td>0.007</td>
<td>0.007</td>
<td>0.021</td>
<td></td>
</tr>
<tr>
<td>0.014</td>
<td>0.014</td>
<td>0.029</td>
<td></td>
</tr>
<tr>
<td>0.587</td>
<td>0.617</td>
<td>0.544</td>
<td></td>
</tr>
</tbody>
</table>

#### Description:

According to the environmental groups Pd3 is the least damaging design for the environment. For the shipping company the most attractive port is Pd2.

#### Appendix: X-2

Name: Scores

Section number: 4.2.5

Scale:
<table>
<thead>
<tr>
<th>Equal</th>
<th>Score</th>
<th>Score * weight</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pd1</td>
<td>Pd2</td>
</tr>
<tr>
<td>0.077</td>
<td>1.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.077</td>
<td>0.50</td>
<td>1.00</td>
</tr>
<tr>
<td>0.077</td>
<td>0.50</td>
<td>0.25</td>
</tr>
<tr>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>0.077</td>
<td>0.75</td>
<td>1.00</td>
</tr>
<tr>
<td>0.077</td>
<td>0.75</td>
<td>0.50</td>
</tr>
<tr>
<td>0.077</td>
<td>0.75</td>
<td>0.50</td>
</tr>
<tr>
<td>0.077</td>
<td>1.00</td>
<td>1.00</td>
</tr>
<tr>
<td>0.077</td>
<td>0.00</td>
<td>0.50</td>
</tr>
<tr>
<td>0.077</td>
<td>0.25</td>
<td>0.25</td>
</tr>
<tr>
<td>0.077</td>
<td>0.50</td>
<td>0.50</td>
</tr>
<tr>
<td>1.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Description:**
With the use of equal weights designs 2 and 3 score equal.

**Appendix:** X-3

**Name:** Scores

**Section number:** 4.2.5

**Scale:**
Appendix XI: Financial results

An extensive MS-Excel sheet is made to calculate the projects NPV and IRR as explained in 4.3.5. Factors as growth of throughput, discount rate and revenues can be varied. In this appendix per design for each throughput scenario the graphs with the cash flows and NPV as well as the graph with the IRR is shown. The throughput varies from 3% to 5% to 7%.
### Description:
Dependent on the throughput scenario interim investments are needed to expand the port. These investments improve the NPV but the IRR remains almost the same.

### Appendix: XI-1

**Name:** NPV and IRR Pd1  
**Section number:** 4.3.5  
**Scale:**
Description:
The investments are too high or the tariffs are too low to make the design feasible. The IRR is around 5%, which is lower than the discount rate.

Appendix: XI-2
Name: NPV and IRR Pd2
Section number: 4.3.5
Scale:
**Description:**
This design is the best option; the NPV and IRR are higher compared to Pd1 and Pd2. However, the IRR is under 15%, which is still too low.

**Appendix:** XI-3

**Name:** NPV and IRR Pd3

**Section number:** 4.3.5

**Scale:**

---

**Ihavandhippolhu Atoll Transshipment Port**

**Cash flows and NPV (3%)**

<table>
<thead>
<tr>
<th>Year (m US$)</th>
<th>Project Cash Flow</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**IRR Pd3 (3%)**

<table>
<thead>
<tr>
<th>Year</th>
<th>IRR Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>-10.0%</td>
</tr>
<tr>
<td>2006</td>
<td>-5.0%</td>
</tr>
<tr>
<td>2008</td>
<td>0.0%</td>
</tr>
<tr>
<td>2010</td>
<td>5.0%</td>
</tr>
<tr>
<td>2012</td>
<td>10.0%</td>
</tr>
<tr>
<td>2014</td>
<td>15.0%</td>
</tr>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td></td>
</tr>
<tr>
<td>2026</td>
<td></td>
</tr>
<tr>
<td>2028</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
</tr>
</tbody>
</table>

**Cash flows and NPV (5%)**

<table>
<thead>
<tr>
<th>Year (m US$)</th>
<th>Project Cash Flow</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**IRR Pd3 (5%)**

<table>
<thead>
<tr>
<th>Year</th>
<th>IRR Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>-10.0%</td>
</tr>
<tr>
<td>2006</td>
<td>-5.0%</td>
</tr>
<tr>
<td>2008</td>
<td>0.0%</td>
</tr>
<tr>
<td>2010</td>
<td>5.0%</td>
</tr>
<tr>
<td>2012</td>
<td>10.0%</td>
</tr>
<tr>
<td>2014</td>
<td>15.0%</td>
</tr>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td></td>
</tr>
<tr>
<td>2026</td>
<td></td>
</tr>
<tr>
<td>2028</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
</tr>
</tbody>
</table>

**Cash flows and NPV (7%)**

<table>
<thead>
<tr>
<th>Year (m US$)</th>
<th>Project Cash Flow</th>
<th>NPV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2012</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2016</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2026</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2028</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**IRR Pd3 (7%)**

<table>
<thead>
<tr>
<th>Year</th>
<th>IRR Pd3</th>
</tr>
</thead>
<tbody>
<tr>
<td>2004</td>
<td>-10.0%</td>
</tr>
<tr>
<td>2006</td>
<td>-5.0%</td>
</tr>
<tr>
<td>2008</td>
<td>0.0%</td>
</tr>
<tr>
<td>2010</td>
<td>5.0%</td>
</tr>
<tr>
<td>2012</td>
<td>10.0%</td>
</tr>
<tr>
<td>2014</td>
<td>15.0%</td>
</tr>
<tr>
<td>2016</td>
<td></td>
</tr>
<tr>
<td>2018</td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
</tr>
<tr>
<td>2022</td>
<td></td>
</tr>
<tr>
<td>2024</td>
<td></td>
</tr>
<tr>
<td>2026</td>
<td></td>
</tr>
<tr>
<td>2028</td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
</tr>
</tbody>
</table>
Appendix XII: Specifications of terminal equipment

In all concepts some specifications on the terminal handling equipment are used in the equations to determine the cycle time. The most important are the required widths of the equipment, the travelling speeds on the lanes, the travelling speeds on the stack and the hoisting speeds. This appendix gives the specifications.
**Ihavandhipholhu Atoll Transshipment Port**

**Typical dimensions and clearances of a RTG**

<table>
<thead>
<tr>
<th>Width</th>
<th>Span (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4 + lane</td>
<td>18.0</td>
</tr>
<tr>
<td>5 + lane</td>
<td>20.8</td>
</tr>
<tr>
<td>6 + lane</td>
<td>23.6</td>
</tr>
<tr>
<td>7 + lane</td>
<td>26.4</td>
</tr>
<tr>
<td>8 + lane</td>
<td>29.2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Height</th>
<th>Lifting Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 over 3</td>
<td>12.34</td>
</tr>
<tr>
<td>1 over 4</td>
<td>15.24</td>
</tr>
<tr>
<td>1 over 5</td>
<td>18.14</td>
</tr>
<tr>
<td>1 over 6</td>
<td>21.04</td>
</tr>
</tbody>
</table>

**Performance Data RTG**

- **Lifted load**: 40.6 t or 50.8 t
- **Hoist speed with load**: 26 m/min
- **Hoist speed empty spreader**: 56 m/min
- **Trolley travel speed**: 70 m/min
- **Gantry long travel speed**: 135 m/min

**Description:**
The picture shows an example of an RTG, in concept 3 an 8 + lane and 1 over 4 is used.
Description:
In concept 4, with the automated RMG, the manual operational area is on the quay side of the stack, instead of driving lanes. However, the specifications remain the same as above. [18]

Appendix: XIII-2

Name: Specifications RMG

Section number: 5.6

Scale:
Appendix XIII: Tables queuing theories

In sections 5.3.3 to 5.6.3 the queuing theories are used to calculate the waiting times for the terminal handling equipment. In equation 5.11, $W(0,1,u)$, $W(1,0,u)$ and $W(1,1,u)$ have to be found, these are the waiting times in respectively the $D/M/n$, $M/D/n$ and $M/M/n$ system. In this appendix the corresponding tables are shown. In these tables one can look up the required waiting times to use them in the equation.
Appendix XIV: Autocad drawings

In this appendix a few autocad drawings are included to give an impression of the port within the area.
Description:
This top view shows the main dimensions of the port calculated in chapters 3 and 5.

Appendix: XIV-1
Name: Top view on terminal
Section number: 5.8
Scale:
Ihavandhippolhu Atoll Transshipment Port

Description:
Name: Detailed and aerial view
Section number: 5.8
Scale:

Appendix: XIV-2
Name: Detailed and aerial view
Section number: 5.8
Scale:
### Description:

- **Name:** Detailed and aerial view
- **Section number:** 5.8
- **Scale:**

### Appendix: XIV-3

- **Name:** Detailed and aerial view
- **Section number:** 5.8
- **Scale:**