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MSc Thesis

Port Master Plan for the Port of Beira, Mozambique

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PREFACE

This study is the final report of my Master Thesis ‘Port master plan for the Port of Beira, Mozambique’. This thesis completes my study Hydraulic Engineering, specialization Port and Waterways, at the faculty of Civil Engineering and Geosciences of the Delft University of Technology. DHV B.V. offered the subject of this thesis before they merged into Royal HaskoningDHV. They provided me with the opportunity to work on this project at their main office in Amersfoort, The Netherlands.

I would like to thank my graduation committee members for their guidance, critical remarks and contribution during the process. I would like to thank Chairman Prof. ir. T. Vellinga from the Chair of Ports and Waterways who guided me during my thesis and moreover, already from the start of my masters. I would also like to thank ir. M. de Jong, who introduced me to the subject and the company Royal HaskoningDHV. Special thanks to ir. T. De Boer, my daily supervisor at Royal HaskoningDHV, who guided me during my thesis and was always available for questions and discussions. From the section Transport and Planning, I would like thank Dr. ir. W. Daamen, who supervised me with the capacity model Harboursim and shared part of her knowledge with me. Last, but not least, I would like to show my gratitude to ir. P. Taneja. She took the time to explain the adaptive port planning framework and helped me with the implementation in this study.

Jori van der Meer

January 2013, Amersfoort

ABSTRACT

The port of Beira is an essential driver for economic growth in Mozambique. Its location, with strong connections to the hinterland, creates a promising future for the further development of the port. The port authority requires a new port master plan in order to optimise throughput over available ground and (wet) infrastructure, and to extend its capacity in the coming decades. This report presents in structured way the development of a new port master plan for the Port of Beira.

Analyses of the Port of Beira
The Port of Beira is the second largest port in Mozambique and the nearest comparable ports are located 1000 km away. Throughput is divided in four different cargo segments: Container, general cargo & dry bulk, coal and fuel, which are handled at designated terminals. Inside the current port boundaries, there is area available for possible future expansions. Moreover, a recently completed land reclamation site is designated for future port use.

For hinterland transportation, cargo through the Port of Beira is divided over three modalities: road, railroad and a fuel pipeline. The adjoining Pungue River is too shallow for inland waterway transport. Truck traffic leads to congestion in the port and at the main gate.

The 19 nautical miles (35 km) long access channel allows only for one-way traffic and has a minimum guaranteed depth of -8 m CD. Currently only daylight sailing is permitted in the access channel. The tidal conditions have a big impact on the ports performance. The water level variation is high and causes tidal windows for the calling ships, which increase the waiting times. The sedimentation processes are complicated and the resulting sedimentation volumes in the access channel are on average 2.7 million m^3 per annum.

Three throughput development scenarios are made: Low, most likely and high. The throughput in Beira Port is expected to grow the coming years for all cargo sectors. Recently large coal reserves have been found in Mozambique and the Port of Beira has the potential to facilitate the export, but the port depends on the uncertain expansion of the hinterland railroad connection. This results in a wide range in forecasted coal throughput in the three scenarios.

Master plan development
Two master plan alternatives are created, which are flexible for the three scenarios. The master plan alternatives are presented in a plan view drawings, including: the required berths, the terminal areas, transport axles and hinterland connections. Also, the wet layout is taken into account, for which several improvements are proposed and tested with Harboursim. Each master plan alternative is accompanied by the preferred wet layouts.

Additional design decisions are made to determine the following main cost aspects: Dredging, terminal areas, quays, jetties, roads, railroads and overall cost. It is concluded that the capital dredging and quay extension costs are the main cost drivers of the master plan. All investment and maintenance costs are accumulated and the net present values of the two alternatives are determined to make a cost comparison.

Following the results of a multi criteria analysis, a preferred master plan alternative is chosen. The preferred master plan scores best at most criteria and the accumulated score is the highest for diverse weighings of the criteria. For four sub-criteria it scored less than the second alternative. It is recommended to find improvements for the preferred master plan in the other alternative. Further research is recommended to validate the assumptions made in this study.

The preferred master plan is presented in a plan view drawing in Figure 0-1. In order to facilitate the throughput in scenario low, the current berth configuration can be used with one additional fuel jetty. For the scenarios most likely and high, the current port configuration is not sufficient

and has to be altered significantly. In order to reduce the traffic congestion, a new gate system is proposed for all scenarios and an improved main gate is designed. Adaptions to the wet layout are unavoidable as ship traffic and dimensions increase in all scenarios. Facilitating 24 hour sailing is necessary and in scenario most likely the access channel is two-way and lowered to -10 m CD.

The rail workshop is for all scenarios relocated outside the port area boundaries, realizing space for the container terminal expansion. The coal terminal is relocated to the reclamation site, in order to facilitate the container cargo in scenario most likely on one interconnected storage site. In scenario high no additional relocation takes place compared to scenario most likely and all terminal expansions are found close to the terminals.

Harboursim
In Beira, waiting times are known to be very long and the port authorities have the desire to improve the port performance on this matter. Therefore a Harboursim model of the present situation of the Port of Beira is built, which is used to simulate the maritime traffic.

For Beira Port, processes are added to the Harboursim model code to make a good representation of the reality. Furthermore, the Harboursim model is improved, by fixing errors in the model code. The adaptions made in the code are generally applicable for all future Harboursim models.

The Harboursim model of the present situation is adapted to simulate the new port layout alternatives in the different scenarios. The model is used to determine the preferred wet layouts for the port layout alternatives. The model gives accurate results for widely distributed inter arrival and service times.

For the preferred master plan, it is concluded that in scenario most likely and high all ships have acceptable mean waiting times. In scenario low, the waiting times are higher than accepted standards, in order to reduce the investment costs.

It is recommended that the original Harboursim model is discarded or that the manual is adapted to the observed errors. Especially the errors in the depth calculation and the required quay length rule should be mentioned for future users of the 'old' model. It is recommended that future users of Harboursim use the improved version.

Adaptive Port Planning
This study is a case study for the 'Adaptive Port Planning' (APP) framework, which is an addition to the master plan development. Using the framework, differences in the robustness of the master plan alternatives are determined. Furthermore, the robustness of the chosen alternative is increased, because actions for dealing with the vulnerabilities and opportunities associated with each alternative are determined.

The APP framework is only applied on assumptions related to the expansion of the capacity of the railway hinterland connection (Sena railway line). These particular assumptions are handled, because it is highly uncertain if and when these expansions will take place. The robustness for the expansion of the Sena railway line is increased, by devising actions for the determined vulnerabilities. No opportunities could be detected in this particular region of assumptions, which shows the importance of the expansion of the railway line for the Port of Beira.

This case study shows the application of the APP framework. In this study, just one region of assumptions was investigated. However, all the assumptions should be treated to fully realize a master plan robust across many futures. It is concluded that by devising actions for the vulnerabilities, new vulnerabilities are created for which again actions must be devised.

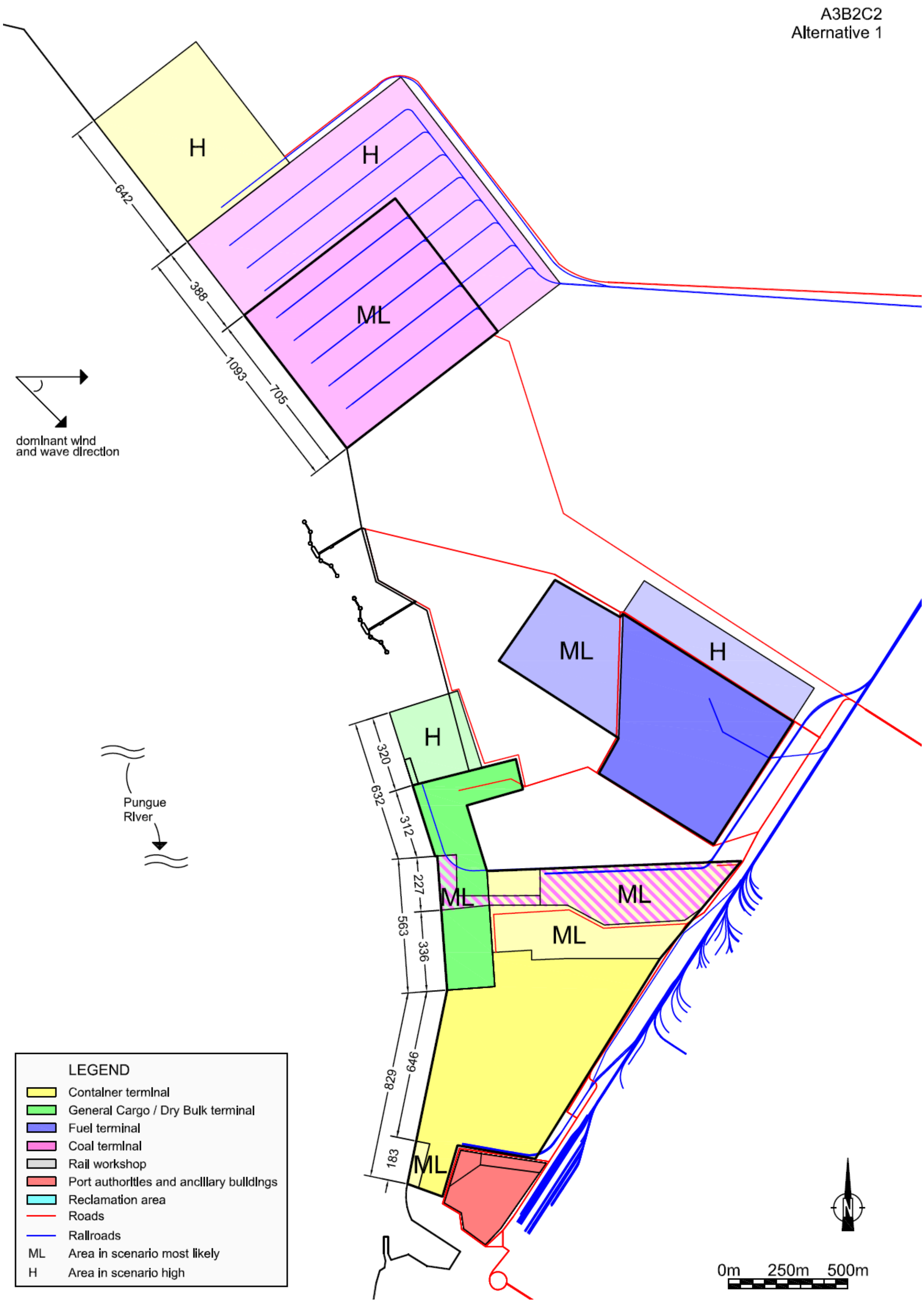

Figure 0-1 | Preferred master plan

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LIST OF ABBREVIATIONS

ABP	Assumption-Based Planning
APP	Adaptive Port Planning
APM	Adaptive Policymaking
BAGC	Beira Agricultural Growth Corridor
CD	Chart Datum
CdM	Cornelder de Mozambique
CEPM	Coal Exploration & Production Mozambique
CFM	Companhia de Ferro de Mozambique
CFS	container freight station
CPMZ	Companhia do Pipeline Mozambique-Zimbabwe
CR	corrective action
CP	capitalizing action
DA	defensive action
DHV	Dwars Heederik en Verhey
DWT	deadweight tonnage
E	East
ENE	East-northeast
ESE	East-southeast
E_k	Erlang-k distribution
FAO	Food and Agriculture Organization of United Nations
GC-DB	general cargo and dry bulk
GDP	gross domestic product
H	scenario High
HA	hedging action
HW	High Water
JICA	Japan International Cooperation Agency
L	scenario Low
LAT	Lowest Astronomical Tide
LOA	length over all
LW	Low Water
M	negative exponential distribution
MCA	Multi Criteria Analysis
MHW	Mean High Water
MHWN	Mean High Water Neap
MHWS	Mean High Water Spring
ML	scenario Most Likely
MLW	Mean Low Water
MLWN	Mean Low Water Neap
MLWS	Mean Low Water Spring
MSL	Mean Sea Level
MTPA	million tons per annum
MWT	mean waiting time
MWT [ST]	mean waiting time in ratio to the service time
N	North
NE	Northeast
NEDECO	Netherlands Engineering Consultants
NNE	North-northeast
NNW	North-northwest
NPV	net present value
NW	Northwest
OCC [ST]	Occupancy in ratio to the service time

OCC [ST+W]	Occupancy in ratio to the summed service and waiting time
OCC [ST+W+R]	Occupancy in ratio to the summed service, waiting and reservation time
OGV	ocean going vessel
RT	Rio Tinto
S	South
SE	Southeast
SHA	shaping action
SSE	South-southeast
SSW	South-southwest
ST	Service Time
SW	Southwest
SWOT	strengths weaknesses opportunities threats
RE	reassessment
RT	Reservation Time
TEU	Tonnage Equivalent Unit
TT	Tonnage equivalent unit Twin-lift
TX	maximum temperature [^{o}C]
TN	minimum temperature [^{o}C]
TM	mean temperature [^{o}C]
UU	relative humidity [%]
RR	rainfall [mm]
UNCTAD	United Nations Conference on Trade And Development
US	United States
W	West
WNW	West-northwest
WSW	West-southwest

LIST OF UNITS

ha	hectare
kn	knots
m	meter
min	minutes
s	second
t	tons

LIST OF SYMBOLS

B	Beam [m]
C	design annual throughput [tons/year]
C_i	number of TEUs per year per type of stack [-]
C_{ts}	fraction of total annual throughput C_s that passes the transit shed [-]
d	draft [m]
E_d	average dwell time of cargo [days]
F	required area per TEU including equipment travelling lanes [m^2]
f	factor accounting for difference between gross and net area [-]
f_1	proportion gross/net surface in connection with traffic lanes [-]
f_2	bulking factor due to stripping and separately stacking [-]
h	average stacking height [m]
L_{quay}	quay length [m]
$L_{max\ ship}$	length of maximum ship [m]
m_i	acceptable average occupancy rate [-]
m_s	storage occupancy [-]
m_{ts}	average rate of occupation of the transit shed or storage [-]
O	area required [m^2]
r	average stacking height / nominal stacking height [-]
$\bar{t_d}$	average dwell time [days]
W	channel width [m]
W_B	bank clearance width [m]
W_{BM}	basic channel width [m]
W_i	additional channel width [m]
W_P	lane separation distance [m]
€	euro
#	number
ṗ	average cargo density [tons/m^3]

1 INTRODUCTION

In this chapter an introduction of the study is given. First, the background of this study is discussed and the necessity of a new port master plan is explained. The research objectives are presented in the second paragraph. The applied approach, in order to reach the objectives, will be discussed in paragraph 1.3. In the final paragraph, the contents of the report are discussed.

1.1 Background

The port of Beira is an essential driver for economic growth in Mozambique. Its unique location, with strong connections to the hinterland and close proximity to its neighbour, landlocked Zimbabwe, creates a promising future for the further development of the port. The port authorities aim to double the annual throughput of 2011 of the port of Beira in the year 2015. Recently large coal reserves have been found in Mozambique and the Port of Beira is situated closest to the mines of all existing ports. They foresee a sharp rise in coal export through the completion of an improved hinterland connection and a dedicated terminal in the port. Many different expansions and changes in the port configuration and use are foreseen.

The current master plan for the port of Beira dates from 1982. In the last 30 years, there has not been an update to the plan. In the meantime, the world has changed and the sketched scenarios no longer hold. The port authority Companhia Ferro de Mozambique CFM needs a new port master plan in order to optimise throughput over available ground and (wet) infrastructure, and to extend its capacity in the coming decades.

After having done several projects in the Port of Beira, Royal HaskoningDHV has been requested by the port authorities to draft a Terms of Reference and proposal for the development of a new port master plan. The proposal has been approved and Royal HaskoningDHV will start the development of a new port master plan when the contract is signed.

1.2 Research objective

The aim of this study is to develop a master plan for the Port of Beira. Additionally, the study is a case study for the 'Adaptive Port Planning (APP)' method. The steps of APP will be added to the master planning process. The result will be used to map differences between the master plan alternatives robustness's. It is aimed to increase the insight for the selection of the best master plan alternative and to increase the robustness of the developed master plan.

A more in-depth research to define the maritime capacity of the Port of Beira will be performed to simulate the maritime traffic by using the model 'Harboursim'. Hereby it is aimed to improve the existing Harboursim model in order to model the Port of Beira in the present situation and the master plan alternatives in developed scenarios. If necessary, improvements to the current Harboursim model will be made for future users. It is aimed to make the improvements generically applicable for all future users of the 'Harboursim' model.

Thus the three main objectives are:
1. Develop a master plan for the Port of Beira.
2. Add the 'Adaptive Port Planning' framework to the master plan alternatives evaluation
3. Determine the maritime capacity of the Port of Beira in the present situation and the master plan alternatives in developed scenarios. If necessary, improve the current Harboursim model for future users.

1.3 Research approach

A structured research approach is discussed in this paragraph. First, an analysis should be done on the present port and the future needs. Second, a synthesis is developed in the form of master plan alternatives. Last, the alternatives are evaluated. The research is structured into several phases, which are shown in Figure 1-1. In general, the 'conventional' steps of port master planning are followed. Additionally, in-depth research in the maritime capacity with the help of the Harboursim model and the adaptive port planning framework are added, indicated by the blue boxes. On the next two pages, the each phase will be discussed.

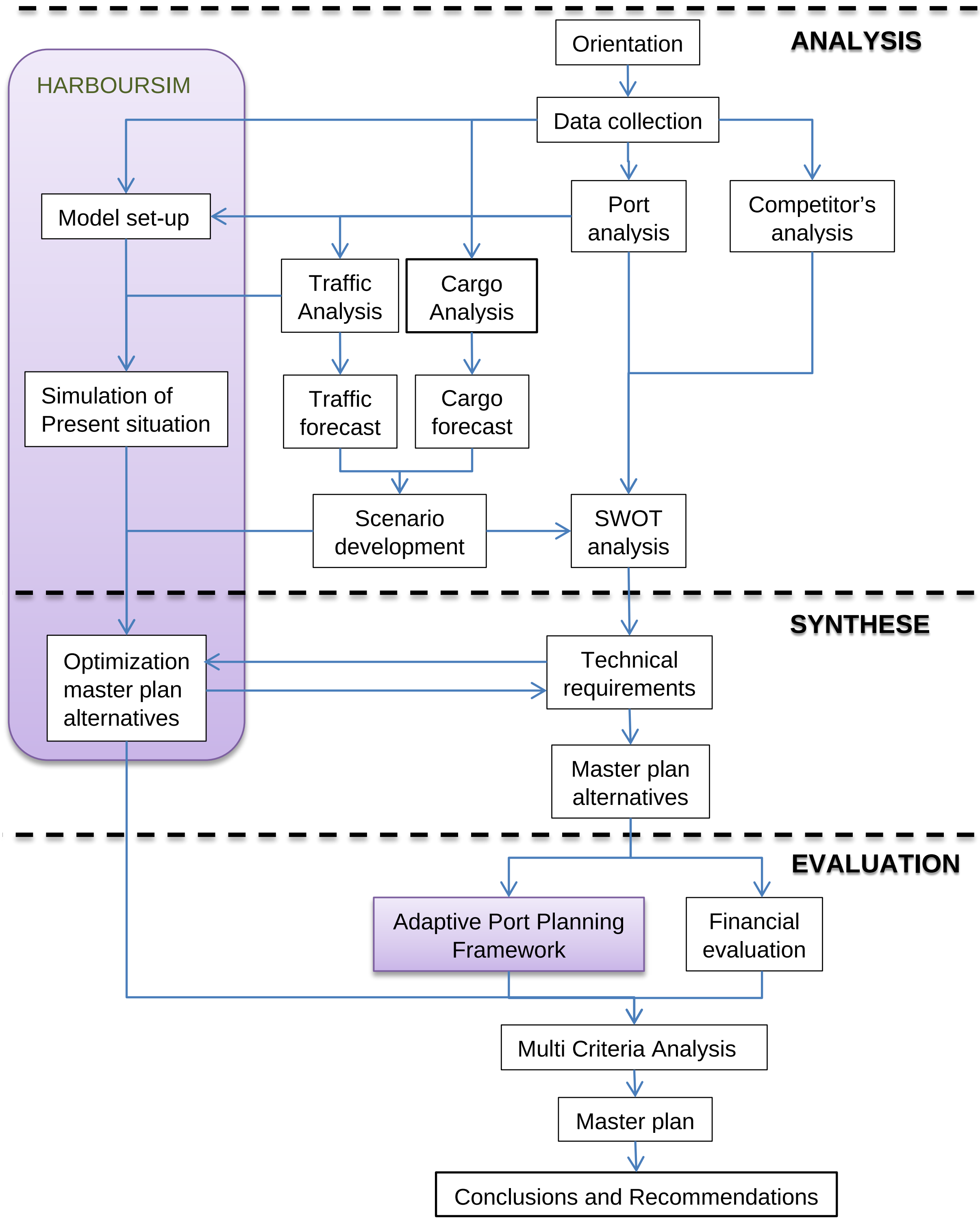


Figure 1-1 | Flow chart of research structure

ANALYSIS

Orientation

The orientation phase holds getting familiar with the subject and setting the project boundaries. The objectives are defined and this research approach is the result of this phase.

Data collection

The aim of the data collection is to gain insight on:

- The present situation of the Port of Beira
- The environmental boundary conditions affecting the Port of Beira
- The cargo and traffic calling the Port of Beira
- The state and applicability of the Harboursim model
- The adaptive port planning framework

Data collection starts after the orientation, but continues during the research when additional information is required. Data collection will be done with help of Royal HaskoningDHV and the Technical University of Delft. When the data collection is finished, it is expected that not all data are available and this means that some assumptions have to be made. The data are input for the cargo, traffic, port and competitor's analysis,

Port analysis

The port analysis will be done to identify the present port infrastructure and operations. The landside port boundaries will be determined, as well the maritime access.

Competitor's analysis

Competing ports have to be identified and analysed. The competitive hinterland has to be determined as input for the cargo forecast, as cargo could be transported through these ports.

Harboursim: Model set-up

The available data are fitted to build a Harboursim model of the present situation of the Port of Beira. This model will be the basis for all Harboursim simulations to design the master plan. The goal is to build a model that represents the present situation and which can be further expanded to simulate the master plan alternatives.

Cargo analysis and forecast

The cargo analysis identifies the throughput of the Port of Beira in the last 10 years. Trends in the cargo data will be localised. The macro-economic growth will be determined from historic data. Additionally, cargo opportunities will be identified for the future Port of Beira. Based on this, throughput forecasts will be made in a range of scenarios.

Traffic analysis and forecast

The traffic analysis identifies the present ship traffic calling the port. Trends in the ship traffic will be localised and forecasts are made.

Harboursim: Simulation of present situation

The model overall performance of the model will be checked by comparing the model outcomes of the present situation with measured data from the traffic analysis. The model will be adjusted, when the results are not matching.

Scenario development

This phase holds the implementation of the produced trend lines and distributions from the cargo and traffic analyses. Different forecasts will be put together to form three future scenarios. The scenarios will be input for the technical requirements calculations and the Harboursim simulation for the optimization of the master plan alternatives.

SWOT Analysis
Strengths, Weaknesses, Opportunities and Threats of the present port will identified, with the previous analyses, the Harboursim simulations of the present situation and scenarios as input.

SYNTHESIS
Technical requirements
The SWOT analysis and the simulation results of Harboursim will be the input for the technical requirements. Main objectives in this phase are to specify required terminal areas, quay lengths and waterway dimensions.

Alternative master plans
Different master plan alternatives for the Port of Beira will be created. The master plan alternatives will be presented in a plan view drawing. Each master plan will include:

- Specified terminal areas
- Proposed terminal equipment
- Quay lengths
- A road and railroad plan
- Wet layout specifications for the maritime access
- Hinterland connections

Optimization alternative master plans
The master plan alternatives for the three scenarios are modelled in Harboursim. The scenarios are simulated in the models to show the performance of the alternatives. The master plans will be optimized to the required service levels.

EVALUATION
Adaptive Port Planning
The result will be used to map differences between the master plan alternatives robustness's. In this study, the adaptive port planning method is applied on the two alternatives for Port of Beira. This will increase the insight in the robustness criterion for the selection of the best alternative. Furthermore, the robustness of the chosen alternative is increased, because actions for dealing with the vulnerabilities and opportunities associated with each alternative are determined.

Financial evaluation
In the framework of this study, only a cost estimate will be done as a financial evaluation. The implementation costs of each alternative master plan are estimated. Additionally, the maintenance costs are estimated and the net present value of the alternatives is determined by discounting the costs.

Multi Criteria Analysis
The alternatives for a port layout entail many parameters that should be taken into account when deciding for the optimum. In order to deal with all these affecting parameters a Multi-Criteria Analysis (MCA) is applied.

Master plan
The result of the MCA will identify the preferred master plan alternative.

Conclusions and Recommendations
Conclusions and recommendations will be done on further research, the master plan development, the preferred master plan and other notions that come across during the research.

1.4 Structure of the report

The structure of the report is the result of the applied research approach. The starting point of the first chapters is the result of the orientation and data collection. The report is divided in three parts: Analysis, synthesis and evaluation.

Part A: Analysis
In chapter 2 the port orientation is presented, by discussing its surroundings and connections with the hinterland. The chapter continues with a cargo analysis, where the throughputs of the last decade are discussed. By adding the results of the competitor's analysis, a satellite view of the port is created. In chapter 3, a more detailed view of the present Port of Beira is given by discussing the port layout. The different terminals are presented, including their infrastructure, operations and calling ships. More insight is gained on the ship processes by examining the environmental boundary conditions in chapter 4. Especially the tidal conditions and morphology are of importance to the development of the master plan.

In chapter 5, the Harboursim model set-up commences. From the previous chapters the necessary input is gathered to build the model of the present situation. The port processes in Beira are translated into Harboursim model processes. The results of the simulation of the present situation are discussed and the further application of the model in this study. In order to make a good representation of the reality in the Port of Beira, adaptations to the original Harboursim model code are made for this study. In chapter 5, these adaptions for the Port of Beira model are discussed. Moreover, the adaptions to the Harboursim model code are made generally applicable for all future models and discussed in this generic way in appendix II.

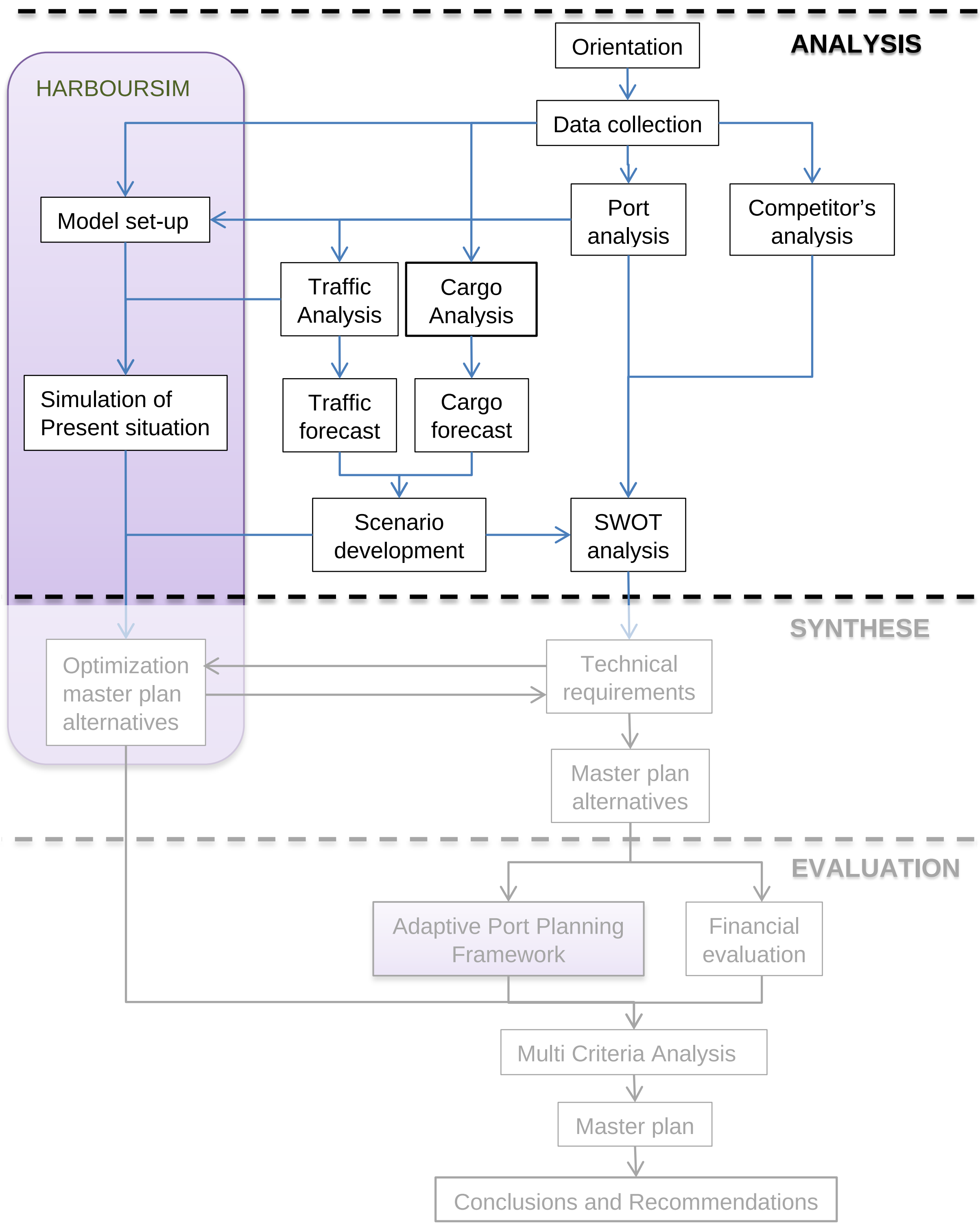
Chapter 6 commences with a cargo forecast, which is followed by a ship forecast. Together these result in the development of three scenarios in the concluding paragraphs. Chapter 7 presents a summary of the strengths, weaknesses', opportunities and threats raised in the previous chapters in the form of a SWOT analysis.

Part B: Synthesis
In chapter 8, a guideline for the development of the master plan alternatives is established in the form of the technical requirements. In this chapter the terminal area, berth, access channel and gate requirements to facilitate the throughput in the three scenarios are discussed. In chapter 9, the landside layout alternatives for each of the scenarios are presented, followed by options to improve the wet layout capacity. The port layouts and wet layouts are combined in the Harboursim simulations in chapter 10. For each port layout alternative, the constructed Harboursim model is discussed. The results of the simulations and preferred combinations of wet and port layout are concluded. Chapter 11 is the result of the master plan alternatives development. Two master plan alternatives are discussed and visualized by a layout drawing, which includes the flexibility for the three scenarios.

Part C: Evaluation
Chapter 12 commences with an explanation of the adaptive port planning framework and the precise implementation in this study. The steps of APP are conducted and the results are discussed. The cost estimate is done for the two master plan alternatives in chapter 13. In this chapter, also some additional design decisions are made on the different cost aspects. Phasing of the implementation of the master plan alternatives is discussed and the net present value is calculated.

Using a Multi Criteria Analysis (MCA) the master plan alternatives are compared in chapter 14. Finally, in chapter 15 the conclusions and recommendations on the master plan development, the Harboursim model and the adaptive port planning framework are discussed.

Part A: Analysis



2 PORT ORIENTATION AND CARGO ANALYSIS

This chapter is an introduction to the Port of Beira and its surroundings. The orientation of the port with respect to its hinterland will be discussed as part of the port analysis. The current throughput figures will be given and linked to their hinterland source. Furthermore a start is made with the competitor's analysis by discussing other ports in the region.

First, the geography on a macro scale is shortly described. The hinterland connections are the lifelines for the port and are therefore discussed in paragraph 2.2. An introduction to the maritime aspects of Beira Port is given by explaining its access from the open sea. Rough information is known about the cargo throughput in the port of Beira. CFM provided throughput figures, which are discussed in paragraph 2.4. There are two other ports along the Mozambique coast, Maputo and Nacala, respectively 1000 km south and north. Their competitiveness to Beira Port is discussed in chapter 2.5. Finally, conclusions are made relevant to the master plan development.

2.1 Geography

The republic of Mozambique is located on the eastern coast of Southern Africa. The total area of the country is about 802,000 km^2. The length (north-south direction) of the country is approximately 2,000 km. The northern part shares the borders with Tanzania, Malawi and Zambia. To the west, it borders Zimbabwe, South Africa and Swaziland. The eastern side is facing the Mozambique Channel, separating the country from Madagascar. The Mozambique Channel is connected to the Indian Ocean. The above is visualized in Figure 2-1. The coastal line is 2,800 km long with an abundance of bays and inlets. The plains and hilly districts cover 60% of the land of the country. High land of altitude 500 m to 1,000 m in the western and northern territories constitute 30% and the mountainous regions cover the last 10 % of the country. Several large rivers run through the country to the Indian Ocean. Lake Malawi and Cabora Bassa Lake are located in the north. Mozambique is an agricultural country with fertile land.

Figure 2-1 | Location of Port of Beira

Beira is the second largest city and port in Mozambique. Beira lies in the central region of the country in the Sofala Province, where the Pungue River meets the Indian Ocean. The port of Beira acts as a gateway for both central Mozambique as well as the land-locked nations of Zimbabwe, Zambia and Malawi. The largest port in Mozambique is located in southern Maputo. Nacala port in the north is a smaller, but natural deep-sea port. The two remaining small ports of Pemba and Quelimane, closest to Beira, are not comparable in size and throughput with Beira Port. In addition to regional sea links, the Port of Beira has a direct link to Europe, Asia and the world at large. (US department of state, 2011)

2.2 Hinterland connections of Port of Beira

Cargo through Beira Port is divided in three modalities for hinterland transportation. The cargo is transported over the road, railway and via a fuel pipeline. The Pungue River is too shallow for further transport of goods.

2.2.1 Roads

In Figure 2-2 the main road connections are drawn in black in a satellite picture. The port is directly linked by road to landlocked Malawi, Zambia and Zimbabwe. Beira is the port with the shortest connections to the capitals of these countries. The coastal area of Mozambique is well connected by a coastal highway. The main roads have two-lanes in each direction and are asphalted, but maintenance is poor (BAGC, 2010).

Figure 2-2 | Main rail (white) and road (black) connections

2.2.2 Railway

Beira Port is connected to two main railway lines as shown in white in Figure 2-1. The first is the Machipanda line linking Zimbabwe. International traffic on the Machipanda line was supposed to rise from 480,000 tons per annum in 2004 to 650,000 tons in 2009, but in fact, not a single kilometre was upgraded (Xinhua, 2012). In January of this year, work has begun on the reconstruction of parts of the line, it is unknown when it will be finished and what the capacity will be.

Reconstruction of the second line, the Sena Railway line, has recently been completed. This line links Beira to Moatize, which has one of the largest coal reserves in the world. The Sena railway is currently used to its maximum capacity of 3 million tons per annum (CFM, 2010), largely by coal trains from Moatize. The Sena Railway continues to Malawi and its capital Lilongwe. Due to its railway connection, Beira port has an advantage on other ports to serve Harare (600 km), Lusaka (1050 km), Blantyre (650 km) and their adjacent area. The Mozambiquan ports and railways are both operated by CFM.

2.2.3 Pipeline

A pipeline constructed in 1960 links Beira Port with Zimbabwe. Companhia do Pipeline Moçambique-Zimbabwe (CPMZ) owns and operates the pipeline. The transport capacity is 1.6 million m^3/year of refined petroleum products from the port of Beira to Feruka in Zimbabwe (ACIZ, 2008). Currently the full capacity is reached, which is further explained in 3.8.

2.3 Maritime access

The seabed along the Beira coast has a mild slope of about 1:1000. The -5 m and -10 m CD depth contour are drawn along the coast. These depth contours are subject to changes, due to the morphological behaviour of the seabed. In paragraph 4.5, the morphological behaviour is discussed in more detail. Shoals are present in the river mouth. For ships coming from the Mozambique Channel there is one designated anchorage located southeast of the entrance to the access channel. The anchorage lies in deep water and has no physical boundaries and thus no maximum number of ships. The navigation channel at the Port of Beira is 19 nautical miles long (from beginning of the channel to the first quay) and is the way to enter the port. The minimum guaranteed depth in the channel is -8 m CD. The width of the channel ranges from 135 m to 160 m on outer sections. The width in bends is larger, up to approximately 300 meters. In Figure 2-3 the access channel and anchorage is shown in green. For completeness the main access road in black and the railway in white are also shown.

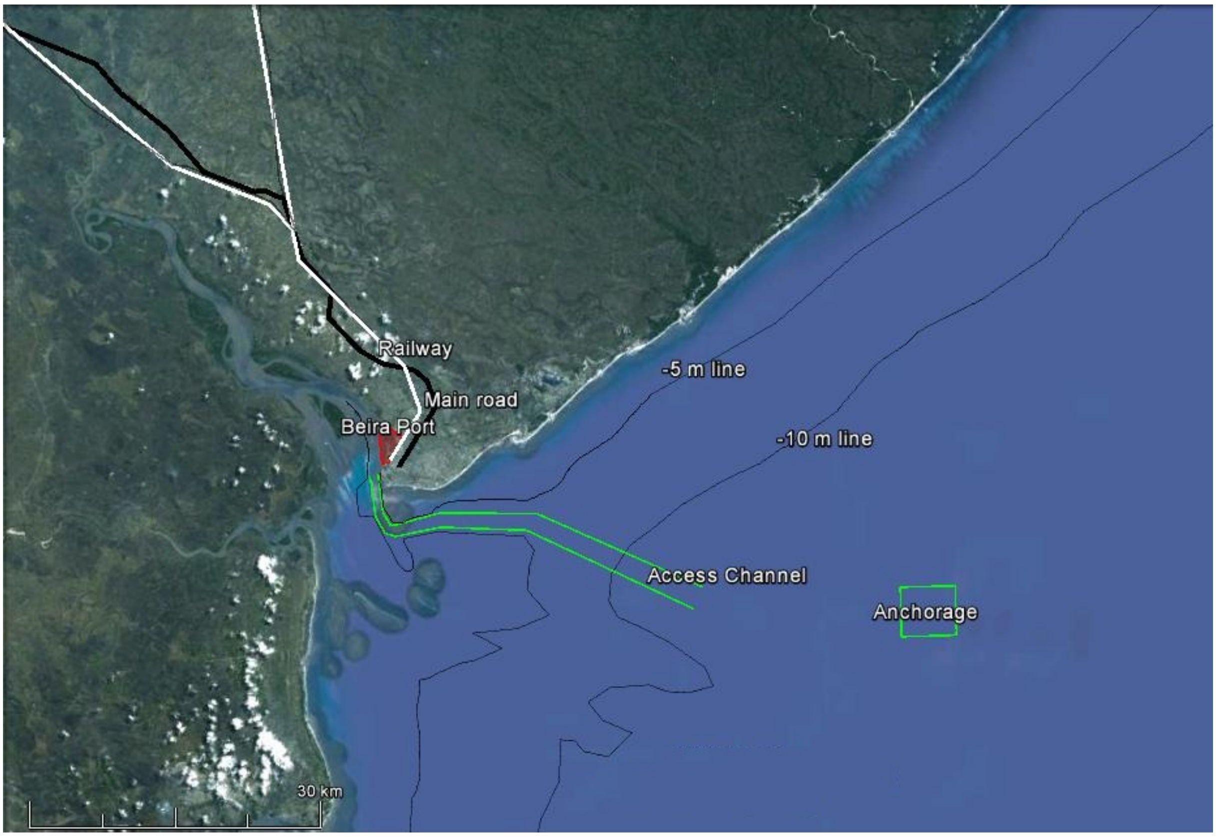


Figure 2-3 | Beira Port with access channel, anchorage, main access road and railway

The channel layout allows for one-way traffic only. Because of the limited aids to navigation, night navigation is not allowed for vessels larger than 140 m (LOA) or with a draft of more than 7 m. The port is examining the possibilities of 24-hour navigation by installing a complete illuminated buoyage system for the entire channel. When the buoys are in place, it is expected that 24-hour navigation can be safely done. Pilotage is compulsory in the Beira port area. Two tugboats are available for manoeuvring and berthing at the quays. (ACIZ, 2008)

2.4 Cargo analysis

Now it is known where Beira is located and how it is connected, the cargo flows are identified. The cargo flows through Beira Port explain why the different terminals are present in the port. The figures given in this paragraph form the basis to calculate the number of calling ships at the different terminals.

Rough information is known about the cargo throughput in the port of Beira. CFM provided throughput figures, which are discussed in this paragraph. There are two other ports along the Mozambique coast, Maputo and Nacala, respectively 1000 km south and north. Their competitiveness to Beira Port is discussed in chapter 2.5.

Comparable to the throughput figures, the Port of Beira throughput is divided in four different cargo segments: container, combined general cargo and dry bulk (GC DB), coal and fuel. The general cargo and dry bulk figures are combined, because these are both handled at the same terminal. The throughput of the coal export is separately handled, because coal is handled at a specialized terminal.

2.4.1 Container throughput

It can be seen that the container throughput is rising, as is the trend around the world. Total container transport in 2009 is known to be 92,200 TEUs, as shown in Figure 2-4. Of which is 42,400 import, 29,400 export, 700 cabotage and the remaining TEUs empties.

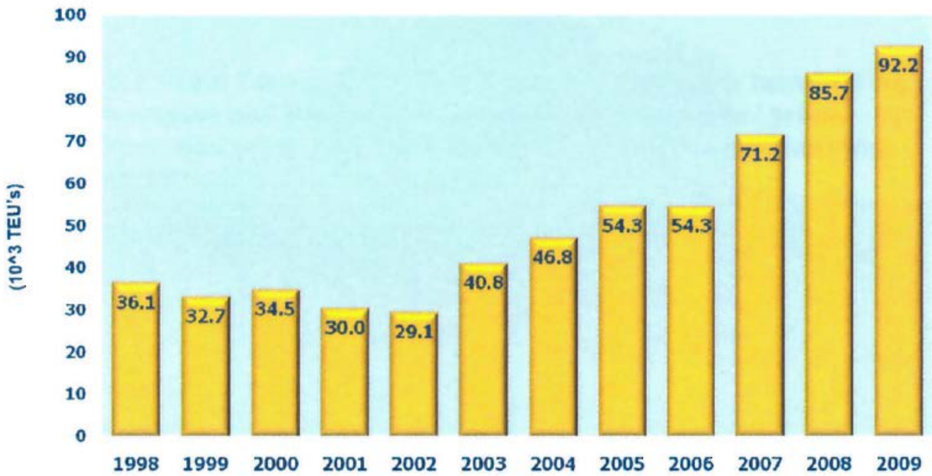


Figure 2-4 | Total container traffic between 1998 and 2009 (CFM, 2009)

2.4.2 General cargo and dry bulk throughput

The combined general cargo and dry bulk throughput in 2009 is 980,000 metric ton, as shown in Figure 2-5. Excluded is the coal transport, which is handled separately. The assumption is made that the distribution between import and export is the same as for the container traffic, being 3:2. Therefore, 580,000 tons import and 400,000 tons export are assumed.

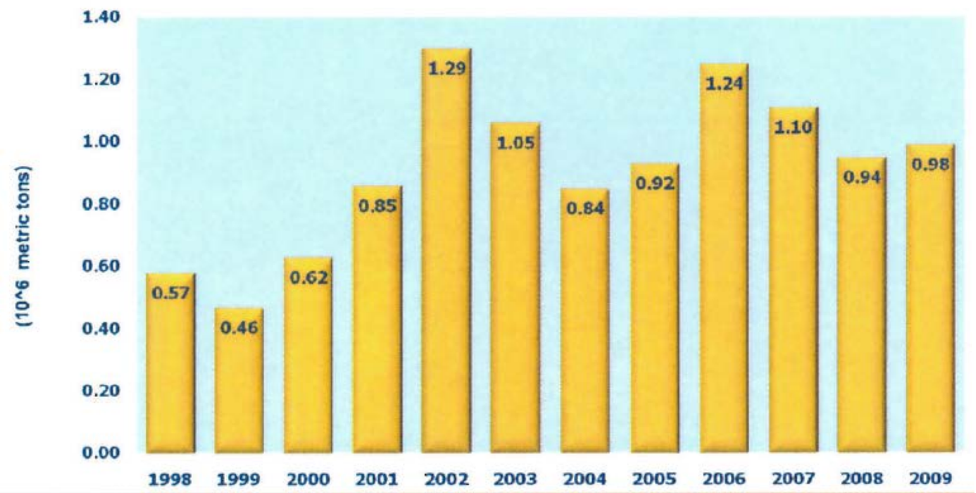


Figure 2-5 | Combined general cargo and dry bulk traffic between 1998 and 2009 (CFM, 2009)

2.4.3 *Coal throughput*

Tete province's coal reserves are among the largest in the world. However, exploitation through Beira Port was hampered by delays in the rehabilitation of the Sena railway line. No historic records are known about the coal export. At present Vale and Rio Tinto are expanding their coal export capacity in Beira Port to a total of 5 million metric tons per year in 2013. 3.4 million of which is to be transferred by Vale and 1.6 million by Rio Tinto. All coal should be transported from the mines to Beira Port by the Sena railway line. The coal transport is relying on the expansion of the line, which current capacity is only 3 million tons per annum as explained in the previous chapter.

2.4.4 *Fuel Throughput*

Mozambique does not produce any of its own fuel. At present, there is no refinery in Mozambique so therefore all petroleum products need to be imported. Fuel throughput figures are known of the last 17 years, as shown in Figure 2-6. A pipeline connects Beira Port with Zimbabwe and therefore the major share of the fuel import is transported through Mozambique to Zimbabwe. The capacity of the line is 1.6 million m^3, which is equal to 1.28 million ton. The last 2 years it is close to full capacity. Import for within Mozambique is steady around 200.000 tons per annum.

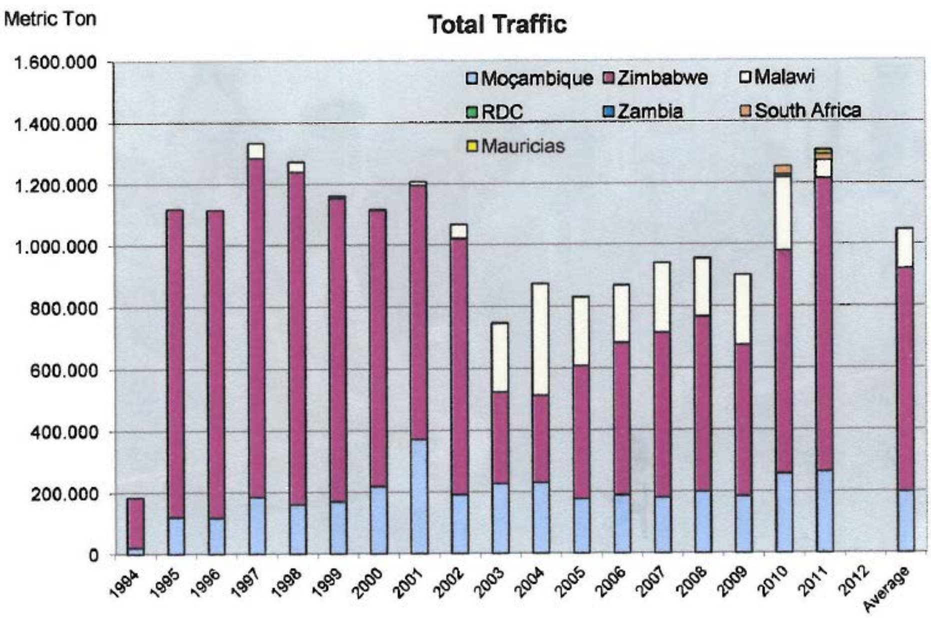


Figure 2-6 | Total fuel import in metric ton (CFM, 2009)

2.5 Other ports in the region

Maputo and Nacala port are the only two international ports in Mozambique who are comparable in size and throughput with Beira. A short description of the ports is given in the next paragraphs. Thereafter there competitive hinterland is illustrated in paragraph 2.5.3.

2.5.1 Maputo port

The Port of Maputo is located in the southeast of Mozambique, 120 kilometres from the South African border and 80 kilometres from the border with Swaziland, see Figure 2-2. Maputo Port has direct road and rail connections with Pretoria (550km), Limpopo, Swaziland and Zimbabwe. The main railway line to South Africa has capacity for 13 million tons per annum. The port access/exit road separates port traffic from downtown Maputo and connects the harbour direct with the M4 Highway running 600km westwards through South Africa. (Ports & Ships, 2010)

There are two main terminals in the port, the Maputo Cargo Terminals (Figure 2-7), which include the Citrus, Sugar, Container, Ferro and Scrap terminals and, 6 km further upriver, the Matola Bulk Terminals (Figure 2-8) with four deep water berths for handling bulk Minerals, Petroleum, Aluminium and Grain. In total, the port has 16 linear berths totalling approximately 4,000m. (Ports & Ships, 2010)

The depth of the access channel to the quays is -11 m CD and ships can sail 24/7. The 3 m depth difference with Beira makes it for large ships sailing along the African coast and calling Maputo impossible to port Beira too. The majority of the throughput of the Maputo port is transported to and from South Africa and Swaziland.

Figure 2-7 | Aerial view of Maputo Cargo Terminals

Figure 2-8 | Aerial view of Matola Bulk Terminals

2.5.2 Nacala port

The Port of Nacala is situated in a wide and deep bay 1000 km north of Beira, as shown in Figure 2-2. The port has natural conditions, which permit the entry and exit of vessels of whatever draught 24 hours per day. The Port of Nacala is composed of a General Cargo and Fuel

Terminal, which is 631 metres long and has a depth of 9.7 metres. The Container Terminal is 372 metres long and has a depth of 14 metres. Typical cargoes handled include containers, agricultural products, tobacco, timber, coal, cement, petrol and grains.
The Nacala Port serves its own hinterland and Malawi to the west, which is served by a 914km railway passing Lilongwe. At present, the railway is rehabilitated and extended to the Moatize coal reserves. Currently no coal is shipped from Nacala, but with the railway in place, it becomes a competitor to Beira. A coal exporter is also looking into the possibility of using the Sena railway around Malawi to Nacala. (Ports & Ships, 2010)

2.5.3 *Competitive hinterland*

In Figure 2-9, hinterlands of Nacala and Maputo are drawn in red and the hinterland of Beira in green. The competitive hinterland is where the areas overlap and shown in orange. The areas are roughly based on the main transport axles, which are shown in white (railway) and black (roads).

As for competitive hinterland with Maputo, only southern Zimbabwe and southern Mozambique can be considered. Still, Beira has an advantage on Zimbabwe through its rail connection with Harare, which is much shorter than to Maputo. The southern part of the hinterland of Beira stretches halfway along the coastal highway to Maputo.

The competitive hinterland with Nacala is thought to be much larger, especially when the direct railway line from Moatize to Nacala comes into place. However, Beira still has the advantage of being closer to the Moatize coal mines. The northern part of the hinterland stretches halfway along the coastal highway. Malawi has both a rail connection with Nacala as with Beira and can therefore be considered as competitive hinterland.

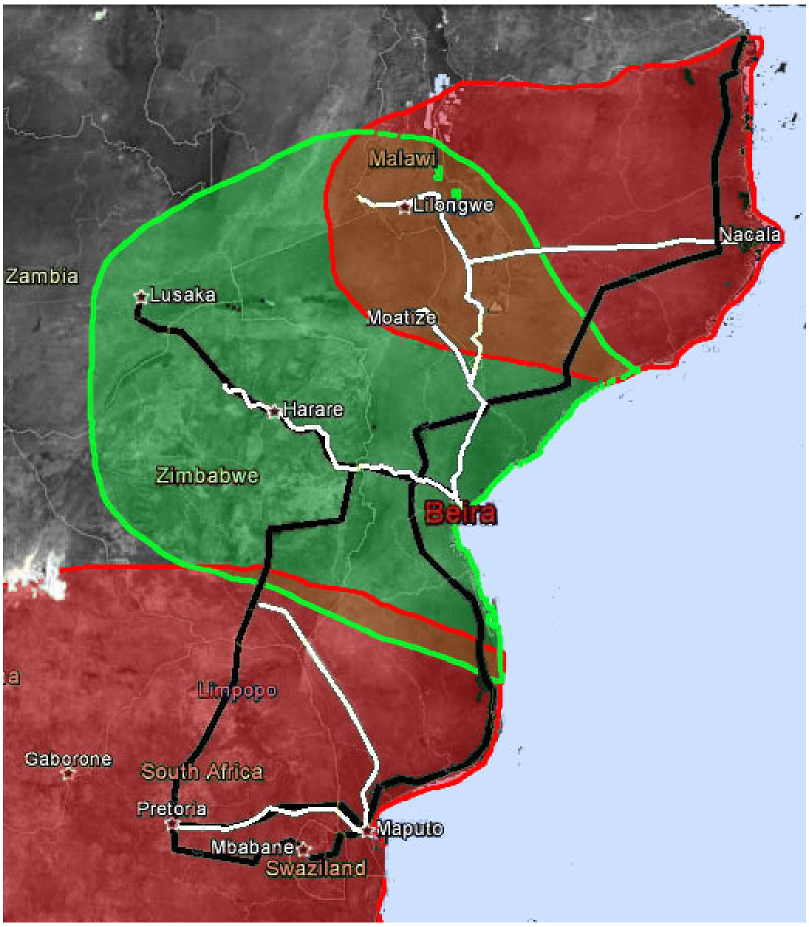


Figure 2-9 | Hinterland Beira (green) and Nacala/Maputo (red)

2.6 Conclusions and recommendations

The hinterland of Beira is vast and little competition is present, because comparable ports are located over 1000 km away. Beira is the nearest port city for the landlocked countries Malawi, Zambia and Zimbabwe.

The Port of Beira throughput is divided in four different cargo segments: container, general cargo & dry bulk, coal and fuel. Throughput figures of the last 10 years are known for these segments, except for the coal export, because operations just started in the port. There is an opportunity for the port to expand the coal export, but Nacala Port can become a competitor. For the master plan, the historic throughput figures and opportunities will be further investigated in chapter 6 to develop scenarios.

No waterway options exist for the hinterland transport, thus road, railroad and pipeline remain as modalities. The hinterland railway lines are used at full capacity, which hampers expansion of the coal export through Beira. The fuel throughput to Zimbabwe is at maximum capacity of the installed pipeline. To increase Beira's fuel throughput the capacity of the pipeline should be expanded or different modalities should be used. Capacity and intensity figures of the hinterland road connections were not found.

The long access channel allows only for one-way traffic and has limited depth. Only daylight sailing is permitted in the maritime access to Beira Port. Initiatives to implement night sailing are present, but not yet commenced.

3 PRESENT PORT OF BEIRA

Now that it is known how the port is orientated and connected to its surroundings, the current Port of Beira will be described in more detail. The port elements are described and problems are identified. In this chapter, the port analysis is continued and the traffic is analysed per terminal.

In paragraph 3.1 the layout of the port will be given, which will be the basis for the elaboration of the terminals and quays, which are introduced in the history of the port in paragraph 3.2. The fishery port is not under the control of the Beira port authorities, but an expansion of Beira Port could be made using the fishery port, which is discussed in paragraph 3.3. Four terminals with adjoining quays can be identified, which are discussed in paragraph 3.4 to 3.8. For each terminal, the infrastructure is discussed and quay constructions are explained. These are required to identity the limitations on the terminal operations. The calling ships are elaborated using the throughput figures and the maritime access from the previous chapters. Inside the port, cargo and people are transported by road and railway. The bottlenecks of the main infrastructure of the port are identified in paragraph 3.9. Recently, land is reclamated to make expansion of the port possible. These open grounds are discussed in paragraph 3.10.

From the throughput figures and some assumptions based on the opinion of colleagues at DHV, derivations are done for the ship movements. The year 2009 is used as a base year for the present situation, because data for all terminals is available for this year. In 2009, no coal was exported through the port. For the Harboursim model, which is used later in the research, the coal terminal should be modelled too, because the coal terminal started recently with operations. As there are no throughput figures known of recent years, the design throughput of the present coal terminal is used for the coal ship movements.

In the following paragraphs the mean service times of the calling ships per terminal are calculated, which are later used in the Harboursim simulations. The mean service time comprises of the mooring, unloading, loading and unmooring time. Mooring and unmooring time is estimated from experience at 90 minutes total. Using handling speeds of the terminal equipment the (un)loading times of the ships are calculated, an additional 90 minutes is added to represent the start-up and end time of service operations (DHV BV, 2011b).

3.1 Layout of port

Twelve berths are located along the Pungue riverside as shown in Figure 3-1. Coming from the sea, the first berth is assigned to fishing vessels. From berth number 2 to 5, along 646 meter quay, multipurpose and container vessels are handled. Berth number 6 to 10 have a total length of 858 meter. Berth 6, 7, 9 and 10 handle general cargo and dry bulk, number 8 is dedicated to coal export. Berth number 11 was the official tanker berth, but it is now in a dilapidated state and no longer used. The newest berth, located approximately 1 km upstream from berth 11, is a fuel jetty. In Table 3-1 an overview of the quays is given, in the next paragraphs each terminal is discussed in detail.

Table 3-1 | Quays with lengths, depths and latest rehabilitation

Quay	Terminal	Length [m]	Depth (-CD) [m]	Year in use
1	Fishery port	183	Variable	<1964
2-5	Multi-purpose / container	646	11	1992
6-7	General cargo and dry bulk	336	10	1964
8	Coal	188	10	2011
9-10	General cargo and dry bulk	335	10	1967
11	Old fuel (no longer in use)	128	12	1981
12	Fuel	264	12	1994

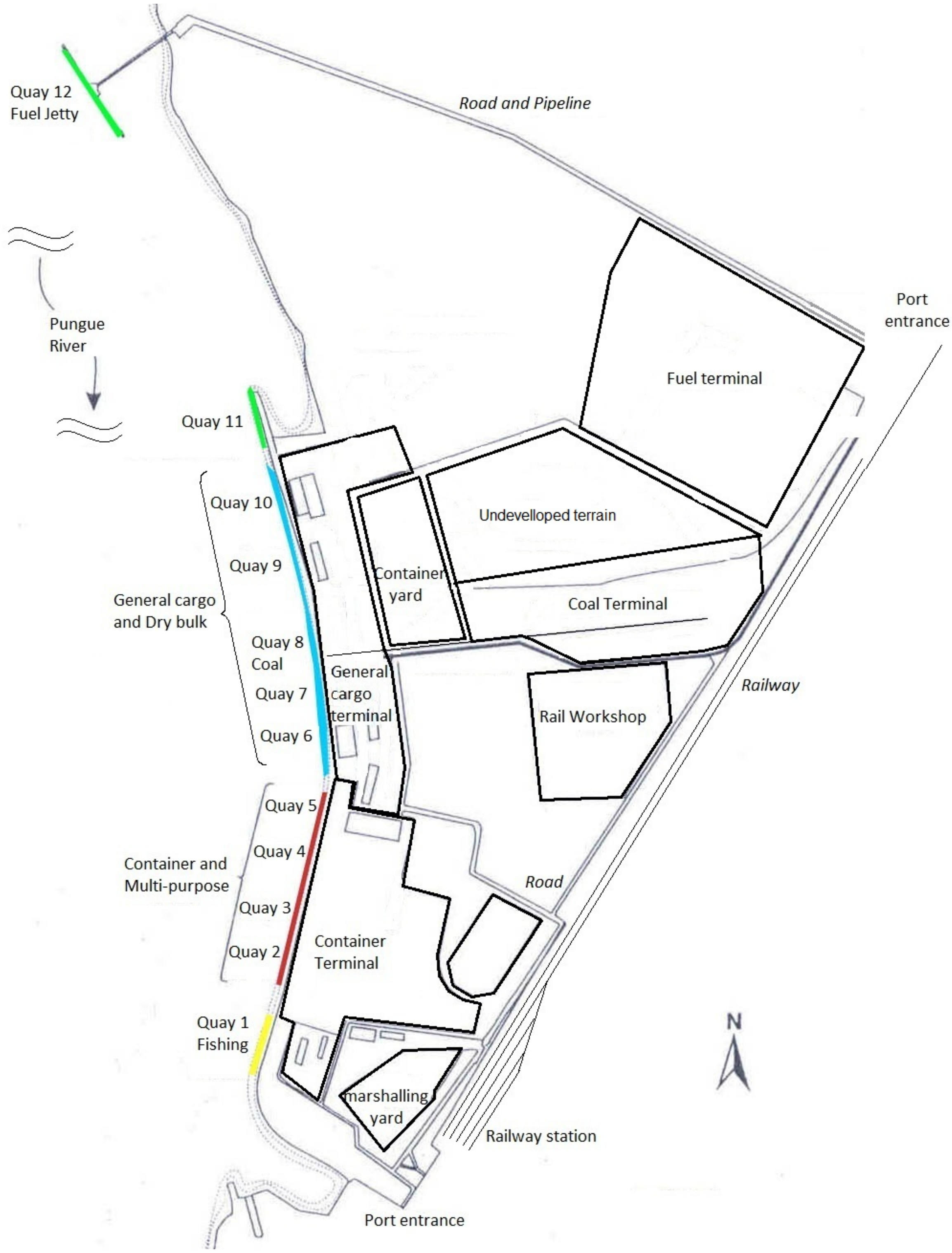


Figure 3-1 | Sketch layout of Beira Port, with quays, terminals, roads and railway

3.2 History of the port

The town of Beira was founded late 19th century, after being identified as a potential port by the Portuguese explorer Paive de Andrade. De Andrade's report was followed by a hydrographical survey of the river and bar. A Portuguese military post was established in 1887, out of which the town grew. By 1889 channel buoys marked the entrance to the Pungue estuary and six years later work began on the first landing stage. A wooden pier was also constructed to serve the railway, which was then under construction. The railway quickly became the lifeline of the port and for many years carried much of the cargo and passengers to and from the landlocked Rhodesias (now Zimbabwe and Zambia) as well as Nyasaland (now Malawi).

By the mid to late 1920s, construction of deep water berths and improvement of the anchorage facilities at Beira had begun under the control of the company named Companhia do Porto da Beira. Major extensions took place after 1930 with the construction of quays 2 to 5. In 1949, the Mozambique Ports & Railways Company (CFM) took over administrative control of the port. In the 60's, quays 6 to 10 were constructed for general cargo and dry bulk. In addition, the port was linked to Zimbabwe by a fuel pipeline. The port was further expanded upstream with the construction of quay 11 in 1981.

Before Mozambique's independence from Portugal in 1975, the port was noted to be one of the major facilities in tourism, fishing and trade. However, with the exodus of trained Portuguese personnel, the newly independent country had no skilled professionals to maintain its infrastructure and the economy plummeted. Mozambique was ravaged by a civil war from 1977 to 1992. After the war, Mozambique ranked amongst the poorest countries in the world. Beira was relatively spared, mostly because of hinterland influences. During the civil war, Zimbabwean troops protected the railway and highway from Beira to Mutare in order to continue trade.

The Beira Corridor Authority (BCA) was established in July 1987 to implement the programs included in a 10-year development plan. Under the control of BCA, infrastructure rehabilitation and re-equipment of the port as well as technical assistance and training required for the implementation and operation of the port facilities were carried out. Quays 2 to 5 were renovated into a multipurpose and container terminal and a new fuel terminal was constructed. In 1998, a joint venture was formed between Cornelder Holding, based in Rotterdam (67%) and CFM (33%) for the main stevedoring activities of the container and general cargo dry bulk terminals by Cornelder de Mozambique (CdM). The Port of Beira has developed quickly since. (Cornelder de Mozambique, 2010)

3.3 Fishery port and service area with dry dock

The fishery port is the southern boundary of the current port. To see whether the port could expand beyond this boundary it is briefly discussed. The fishery port contains a small basin and quay 1 along the Pungue River. The layout of the small basin is given in Figure 3-2. The basin can accommodate small fishing boats, as can be seen in the satellite image in Figure 3-3. The catch is for the local market and not on an industrial scale. It can be seen that the quay length is long enough to accommodate ships of up to 200 m, but the depth limitation of CD -3.20 m is much too shallow. The basin includes a service area with a dry dock, which dimensions are 100 x 20 meter and depth 1.8m. Private companies are involved in ship repairs and maintenance of ships up to 110 meter length. (JICA, 1998)
Quay 1 is located north of the small basin. It is the oldest quay of the port and is in bad shape. This quay could be used to extend the current container quay. Its design depth was - 7.75 m CD and 183 m long. Mostly shrimp fishing vessels use the quay.

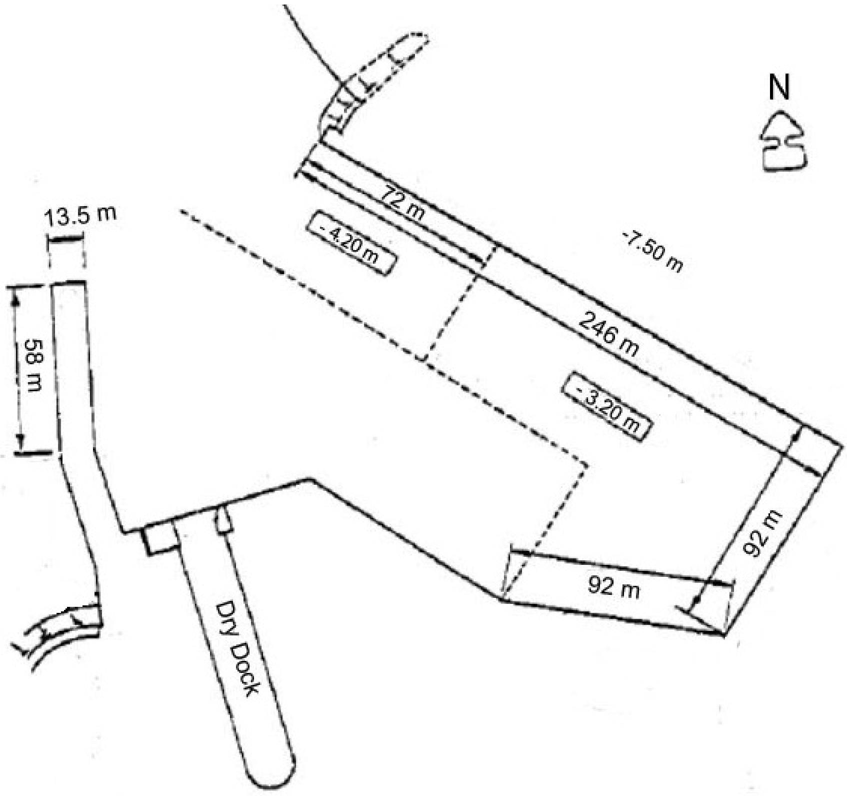


Figure 3-2 | Layout of fishery and service port (NEDECO, 1982)

Figure 3-3 | Satellite image of the fishery and service port with quay 1 (Google, 2011)

3.4 Multi-purpose and container terminal

3.4.1 Terminal infrastructure

The multi-purpose and container terminal is located at berths 2 to 5. A satellite image of the terminal and three moored ships is shown in Figure 3-4. The quays have an open berth structure with a fender piece in front. A cross section is given in Figure 3-5. The foundation is on steel tubular piles with a concrete deck on top of it. The area between the piles is protected with rubble mound armour. Piles are designed to bear compression and tension loads only. The load the structure has to bear is that of the ship-to-shore gantry cranes. The first and fourth row of steel piles carries the crane weight, and thereby governing this weight. The design depth in front of the quay is - 11 m CD. The cross section shows that the piles do not go much deeper, it is foreseen that for a deepening of the berth a new construction must be made. If the structure is combined with a retaining wall, the berth in front can be deepened. However if bigger ships are to be berthed also the horizontal mooring forces should be checked.

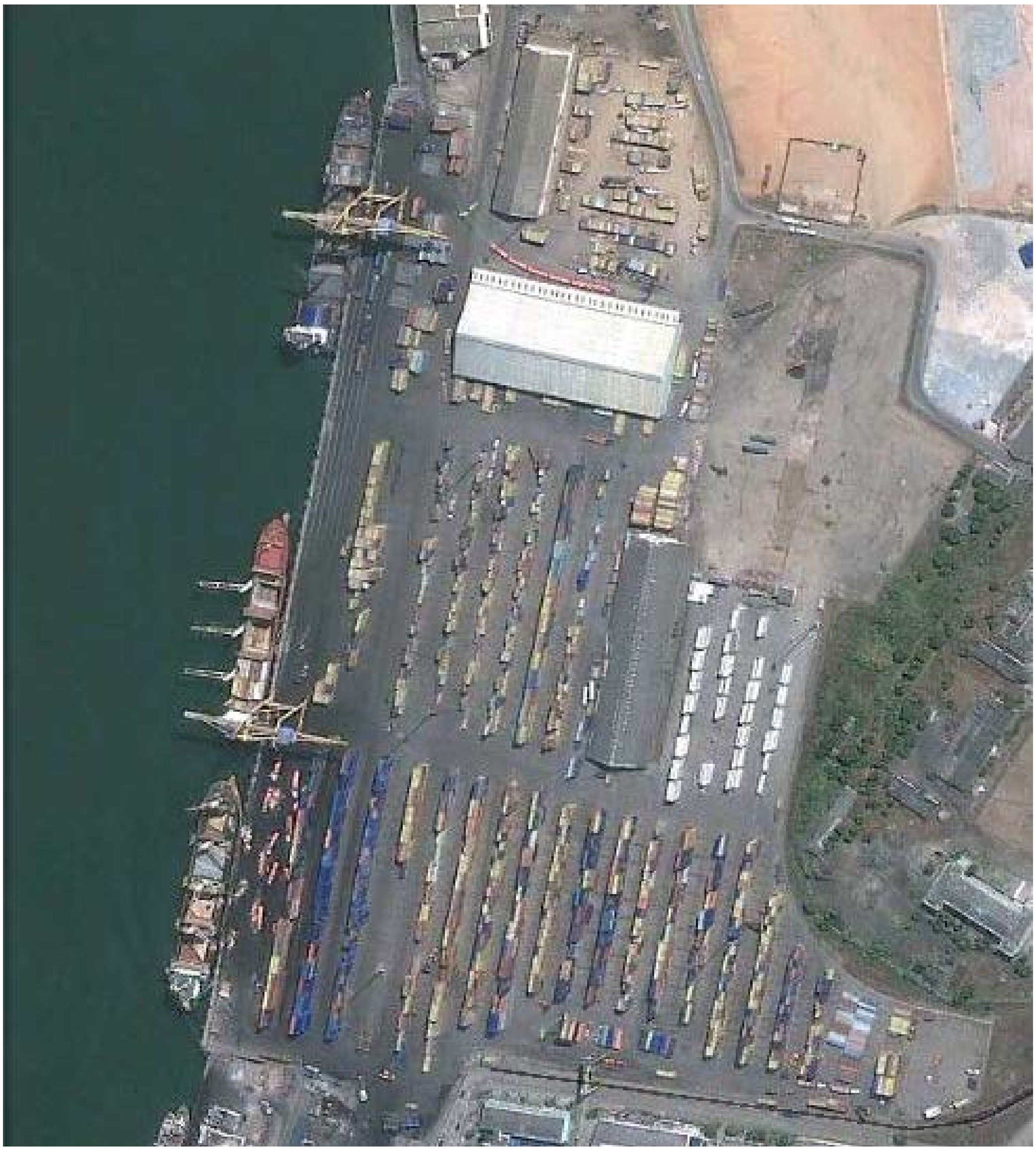


Figure 3-4 | Satellite view of container and multipurpose terminal (Google, 2011)

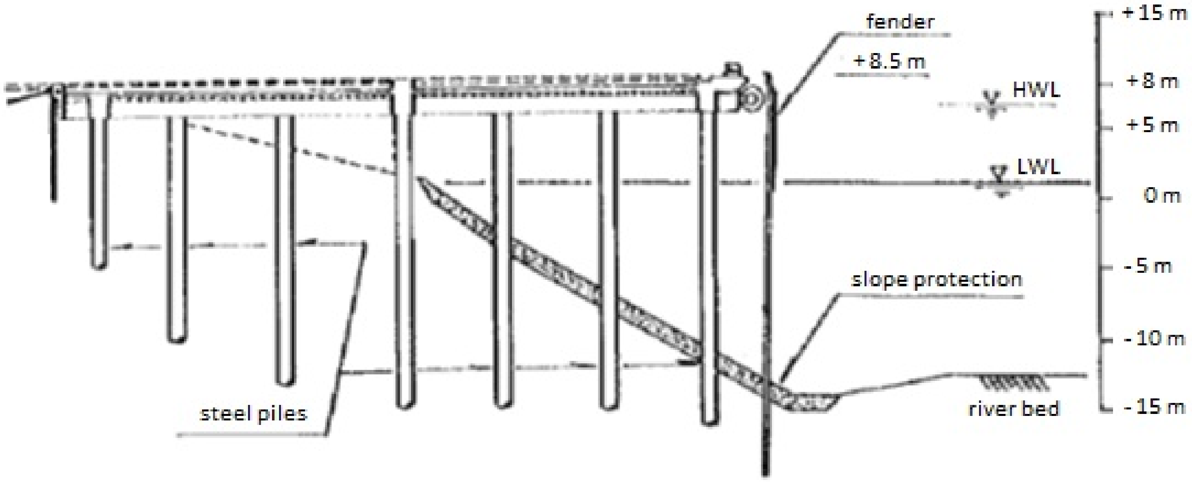


Figure 3-5 | Cross section of multi-purpose and container quay 2-5 (NEDECO, 1982)

Containers are stored on a 200.000 m^2 well illuminated yard, with a nominal stacking height of three containers, which can be seen in Figure 3-6. With this stacking height and reserving space for the terminal equipment on average 30 m^2 is required to store a container. A total of 7000 containers can be stored on the yard. An additional 144 electrical reefer points are available for refrigerating cool containers. There is one bonded transit house warehouse of 8400 m^2 for stuffing and stripping containers.

Figure 3-6 | The container terminal and quay 6 to 11 in the distance

3.4.2 *Terminal operations*

The terminal design capacity is 100.000 TEU per annum. Two rail mounted ship-to-shore gantry cranes are available with an under hook lifting capacity of 50 tons each. CdM ordered two new ship-to-shore cranes for 2013 to replace the current cranes. The ordered STS cranes have an outreach of 40 m and a lifting capacity of 65 ton under spreader. The cranes are designed to handle twin lift operation, increasing gross crane productivity, which is now estimated at 20 moves per hour. One rail mounted gantry crane is available with 50 tons for loading and offloading of wagons. An overview of the available stevedoring equipment is given in Table 3-2.

Reach stackers transport the containers within the storage area and can stack 3 containers on top of each other. The terminal tractors transport the containers to and from the quay. The used method is labour intensive, which is cheap in Beira. For better space usage, the reach stackers could be replaced by a gantry crane system for transporting the containers within the yard.

Table 3-2 | Stevedoring equipment available on container yard (CFM, 2010)

Stevedoring equipment	Quantity	Capacity
Wagon gantry crane	1	50 T
Ship to shore gantry crane	2	50 T (65 T in 2013)
Reach stacker	14	45 T
Top loader	3	45 T
Heavy forklift	3	30 – 42 T
Terminal tractors	35	
Forklift	8	2-5 T

3.4.3 *Calling container ships*

The average calling vessel is assumed from DHV experience to carry 900 TEU. A typical 900 TEU ship has a length of 154 m and a loaded draught of 8 m (Thoresen, 2010). Trade routes are along African ports, where multiple ports are called before ships sail to other continents. Therefore, an assumption must be made on the amount of TEU each ship transfers at the port of Beira. From DHV experiences, this is assumed 200 TEU import and 150 TEU export containers. In order to calculate the number of container ships calling Beira Port the import is governing. It is assumed that ships that unload containers for import, load the exported containers and no extra ships are needed. Additionally the ships transport the empties, which are equally divided over the import and export. The formula below is used to calculate the number of container ships calling the port. This results in the parameters shown in Table 3-3.

$$number\ of\ container\ ships = \frac{\left(TEU\ imported + \frac{1}{2}\cdot TEU\ empties\right)}{average\ ship\ load}$$

Table 3-3 | Fleet data container ships with reference

Container ships	Quantity		Reference
total throughput in 2009	92,000	TEU	sheets CFM
Import	42,200	TEU	sheets CFM
Export	29,000	TEU	sheets CFM
Empties	21,000	TEU	sheets CFM
number of vessels in 2009	387	-	calculated
mean inter-arrival time	2,502	min	calculated
average vessel size in 2009	900	TEU	DHV experience
LOA	154	m	(Thoresen, 2010)
draught	8	m	(Thoresen, 2010)
import per ship	200	TEU	DHV experience
export per ship	150	TEU	DHV experience
mean service time	579	min	calculated

3.5 General cargo and dry bulk terminals

3.5.1 Terminal infrastructure

The general cargo and dry bulk (GC-DB) terminal comprises of berth 6, 7, 9 and 10, shown in the satellite view of Figure 3-7. It can be noticed in the lower edge of the picture that there is a small angle between quay 5 and 6. Thereby a border is created between the container and GC-DB terminal. Quay 8 is located in between and is dedicated to coal ships. The conveyor band of the runs through the GC-DB terminal and divides it in two. The GC-DB terminal is effectively divided into two terminals, with separated berths. From quay 7 to quay 8 a small angle exists, therefore it was already less flexible for callings of different ship sizes than with one long straight quay.

The terminal has a storage area that consists of five covered warehouses with a total of 15,000 m^2 and 12,000 m² paved open space for ferro-chrome, granite, steel and other break bulk cargoes. The terminal area covers about 100,000 m^2. Total handling capacity is said to be 2.3 million tons per annum. (CFM, 2010)
Berth 6 is for refrigerated cargo including citrus, vegetables and other fresh products. There are 15 cooled storage chambers for citrus fruit with an 1100 tons capacity and a deep freeze with a capacity of 490 tons is available. (CFM, 2010)

Figure 3-7 | Satellite view of quay 6 to 11 (Google, 2011)

In Figure 3-8 the cross section of quay 6 and 7 is sketched. This is a concrete structure with grout anchors to bear the bollard forces. Figure 3-9 shows the cross section of quay 9 and 10, they are made out of concrete caissons filled with sand. The design depth is -10 m CD and deepening without adapting the quay foundation is not possible.

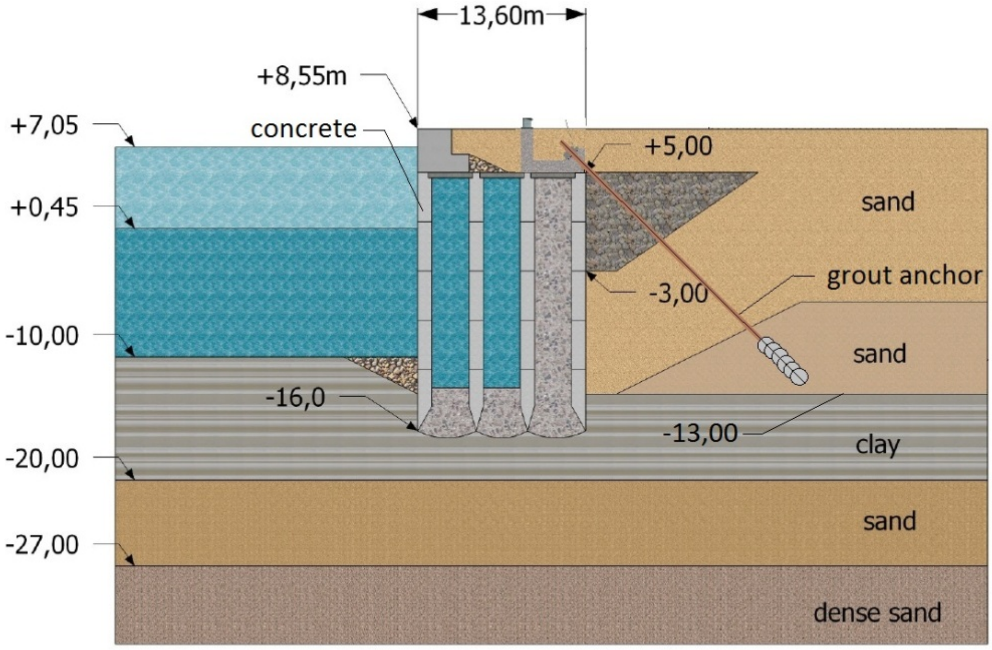


Figure 3-8 | Cross section GC-DB quay 6-7 (DHV BV, 2011c)

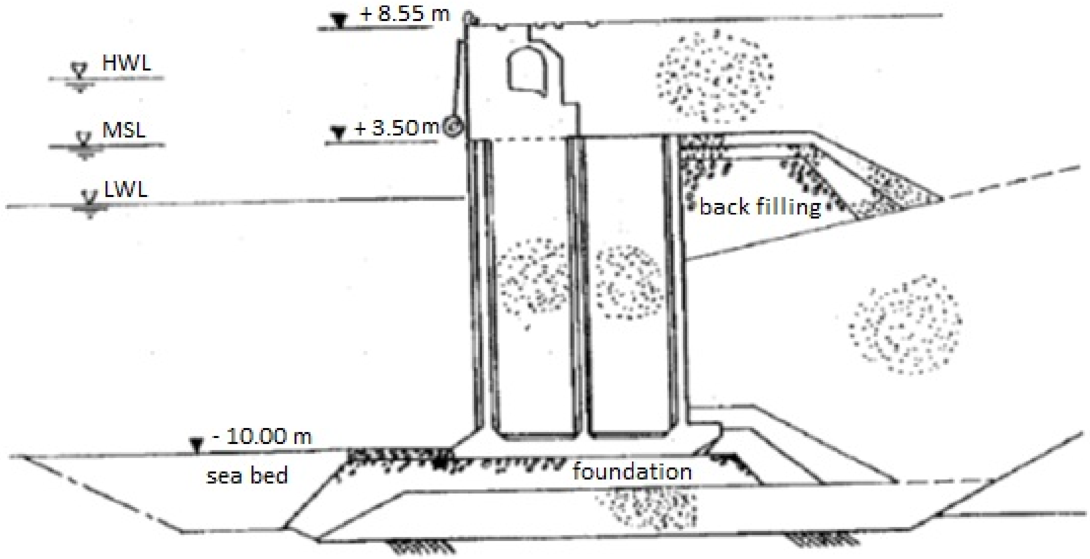


Figure 3-9 | Cross section GC-DB quay 9-10 (NEDECO, 1982)

3.5.2 Terminal operations

Import comes from dry bulk vessels, which are unloaded with mobile grab cranes in bagging machines each with a capacity of 120 tons per hour. The bags are further transported from the quay by trucks. This operation is illustrated in Figure 3-10. Ships could be serviced faster if the dry bulk is first transported in bulk to a storage area. In the storage area, the bulk could be bagged. All available stevedoring equipment is listed in Table 3-4.

Table 3-4 | Stevedoring equipment GC-DB terminal (CFM, 2010)

Stevedoring equipment	Quantity	Capacity
Mobile crane (with grabs)	2	35 and 45 T
Sidelifter	1	16 T
Front loader	1	42 T
Mac lifter	1	25 T
Terminal tractors	10	60 T
Forklift	6	3 – 10 T
Timber loader	1	12 T
Bagging machines cereals	4	120 T/hour
Bagging machine fertilizer	2	120 T/hour

Figure 3-10 | View from quay 8 on unloading activities at quay 7, with 50 T crane and bagging machine

3.5.3 *Calling ships*

The average calling ship is assumed to carry 7,500 metric ton, with a length of 113 m and a loaded draught of 8.5 m. As with the container ships, sailing routes call multiple ports in the region before sailing over the ocean. From experience at DHV, it is estimated that the general cargo and dry bulk ships tranship on average 2500 tons. In order to calculate the number of general cargo and dry bulk ships the same formula as for the container ships is used, only without the empties and in metric tons. In Table 3-5 the GC-DB fleet parameters are summarized.

$$number\ of\ general\ cargo\ ships = \frac{cargo\ imported}{average\ ship\ load}$$

Table 3-5 | Fleet data GC-DB with reference

GC-DB ships	Quantity		Reference
total throughput in 2009	980,000	ton	sheets CFM
Import	580,000	ton	estimated
Export	400,000	ton	estimated
number of vessels in 2009	387		calculated
mean inter-arrival time	1,359	min	calculated
Maximum vessel	15,000	DWT	lecture notes
LOA	158	m	lecture notes
draught	9	m	lecture notes
average vessel in 2009	7,500	ton	DHV experience
LOA	113	m	lecture notes
draught	8.5	m	lecture notes
import per ship	1,500	ton	DHV experience
export per ship	1,000	ton	DHV experience
mean service time	724	min	calculated

3.6 Coal terminal

3.6.1 Terminal infrastructure

The coal terminal, projected during the 80's to export 1.2 million tons per year, is undergoing a phase of rehabilitation and revamping so that it can handle volumes of over 5 million tons. In order to do so, quay 8 is now solely reserved for handling coal. The privately owned companies Vale (67%) and Rio Tinto (33%) operate the terminal. In Figure 3-11 a satellite view of the coal terminal can be seen. The total terminal area is 120,000 m^2 and there is additional space to the north available for possible expansion.

Figure 3-11 | Satellite view coal terminal (Google, 2011)

Quay 8 has been rehabilitated in 2011 to handle Handymax coal ships. Figure 3-12 shows a top view of quay 8 with a moored ship. It can be seen that the ship takes space of quay 7 to be moored. The construction of quay 8 comprises of concrete piles with a concrete deck on top of it. In front of the deck are two breasting dolphins on which the ship is moored, see Figure 3-13 for a cross section.

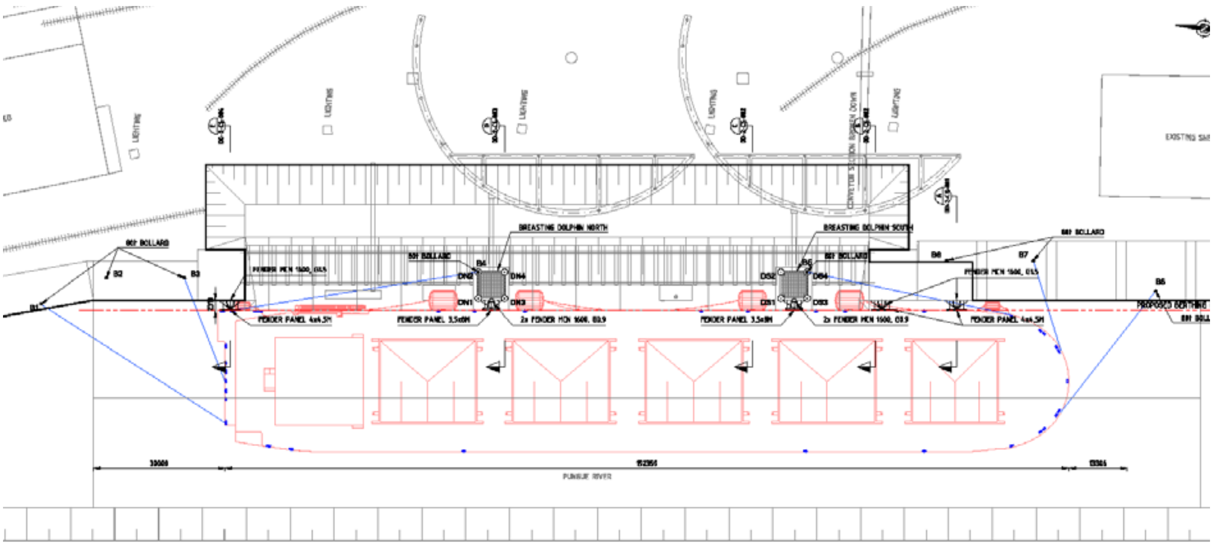


Figure 3-12 | Top view quay 8 with moored ship (DHV,2012)

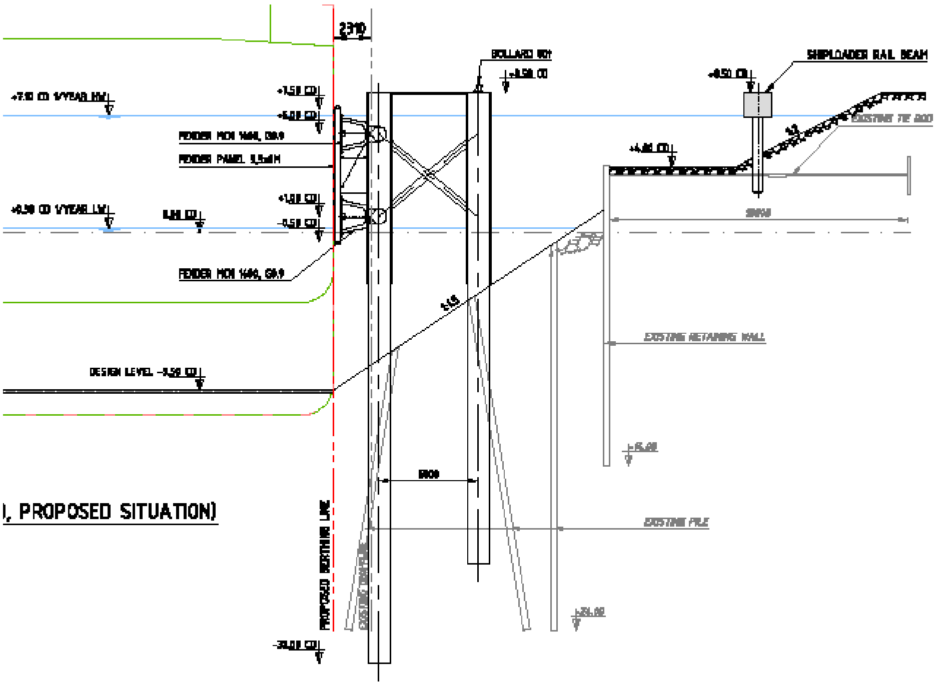


Figure 3-13 | Cross section quay 8 breasting dolphin (DHV, 2012)

The capacity of quay 8 is thought by Vale to be insufficient to handle all future coal throughputs. Vale has requested DHV for a basic design for the upgrade of quay 6 and 7 for the use of coal shipping. The berth pocket has to be deepened to -12.5 m CD for Handymax vessels with a capacity of 55,000 DWT.

3.6.2 *Terminal operations*

The coal arrives at the terminal by rail from the Tete province. The unloading rate from the railway wagons on to the stockyard is 400 tons per hour. From the stockpile to the quay, a single conveyor of 600 m feeds two telescopic telestackers on rails. In Figure 3-14 the conveyor belt and the stockyard is shown. At the quay, the vessels are loaded with the telestackers with a capacity of 1200 tons per hour each, see Figure 3-15. It is assumed that the commercial loading rate of the system is 1700 tons per hour. This is the average loading rate when the conveyor system and telestackers are running and includes stoppages for changing holds, maintenance, break downs, etcetera. It is assumed that maintenance can be performed when the vessel is not at berth. No import activities (or coal unloading) are foreseen at the quay. (DHV BV, 2011b)

Figure 3-14 | Coal conveyor belt of Beira Port with coal storage on both sides

Figure 3-15 | Coal vessel being loaded at Beira port

3.6.3 *Calling ships*

Rio Tinto uses Handymax vessels, which are loaded to a maximum of 30.000 DWT. The loaded draught is 9.2 m, the maximum draught in the berth pocket. Rio Tinto is aiming to transfer 1.6 million tons of coal per year, meaning 54 calls have to be made. See Table 3-6 for all fleet data of Rio Tinto ships.

Vale is aiming to transfer 3.4 million metric tons of coal per year. It uses Ocean Going Vessels (OGV) of over 160,000 DWT with a loaded draught of over 15 m. Vale needs to make 21 calls per year. Two specialised trans-shippers are used to sail maximum 30,000 tonnes of coal out from Beira Port and load the OGV at anchorage in deeper waters. The distance travelled by the ships from the access channel entrance to the offshore transhipment site is approximately 11.6 miles. To efficiently load an ocean-going vessel with a minimum of 160,000 tons of coal, seven trips are required. The ship that loads the OGV 4 times sails its first track first, and when serviced at the offshore mooring point, is followed by the other coal ship. This incurs that the 4 times loader transfers the first and last cargo for the ocean going vessel. (DHV BV, 2011b)

The five (one for each hold) cranes on board the trans-shippers discharge the coal into deck-mounted hoppers on the starboard side, which in turn feed a conveyor and long-travelling ship loader boom on the port side. The conveyor belt loads the coal into the Ocean Going Vessels. The operation is illustrated in Figure 3-16. The handling system has a peak loading rate of 5,500 tons/hour, guaranteeing an average loading rate in excess of 3,000 tons/hour in all conditions. (Coeclerici Logistics, 2011). In Table 3-7 all Vale fleet data is summarized.

Table 3-6 | Fleet data Rio Tinto coal with reference

Coal Rio Tinto ships	Quantity		Reference
total throughput	1,600,000	ton	DHV quay 8 report
number of OGV's Rio Tinto	53		calculated
mean inter-arrival time	9,855	min	calculated
OGV Handymax Rio Tinto	30,000	DWT	DHV quay 8 report
LOA	185	m	DHV quay 8 report
draught full	9.2	m	DHV quay 8 report
draught empty	5.5	m	DHV quay 8 report
mean service time	1,133	min	calculated

Table 3-7 | Fleet data Vale coal with reference

Coal Vale ships	Quantity		Reference
total throughput	3,400,000	ton	DHV quay 8 report
number of OGV's Vale	21		calculated
mean inter-arrival time	24,734	min	calculated
OGV size Vale	160,000	DWT	DHV quay 8 report
Handymax Vale	27,000	ton	DHV quay 8 report
LOA	194	m	DHV quay 8 report
draught full	9.2	m	DHV quay 8 report
draught empty	5.5	m	DHV quay 8 report
mean service time quay	1,133	min	calculated
mean service time offshore	720	min	calculated
number of loadings	7		DHV quay 8 report

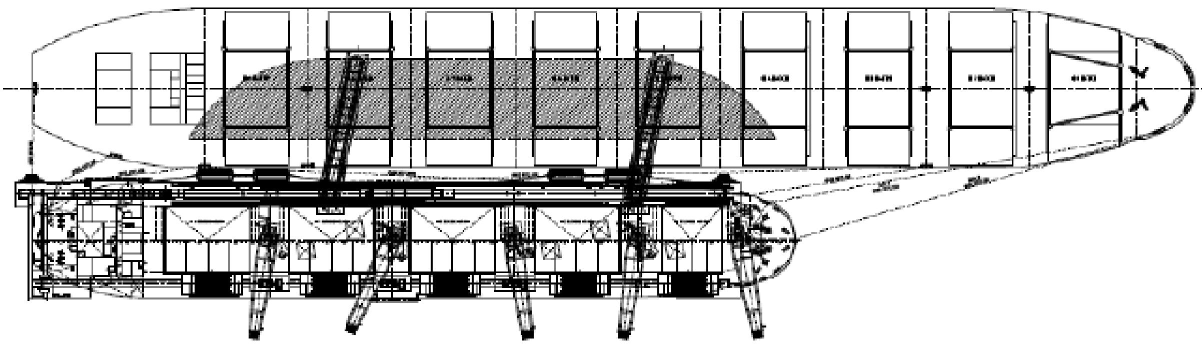


Figure 3-16 | Example of Self-unloading vessel connected to a large sea going vessel (DHV BV, 2011b)

3.7 Old Oil quay

The old oil quay was built as a pier construction as shown in Figure 3-17, but is now in a detoriated state. CdM has determined to renew and to extend the quay for multi-purpose container use. The proposed length is 290 m, measured from the corner of quay 10. Behind the quay 290 x 500 m terminal area is to be created. The quay shall be developed as an open berth embankment type of structure. The berth pocket shall be dredged to a level of -13.5 m CD. The project has started the preliminairy design phase, which means that the plan can be changed in the new master plan. However, the dimensions show the vision of CdM to create space for deeper ships. Panamax ships could be berthed at the proposed quay.

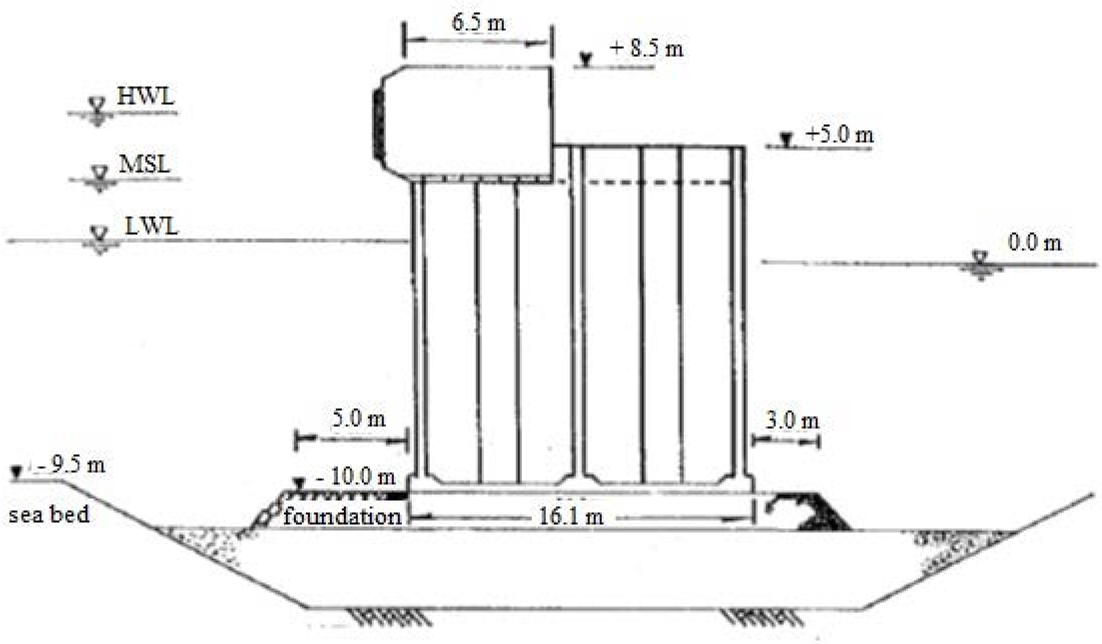


Figure 3-17 | Cross section of old oil quay 11 (NEDECO, 1982)

3.8 Fuel terminal

3.8.1 Terminal infrastructure

Figure 3-18 is a satellite view of the fuel jetty and tank farm. The jetty is connected to a tank farm 2.3 km in-land, offering a strategic fuel reserve. The tank farm covers an area of 360,000 m^2 and is connected to Zimbabwe by a pipeline. The jetty can accommodate tankers from 500 up to 50.000 DWT. Dimensions of the jetty are shown in Figure 3-19 and Figure 3-20.

Figure 3-18 | Satellite view of Fuel jetty and tank farm

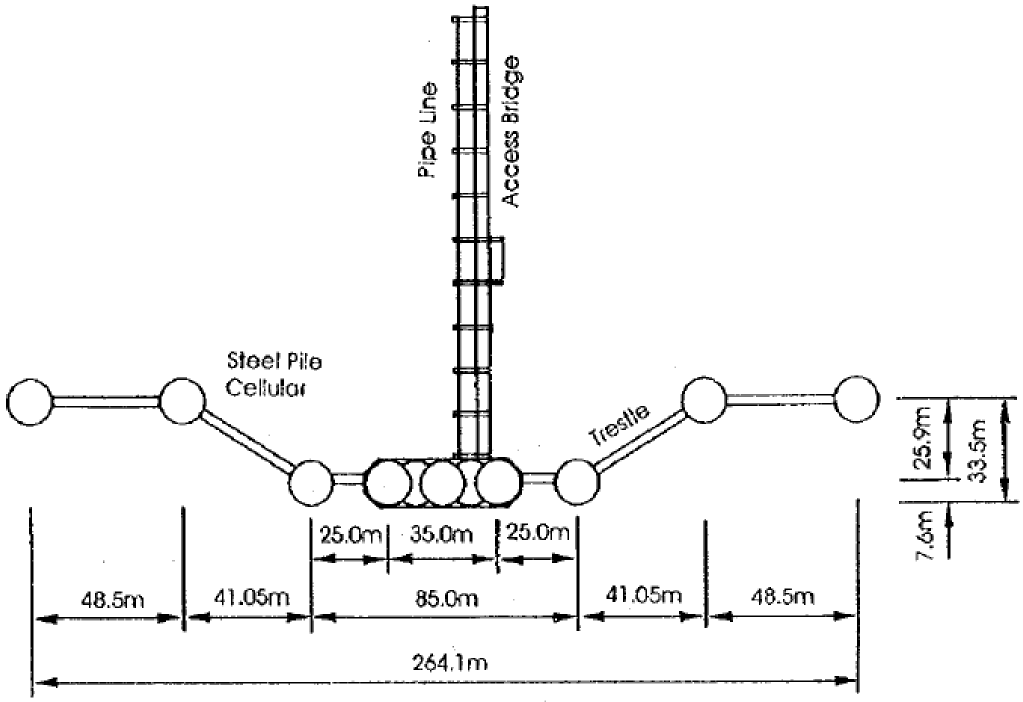


Figure 3-19 | Plan view of fuel jetty

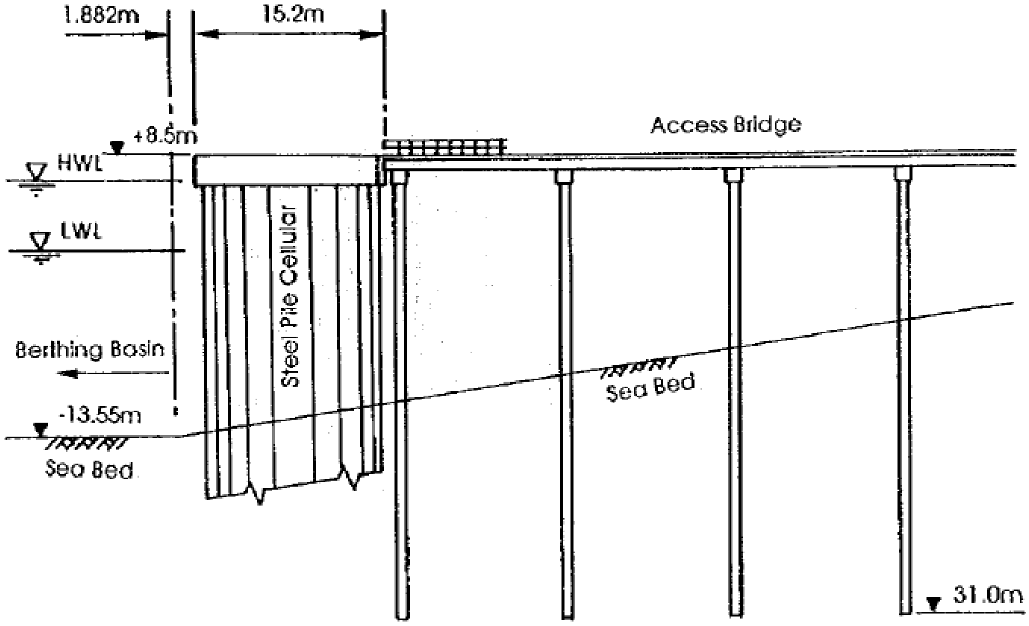


Figure 3-20 | Side view of fuel jetty

3.8.2 *Terminal operations*

The fuel jetty, which was inaugurated in 1994, has a capacity of unloading tankers of 2.5 million tons per annum. Only import facilities are present at the jetty. A system of four pipelines transports the diesel (16”), petrol (16”), Jet Avgas (16”) and fuel oil (12”) to the tank farm. The berth has a handling rate of 1200 ton per hour. The optimization of the use of the jetty in conjunction with the use of the different tank farms is subject of study. (JICA, 1998)

3.8.3 *Calling ships*

Total fuel traffic in 2009 is 900,000 metric ton, distributed over 90 vessels, as shown in Figure 3-21. The maximum DWT of a vessel is approximately 50,000. This ship would have had the maximum allowable draught of 11 m and a length of 180 m (Ligteringen, 2007). On average, a ship unloads 10,000 metric ton, combining Figure 3-21 and Figure 2-6, which takes about 10 hours. A typical 10,000 DWT ship has a loaded draught of 10 m and a length over all of 130 m (Ligteringen, 2007). All fuel ship parameters are summarized in Table 3-8.

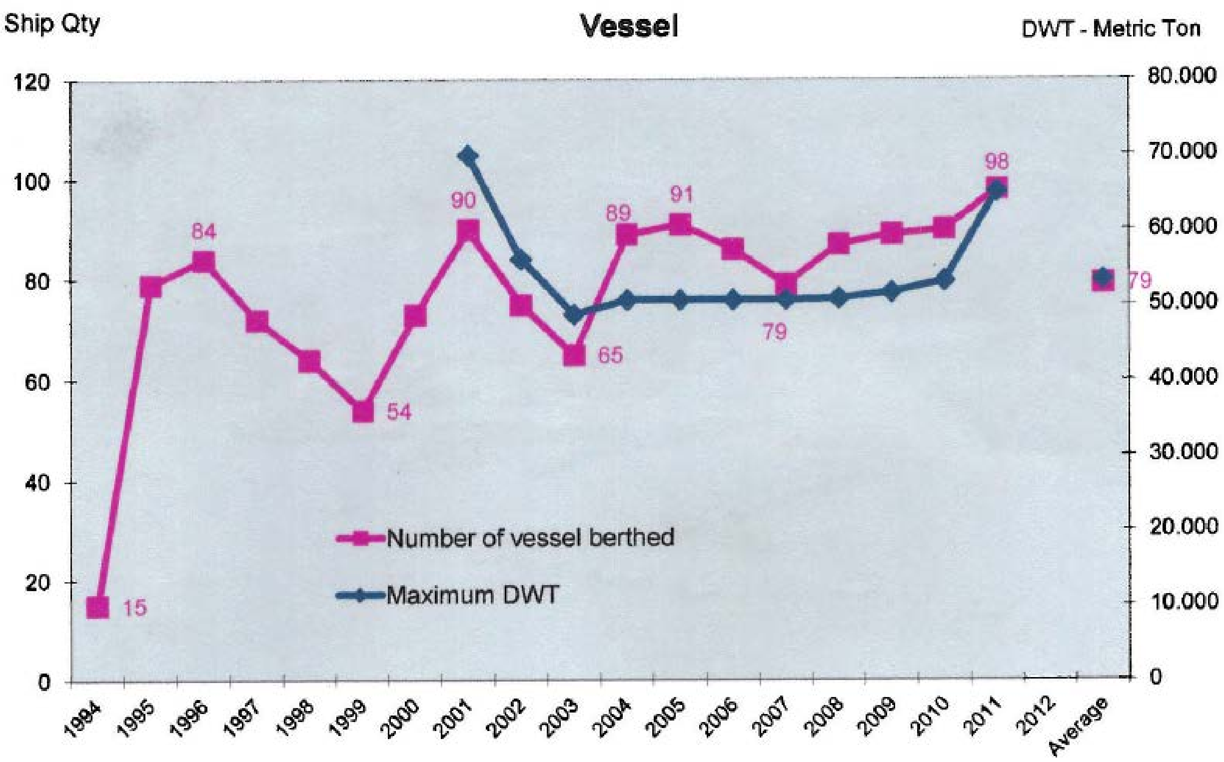


Figure 3-21 | Number of fuel ships berthed and maximum DWT per ship (CFM, 2010)

Table 3-8| Fuel fleet data with reference

Fuel ships	**Quantity**		**Reference**
total throughput in 2009	900,000	ton	sheets CFM
Import	900,000	ton	port analysis
number of vessels in 2009	90	-	sheets CFM
mean inter-arrival time	5,840	min	calculated
number of max vessel	2		estimated
Maximum vessel in 2009	50,000	DWT	sheets CFM
LOA	180	m	lecture notes
draught	11	m	maximum
number of average vessels	88		calculated
average vessel in 2009	10,000	ton	calculated
LOA	130	m	internet
draught	10	m	internet
mean service time	680	min	calculated

3.9 Roads and railway inside the port area

In Figure 3-22 the main roads and railway tracks are indicated. The red circles are road-rail crossings and are further explained in this paragraph. The railway inside the port area is connected to the container, GC-DB and coal terminal. There is a workshop for maintenance and repairs on the wagons. The local roads to and in the port are paved.

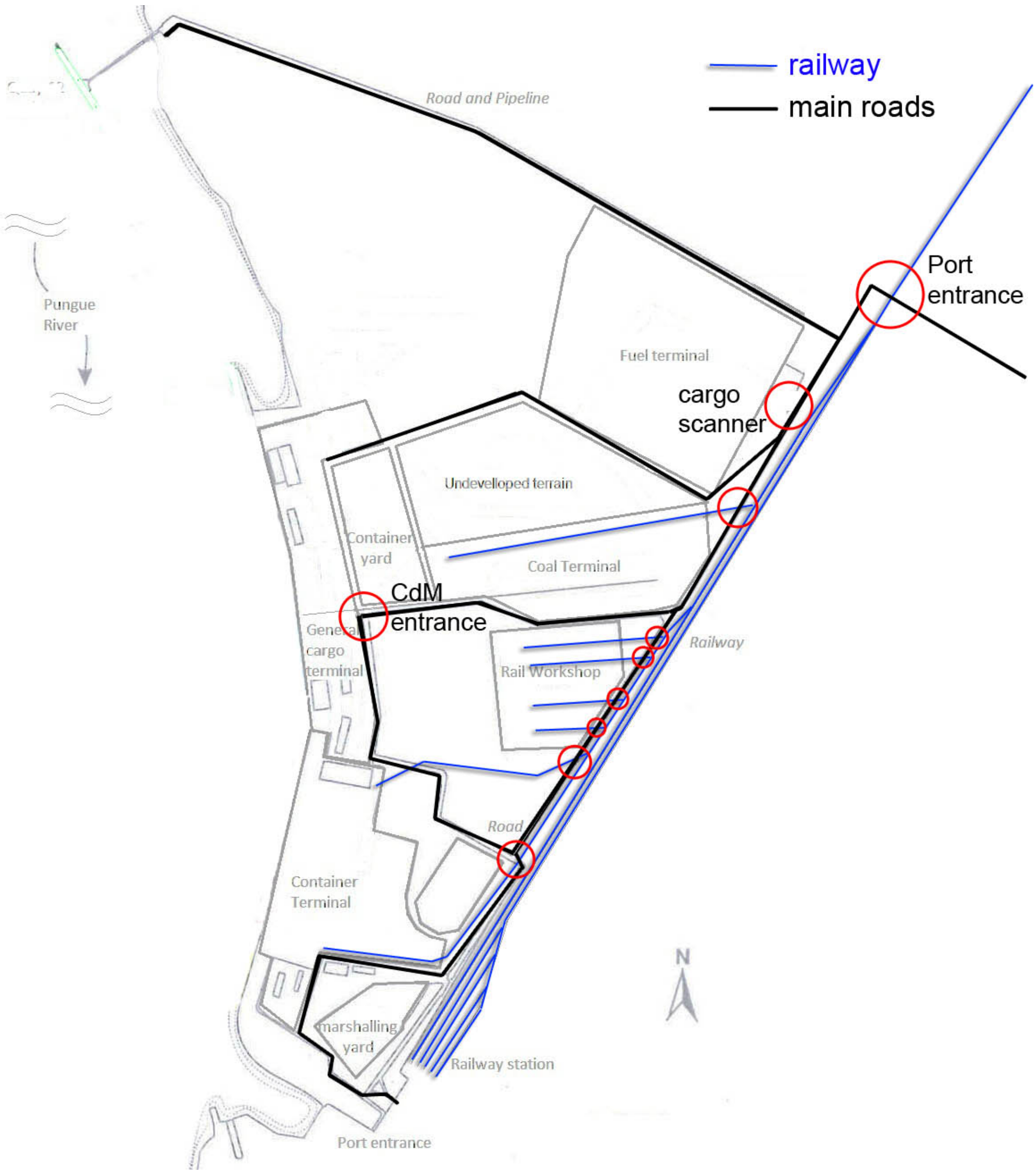


Figure 3-22 | main roads and railway line inside the port area

The port currently avails over a single access/exit gate, located in the northeast of the port area, indicated in Figure 3-22 by the largest red circle. There is just a 2x single lane access/exit provided to the public road. Due to the large number of trucks arriving and leaving the port, this is insufficient and long queues of waiting trucks are formed along the side of the road. Due to poor driving mentality, trucks frequently overtake the waiting line and potentially block the entire access to the port. Just before the gate, the road crosses the railway line to the port, blocking entry/exit for several minutes when long trains manoeuvre in or out the port. (DHV BV, 2011a)

Figure 3-23 | the main gate for trucks and rail

All arriving and leaving trucks, except empty trucks, need to go through a cargo scanner, located close to the main port entrance, indicated by the second red circle following the road from the port entrance. Queues and manoeuvres frequently lead to congestion of the access/exit road.

Inside the port area, there is a second gate to the port areas managed by Cornelder de Mozambique, located in the most left red circle in Figure 3-22. There is only a single access/exit gate provided. Due to increasing cargo volumes and strong reliance on truck transport, there is frequent congestion at the gate area, for which there is no dedicated parking area available. (DHV BV, 2011a)

The internal port roads are all dimensioned at 8 m wide, allowing for 2x1 traffic lanes. Since there is no physical boundary between the two driving directions and frequently truck or cars are left unattended at the side of the road, there are frequent gridlocks on the port roads. Moreover, not all roads are well paved, resulting into large potholes and uncomfortable / potentially unsafe driving conditions. (DHV BV, 2011a)

Figure 3-24 | Insufficient road dimensions and inadequate use

There are no dedicated parking areas for waiting trucks, neither inside nor outside the port area. This poses problems to truck drivers that need to wait to enter the terminal to pick up their cargos, or for trucks that need to wait for their paperwork to be finished. Current practice is parking alongside the port roads, reducing the capacity of the roads and potentially causing congestion. There are some dedicated parking areas, but these are owned by private companies and trucks need to pay, which they do not want to, considering these parking lots are usually underutilized. (DHV BV, 2011a)

Currently there is a single rail access point to the port, which is at the same location as the road access. The rail branches cross the main port road several times to reach the storage areas and port terminals, indicated by the small red circles. Due to the layout of the rail network within the port, most trains need to be shunted and return via the same track. There are no rail loops provided. (DHV BV, 2011a)

3.10 Open grounds

Figure 3-25 shows a top view of the land reclamation site, with measured dimensions. The land is acquired with sand from dredging works in the port access channel in 2011. The land currently serves no use and is available for future port expansion. The location is 1 km north of the fuel jetty, which is partly visible close to the lower edge of the figure.

Figure 3-25 | Satellite view of land reclamation

3.11 Conclusions

The port of Beira has dedicated terminals for container, coal and fuel. All other cargo is serviced at the combined general cargo dry bulk (GC-DB) terminal.

The Port of Beira has a long history, which has led to the current terminal layout shown in paragraph 3.1. The fishery port forms the southern boundary and currently the port is bounded in the north by the fuel jetty. North of the jetty, a land reclamation site is present, which is designated for future port use. The layout shows that inside the port boundaries there is also area free for possible future expansions.

The fishery quay 1 and the old oil quay 11 are in a deteriorated state and currently not in uses. Quay 11 is used for the mooring lines of ships berthing quay 10.

The quays are all ideally situated along the riverbank; however, bends in the quay front make it inflexible for changing berth configurations. The berths are all packed together and only extensions could be built at the boundaries. The deteriorated fishery quay 1 could be used for the extension of quay 2 for the Port of Beira. Next to quay 10, there is room for possible quay extension further northwards.

The terminal operation and calling ship figures depicted in this chapter are sufficient for the further development of the master plan. They can be used as input for the capacity simulations.

The port truck traffic leads to congestion in the port and at the main gate. The current road layout does not suffice for the occurring traffic. An adequate solution should be found for the truck delay.

4 ENVIRONMENTAL BOUNDARY CONDITIONS

Port operations can be influenced by weather conditions, for that reason the climate in Beira is discussed. Also wind and wave conditions are discussed for that matter. By discussing the calling ships, a start was made with the traffic analysis. More insight is gained on the ship processes by examining the tidal conditions, because these determine the tidal window for the ships. The morphological processes are of great importance to the port of Beira, because of its influence on the depth limitation of the port and the access channel. As a basis for the new master plan the sedimentation and dredging is extensively treated.

The chapter commences with discussing the climate in which the Port of Beira is situated. The wave conditions inside the port basin and in the access channel are discussed in paragraph 4.2. Next, the wind conditions in the port are treated. In paragraph 4.4 the tidal conditions are discussed. The morphology is explained in paragraph 4.5, by discussing the bottom sediment classification, the sediment volumes and the available dredging equipment. The chapter is closed by the conclusions.

4.1 Climate

The temperature in Beira varies between 20 °C and 29 °C, indicated by Table 4-1. The mean annual temperature is 24 °C. The maximum and minimum monthly mean temperatures are 26 °C and 24 °C, respectively, which indicate that here is little variation in temperature throughout the year. This means that temperature changes do not hinder port operations. The mean annual relative humidity is 72 % with small difference between the wet season and the dry season. (JICA, 1998)

The mean annual rainfall is approximately 1,400 mm, where the monthly variation is high. There is a clear rain season from December to April, as can be seen in Table 4-1. Records state monthly rainfall of more than 400 mm occurs with a frequency of 1 in 2 years. Between 1961 and 1997, there have been 23 cyclones that strongly affected Mozambique. Cyclones are generated in the South-Western Indian Ocean from November to April. They affect Beira mostly around February and March. Cyclones cause large wind speeds, heavy rainfall and high waves. A cyclone is expected once every 2 years (0.64 times per year). For a cyclone, a downtime of 5 days is expected. The dry season from June to October has very little rainfall with a minimum mean monthly in September of 12 mm. (JICA, 1998)

Table 4-1 | Meteorological records from Beira Meteorological Station (1987-1996);

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
TX	29	29	28	27	25	23	22	22	24	26	27	29	26
TN	27	27	27	25	23	21	20	21	22	24	25	26	24
TM	28	28	27	26	24	22	21	22	24	25	27	27	25
UU	72	73	73	73	75	73	74	74	71	69	69	70	72
RR	255	233	230	114	80	48	40	39	12	40	81	167	1338*

TX: maximum temperature [°C]; TN: minimum temperature [°C]; TM: mean temperature [°C]; UU: relative humidity [%]; RR: rainfall [mm] *annual total

4.2 Wave conditions

Wave data are available at two locations: one offshore at depth 13m and near the coast at depth 5m. Offshore the waves go up to 3.25 m and the significant wave height is 1-2 m. Near the coast the maximum wave height is 1.8 m, with a significant wave height smaller than 1 m. (JICA, 1998)

The wave climate is very mild and berths are protected for the predominant wave directions, which are east and southeast. Due to refraction, the waves are diverted to the adjoining coast and the wave climate inside the port is even milder. Waves are expected to be low on the Pungue River in front of the quays and do not influence the behaviour of the vessels.

4.3 Wind conditions

The figure below presents the wind climate for Beira. The data are taken from the quay 11 weather station, over a time span of approximately one year. From the table it follows, that in Beira the most common wind direction is ENE to SE (roughly 45% throughout the year). The probability of wind speeds exceeding 10 m/s is less than 1%. (JICA, 1998) Port operations will not be hindered by these low wind speeds. For sailing the access channel manoeuvring pilotage is already required and if necessary tug boats are available for safe manoeuvring with higher wind speeds.

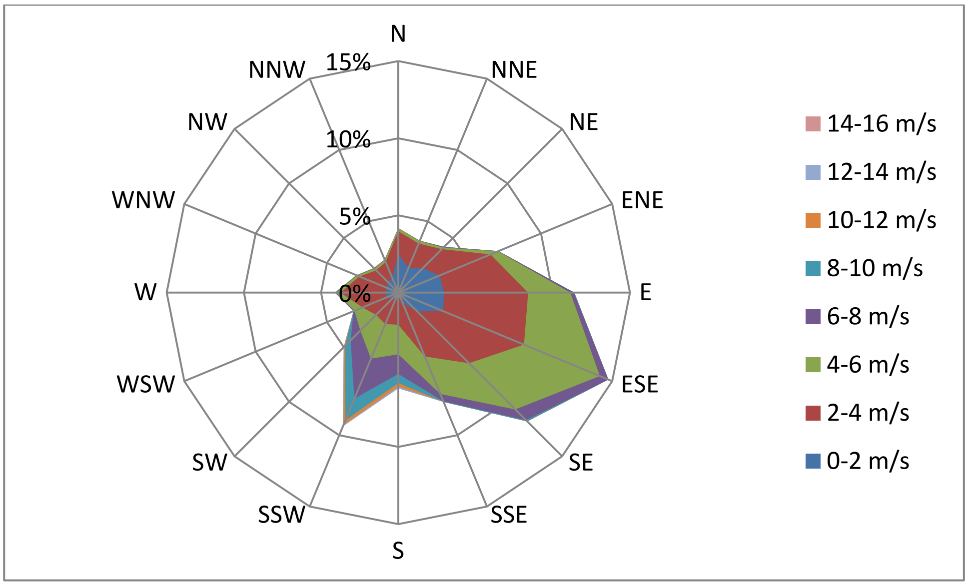


Figure 4-1 | Distribution wind speed and direction in wind rose (Metocean 2008)

4.4 Tidal and current conditions

Table 4-2 shows the magnitude of the tidal variations in the Port of Beira with its reference. The levels are given inside the port basin. The large variations in tide come with current velocities in the port area. Both the water level (draft) and the current (safe manoeuvring) can be a limitation on the port operations. Beira Port has a long access channel, where tidal conditions vary. To be able to calculate the tidal variations over the access channel, DHV made a Delft3D modelling of the Pungue estuary. The tidal conditions are provided in the form of current patterns and tidal levels every 30 minutes for a full tidal cycle. The model was verified to an actual tidal cycle in February 2007 with comparable results.

In Table 4-3 the tidal variation is given between the offshore access channel entrance, the Macuti bend (half way the access channel) and at the berths. Maximum and minimum water levels do not differ much, but current velocities are much higher at the berths. The maximum velocities are governed by the discharge of the Pungue River. Still velocities are low enough for safe manoeuvring. Figure 4-2 shows that the rising tide is a bit shorter than the falling tide. This is positive for the ships manoeuvrability, because the corresponding tidal current velocities are lower in the direction of the river discharge.

Figure 4-3 shows that the tidal lag at the berths is at maximum 1 hour at low tide. At MSL this lag is less than half an hour. This means for the calling ships that the tidal window going towards the port is about 1 hour longer than sailing out of the port.

Table 4-2 | Tidal Variation at Beira

Level	Level	Height (m CD)	Reference
HWL	Highest Water Level	+7.5 m	Based on recent measurements, to be verified
1/y HW	1/year High Water	+7.1 m	Metocean (1998)
MHWS	Mean High Water Spring	+6.5 m	Nautical chart Beira
MHW	Mean High Water	+5.4 m	Nautical chart Beira
MHWN	Mean High Water Neap	+4.2 m	Nautical chart Beira
MSL	Mean Sea Level	+3.6 m	Nautical chart Beira
MLWN	Mean Low Water Neap	+2.8 m	Nautical chart Beira
MLW	Mean Low Water	+1.8 m	Nautical chart Beira
MLWS	Mean Low Water Spring	+0.8 m	Nautical chart Beira
1/y LW	1/year Low Water	+0.3 m	Metocean (1998)
LAT	Lowest Astronomical Tide (=CD)	+0.0 m	

Table 4-3 | Maximum tidal water level and current variation (DHV, Delft3D)

	Max water level [m CD]	Min water level [m CD]	Ebb current [m/s]	Flood current [m/s]
Channel entrance	6.52	0.68	0.93	0.93
Macuti Bend	6.70	0.53	1.46	1.46
Berths	6.84	0.52	1.59	0.90

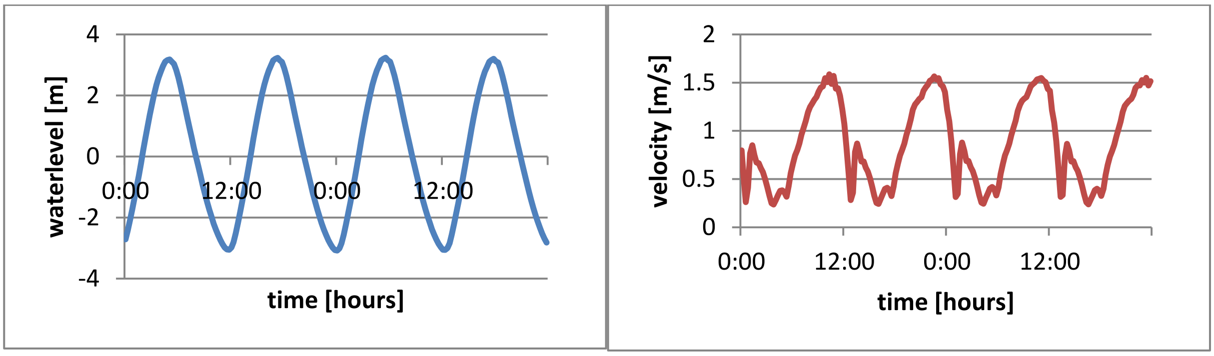


Figure 4-2 | Spring tide water levels and currents at berth (DHV, Delft3D)

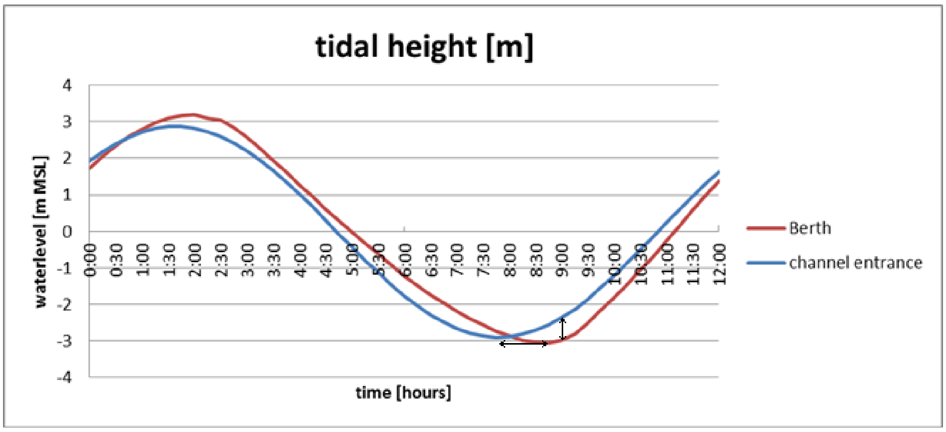


Figure 4-3 | Tidal variation between berth and access channel entrance (DHV, Delft3D)

4.5 Morphology

4.5.1 Bottom sediment classification and littoral drift

Concerning the access channel, sand is predominant, but silt exists in the inner bend of the Macuti Bend and at the access channel entrance. Coarse sand exists in the vicinity of the outer bend of the Macuti Bend. While in the offshore, fine sand is predominant, silt occurs more at the north side than at the south side of the access channel. (JICA, 1998)

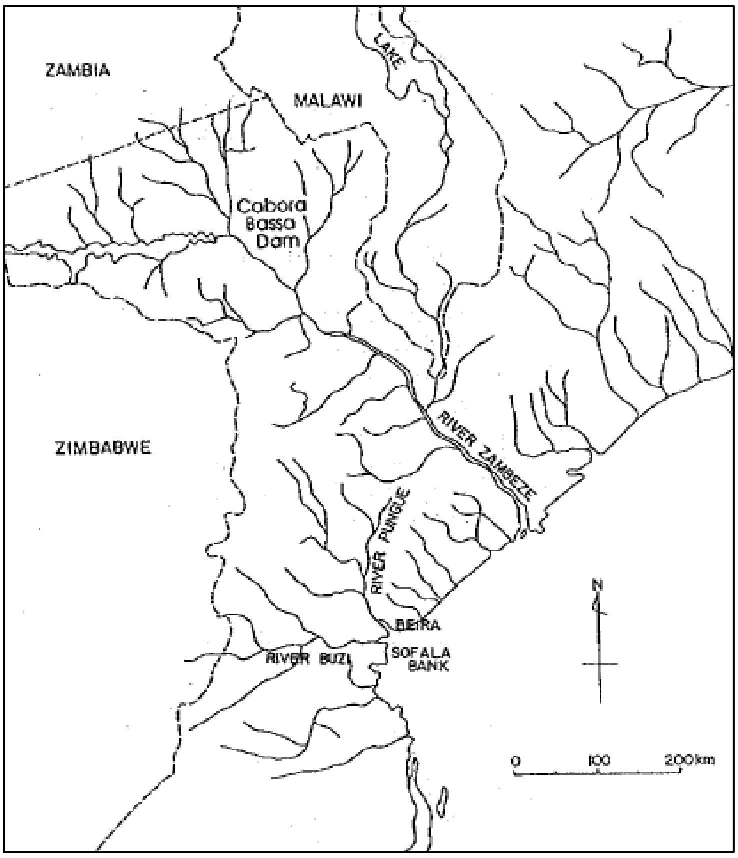


Figure 4-4 | Catch area of Pungue, Buzi and Zambeze river

The extensive shoal area in front of Beira Port is called the Sofala Bank. It seems to have been formed by the sand discharged from the Pungue and Buzi Rivers and littoral drift transported along the coast. The origin is the mouth of the Zambeze River in the north and the mouth of rivers in the southern area. In Figure 4-5 an overview of the littoral drift is given around the access channel. It is the most influential in the formation of the Macuti Shoal, because the drainage area of the Zambeze River is very extensive in comparison with the rivers of Pungue, Buzi and others as shown in Figure 4-4. However, in recent years, the littoral drift propagating from the north has been decreasing because of the decrease of sand discharged from the mouth of the Zambeze River due to the construction of a dam in the upper stream. As a result, the Macuti Beach located in the east of Beira Port is eroded as well as the further northern coast. Because of the beach erosion, many groins for beach protection have been constructed along the Macuti Coast. (JICA, 1998)

The river of Pungue and Buzi are not comparable with the Zambeze River in the scale of drainage area, but they play an important role in the phenomena of sediment transport of the Sofala Bank. The Pungue and Buzi Rivers originate in the mountainous area close to the border with Zimbabwe. The Pungue River, playing an important role in the sedimentation condition of the access channel of Beira Port, reaches the coastal plain some 55 km upstream from Beira. The width of the estuary extends to 5 km in front of Beira Port. The maximum river discharges in the

Pungue and Buzi Rivers respectively are about 600 m^3/s and 300 m^3/s in the wet season, and 80 m^3/s and 50 m^3/s in the dry season. (NEDECO, 1982) However, sediments discharged from the estuary of the Pungue River in general seem to be fine sand silt owing to the flat bottom slope. These fine sand and silt mostly seem to deposit westerly in the wide mouth area excluding the narrow area along quays of Beira Port and in the south of the Macuti Channel. The sand transported from the Macuti Shoal by strong tidal currents mostly enters into the Macuti Channel, which grow into large amounts when the bottom sand is suspended by storm waves. (JICA, 1998)

As described in the previous sections, heavy rainfall and storm waves occur in the wet season from December to March. Therefore, the sand transport in the Access Channel to Beira Port is more active in the wet season than in the dry season. Along the Macuti Coast, the predominant offshore waves come from the direction SE and E, so that alongshore sand transport occurs toward Beira Port. (JICA, 1998)

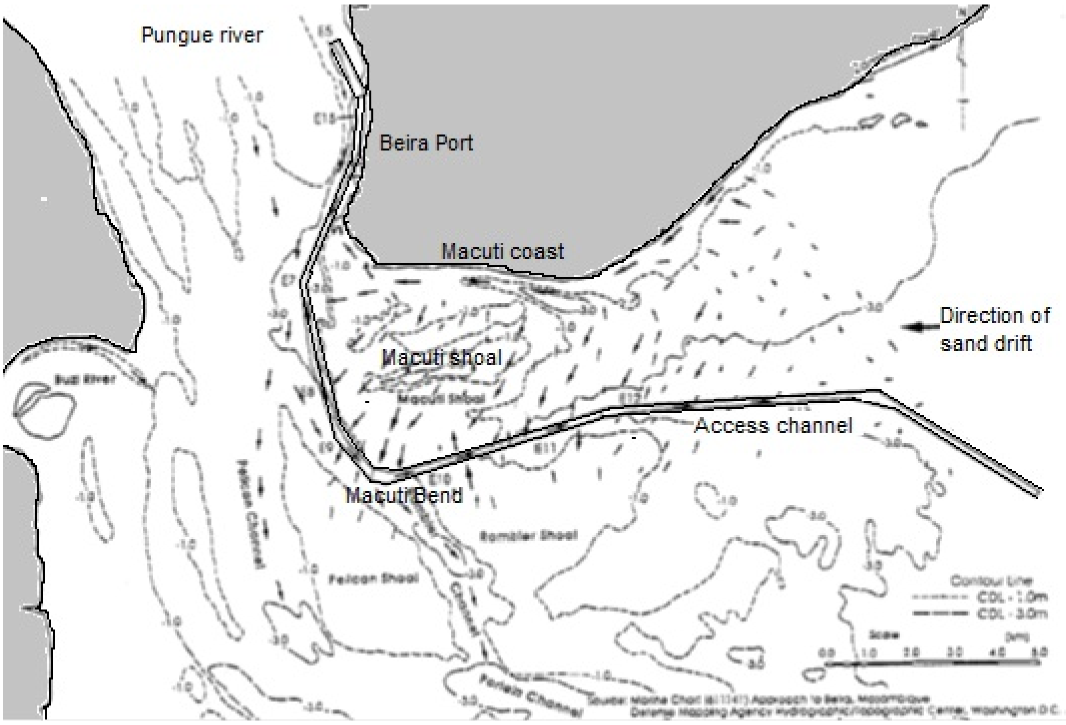


Figure 4-5 | overview of littoral drift in the vicinity of the access channel (JICA, 1998)

4.5.2 *Sedimentation volumes*

From 1990 to 1996, extensive research is done to define the sedimentation rate of the access channel. As explained above it is a comprehensive system where multiple factors play an important role. In the monitored years, seasonal fluctuations occur and unpredictable storms add to the uncertainty. Predictions on mean annual sedimentation rate range from 2.1 to 2.7 million m^3. (JICA, 1998)

4.5.3 *Dredging equipment*

With the presently available two trailing suction hopper dredgers of 1,000 m^3, an annual capacity of 2.5 million m^3 could be reached. Due to improper dredging plans, the hoppers only dredge 1 million m^3 on average. A catching example of this poor execution is that 2 hoppers sank in the access channel. The access channel was dredged to 9 meters in 1997, but has silted up again. In 2010, Van Oord was awarded a contract to dredge 9 million m^3 to set the entrance channel to -8 m CD again (DHV BV, 2011f). In 2011, the project was completed. To ensure maintenance dredging works could be sufficient, CFM ordered a new trailing suction hopper dredger with a capacity of 2,000 m^3. The new hopper is expected to be available in 2013 report several local websites.

4.6 Conclusions

The port of Beira has little to no hindrance of its climate. The wave and wind climate is relatively calm and no restrictions for the master plan development are present.

The tidal conditions have a big impact on the ports performance. The adjoining water levels cause tidal windows for the calling ships, which will increase the waiting times. Furthermore, the tidal currents induce an extra sand drift towards the port area and access channel.

The sedimentation volumes are comprehensive, with the Pungue River being the main source of sediment. The sedimentation processes are complicated and have proven to be unpredictable. Maintenance dredging proved to be insufficient to counteract sedimentation of the access channel. Resulting in shorter tidal windows and thus longer waiting times. In theory, the newly ordered dredging equipment is sufficient to maintain the access channel depth of -8 m CD.

5 HARBOURSIM SIMULATION OF PRESENT SITUATION IN PORT OF BEIRA

Waiting times in Beira are known to be very long and the port authorities have the desire to improve the port performance on this matter. Therefore a logistic model of the Port of Beira is built, which will be used to design the new port master plan.

To check whether a new port or an extension of an existing port satisfies the design requirements Delft University of Technology developed a simulation tool, Harboursim, to estimate the capacity and to assess safety of the port. Harboursim is a simulation model developed in the simulation software Prosim. A simulation run in Prosim does not simulate every minute, but the state of the model changes at a discrete point of time. This type of modelling reduces the total runtime considerably. Harboursim covers the maritime infrastructure of the Port of Beira. It simulates the vessel and port processes within the model boundaries. Appendix I gives a brief description of Harboursim written by the author as an introduction to the model, for a complete explanation and manual, reference is made to the Harboursim manual (Groenveld, 2004).

Harboursim will be used to build a model of the present situation of the Port of Beira. This model will be the basis for all Harboursim simulations to design the master plan. The goal is to build a model, which represents the present situation, and which can be further expanded to simulate the master plan alternatives.

Adaptations to the original Harboursim model are necessary, due to some characteristic features of the Port of Beira. Processes are added to the Harboursim model code to make a good representation of the reality. The adaptions made in the code are made generally applicable for all future models. Moreover, the model code is adapted to make the results compliant with the software ‘Microsoft excel’, thereby enabling fast processing of the results.

The present situation in the Port of Beira is schematized and thereafter simulated in Harboursim. This chapter commences with stating the foreseen output of the simulation. In paragraph 5.2, a physical schematization of the port layout is made. Thereafter all port operations are schematized and explained in ‘Port processes’. The required adaptions to the Harboursim model code are discussed in paragraph 5.4. Considerations about the model input are discussed in paragraph 5.5. The output of the Harboursim model is not directly applicable, additional calculations and translations were made in Microsoft excel, these are discussed in paragraph 5.6. The results are and discussed in paragraph 5.7. Finally, conclusions are drawn about the results and the further applicability of the model in this study.

5.1 Foreseen output of simulation

The goal of this simulation is to determine the model performance and to be a basis for the next simulations. Therefore, the following output is foreseen:

Occupancy rate
The occupancy rate is the rate of time the quay is used. A low occupancy means inefficient use of the quay. The terminal operator wants to have a high occupancy to make efficient use of its quay and terminal (un)loading equipment. The quay is most efficiently used if it is only used for servicing the ships. Waiting at the quay should be avoided when other ships wait to be serviced at the quay. Therefore, the occupancy due to waiting at the quay should also be monitored. The occupancy rate of the quay should not be too high, because ships do not arrive at a constant pace and waiting times will rise. A balance should be found between the allowable waiting time and the occupancy of the quay. In literature, the tolerated lower limit for the occupancy rate is 0.4, for a reasonable profit for the terminal operators (DHV BV, 2008).

Waiting times
The waiting time of a calling ship is an important parameter for ship owners to choose a certain port. Waiting time is lost time and therefore lost money. The total mean waiting time as a percentage of the service time is used in practice as a port performance indicator. This ratio is widely used as a measure of the level of service provided by a terminal, as would seem logical, for ships that have less cargo to discharge cannot afford to wait as long as ships that have more. Tolerated waiting times in literature are around 0.05-0.2 (Ligteringen, 2007).

Ships can wait on arrival and/or on departure. The waiting time on arrival in Beira Port comprises of waiting times due to occupied berths, occupied access channel and tidal depth limitations. The waiting times on arrival are used to see the effects of the proposed improvements to the model.

The waiting time on departure does not depend on the occupancy of the terminal; it only depends on the maritime exit of the port. If the waiting time on arrival and the waiting time on departure are compared, the occupancy of the terminal can be valued. It can be concluded if there is relative much additional waiting time due to high berth occupancy.

Accuracy
The accuracies of the above mentioned output parameters are necessary to determine the predictive skill of the model. The predictive skill of the model is given by the quality of the model and the accuracy of the model predictions. By doing multiple simulation runs, the accuracy can be approximated.

5.2 Physical schematization

The physical layout of the port of Beira is schematized in Figure 5-1. The port layout is divided in different sections (S1 to S10), straight lines represent sailing sections and the ellipses manoeuvring sections. The boxes represent stationary points for the ships (berths and anchorage).

S1 represents the access channel. In section S2, the ships manoeuvre between access channel and berth. This section can be seen as the turning circle and only one ship can be in this section at the time. S3 to S7 represent the manoeuvring towards the different quays. S9 represents the path the Handymax coal ships sails towards the offshore coal trans-shipping location, as explained in paragraph 3.6.3. Here two-way traffic is possible, because there are no depth limitations. Manoeuvring the Handymax coal ship towards the ocean going vessel is represented by S10.

When a ship sails a section it occupies it for a predefined time. Mooring and unmooring takes place inside the berth pocket and is part of the ship's service time. All section attributes are listed in paragraph 5.5.6.

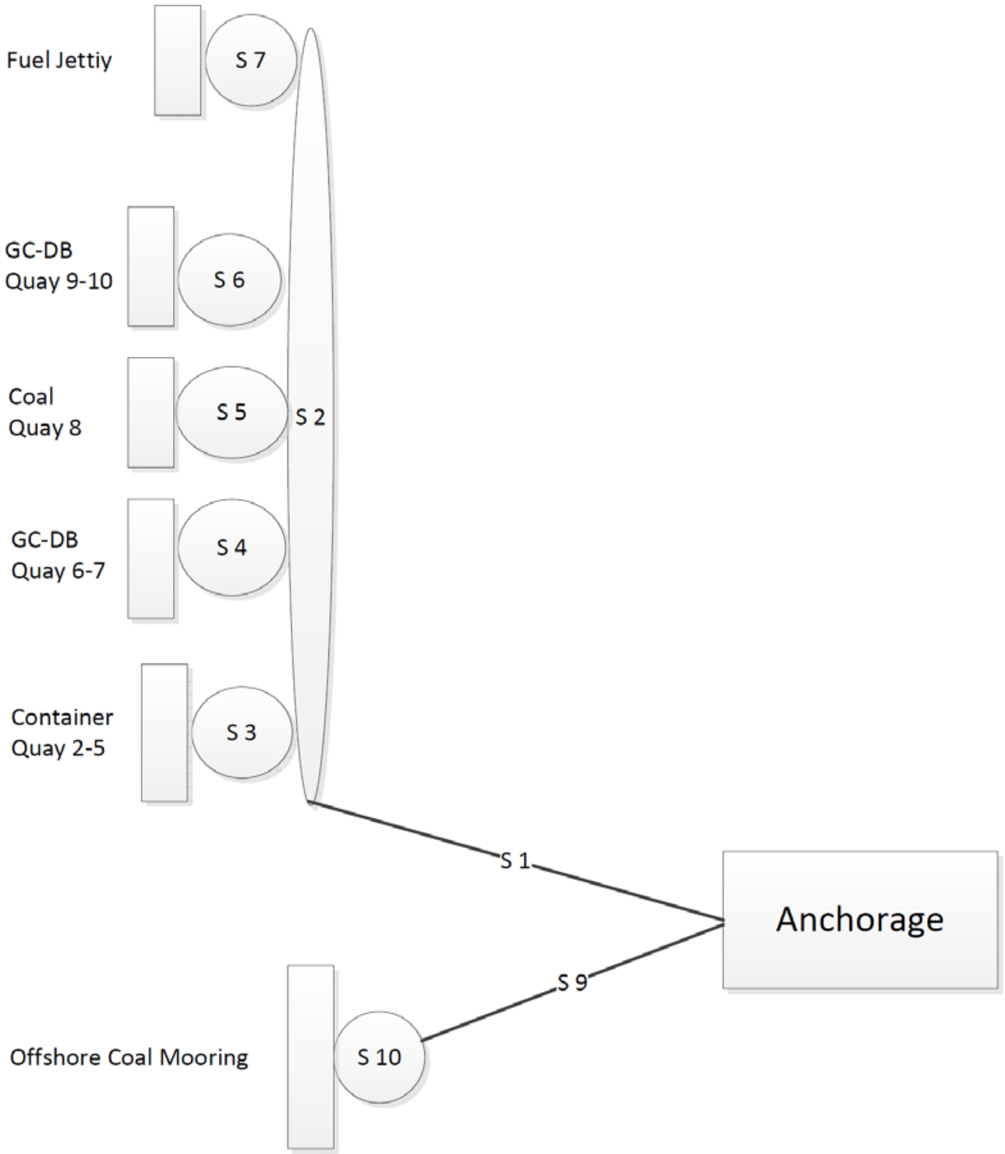


Figure 5-1 | Schematization of port layout used in Harboursim

5.3 Port processes

Harboursim is chosen as a basis to construct a model of the Port of Beira. In this paragraph, the port processes in Beira are translated into Harboursim model processes. First, the ship movements in the port are discussed, with special attention to the transferring coal ships of Vale. Thereafter the tidal window and daylight sailing limitations are given.

5.3.1 Ship movements

In reality, 5 different type of ships call Beira Port: container, GC-DB, Rio Tinto coal, Vale coal transfer and fuel ships. Container, fuel and Rio Tinto coal ships have only one quay where they can be serviced. The general cargo and dry bulk ships can be allocated to quay 6-7 or 9-10. The model first checks for free quay length along quay 6-7 and alternatively along quay 9-10. Table 5-1 summarizes the ship movements. The coal transfer ships sail back and forth between the offshore mooring point and quay 8 to fill an OGV at the offshore mooring point. Below, the transfer ship processes will be further elaborated.

Table 5-1 | Ship movements

Fleet	Sections	First quay	Alternative quay
Container	1-2-3	Container 2-5	
GC-DB	1-2-4 or 1-2-6	GC-DB 6-7	GC-DB 9-10
Coal Vale transfer ships	1-2-5-9-10	Offshore coal	Coal 8
Coal Rio Tinto	1-2-5	Coal 8	
Fuel	1-2-7		

Coal ships of Vale

Two dedicated trans-shipping coal ships of Vale sail back and forth to load an ocean going vessel at the offshore mooring site. Seven loadings are required to fill one OGV. To simulate this two fleets are created, one for each trans-shipping coal ship. They have the same inter-arrival time and corresponding distribution, so they are generated at the same time in the model. ‘Coal Vale 1’ loads the ocean going vessel four times and ‘Coal Vale 2’ loads three times.

The ocean going vessel is modelled as a fictional offshore terminal, where ‘Coal Vale 1 and 2’ are serviced. 'Coal Vale 1’ sails its first track first, and when serviced at the offshore terminal, is followed by ‘Coal Vale 2’. This incurs that ‘Coal Vale 1’ transfers the first and last cargo for the OGV. In Harboursim it means that ‘Coal Vale 1’ ship performs the following actions:

Table 5-2 | tracks and actions 'Coal Vale 1' and OGV

Track	‘Coal Vale 1’ action	OGV action
	Start in model	Berth at offshore mooring point
1	Berthing at offshore berth	
	Unload cargo 1 at offshore berth	Service time cargo 1
2	Sail towards coal terminal	
	Load cargo 2 at coal terminal	
3	Sail towards offshore berth	
	Unload cargo 2 at offshore berth	Service time cargo 3
4	Sail towards quay 8	
	Load cargo 3 at coal terminal	
5	Sail towards offshore berth	
	Unload cargo 3 at offshore berth	Service time cargo 5
6	Sail towards quay 8	
	Load cargo 4 at coal terminal	

7	Sail towards offshore berth	
	Unload at cargo 4 offshore berth	Service time cargo 7
8	Sail towards quay 8	Deberth
	Load cargo 1 at coal terminal	
9	Sail towards offshore berth	
	Leave model	

After the last cargo is unloaded into the OGV, the transfer ship sails back to quay 8 to load the cargo for the next OGV and the OGV deberths. Now all ship movements of the trans-shipping coal ships are simulated.

Ocean going vessel processes

The ocean going vessel does not enter the port, so its ship movements are not of importance. However, we are interested in the mean waiting time and occupancy of the ocean going vessel. The OGV is modelled as an offshore berth, so the mean waiting time is not monitored. The waiting time of the OGV is in reality the dwell time of the OGV at the offshore mooring point minus the service time of the OGV. The dwell time of the OGV can be found using Table 5-2, where the actions of 'Coal Vale 1' are compared with the actions of the OGV. The actions after the service time of cargo 7 at the OGV should be subtracted from the dwell time of 'Coal Vale 1' in the model. The above is summarized by the following:

Dwell time OGV = 'Coal Vale 1' dwell time - sailing time track 8 – sailing time track 9 – service time at quay 8

Waiting time OGV = Dwell time OGV – 7 x service time of 'Coal Vale 1' at OGV

The service time of the OGV is seven times the service time at the offshore berth plus the mooring time of the OGV (90 minutes).

5.3.2 *Tidal window and daylight sailing*

Due to the tidal water level variations in the Port of Beira, calling ships need a tidal window to enter the port basin. This means that when the water level is too low for safely navigating the access channel, the ship has to wait. Ships on arrival have to wait at the anchorage for sufficient depth to enter the port. When leaving the port the ships again have to wait for a tidal window to sail out. In Harboursim the water levels can be simulated and when a ship asks permission to sail it checks the draft with the actual depth, see the manual for more on this subject (Groenveld, 2004).

At the moment, ships are allowed to sail in the access channel and the port basin only during day time. Sunset and sunrise times in Beira differ year round relatively little as can be seen in Figure 5-2. For the Harboursim model of Beira Port the mean sunset and sunrise over 1 year is estimated, indicated by the dark blue and red line in Figure 5-2. It is assumed that ships are allowed to sail from 5:30 to 18:00.

Due to the combination of daylight sailing and tidal windows very long waiting times can occur. When a tidal window occurs during the night, the ships are not able to use this and thus have to wait for the next window during daylight. In the original Harboursim model, ships sail 24 hours a day. The model code should be adapted, in order to correctly model the occurring processes.

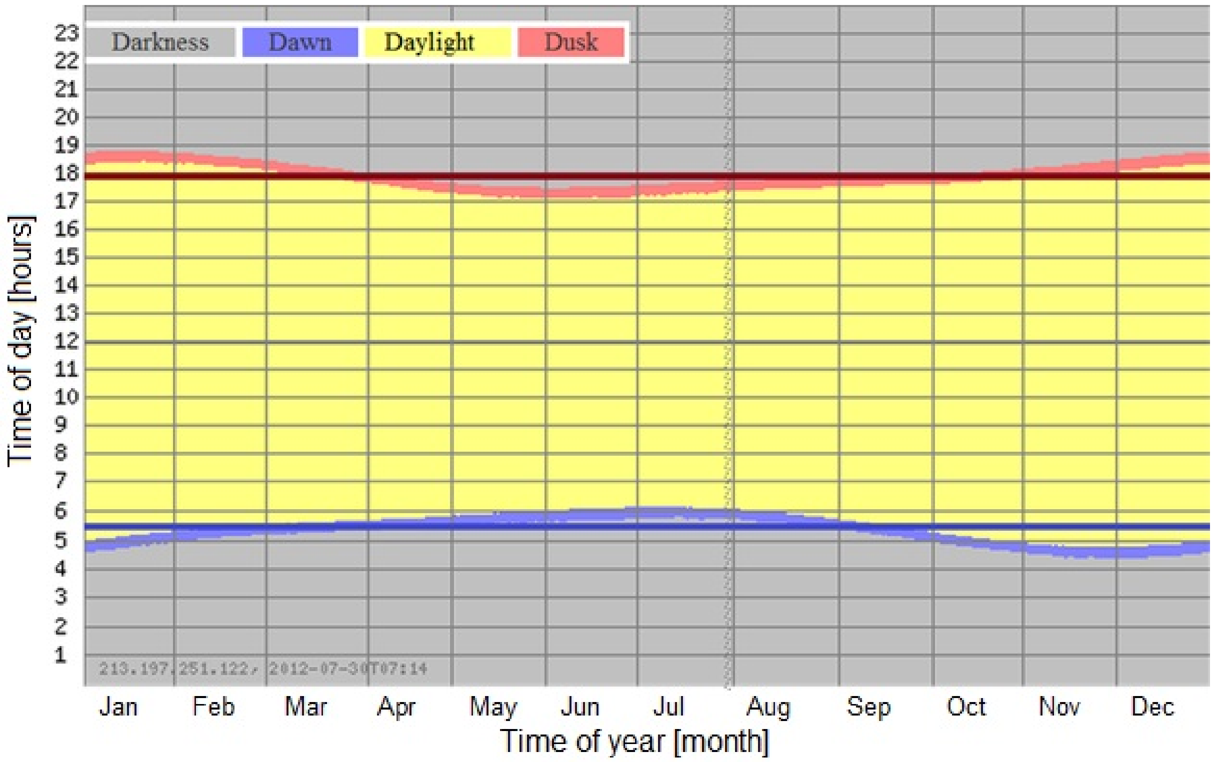


Figure 5-2 | Graph with sunset, sunrise, dawn and dusk times over 1 year

5.4 Required adaptions to the Harboursim code

While modelling the Port of Beira in Harboursim, problems arose. Limitations of the original Harboursim model made it impossible to make a good representation of the Port of Beira processes.

For Beira Port, processes should be added to the Harboursim model code to make a good representation of the reality. The adaptions made in the code are made generally applicable for all future models. The following additional features were written for the model:

- Daylight window
- Terminal arrival queue for offshore berth
- Terminal departure queue for offshore berth
- Erlang k distribution as service time distribution
- Dwell time in the model per fleet
- Making Harboursim compatible with excel

The model adaptions with their relevance for the Port of Beira are given in this paragraph in the presented order.

As all future users of Harboursim should benefit from this study, the adaptions are implemented in a way that they are applicable for all new Harboursim models. The added functionalities explained in this chapter are handled in more detail in appendix II: Harboursim Improvements.

Furthermore, during installation of the additional processes, errors were found in the model code:

- The tidal window calculation is oversimplified in Harboursim
- The required quay length per berthed ship does not use the accepted design rule
- The water level calculation uses only the depth of one section

These errors are of such influence on the Port of Beira model performance, that they had to be fixed. While writing the code for the additional processes for the Port of Beira, insight was gotten in the model code. This knowledge is used to repair the errors and presented in appendix II. This appendix should be used by all new users of the adapted Harboursim model constructed in this study.

5.4.1 Day and night sailing

In the original Harboursim model, ships sail 24 hours a day. Currently, ships are allowed to sail in the access channel and the port basin only during day time. A feature is added to Harboursim which keeps track when there is daylight and the ships are allowed to sail. This feature can be toggled off in order to see the effect of allowing night traffic.

5.4.2 Terminal arrival queue for offshore berth

The Handymax coal ships travel back and forth between the coal quay and the offshore site. At the offshore berthing site, there is enough space for additional ships to anchor and wait to be serviced. Harboursim lets a ship sail to its next destination when the designated quay length is free. In reality, a ship can already sail to the offshore berth before the berth is free. Therefore, a ‘terminal arrival queue’ is added to the offshore berth.

A ‘terminal arrival queue’ is added as an option for terminals in the Harboursim program. This addition makes it possible for ships to sail to their designated terminal even if there is no free quay length. The ship reserves a spot in the arrival queue and set sail towards the terminal. On arrival, the free quay length is checked again for space for the ship. Until the required quay length becomes available, the ship waits in the arrival queue.

5.4.3 Terminal departure queue for offshore berth

If a coal ship has unloaded at the offshore transhipping-site, but the ship cannot sail through to quay 8, it will wait offshore. The next coal ship, which is waiting in the terminal arrival queue can now be serviced. This is simulated in the model with a departure queue, where the unloaded ship will wait. Similar to the arrival queue this is a place for ships to wait next to the terminal. The ship waits in the departure queue until it can sail through to its next destination. This waiting time is monitored and added to the waiting time on departure. The quay is already made free for the next ship to be serviced.

5.4.4 Erlang k distribution as service time distribution

The Erlang k distribution is the most used distribution for service times. In Harboursim, the Erlang k distribution could only be used as inter arrival time distribution. A macro is added to the model to make use of the Erlang k distribution as service time distribution. In the Harboursim manual (Groenveld, 2004) is explained how samples are taken from the Erlang k distribution.

5.4.5 Dwell time in the model per fleet

A feature is added to Harboursim to monitor the mean dwell time per fleet and to add it to the results file. The dwell time is the time a ship is present in the model. The mean dwell time per ship type is used to calculate the occupancy and the mean waiting time based on the service time of the OGV of Vale. The mean dwell time of the OGV is equal to the mean dwell time of fleet ‘Coal Vale 1’, because ships from this fleet load the first and last shipment in the OGV.

5.4.6 Making Harboursim compatible with excel

Harboursim creates results.txt as the output file. For further analysis of the results, the Microsoft office program excel is used. Harboursim is reworked to create results.txt files that are compatible with excel. In excel a macro is written to create a clear view of the results.

5.5 Model input

In this paragraph, all the model input considerations are explained. For an explanation of the required input for the Harboursim model, reference is made to the manual (Groenveld, 2004). The information about the present situation, presented in the previous chapters, is translated to Harboursim model input in 13 subparagraphs. The last paragraph summarizes the resulting input in table form.

5.5.1 Fleets specification

The year 2009 is used as a base year for the present situation, because data for all terminals is available for this year. In 2009, no coal was exported through the port. For the Harboursim model, the coal terminal should be modelled too, because the coal terminal started recently with operations. As there are no throughput figures known of recent years, the design throughput of the present coal terminal is used for the coal ship movements.

The calling ships are discussed in paragraph 3.4 to 3.8. The calling coal ships are divided in three fleets: one for Rio Tinto and two for the transhipping coal ships of Vale, as explained before. In Table 5-3 a summary is given of the used ship specifications in Harboursim. Vale uses two transfer ships, which are given the fleet names Coal Vale 1 and 2.

Table 5-3 | Average ship specification

Fleet	Load [tons*]	d in [m]	d out [m]	LOA [m]	# of vessels
Container	350	8	8	154	263
GC-DB	2500	8.5	8.5	113	387
Coal Vale 1	4x27000	5.5	9.2	194	21
Coal Vale 2	3x27000	5.5	9.2	194	21
Coal Rio Tinto	30000	5.5	9.2	185	53
Fuel	10000	10	7	130	90

* in tons per ship, except for container in TEUs

5.5.2 Ship draughts

The entrance channel and port basin is assumed constant at - 8 m CD, as dredged by Van Oord in 2011. In Harboursim, a ship is allowed to sail when the draught is less than the water level. In reality, the ships need keel clearance. The gross under keel clearance consists of the following parameters, as illustrated in Figure 5-3:

- Maximum sinkage due to squat and trim. Between 0.2 and 0.5 m based on experience.
- Vertical motion due to wave response. Very mild wave climate and large ships. Estimated at 0.5 m.
- Remaining safety margin for a sandy bottom. 0.5 m

The gross under keel clearance is set at 1.5 m, and is added to ships draughts.

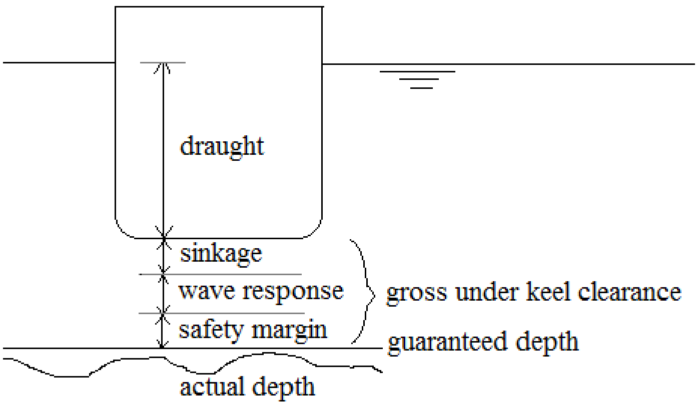


Figure 5-3 | gross under keel clearance

In the Harboursim manual no reference is made to the under keel clearance. However, the influence on the draught input is significant. As the keel clearance depends on several parameters, it is not advisable to implement it in the Harboursim code. However, the manual should mention clearly that the under keel clearance has to be added to the draught.

5.5.3 Depth of the channel sections

In the Harboursim program, it is not possible to assign depths to the different channel sections S1 to S10 as dictated in Figure 5-1. The depth is assigned to a VTS-component, which is the combination of sections a ship sails to get to its next destination. The depths of all VTS-components are set at 8 m CD, according to the minimum depth in the access channel and port basin. An exception is made for the VTS-component, which describes the first and last track of the transhipping Vale coal ships. These tracks represent the mooring and unmooring time of the OGV of Vale. At the offshore berth it is thought to be always deep enough, so a value over springtide (7 m) plus the ships draught (10.7 m) of 18 m CD is chosen.

5.5.4 Currents

In the port analysis, current data are collected from a study done by DHV. The currents around the port of Beira have been modelled in Delft 3D. Spring and neap tide velocities have been adopted from this model. It is chosen to use current patterns calculated around the berths, because they are the most extreme. In reality, the tidal data is not equal everywhere in the model and also not at the same time. The currents in the Delft 3D model are maximum 1.59 m/s, the river discharge is dispersed further seawards. The currents are only used in the Harboursim model to check if it is possible to manoeuvre safe. It is assumed that the ships are never hindered by the prevailing currents. Therefore, the accuracy of the currents is not important. It should be noted that the current data is not based on direct measurements. For instance, locals estimate the currents at 2.5 m/s. For decision making about navigation and manoeuvring, real time current measurements need to be available for multiple locations in the navigation channel.

In reality, the vessels sail with a sail velocity relative to the current velocity. Therefore, currents influence the sailing speed of the vessels and thus the sailing time. In Harboursim, the sailing time has no relation with the current velocity. Harboursim works with a constant sailing time for each section per fleet. According to the Delft 3D model, the mean current velocity is around 0.5 m/s directing towards the ocean, due to river discharge. The velocity is fluctuating, because of the tidal currents. It is chosen to neglect the influence of the current velocity on the vessel speed.

5.5.5 Water levels

The water levels in the access channel to Beira Port are prone to large tidal differences. The data set from the Delft 3D model is used for the water levels. In Harboursim only one neap and one spring tidal cycle is used to calculate the water levels in the entire model at the same time. In reality, the tidal levels vary along the access channel. The tidal amplitude of the spring tide in the port basin is almost 1 meter larger than at the access channel entrance. The tidal levels in the port basin are chosen for the entire model, because they are governing for the vertical tidal window of the ships.

5.5.6 Sailing times per section

In the access channel only one-way traffic is possible, so no overtaking or encounters. In an input file, the tracks of the different fleets are specified. Each track has sections assigned that will be sailed. For each section the sailing time is specified. A loaded sailing speed of 9 knots and an empty sailing speed of 10 knots are assumed.
Table 5-4 summarizes the sailing and manoeuver times and there reference. In section S2, the ships manoeuvre between access channel and quay. The distance between the end of the access channel and the quay is different for each quay; this extra sailing time is added to the base time mentioned in Table 5-4.

Table 5-4 | Section manoeuvre times with reference

section	manoeuver	time		reference
S1	loaded sail time access channel	120	min	calculated
S1	empty sail time access channel	110	min	calculated
S2	Manoeuvring channel-quay	30	min	DHV quay 8 report
S2	Manoeuvring quay-channel	10	Min	DHV quay 8 report
S3-S7	berthing at quay	10	min	DHV quay 8 report
S3-S7	deberthing from quay	10	min	DHV quay 8 report
S9	loaded sail time access channel entrance to offshore berth	80	min	calculated
S9	empty sail time offshore berth to access channel entrance	70	min	calculated

5.5.7 *Inter arrival distributions*

Mean inter arrival times are calculated from the number of calling ships. Ships enter the port at a random pace around the mean calculated inter-arrival times. There is no data available to fit an inter arrival distribution to the different fleets. In literature, the Erlang k distribution is proposed, also in Harboursim this is the proposed distribution. The most commonly used value for k is 1; this represents the Negative Exponential Distribution (NED) (Groenveld, 2001). This represents completely random arrivals, with a standard deviation equal to the mean. The coal ships are expected to arrive less random, because of the continuous demand to export the coal. The inter arrival distribution of the coal ships is therefore chosen Erlang 10; the other ships have a Negative Exponential Distribution.

5.5.8 *Service time distributions*

The total service time consists of several different stages, which is also the nature of the Erlang-k distribution. The service times are subject to handling speed, available surface area, available equipment and berthing time and more factors. Each stage is thought to have an exponential distribution of service time. There is no statistical data available to fit an Erlang k distribution through. Based on experience a k-value of 5 is chosen, which results in a coefficient of variation of 0.5. The coal ships do all carry the same amount of cargo. Therefore, a higher value of k=10 is chosen for all the coal fleets. For an explanation of the Erlang k distribution in service times, see (Groenveld, 2001).

5.5.9 *Model quay lengths versus real quay lengths*

For a single berth the quay length is determined by the length of the largest vessel frequently calling at port, increased with 15 m extra length fore and aft for the mooring lines. However, Harboursim does not distinguish between single and multiple berths, because only quay lengths are input. The free quay length calculation as mentioned in appendix II-A is used for single berths too. The quay lengths of quay 8 and the fuel terminal are adapted to ensure that all calling vessels can berth at the quay. Their model quay length must be at least:

$$L_{quay} = 1.1 \cdot (L_{\max \quad ship} + 15)$$

The calling ships at quay 8 are as long as the quay. For the berthing gap they use space of quay 7. Therefore, an extra adaption of the quay length of the GC-DB quay 6-7 has to be made.

From port observations, a maximum number of ships at the quay is defined and matched with possible maximum number of ships in Harboursim. The quay length for each terminal is shown in Table 5-5:

Table 5-5 | Real and model quay length with ship lengths and maximum number of ships

Terminal	ship length	Real quay length	Model quay length	Max # of ships
Container	154 m	646 m	646 m	3
GC-DB 6-7	113 m or 158 m	336 m	321 m	2
Coal	194 m	188 m	230 m	1
GC-DB 9-10	113 m or 158 m	336 m	336 m	2
Fuel	130 m or 180 m	264 m	215 m	1
Offshore	188 m		230 m	1

5.5.10 Wave climate

A wave climate can be set for each quay. It is assumed that these climates are always very mild inside the port and no downtime is affiliated to this matter. At the offshore location, waves can cause downtime for the operations. If the significant wave height is over 2.0 meters, the operations will be stopped. In Harboursim, the wave climate can only be set for an amount of days. Therefore, the downtime due to a typhoon is only taken in account. An average typhoon lasts 2 days.

5.5.11 Average cargo load container and GC-DB ships

The container and GC-DB ships sail the African east coast, calling different ports on their way. No data is available about how much cargo is transhipped per shipment. From experience at DHV, it is estimated that the container ships and GC-DB ships, respectively tranship on average 350 TEUs and 2500 tons. The average cargo load determines the amount of ships calling and subsequently the inter arrival times. In the inter arrival time distributions the uncertainty of the average transhipment is taken in account.

5.5.12 Adding empty sailing time in S9 and S10 of Vale coal ships to service time

When a coal ship is unloaded at the offshore berth it has to wait until quay 8 is free and the access channel is available to sail to the port for a new load. The sailing time from offshore berth to anchorage is 80 minutes, including deberthing in S10. In reality, this part can already be sailed before the ship can sail through to the port. However, Harboursim does not have the functionality to sail part of the total track (S10, S9, S1, S2, and S5). A solution is found in adding 80 minutes to the mean service time at the offshore berth and neglect the sailing time in S9 and S10.

5.5.13 Simulation runtime

The runtime of the model is an important parameter in the model. The runtime has to be long enough to arrive at the desired accuracy. However, it takes more real time to make the model accurate.

Two cycle times are present in the model, one for the tidal cycle and the other for the day-night-cycle. Cycle times are respectively 745 and 1440 minutes. To ensure that both the tidal and day-night-cycle are finished at the end of the runtime, the runtime must be a multiple of 21600 minutes (29 tidal and 15 day-night-cycles). After some test runs it is chosen to use a runtime of six times 21600 minutes, where the accuracy of the model predictions is stabilizing.

Note that there is also the spring-neap-cycle, which is 28 tidal cycles (20860 minutes) long, but in order to synchronize this cycle the runtime will become too long. In paragraph 5.7 it will be discussed whether the desired accuracy is acquired with the chosen runtime.

5.5.14 *Summarised input in tables*

The input parameters for the Harboursim model, discussed in the previous subparagraphs, are summarised in Table 5-6 to Table 5-8.

Table 5-6 | Throughput [tons] through Beira Port

Fleet	Import	Export	Empties
Container*	42,000	29,000	21,000
GC-DB	580,000	400,000	
Coal Vale		3,400,000	
Coal Rio Tinto		1,600,000	
Fuel	900,000		

* TEUs

Table 5-7 | Fleet input specification

Fleet	Load*	d in [m]	d out [m]	LOA [m]	# of vessels	inter arrival time [min]	Erlang distr.
Container	350	9.5	9.5	154	263	2,500	1
GC-DB	2500	10	10	113	387	1,360	1
Coal Vale 1	4x27000	7	10.7	194	21	24,730	10
Coal Vale 2	3x27000	7	10.7	194	21	24,730	10
Coal Rio Tinto	30000	7	10.7	185	53	9,860	10
Fuel	10000	11.5	8.5	130	90	5,840	1

* in tons per ship, except for container in TEUs

Table 5-8 | Terminal specification

Terminal	quay length [m]	handling speed [tons/hour]	service time [min]	Erlang distr.
container	631	40 (TEU/hour)	579	5
GC-DB 6-7	306	240	724	5
Coal quay 8	230	1700	1133	10
GC-DB 9-11	321	240	724	5
Fuel	215	1200	680	5
Coal offshore	224	3000	800	10

5.6 Conversion of model results with Excel

Results.txt gives detailed model simulation results. We would like to compare different simulation results, for which the relevant results must be filtered and put into tables. The following is considered as relevant information for comparison, as explained in paragraph 5.1:

- The mean occupancy per terminal
- The mean waiting time per ship type over all runs on arrival
- The mean waiting time per ship type over all runs on departure
- The total mean waiting time per ship type over all runs
- The accuracy of the above mentioned parameters

To calculate the acquired accuracy of the model results, the standard deviation of the runs has to be determined. This done with the help of the following formula:

$$s = \sqrt{\left(\frac{1}{N-1}\right)\left[(x_1-\mu)^2+(x_2-\mu)^2+(x_3-\mu)^2\right]} \quad ; \quad with\ \mu = \frac{1}{N}(x_1+x_2+x_3)$$

s is an approximation of the standard deviation for a sample of a population. x_1 to x_i are the model results. The factor N-1 is known as Bessel's correction, where N is the number of runs. With the estimated standard deviation, the accuracy d [minutes] of the results will be determined using the next formula:

$$d = \frac{s \cdot Z}{\sqrt{n}}$$

Where a probability ($Z_{\alpha/2}$) of 95% will suffice and with the help of a table for the area under the standard normal curve, Z is 1.96. The Harboursim model takes about twenty minutes to run, which is short and thus the maximum of 10 runs is chosen for all simulations and used in the output macro in Excel, so n=10

A macro is written in excel which reads the results.txt file and calculates means and standard deviations of the results over all runs. With the above formulae, the accuracy of the model predictions is calculated. This is done for the occupancy, the mean waiting time on departure, arrival and total mean waiting time. The accuracy is given in minutes and as a percentage of the mean over all runs.

In the worksheet per simulation now detailed results can be found. In the worksheet 'results' the most important results of different simulations are collected so they can be compared. In paragraph II-D: Conversion of model results with Excel of appendix II, the conversion of the results.txt file into comparable results is explained in more detail.

5.7 Results of the model

In this paragraph, the results of the Harboursim model are shown and explained. The goal is to see whether the results correspond with the reality. As no measured data are available, the comparison will be done in a qualitative way. Furthermore, the results for the present situation are quantitatively discussed in relation with the tolerated limits from literature as discussed in paragraph 5.1. In literature, the tolerated lower limit for the occupancy rate is 0.4, for a reasonable profit for the terminal operators (DHV BV, 2008). Tolerated waiting times in literature are around 0.05-0.2 (Ligteringen, 2007).

The occupancy of the different terminal quays is discussed in the first section. Thereafter the waiting times on arrival and on departure are discussed. The accuracy of the mean total waiting time per ship type is calculated and elaborated. In the last section the influence of the Erlang k values are shown and discussed.

5.7.1 Occupancy of terminal quays

There are no measured data available about the real terminal occupancies. Still some remarks can be made on the occupancy rates calculated by the Harboursim model. Table 5-9 shows the occupancy rates of the terminals and the OGV of Vale.

In the second column the occupancy rate per terminal based on the service time is given. This is the total service time of all ships at the quay divided by the total modelling time. The occupancy rate based on the service time is directly proportional to the usage rate of the terminal (un)loading equipment. A low occupancy rate means inefficient usage of (un)loading equipment and therefore higher costs for the terminal operator. For the sake of the terminal operator the occupancy should be as high as possible, but without increasing the waiting times too far.

In the third column, the waiting time on departure at the terminal is added to the service time to calculate the occupancy. For Beira Port, this is the real occupancy of the berth, because no other ship can be serviced.

The fourth column gives the occupancy rate based on the service, waiting and reservation time. The reservation time is the time the berth is reserved for an arriving ship, actually the sailing towards the berth. The difference between the second and fourth columns is an indicator for the efficiency of the port. It states how long the terminal equipment is ready, but ships are not moored. In Beira Port these figures are high, because of the long and single lane access channel; Table 5-9 underpins this statement.

Table 5-9 | Occupancy rate per terminal based on service (ST), waiting (W) and reservation (R) time

	OCC[ST]	OCC[ST+W]	OCC [ST+W+R]
Container	0.059	0.107	0.12
General Cargo Q 6-7	0.15	0.23	0.27
Coal 8	0.32	0.37	0.42
General Cargo Q 9-11	0.13	0.19	0.22
Fuel	0.12	0.17	0.20
Coal OGV	0.39		

Occupancy rates of the container, GC-DB and fuel terminal are very low. This implies that there is additional capacity at these berths. In theory more ships can be serviced. The occupancy of coal quay 8 is just at the lower limit of 40%. A profitable occupancy is foreseen, as the simulation is run with the designed intensity of the terminal.

The fuel terminal has a low occupation in Harboursim, but in reality this jetty is almost always occupied. The fuel jetty is servicing multiple competing private companies. They keep the jetty occupied by their ships, so that their rivals cannot import fuel. The simulation shows that the capacity of the jetty is not a problem, but management is.

5.7.2 *Waiting time on arrival*

The waiting time on arrival in Beira Port comprises of waiting times due to occupied berths, an occupied access channel and tidal depth limitations.

Low terminal occupancy means normally short waiting times on arrival. This can be seen if we compare Table 5-9 with Figure 5-4. Coal Rio Tinto ships call coal quay 8. Coal quay 8 has a high occupancy rate based on service, waiting and reservation time of 0.42. The mean waiting time on arrival of the Rio Tinto coal ships is also high, as can be seen in Figure 5-4. Even with night sailing permitted the waiting time is more than 8 hours. Compared to arriving fuel ships, which have a larger draft, the Rio Tinto ships still have a longer waiting time. The conclusion is that this is due to the high berth occupancy of coal quay 8.

The effect of the night sailing limitation is visualized in Figure 5-4 where the mean waiting time (MWT) on arrival for both situations is charted. The container fleet would have almost no waiting time on arrival if night sailing were permitted. This corresponds to the fact that the container ships have shallow drafts and low berth occupancy and their waiting time must come from the daylight sailing limitation.

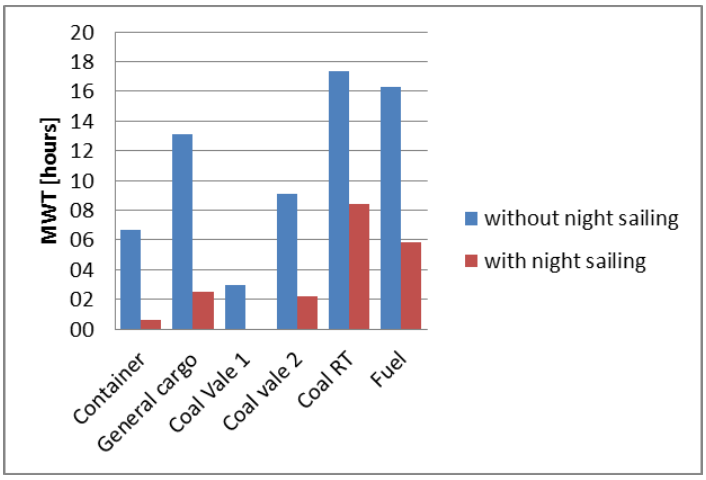


Figure 5-4 | Mean waiting time (MWT) on arrival with and without night sailing

5.7.3 *Waiting time on departure*

The waiting time on departure in Beira Port comprises of waiting times due to an occupied access channel, night and tidal depth limitations. In Figure 5-5 the mean waiting time (MWT) on departure is charted for the different terminals. In case of the coal transfer ships, occupied berths also add to the waiting time, because the ship sail back and forth between two berths, this is further explained below.

The waiting time on departure for the Coal Vale 1 and 2 ships is all the waiting times it has at quay 8 and the offshore berth, divided by the number of times it is serviced at these places. In case of Coal Vale 1, this is four times at the offshore berth and four times at quay 8. Considering the service time offshore is on average 400 minutes shorter than at quay 8, Coal Vale 1 still occupies quay 8 when Coal Vale 2 is ready to sail. When Coal Vale 1 is loaded, it possibly has to wait for a sailing window and thereafter needs time to sail through the access channel. All this time Coal Vale 2 has to wait too. In the appendix, this is illustrated by the 'coal vessels ideal schedule'. It can be seen that in an ideal schedule without a tidal window and with 24 hour sailing, the total waiting time is already over 1800 minutes (30 hours).

The mean waiting times for the coal ships can be compared to figures from a simulation done by TBA about quay 8 operations (DHV BV, 2011b). In this study the mean waiting time for the transfer ships is expected to be 20.4 hours, without night sailing and 14.4 hours with 24 hour sailing. This shows a poor relation with the findings for Coal Vale 1 as shown in Figure 5-5.
The difference is that their simulations are based on far more conservative port regulations. The ships in their model are only allowed to sail the access channel on a flood tide minus 1 hour. Effectively this gives a tidal window of just 5 hours and consequently waiting times are much longer.

If we compare the waiting times of the container, GC-DB, coal RT and the fuel ships a relation can be found with the service times at their corresponding terminals. Ships are only allowed to sail during daylight and the mean service time of container ships is 12 hours. Container ships must always wait for daylight, before they can exit the port. The mean service time of the GC-DB and fuel ships is around 14 hours and therefore their waiting time for daylight is shorter. For coal Rio Tinto, with a service time of 18 hours the mean waiting time for daylight is even shorter. The effect is less for the Rio Tinto ships, because their tidal window is shorter and chances are they have to wait for window the next day.

We see a weak relation between the ships draughts and the waiting time on departure. The deepest ships on departure are the coal Rio Tinto ships, they have the longest waiting time when night sailing is allowed. The mean waiting time for a tidal window is for all ships under 1 hour, so the depth limitations of the port are not of big influence on the port performance.

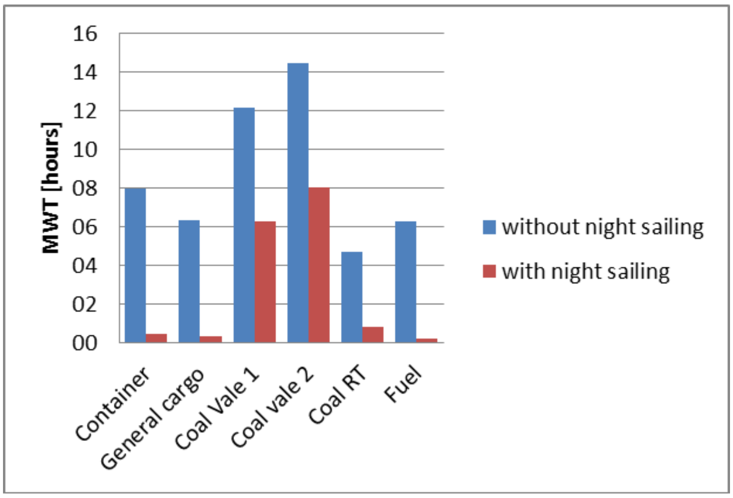


Figure 5-5 | Mean waiting time (MWT) on departure with and without night sailing

5.7.4 The waiting time for Coal Offshore

The mean waiting time of the OGV's of Vale is 131 hours, which is 1.56 times its total mean service time. The mean dwell time of an OGV is 215 hours in the Harboursim model, compared to 285 hours in the report on quay 8 of DHV (DHV BV, 2011b). The difference can be explained by the earlier explained difference in tidal window. Additionally the service times at the offshore mooring point are shorter in the Harboursim simulations. In the study of DHV a handling speed of 2000 tons per hour is considered, where the shipping company (Coeclerici Logistics, 2011) and current operators state a handling speed of 3000 tons per hour.
The waiting times for the OGV's are thus very long considering the conventionally accepted waiting times of 40% of the service time. For now, it is assumed that Vale takes these long waiting times for granted, otherwise they would not have invested in the terminal.

5.7.5 *Accuracy*

It must be noted that the accuracy given in this paragraph is the accuracy of the model predictions, but says nothing about the accuracy of the input. The model predictions are based on the input, which has its own accuracies. The accuracy of the model predictions is a parameter for the model performance, but is not the accuracy of the results.

The accuracy of the input for the Beira Port model is not calculated. The accuracy of the model predictions is however more important for the coming model calculations for the new alternative master plans. These deviations will be much more significant than the deviations calculated for the model predictions of around 10%. The accuracies of the model predictions are given in Table 5-10. For an explanation of the accuracies, reference is made to paragraph 5.6. The accuracy is below 20% for most predictions. This shows that the model gives accurate results for widely distributed inter arrival and service times.

The accuracy of the mean waiting time on arrival of the coal ships of Vale is low. This can be explained by the fact just 21 OGV's call the port. However, the total accuracy of the mean waiting time of the coal transfer ships is 12% of the mean. This parameter is a much more import parameter, because it determines the mean waiting time of the OGV of Vale. The OGV's total waiting time is for Vale an important parameter, because it determines how long the ship is present in the port. The occupancies of the terminal quays, given in Table 5-11, are also accurately predicted.

Table 5-10 | Accuracy of Harboursim model predictions as a percentage of the mean

Ship type	MWT on arrival	MWT on departure	MWT total	Dwell time
Container	7%	6%	5%	3%
GC-DB	19%	4%	14%	8%
Coal Vale 1	46%	12%	12%	4%
Coal Vale 2	39%	13%	14%	4%
Coal Rio Tinto	11%	16%	9%	5%
Fuel	27%	9%	19%	13%
OGV Vale			7%	

Table 5-11 | Accuracy of Harboursim model predictions as a percentage of the mean

Terminal	Occupancy
Container	9%
GC-DB 6-7	4%
Coal quay 8	9%
GC-DB 9-10	11%
Fuel jetty	12%
OGV Vale	4%

5.7.6 *Influence Erlang k inter arrival time distribution*

In order to evaluate the influence of the chosen Erlang k values for the inter arrival time distributions, two additional simulations have been done. One where the Erlang k value of the coal ships is set at 100 and another where the Erlang k value of the GC-DB, container and fuel ships is at 3.

Figure 5-9 shows the consequence for the mean waiting times. The Erlang 3 distribution has a huge influence on the waiting times on arrival. It is concluded that the inter arrival pattern is

important for the GC-DB and fuel ships to know to get accurate results. It is recommended to get better insight in these arrival patterns, to make good predictions on the waiting times.
For the coal ships the waiting times do not differ more than the accuracy of the model predictions, concluding the coal ships are not sensitive to changes in the k value from 10 to 100.
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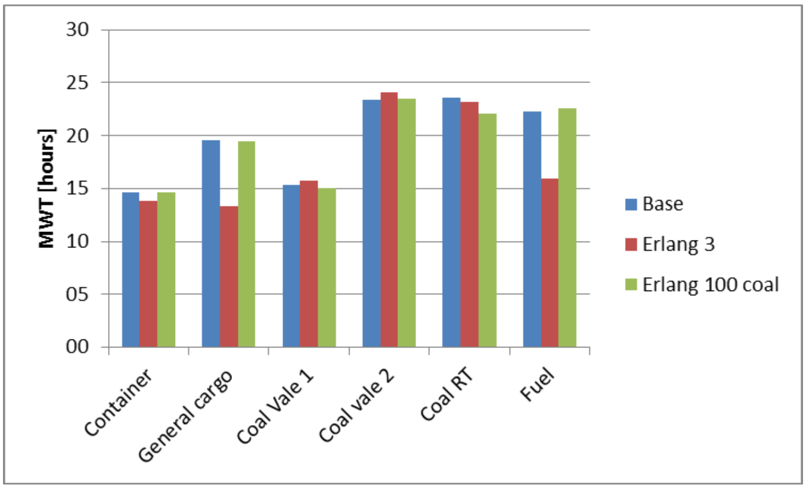


Figure 5-6 | Total mean waiting time per fleet

5.7.7 *Influence Erlang k service time distribution*

The influence of the chosen Erlang k value of the service time distributions is evaluated by comparing two additional simulations with the base simulation. One simulation is done with a k value of 100 for the coal terminal and offshore berth. A second simulation is done with a k value of 50 for the GC-DB, container and fuel terminals. The difference in the generated service times can be seen in Figure 5-7 and Figure 5-8. The resulting total mean waiting times are shown in Figure 5-9. An increase in k value means a decrease in mean waiting time. The mean waiting time of the OGV's of Vale is left out of the figure, because the numbers are on a much bigger scale, but also here for k=100 for the coal ships means a reduction of the MWT of 12 hours.
Still the differences with the base case are not that big, at most 10%, similar to the accuracy of the model predictions, thus it is concluded that model is not too sensitive for the chosen Erlang k values.

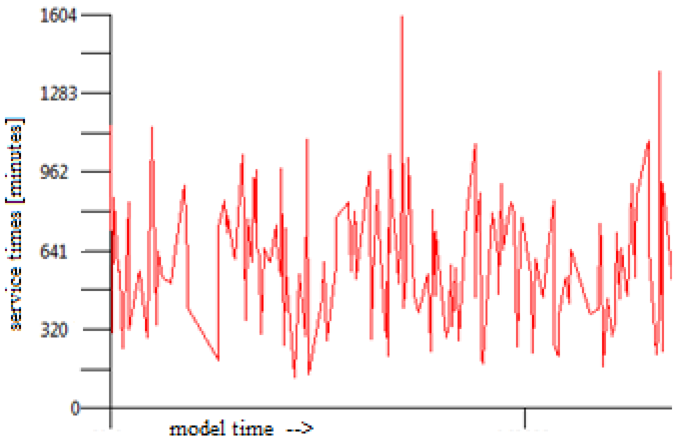


Figure 5-7 | Service time distribution at container terminal with Erlang 5

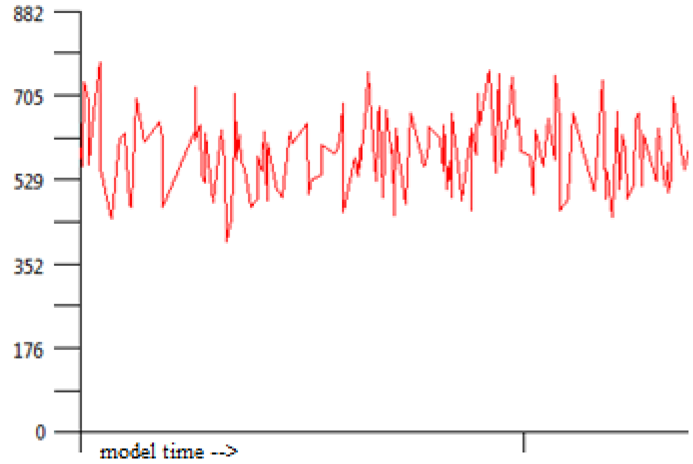


Figure 5-8 | Service time distribution at container terminal with Erlang 50

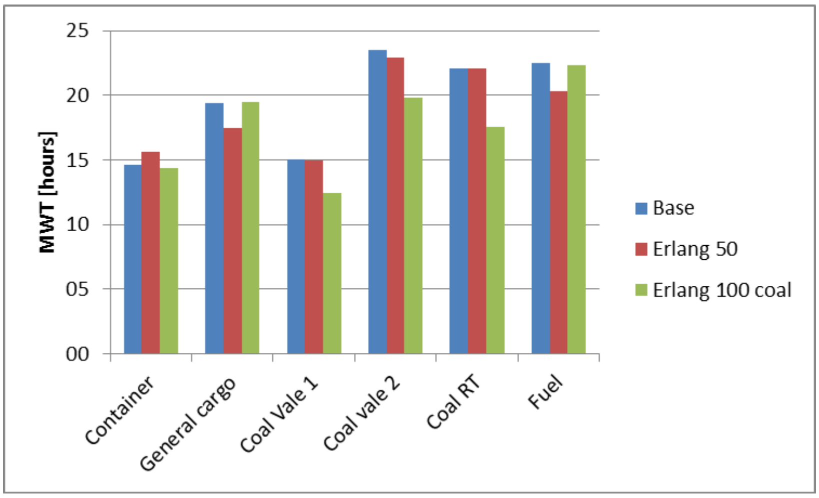


Figure 5-9 | Total mean waiting time per fleet

5.8 Conclusions

For Beira Port, processes are added to the Harboursim model code to make a good representation of the reality. The adaptions made in the code are generally applicable for all future Harboursim models. The following additional features were written for the model:

- Daylight window
- Terminal arrival queue for offshore berth
- Terminal departure queue for offshore berth
- Erlang k distribution as service time distribution
- Dwell time in the model per fleet
- Making Harboursim compatible with excel

The following errors in the Harboursim code are fixed, because of their major influence on the Port of Beira model performance.

- The tidal window calculation is oversimplified in Harboursim
- The required quay length per berthed ship does not use the accepted design rule
- The water level calculation uses only the depth of one section

The adaptions are made generically applicable for future users of this improved Harboursim model and described in appendix II, which should be used by all new users of the adapted Harboursim model constructed in this study.

The results have shown that the model reacts to the input as predicted. A quantitative comparison with measured occupancies and waiting times could not be done. When compared to the simulation results of TBA (DHV BV, 2011b), the differences in results are explained by differences in input of the two models.

The differences in waiting times on departure per fleet are explained by variances in service times and draft. The mean waiting time for a tidal window is for all ships under 1 hour, so the depth limitations of the port are not of big influence on the port performance.

The occupancy of the berths is low for all terminals. This implies that there is residual capacity left at the quays. The fuel terminal has a low occupation in Harboursim, but in reality this jetty is almost always occupied. The simulation shows that the capacity of the fuel jetty is not a problem, but management is.

The waiting times for the OGV’s are thus very long considering the conventionally accepted waiting times of 40% of the service time. For now, it is assumed that Vale takes these long waiting times for granted, otherwise they would not have invested in the terminal.

The results change as expected if model input is changed. The accuracy is below 20% for all relevant model predictions. This shows that the model gives accurate results for widely distributed inter arrival and service times. The model is thought to give reliable results and will be the basis for the simulation of the alternative master plans with the different scenarios. The created spread sheets will reduce analysing time of the results.

It is concluded that the inter arrival pattern is important for the GC-DB and fuel ships to know to get accurate results. It is recommended to get better insight in these arrival patterns, to make good predictions on the waiting times. The coal ships are not sensitive to changes in the Erlang k inter arrival distribution from k values from 10 to 100. The model is not sensitive for the chosen Erlang k values for the service time distributions.

6 THROUGHPUT AND SHIP FORECAST & SCENARIO DEVELOPMENT

The basis for the port master plan is the scenarios developed in this chapter. The scenarios are developed based on forecasted throughputs for the coming 20 years. No throughput forecast has yet been made for Beira Port or the hinterland. Throughput forecasts for 2032 for the different terminals are made with help of historic terminal data and throughput forecast of the hinterland. Historic economic data is available per country.

In paragraph 6.1 the macro-economic growth of the hinterland countries are discussed with the help of historic statistics. First, the GDP growth of the hinterland countries is discussed and trend lines are fitted to the historic data to get an idea of the economic growth. Secondly, the import and export trend of the hinterland countries is analysed. Mozambique is an economy in the rising and opportunities for additional throughputs arise, which are discussed in paragraph 6.2. The historic throughput data per terminal is discussed in paragraph 6.3 and, with the help of the first 2 paragraphs, forecasts are made per terminal. In paragraph 6.4, the ship sizes are discussed of the expected calling ships. Combining the results of the throughput and ship size forecasts, three scenarios are presented in paragraph 6.5. The alternative master plans will later be tested for their performance in the different scenarios.

It must be noted that in the whole analysis towards the scenarios no quantitative confidence bands are used. To investigate the accuracy of the forecast would be a study on itself. It is chosen to work towards three scenarios: Low, most likely and high

6.1 Macro-economic growth from historic statistics

6.1.1 GDP growth

Commonly the gross domestic product growth rate is used to estimate the future growth of an economy. Beira Port is dependable of cargo throughput from its hinterland, comprising of parts of Mozambique, Malawi, Zambia and Zimbabwe. Therefore, the GDP growths of these countries are discussed. It is unknown what percentage of the throughput comes from each country. The economies of the countries have had a vibrant history due to political unrest and civil wars. The last decade the countries are in the rising due to stabilizing politics and international help. Mozambique has achieved an average of 7.4% GDP growth per annum during the last decade, ranking amongst the highest growths in the world. In Figure 6-1 the historic data from 1999 to 2010 is shown for the hinterland countries of Beira Port. Linear trend lines have been drawn to show the GDP growth trend towards 2032. For Mozambique and Zambia, the deviations of the historic data points from the trend line are relative small and can be said to be accurate. However even for Mozambique and Zambia, one trend line does not suffice.

Further data analysis per country is done in appendix V. The trend lines and average lines give a range for the expected growth for each individual country. Not each line has a good fit with the historic data points. In the Malawi data points a jump can be seen from 2005 to 2006. From 2006 over two billion dollars in debt have been cancelled, giving the economy an enormous boost. Due to this jump, the trend line of the last 10 years shows an inaccurate GDP growth rate. Growth rates are declining from 2006 and are expected to do so for the coming years, as is illustrated in Figure 0-19 of appendix V by the trend line of the last 5 years. Zimbabwe data points have a far spread from the trend lines and averages of the last 5 and 10 year. Zimbabwe's economy still suffers from political turmoil, capital flight and mismanagement, there can be made no accurate economic predictions.

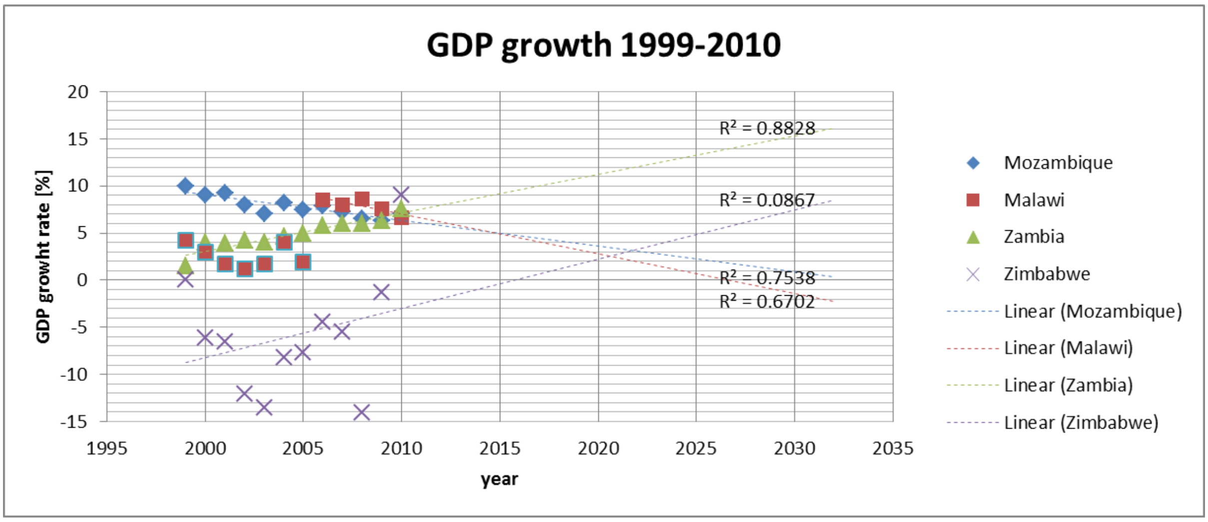


Figure 6-1 | GDP growth rate per annum of Beira Port hinterland with linear trend lines

6.1.2 *Export and Import growth*

Paragraph 6.1.1 showed the growth of the economies of the hinterland. However, for the throughput forecast of the port the export and import figures are more important. In appendix VI, the import and export historic date from 2000 to 2010 are shown in charts. Trend lines over the 10 years and best fit lines over more recent years have been added to the charts. The lines give an expected range wherein the import and export lies.

The average import growth rates per year are calculated for the different countries and they are in the range of 13-19% per year. To use such a high growth rate per year would be unwise, in ten years the import would skyrocket to 20 times the present amount. Another method is to use the average growth rate over 10 year. Still, import figures for 2032 would be very high.
It is chosen to use the linear trend lines over the last decade. In Figure 6-2 the import data of the hinterland are summarized in one chart. For all countries the import would be doubled by 2032. The ranges given in appendix VI between best fit and trend line over 10 years are between 2 and 4 times the present throughput in 2032.

A chart is given for the export data in Figure 6-3. Similar results are found as for the import growth, in the range of 2 to 4 times the present throughput in 2032. However, the trend line over 10 years of Mozambique is close to the best-fit trend line.

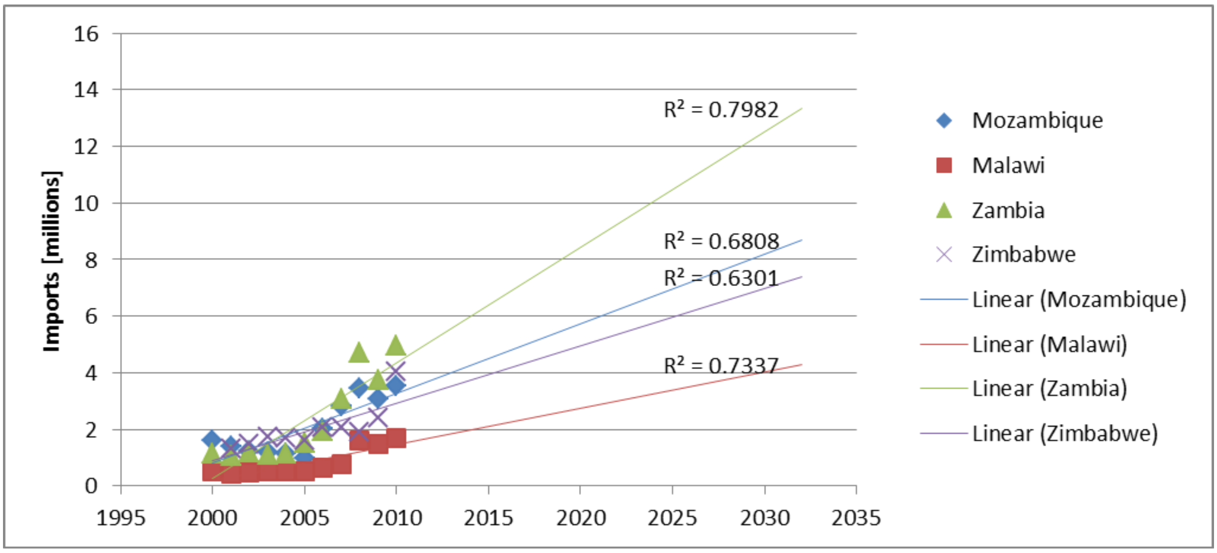


Figure 6-2 | Import data of the hinterland of Beira Port with trend lines

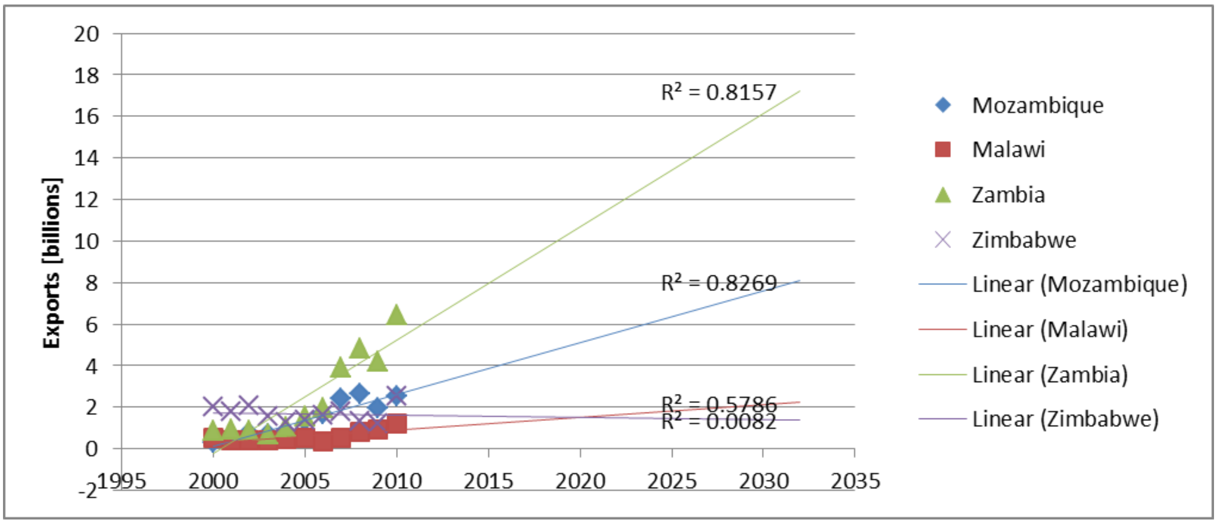


Figure 6-3 | Export data of the hinterland of Beira Port with trend lines

6.2 Opportunities

6.2.1 Beira agricultural growth corridor

The Beira Agricultural Growth Corridor (BAGC) initiative is a partnership between the Government of Mozambique, the private sector and the international community, which aims to stimulate a major increase in agricultural production in the Beira corridor. In Mozambique alone, there are 10 million hectares of arable land with good soils, climate and access to water. Nevertheless, this potential has not been realized. At present, there is hardly any commercial agriculture in the corridor. The rural population is almost entirely reliant on subsistence agriculture and remains very poor. Total arable land area is 10 million hectares, of which only about 1.5 million is currently being used, almost exclusively by smallholder farmers (BAGC, 2010)

The BAGC did a study to investigate the potential new production inside Mozambique. The results of this study are presented in this paragraph. The areas with potential are shown in Figure 6-4. These areas are all well linked with Beira Port. Figure 6-5 shows in short how the potential areas for agriculture were identified. Table 6-1 summarizes the agricultural production potential per annum.

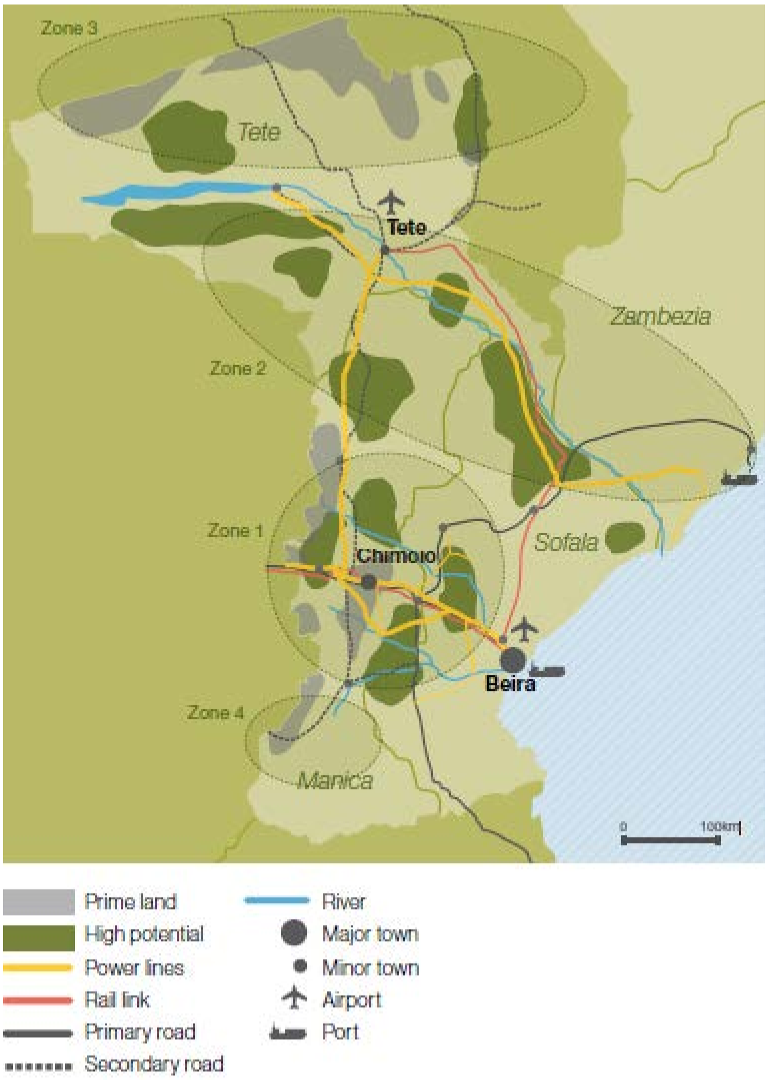


Figure 6-4 | BAGC potential areas in Mozambique (BAGC, 2010)

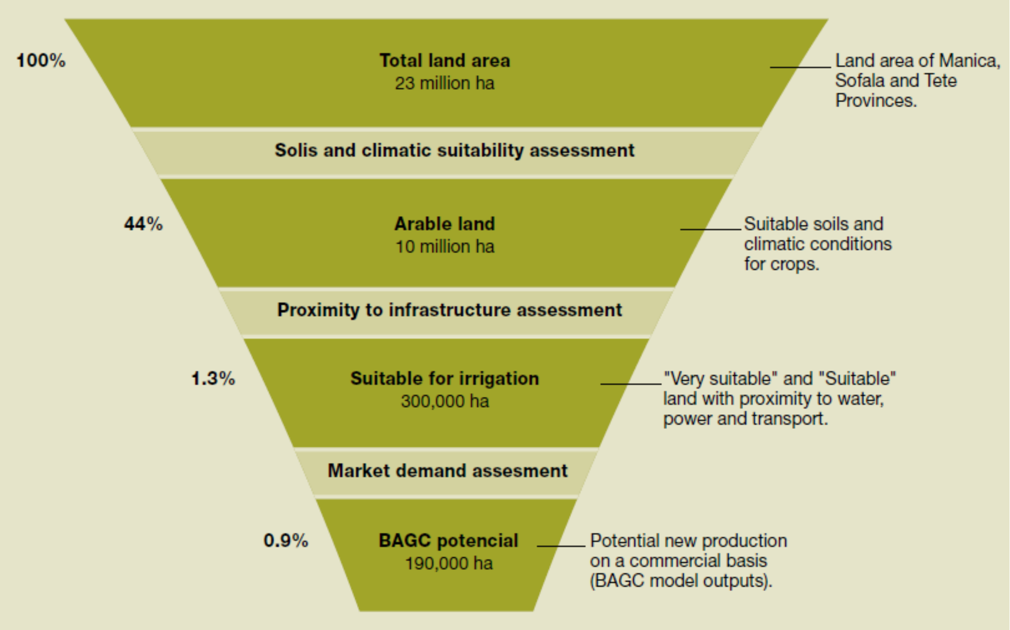


Figure 6-5 | From total area to BAGC potential (BAGC, 2010)

Table 6-1 | Agricultural production potential per annum

Crop	Hectares	Yields (tons/ha)	Production (tons)
Banana	6,000	60	360,000
Citrus	6,000	40	240,000
Mango	4,500	20	90,000
Wheat, maize, soya	55,000	5	275,000
Rice	20,000	6	120,000
Sugarcane	100,000	110	11,000,000
Total	191,500		12,085,000

Growth of wheat, maize, soya and rice production is unlikely to be demand constrained. In the short-term, there are good opportunities in domestic and regional markets (substituting for imports, e.g., Mozambique currently imports 350,000 to 400,000 thousand tons of wheat and a similar volume of rice annually) and in the longer term, Mozambique could supply regional markets. (BAGC, 2010) The effect for Beira Port is that wheat and rice imports will be less.

Sugar is a commodity product, with the potential to convert into ethanol for fuel, for which demand is unlikely to limit Mozambique production. Further improvements on best practices are expected to allow in the short to mid-term an average ethanol productivity of 9,000 litres per hectare (Goldemberg, 2008). This means a maximum production of 900,000 m^3 per year for the Beira corridor. Principle Energy is utilizing 14,000 ha and invests $400 million towards ethanol production from sugar cane. Located in Dombe, the biofuel is expected to flow out of Mozambique through Beira port. (BAGC, 2010) Another possibility is to make sugar out of the cane. Sugar cane must be crushed to extract the juice. The juice is collected, filtered and then boiled to drive off the excess water. The remaining liquid sets into a sugar. Generally, from 10 tons of sugar cane, 1 ton of sugar is made (Practical Action). Thus, a maximum of 1.1 million ton sugar could be produced.

Fertilizer is required in order to reach the proposed yields given in Table 6-1. In literature 100 kg/ha of active product is named to get the proposed yields (FAO, 2000). With 15% active product in the fertilizer, 190.000 x (100/0.15) / 1000 = 130,000 ton of fertilizer is needed per annum. Yara International is investing in a fertilizer terminal at Beira. (BAGC, 2010)

6.2.2 *Coal export*

Huge coal reserves have been found in Mozambique. About 36 mining companies are currently active in Mozambique's Tete province, with activities being dominated by Rio Tito and Brazilian mining company Vale. The Zambeze coal basin, which underlies Tete, is believed to hold some 23-billion tons of coal. Its Moatize sub basin reserves are estimated at 750-million tons, and the Muchana-Vusi sub-basin is said to contain as much as 3.6 billion tons in coal reserves. (Mining Weekly, 2012) It was reported that Mozambique's coal output is expected to jump to around 40 million tons a year in five years' time and 100-million tons in a decade. (Reuters, 2012)

Beira is currently the only port connected to Moatize by a direct railway line. Therefore, further information is sought about the coal export forecasts. Figure 6-6 gives an overview of investments in present coal projects; it used to find more information about coal projects.

Project Name	Project Owner	Project Stage	Project Details	Value	Expected operation
Zambeze	Rio Tinto	Pre-feasibility	New mine development	$800.0 million	2014
Moatize Project	Coal of India	Pre-feasibility	New mine development	$400.0 million	2016
Benga	Rio Tinto	Construction	New mine development	$700.0 million	2011
Jindaal Steel & Power	Jindaal Steel & Power	Construction	New mine development	$440.0 million	March 2012
Ncondzezi	Ncondzezi Coal Ltd	Pre-feasibility	New mine development	$367.0 million	Q4 2014/Q1 2015
Minas Moatize	Beacon Hill Resources	Construction	Existing mine expansion	$38.0 million	2012
Minas de Revuboe	Talbot Group, Nippon Steel, Posco	Pre-feasibility	New mine development	$500.0 million	September 2013
Tete West	Mozambi Coal	Pre-feasibility	New mine development	$300.0 million	2015
Moatize Phase II	Vale	Pre-feasibility	Existing mine expansion	$4 .00 billion	2014

Figure 6-6 | Investments in coal projects 2011-2015 (Tawii, 2011)

Vale is investing heavily in its Moatize project, where output is expected to reach 11 million tons per annum (MTPA) by 2014, comprising of 8.5 MTPA metallurgical coal and 2.5 MTPA thermal. The second phase to double capacity to 22 million ton is planned for 2017 (Reuters, 2012). Vale is already constructing a coal handling and preparation plant with processing capacity of 26 MTPA to serve both phases, so it seems confident that it will proceed with the second phase. (Ford, 2011)

Rio Tinto is involved in the Benga coal project in Mozambique. The project is a joint venture between Rio Tinto (65%) and Tata Steel Limited (35%). Coal resources are estimated at 4.5 billion ton. The Zambeze Project, adjacent to the Benga Coal Project, has an identified coal resource of 9 billion tonnes. Production is scheduled to reach 5.1 million MTPA by 2013: two-thirds of this will be metallurgical coal and one third thermal. (Ford, 2011) Rio Tinto will be potentially producing 25 million tons of product by 2016-17. Benga project, due to begin output in November or December, will ship about 5 million tons of unprocessed coal and may expand to 20 million tons. The adjacent Zambeze project may produce 42 million tons a year, rising to as much as 90 million tons of unprocessed coal. (Bloomberg, 2011)

Beacon Hill Resources owns and operates the Minas mine in Moatize who has started washing coal. The company has focused on developing a larger open pit mine that is targeted to produce 2.35 MTPA of saleable coking and thermal. The total resource at Minas Moatize now stands at 80 million ton. (CEPM, 2011)

Jindal has acquired exploration license for coal blocks and has done extensive drilling to find substantial reserves. Now the company has applied for mining concession. Once commercial mining commences, it will be producing 10 million tonnes of high grade coal per annum. (CEPM, 2011)

The Ncondezi coal project is a $376-million project with a total resource of 1.8-billion tons. Ncondezi's first coal production is scheduled for the end of 2014 or early 2015, and has an estimated 37-year life-of-mine. It is aiming at an open pit 10 MTPA thermal coal operation. (Ford, 2011)

The projects are expected to be in full operation in 5 years. Currently the export capacity from the Tete region is 3 million tons due to the limited railway connection to Beira Port. All miners are looking for a way to export the coal. Beira Port is currently the closest port. However, the amounts of coal are big enough to consider building a new port or transporting the coal to Nacala Port, which has the advantage of having a natural access of 24 m CD. Construction of a railway line through Malawi towards Nacala has already begun and is expected to be operational in 2015. Though, the capacity on this line will not be sufficient to foresee in the expected production. The disadvantage of transporting through Malawi is that it has extra risks in this political unstable region and Malawi asks a price of 8 million dollar per annum for transporting through its country. Mining companies are exploring the possibilities of building an entire new port along the coast of Mozambique with a dedicated railway line. If Beira Port wants to attract the coal exporters, it is depended on the expansion of the capacity of its railway connection.

A summary of the above mentioned coal projects is made in Table 6-2. Total expected production of these projects is 70 MTPA for the coming years.

Table 6-2 | Summary of coal projects

Project name	Project owner	Stage	Recources	Expected production	Expected operation
Moatize	Vale	Pre-feasibility	4 billion T	22 MTPA	2017
Zambeze	Rio Tinto	Pre-feasibility	9 billion T	12.5 MTPA	2017
Benga	Rio Tinto	Construction	4.5 billion T	12.5 MTPA	2017
Minas Moatize	Beacon Hill	Construction	80 million T	2.35 MTPA	
Jindal	Jindal	Construction	700 million T	10 MTPA	
Ncondzezi	Ncondzezi	Feasibility	1.8 billion T	10 MTPA	

Fuel consumption of diesel trains to transport the coal to Beira Port, could be of influence on the local fuel demand. Fuel consumption depends on the terrain and the amount of cargo transported. A rough figure of 100 km/l per ton of cargo is found to make a first calculation of the fuel demand (Freight on rail, 2012). To transport 70 million tons of coal, about 400,000 m^3 diesel is used.

6.3 Throughput per terminal

In the following subparagraphs, a forecast is made for each of the cargo types through Beira Port. Cargo flows through the GC-DB terminal are separated in general cargo and dry bulk throughputs. New information has become known about the fertilizer throughputs over the GC-DB terminal, which is discussed in 6.3.2.

6.3.1 Container terminal

Historic data of container throughput is adopted from paragraph 2.4. In Figure 6-7, trend lines have been added to the historic data. The trend line from 2002 has a better fit with the historic data points than the line from 1998, as indicated by the higher R^2-value. The average growth rate is 18 % since 2002, which coincides with the average import growth rate per year. The trend lines are also similar as with the import and export trend lines, the range is 2 to 3 times the current throughput. Container shipment has become the standard around the world and general cargo is continued to be put in containers. Therefore, container throughput is expected to grow as fast as the best fit trend line. This line is taken as the median. Expected throughput in 2032 is expected to lie between 200.000 and 400.000 TEUs. The assumption is made that the distribution between import and export is the same as for the present container traffic, being 3:2.

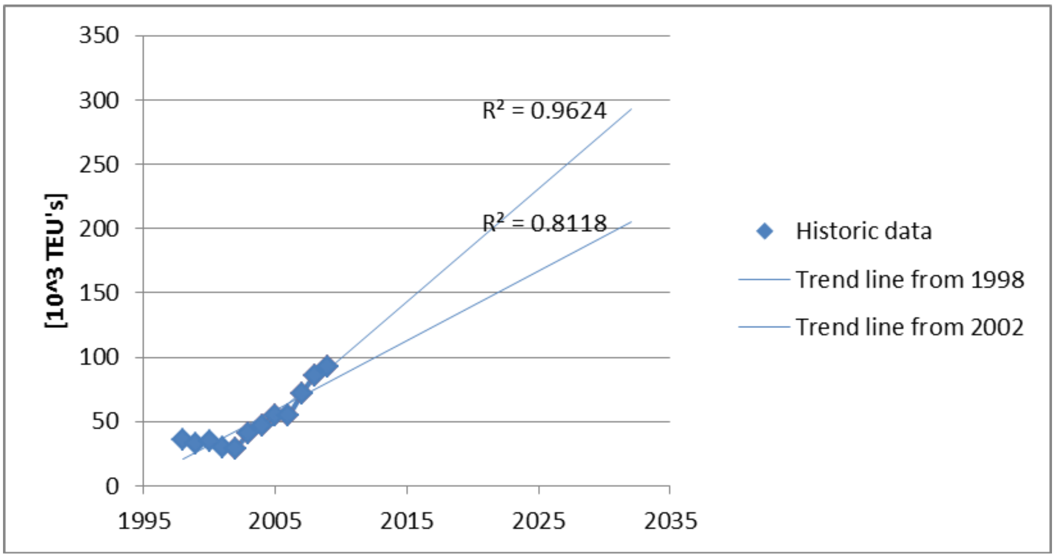


Figure 6-7 | Container historic throughput data with trend lines

The BAGC prospects add an additional reefer transport of 93,000 TEUs, as depicted in Table 6-3. It is assumed that 48,000 bananas fit in one container and an average banana weighs 120 grams (Maersk line, 2012). An average mango or citrus weighs 200 gram and is as big as a banana. Therefore, it is estimated that 6 ton of banana and 10 ton of citrus or mango fit in one reefer.

Table 6-3 | BAGC reefer transport

Crop	Production (tons)	Ton/reefer	Reefers
Banana	360,000	6	60,000
Citrus	240,000	10	24,000
Mango	90,000	10	9,000
Total			93,000

6.3.2 *GC-DB terminal*

At the GC-DB terminal, two types of cargo are handled: general cargo and dry bulk. In the previous chapters, no division was made in the cargo types, as only information on the total throughput of the GC-DB terminal was available. As cargo volumes increase, the division of the two cargo types becomes more important. A simple dry bulk terminal may become justified at a cargo flow of 0.5 million to 2.0 million tons/year (Ligteringen, 2007). Therefore, it is chosen to separately discuss the two cargo types from hereon.

Throughput of the GC-DB terminal is not expected to grow as fast as the container throughput, because relatively more general cargo will be transported in containers. Still, with the foreseen economic growth, throughput will increase. Figure 6-8 shows the historic throughput over the GC-DB terminal. The GC-DB throughput in 2032 is expected to be in the range of 1.5 to 2.5 million ton. The assumption is made that the distribution between import and export is the same as for the present container traffic, being 3:2. It must be noted that the R^2-value is low and thereby the predictive skill of the trend line.

If the BAGC succeeds in its goals, import of wheat and rice will be 400,000 tons less. However, export of sugar can boost the GC-DB throughput with up to 1.1 million ton. The maximum additional throughput over the GC-DB terminal is stated in Table 6-4. It must be noted that the grown sugarcane could also (partly) be used for ethanol production.

New information on the fertilizer throughput has come to light, which means a considerable increase of present dry bulk throughput at the GC-DB terminal as this was not yet included in the GC-DB terminal throughput figures. The import of fertilizer is one of the major cargo flows in the current GC-DB terminal. The fertilizer, with a current annual volume of about 500,000 tons, arrives in bulk ships. (DVH BV, 2011d). The fertilizer is transported to the entire Beira hinterland, explaining why the import is much higher than calculated in 6.2.1. The increase in fertilizer throughput is thought to follow the GC-DB terminal increase, so fertilizer throughput in 2032 will be between 750,000 and 1,250,000 tons.

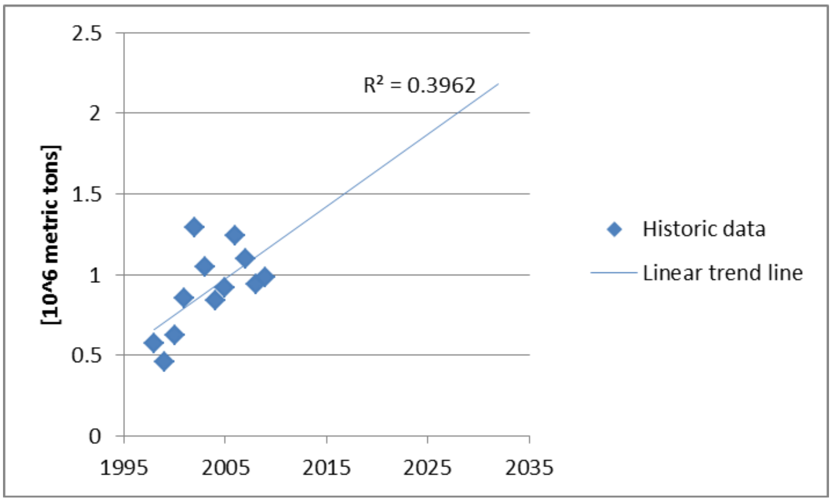


Figure 6-8 | GC-DB historic throughput data with trend line

Table 6-4 | BAGC maximum additional GC-DB throughput

Crop	Import [tons]	Export [tons]
Wheat, maize, soya	- 275,000	
Rice	- 120,000	
Sugar		1,100,000

6.3.3 *Coal terminal*

Total reserves of Beira hinterland are at the moment forecasted at 23 billion ton. Total expected production of started projects is 70 MTPA for the coming years. With this production the lifetime is over 30 years. The share that will be transported through Beira is influenced by the railway connection and competing ports. Construction of the railway line through Malawi will be used to export coal through Nacala, but the capacity of the line is unknown. Vale and Rio Tinto are currently active in Beira and could be persuaded to increase their capacity in the port.

The coal terminal depends on the hinterland connection to the mines. CFM expects to complete a much-delayed refurbishment of the Sena rail line by November this year. This is the first phase of a rehabilitation of this infrastructure to be undertaken by CFM to ensure that the line is able to carry 12 million tonnes per year by 2013 and 20 million tonnes within three years," CFM said in a statement. (Reuters, 2012) It must be noted that plans to rehabilitate and expand the railway capacity are already delayed several years.

Resources in the hinterland of Beira are huge and many plans exist. However, it remains to be seen if all the potential will be transported through Beira.

6.3.4 *Fuel terminal*

Mozambique does not produce any of its own fuel. At present, there is no refinery in Mozambique so therefore all petroleum products need to be imported. The ports of Matola (Maputo), Beira and Nacala all have import terminals and some fuel arrives by road from South Africa.

Fuel throughput figures are known of the last 17 years, see Figure 6-9. A pipeline connects Beira Port with Zimbabwe and therefore the major share of the fuel import is transported through Mozambique to Zimbabwe. The capacity of the line is 1.6 million m^3, which is equal to 1.28 million ton, and in the last years of the 90's the capacity was almost reached. Due to political unrest, the fuel line had a dip from 2003 to 2009, but the last 2 years it is close to full capacity even with an expansion through additional pumping stations. Import for within Mozambique is steady around 200.000 tons per annum. Fuel distribution within Moçambique is by road, the railways do offer a service but due to the poor condition of the rail network and reported losses, this is not used as much.

The import and export forecasts are used for the fuel forecast of Mozambique. Import and export rise with 200 to 400% in 2032. All transport to and from the port is likely to use fuel imported through Beira. The expected coal transport will give an additional demand of up to 400.000 m^3. Concluding that fuel demands for 2032 will be between 2.5 to 5.5 million ton. This throughput through Beira can only be reached if the pipeline capacity of 1.6 million ton is enlarged.

Additionally the terminal can export the ethanol production of up to 900.000 m^3, which is 720,000 tons. A new export pipeline must be installed to Beira Port and on the jetty.

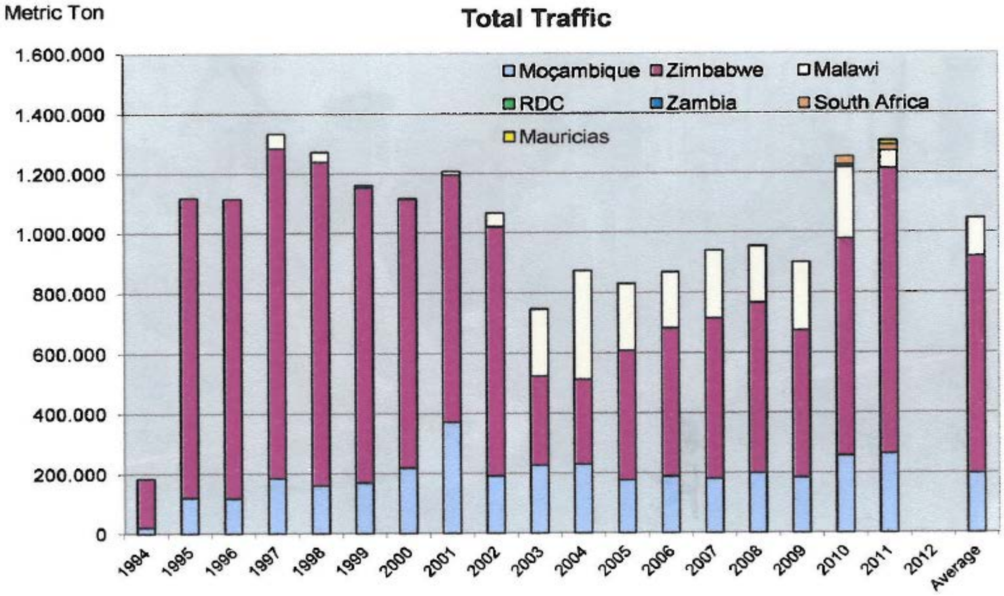


Figure 6-9 | Total fuel traffic in metric ton (CFM, 2009)

6.4 Ship size forecast

It must be noted that the type of calling ships for Beira Port depends on the depth of the access channel. In this paragraph, it is only considered which ship sizes there are and what the expected demand of shipping companies is for calling Beira Port in 2032. In the scenario development paragraphs, the ship sizes will be matched with the expected throughput per scenario.

Starting point for the ship forecast are the current average and maximum ship sizes, which are identified in chapter 3.4 to 3.8, a summary is given in the following two tables.

Table 6-5 | Current maximum ship sizes, * DWT per ship, for container in TEUs

Terminal	Max load*	LOA [m]	Loaded draft [m]
Container	900	154	8
GC-DB	15,000	158	9
Coal	40,000	194	9.2
Fuel	50,000	180	11

Table 6-6 | Current average calling ships, * DWT per ship, for container in TEUs

Terminal	DWT*	Average transhipment*	LOA [m]	Loaded draft [m]	# of ships
Container	900	350	154	8	263
GC-DB	7,500	2,500	113	8.5	387
Coal	40,000	30,000	194	9.2	200
Fuel	10,000	10,000	130	10	90

The draft of the ships is related to the amount and specific weight of the cargo they carry. Most calling ships are not loaded to their maximum tonnage and thus draft. However, for simplicity reasons in this study only fully loaded ships are considered.

Table 6-8 gives an overview of container classes with ship sizes. There is a trend of increasing ship dimensions around the world. Containers will be shipped using liner trades along the African coast and further. The container ships calling Beira will be limited by the maximum allowable draft of Beira Port, but also of the other ports the liner trades call. Table 6-7 lists a number of ports along the southern East-African coast with their maximum allowable draft. It is likely that shipping companies will use ships in the future that match these drafts.

Table 6-7 | Maximum allowable drafts of southern East-African ports (several internet sources)

Port	Maximum allowable draft
Dar es Salaam (Tanzania)	10.0 m
Durban (South Africa)	12.2 m
East London	10.0 m
Maputo	12.5 m
Mombasa	13.5 m
Port Elizabeth	12.0 m
Richards Bay (South Africa)	17.5 m
Tanga (Tanzania)	11.0 m

Table 6-8 | ship sizes of different container classes (Thoresen, 2010)

Generation	Capacity [TEU]	Max Length [m]	Max Beam [m]	Max Draft [m]
ULCS	> 14,500	> 366	> 49.0	> 15.2
8th New Panamax	10,000 – 14,500	366	49.0	15.2
7th Post Panamax	10,000	366	49.0	15.2
7th	8,000	340	42.8	14.5
6th	6,400	320	42.0	14.2
5th	4,400	260	38.0	13.4
4th Panamax	3,900	270	32.2	12.5
3rd	2,800	235	32.2	11.8
2nd	2,100	210	30.5	10.8
2nd	1,700	175	26.0	10.0
1st	< 1,000	152	23.5	8.7

For the design, general cargo ship the best source is found in data acquired by Akakura and Takahashi, given in Table 6-9. It must be noted that currently larger ships are on the market, recognizing that this table is from 1998. The 95% confidence limit gives an indication of the sizes for the different DWT's. This means that 95% of the ships in 1998 had these given maximum dimensions for the listed capacity.
At the GC-DB terminal also dry bulk ships are currently serviced. For the smaller dry bulk ships the same source as for the general cargo ships is used, shown in Table 6-10. For the Panamax and larger ships, Table 6-11 is used.

Table 6-9 | ship size of general cargo ships with confidence limit of 95% (Thoresen, 2010)

Capacity [DWT]	Max Length [m]	Max Beam [m]	Max loaded draft [m]
5,000	122	18.3	7.5
7,000	136	20.1	8.3
10,000	151	22.2	9.3
15,000	172	24.8	10.7
20,000	188	26.9	11.7
30,000	213	30.1	13.4
40,000	233	32.6	14.7

Table 6-10 | Ship sizes of dry bulk ships with confidence limit of 95 per cent (Thoresen, 2010)

Capacity [DWT]	Max Length [m]	Max Beam [m]	Max loaded draft [m]
5,000	113	16.3	6.5
7,000	124	18.1	7.2
10,000	138	20.2	8.0
15,000	155	22.9	9.0
20,000	168	25.0	9.8
30,000	188	28.4	11.0
50,000	218	32.3	12.8

The major destinations for coal exports from Beira will probably be in India and China. An overview of the maximum allowable drafts of the destination ports is given in Table 6-12. Table 6-11 presents the overall breakdown of ship types. Coal is at present mainly shipped in Panamax ships. The largest ship that should be expected at Beira is a large Capesize bulk carrier with a LOA of 290 meters and 150,000 DWT and has a maximum draft of 17.0 meters. (DHV BV, 2012) However, this ship will not be handled at the Beira Port quays. Currently Vale uses transhipping ships of 30,000 DWT to load the Capesize ships.

Table 6-11 | Ship sizes of different bulk carrier classes (Thoresen, 2010)

Name	DWT [t]	Displacement [t]	LOA [m]	Beam [m]	Max loaded draft [m]
Panamax	70.000	90.000	230	38	13.5
Cape-sized	100.000	125.000	250	42	15.0
Cape-sized	150.000	180.000	290	47	17.0
VLBC	200.000	240.000	310	55	19.0
VLBC	250.000	300.000	330	56	20.0
VLBC	300.000	340.000	360	57	21.0
Vale Max	400.000	460.000	412	66	24.0

Table 6-12 | Maximum drafts of coal destination ports (DHV BV, 2012)

Port	Max. allowable draft
Shanghai Ports	11.0 m (lightered ships up to 180.000 DWT)
Ningbo-Zhoushan Ports	/
Guangzhou Port	13.8 m (entire port)
Krishnapatnam Port	18.0 m
Mundra Port	17.5 m
Ennore Port	15.0 m
Paradip Port	12.5 m

Currently refined products are transported by product tankers of up to 100,000 tons. For the transport of crude oil, large tankers (VLCC's) of 200,000 tons or more exist. Typical tanker dimensions are given in Table 6-13. (Ligteringen, 2007) In Beira port, the largest ship calling the fuel terminal was 50,000 DWT, because of depth limitations.
In paragraph 3.8.3 the loaded draft of the currently calling tankers was chosen to be 10.0 m. From now on, this maximum loaded draft is abandoned and the table below is used for determining the draft of tankers.

Table 6-13 | Typical tanker dimensions (Ligteringen, 2007)

DWT [t]	Displacement [t]	LOA [m]	Beam [m]	Max. loaded draft [m]
20.000	26.000	175	21.4	9.2
50.000	65.000	230	31.1	11.6
70.000	87.000	245	35.4	12.8
100.000	125.000	272	39.7	14.6
150.000	185.000	297	44.2	17.1
200.000	240.000	315	48.8	18.9
250.000	295.000	338	51.8	20.1

6.5 Scenario development

This paragraph forms the conclusion of this chapter. The throughputs per terminal are combined with the ship forecast to develop three scenarios. First scenario low is discussed, which is characterized with low economic growth. Thereafter the most likely scenario is discussed and the chapter closes with scenario high.

6.5.1 Scenario low

Scenario low is characterized with low economic growth. Throughputs in all segments see little growth as indicated by the lower bounds in paragraph 6.3. In this scenario it is considered that no large adaptions to the wet layout will be implemented and thus calling ship sizes cannot increase much.

Container throughputs are at the lower bound of 200,000 TEUs, doubled in comparison with current throughput. No additional fruits are exported by the BAGC initiative. The calling container ships will increase little in size.

Throughputs over the GC-DB terminal are 1.5 million tons, of which 900,000 is import and 600,000 export. Half of this throughput is transported by general cargo ships and the remaining by dry bulk ships. In addition, there is the low forecast for the fertilizer: 750,000 import. Then there is additional cargo due to the BAGC initiative. All farmers have chosen to produce sugar cane, but yields are half of its potential. No further fruits, wheat or rice is produced, because profits on sugar cane are higher. The sugar cane is used 50% for ethanol and 50% for sugar production. The 275,000 tons of sugar are exported by bulk ships. In Table 6-14 the total throughput per cargo is given.
The throughput has not increased much relative to the current throughput. Therefore, average transhipment does not have to increase and bulk and general cargo ship sizes stay level.

The Sena railway is only upgraded to 6 million tons per annum capacity, which is mainly used for coal export. The 5 million capacity of the current coal terminal is reached and no further coal is exported through Beira Port. The proposed operations as described in paragraph 3.6.3 are implemented and the same ship sizes are used.

Fuel demands are not expected to rise excessively through Beira Port. Fuel imports see a small rise in throughput by increasing capacity of the hinterland pipeline by more efficient use. The 180,000 tons ethanol export production could be transported in about 20 shipments of 10,000 tons. Larger transhipments would require unnecessary storage area at the terminal. The average and maximum calling ship at the fuel terminal will not increase and on average 10,000 tons will be transhipped.

All throughputs per terminal are summarized in Table 6-14. The chosen design ships are shown in Table 6-15. The chosen average calling ship and the number of ships are given in Table 6-16.

Table 6-14 | Scenario low: Throughput [tons] through Beira Port

Commodity	Import	Export	Empties
Container*	90,000	60,000	45,000
General cargo	450,000	300,000	
Bulk	1,200,000	575,000	
Coal		5,000,000	
Fuel	2,500,000	180,000	

* TEUs

Table 6-15 | Scenario low: Design ship specification

Commodity	Max load [tons]	LOA [m]	Beam [m]	Loaded draft [m]
Container	*2,100	210	30.5	10.8
General cargo	10,000	151	22.2	9.3
Bulk	15,000	155	22.9	9.0
Coal	40,000	194	28.0	9.2
Fuel	50,000	230	31.1	11.6

* TEUs

Table 6-16 | Scenario low: Average ship specification

Commodity	DWT	Average transhipment [tons]	LOA [m]	Beam [m]	Loaded draft [m]	# of vessels
Container	*1,700	*350	175	26.0	10.0	560
General cargo	7,000	2,500	136	20.1	8.3	300
Bulk	7,000	2,500	124	18.1	7.2	710
Coal	40,000	30,000	194	28	9.2	166
Fuel	20,000	10,000	175	21.4	9.2	270

* TEUs

6.5.2 *Scenario most likely*

The most likely growth scenario sees in every sector a medium growth. The BAGC initiative reaches half of its potential. Exception is the sugarcane production, which reaches full potential by increase in demand of bio-ethanol worldwide. The proposed upgrades to the Sena railway, see paragraph 6.3.3, are implemented and the annual capacity is increased to 20 million tons of coal.

This medium scenario foresees in 300,000 TEUs as depicted in paragraph 6.3.1. The ratio import, export and empties will be the same. The fruit production is at half of the potential, meaning an additional 50,000 reefers must be exported.
It is assumed that ship sizes will increase slightly to an average of 2,100 TEU, because economies of scale make it more efficient. Also, the current access channel depth can still cope with these ships' drafts. The design ship is chosen to be one generation newer, with 2,800 TEU. Average transhipment per ship increases slightly with the ship size to 400 TEU per call, resulting in 875 ships per year.

From paragraph 6.3.2, general cargo and bulk throughputs are in the medium scenario 2.0 million tons, of which 1,200,000 is import and 800,000 export. Half of this throughput is transported by general cargo ships and the remaining by dry bulk ships. In addition, there is the medium forecast for the fertilizer: 1,000,000 import. The BAGC initiative has a negative effect on the import of wheat and rice of 200,000 tons. In Table 6-17 the total throughput per cargo is given.
Throughputs in the general cargo sector are doubled and with the current depth limitations, ships with larger drafts can be used. The average calling ship will be 10,000 DWT in both the general cargo as the dry bulk sector. The average transhipment will correspondingly increase slightly to 3,000 tons per ship.

Beira Port has ensured its role in the coal export with an annual throughput of 20 million tons. Mining of all reserves has not yet started, leaving potential for the future. The enormous throughput asks for deepening of the access channel. It is foreseen that the Rio Tinto Handymax and coal transfer ships can now be fully loaded to 40,000 tons, which results in a draft of 11.3 m (DHV BV, 2011b). The Vale coal is still transferred at sea to large ocean going vessels. It is assumed, in correlation with the current operation explained in paragraph 3.6, that 5 trips are required to fill an ocean going vessel.

Fuel throughput is in the middle of the forecasted ranges, 3.75 million tons. The sugarcane sector has increased to its full potential, where it is used to produce 720,000 tons ethanol for export. This export will be in liquid bulk tankers of 20,000 DWT. The average and maximum calling ship at the fuel terminal will not increase and on average 10,000 tons will be transhipped.

Table 6-17 summarizes the throughput through per terminal. The design ships are given in Table 6-18. An average ship size is required for the simulations; these are given in Table 6-19.

Table 6-17 | Scenario most likely: Throughput [tons] through Beira Port

Commodity	Import	Export	Empties
Container	*130,000	*/**140,000	*65,000
General cargo	600,000	400,000	
Bulk	1,600,000	400,000	
Coal		20,000,000	
Fuel	3,750,000	720,000	

* TEUs
** of which are 50,000 reefers

Table 6-18 | Scenario most likely: Design ship specification

Commodity	Max load [tons]	LOA [m]	Beam [m]	Loaded draft [m]
Container	*2,800	235	32.2	11.8
General cargo	15,000	151	22.2	9.3
Bulk	15,000	155	22.9	9.0
Coal	40,000	194	28	11.0
Fuel	50,000	230	31.1	11.6

* TEUs

Table 6-19 | Scenario most likely: Average ship specification

Commodity	DWT	Average transhipment [tons]	LOA [m]	Beam [m]	Loaded draft [m]	# of vessels
Container	*2,100	*400	210	30.5	10.8	838
General cargo	10,000	3,000	151	22.2	9.3	333
Bulk	10,000	3,000	138	20.2	8.0	667
Coal	40,000	40,000	194	28	11.0	500
Fuel	20,000	10,000	175	21.4	9.2	447

* TEUs

6.5.3 *Scenario high*

Scenario high is characterized by very positive future for Beira Port. The coal export of Mozambique will be exploited to its maximum potential. However, with so many initiatives to export the coal through other ports, Beira will not attract the full 70 MTPA. In this scenario 40 MTPA is transported by rail to Beira Port for export. This will give the hinterland of Beira an enormous boost whereby other exports and import will significantly grow. The BAGC will grow to its maximum potential, where Beira will become a major sugar exporter.

The assumption is made that the distribution between import and export for the total GC-DB and container throughput is the same as for the present container traffic, being 3:2. The upper boundary of container throughput forecast of 400,000 TEU is chosen. The reefer fruit export in 90,000 containers, as calculated in paragraph 6.2.1, is added to the container export.
The access channel will be deepened for the coal export. Combining this with the worldwide trend of increasing container ship sizes, it is likely that the Panamax class will become the average ship size. This ship can also call along several other ports along the African coast, see Table 6-7. The loaded draft of the average ship will be less than for the maximum ship, as most ships will not be fully loaded. 1 m is subtracted from the maximum draft, for the average calling ship.

The basis for the GC-DB throughput will be 1.5 million tons import and 1.0 million export; the upper boundary in paragraph 6.3.2. Half of this throughput is transported by general cargo ships and the remaining by dry bulk ships. In addition, there is the high forecast for the fertilizer: 1.25 million tons import. The BAGC reaches its full potential. The sugar export of 1.1 million is added to the dry bulk export. Wheat and rice imports will be 400,000 tons less, which is considered to be transported by dry bulk ships. In Table 6-20 the total throughput per cargo is given.
Maximum dry bulk ship at the GC-DB terminal is expected to be 30,000 DWT, especially due to the large increase in sugar export. Average ship size will be 20,000 DWT and transhipment increases accordingly to 4,000 tons.

40 MTPA coal is exported through Beira. The enormous throughput asks for deepening of the access channel. The coal exporters demand that Panamax vessels of 70,000 DWT could be used for the shipment.

Fuel throughput is also on the upper boundary of the forecasted ranges, 5.5 million tons. The sugarcane sector produces no ethanol in this scenario. The average and maximum calling ship at the fuel terminal will increase and on average of 20,000 tons will be transhipped per call.

Table 6-20 summarizes the throughput through Beira Port. The design ships are given in Table 6-21. Average ship sizes are given in Table 6-22.

Table 6-20 | Scenario high: Throughput [tons] through Beira Port

Commodity	Import	Export	Empties
Container	*180,000	**220,000	90,000
General cargo	750,000	500,000	
Bulk	1,600,000	1,600,000	
Coal		40,000,000	
Fuel	5,500,000		

* TEUs
** Of which are 90,000 reefers

Table 6-21 | Scenario high: Design ship specification

Commodity	Max load	LOA [m]	Beam [m]	Loaded draft [m]
Container	*3,900	270	32.2	12.5
General cargo	20,000	188	26.9	11.7
Bulk	30,000	188	28.4	11.0
Coal	70,000	230	38	13.5
Fuel	50,000	230	31.1	11.6

* TEUs

Table 6-22 | Scenario high: Average ship specification

Commodity	DWT	Average transhipment [tons]	LOA [m]	Beam [m]	Loaded draft [m]	# of ships
Container	*3,900	*500	270	32.2	11.5	980
General cargo	15,000	4000	172	24.8	10.7	313
Bulk	20,000	4000	168	25.0	9.8	800
Coal	70,000	70,000	230	38	13.5	572
Fuel	50,000	20,000	230	31.1	11.6	275

* TEUs

6.6 Conclusions and recommendations

The GDP figures of the last decade indicate that the hinterland of Beira Port is a fast growing economy. The growth in export and import of the hinterland countries suggest a rise in throughput for the Port of Beira.

A major opportunity exists for the Port of Beira to export the enormous coal reserves of the Tete province. However, the port is depending on the expansion of the hinterland connection to the mines, which results in large range of expected throughputs in the three scenarios.

Additional to the economic growth, the port of Beira has the potential to export agricultural products. The fuel, general cargo and container sector will grow about 200% in scenario low to 500% in scenario high.

The ship sizes depend heavily on the depth of the access channel towards the Port of Beira, because larger ship sizes will become the standard and other designated ports have already larger depths.

This chapter aimed at establishing three scenarios, for which the master plan alternatives will be designed. The three scenarios were developed based on forecasts made with limited data. It is recommended to acquire more throughput data from the stakeholders, in order to cope with the mentioned uncertainties and to improve the forecasts.

7 SWOT ANALYSIS

A SWOT analysis is done as a conclusion on the previous chapters. The most important characteristics of the Port of Beira are summarized in the analysis. Strengths are described as those facets that are already there and will help make the further development of the port of Beira a success. Weaknesses are qualities, which are a disadvantage for the planned development. Weaknesses are facets that are possible to turn into strengths in the port master plan. Opportunities and threats are not changeable by the power of authorities and can be helpful or harmful to the development of the port. A graphic explanation of the SWOT analysis is given in the figure on the right-side.

Figure 7-1 | SWOT analysis

The strengths, weaknesses, opportunities and strengths are placed in the following categories:

- Location of the port of Beira, meaning its natural surroundings, environmental conditions and hinterland connections
- Landside port infrastructure and operation, comprising of all the operations and infrastructure within the port area dry boundaries
- Wet infrastructure, including the quays and access channel
- Traffic, including throughput and waiting times of ships

7.1 Strengths

7.1.1 Location

- The nearest ports are 1000 km away, resulting in little competitive hinterland
- Connected to the hinterland by road, rail and pipeline
- Politically stable region
- Open grounds reserved for port expansion
- Natural shelter within tidal estuary
- Tropical climate, stable weather most of the year

7.1.2 Landside port infrastructure and operation

- Railway connection into the port
- Container yard area large enough for current demand
- 24 hour operation
- Coal loading equipment available to handle 5 MTPA
- Storage area for coal available to handle throughput of 5 MTPA
- Quay occupancy off container and GC-DB terminals are low
- Wind conditions do not hinder port operations

7.1.3 Wet infrastructure

- Dredging equipment available with sufficient capacity
- Fuel jetty present to serve ships up to 11 m draft and 50,000 DWT
- Relatively straight quay alignment, resulting in flexible quays
- Waves are low in front of the quays and do not influence the behaviour of ships

7.1.4 Traffic

- Rise of traffic in recent years
- Ports and railway managed by same company

7.2 Weaknesses

7.2.1 Location

- No hinterland connections by river
- Bad state of hinterland connections limiting capacities of road and railway
- Pipeline capacity reached
- Presence of deep sea port of Nacala (-24 m CD)
- Rain season with occasional typhoons
- Tropical climate, harsh working conditions

7.2.2 Landside infrastructure and operation

- Railway line and station limits room for terminal expansion
- City of Beira limits room for terminal expansion land inwards
- Only two ship-to-shore container cranes for 3 berths
- GC-DB quays divided in two by coal terminal
- Inefficient container yard area usage by reach stackers
- Inefficient general cargo and bulk handling with bagging machines
- Single access/exit gate hinders port access for trucks
- Insufficient road dimensions and inadequate use
- Limited parking area before and inside the port area
- Railway and road crossings hinder port access/exit

7.2.3 Wet infrastructure

- Shallow access of -8 m CD
- Sedimentation of the access channel
- Long access channel
- One way in access channel
- No night sailing possible
- Quay closest to sea only accessible to small ships

7.2.4 Traffic

- Long waiting times due to daylight limitation
- Long waiting times due to tidal window
- Extreme waiting times due to depth limitation for coal ships of 160,000 DWT
- Railway rehabilitation and expansion has years delay
- Wind conditions require pilotage in access channel
- Current conditions require tug boat assistance for manoeuvring inside the port basin

7.3 Opportunities

7.3.1 Location

- Closest port to estimated 2.3 billion ton coal reserve
- Rehabilitation and expansion of hinterland railway line
- Rehabilitation of road hinterland connection

7.3.2 Landside infrastructure

- Implementation of new container terminal equipment
- Room for lengthening existing quay along river
- Available area for expansion of terminal grounds along river front

7.3.3 Traffic

- Economic growth in all hinterland countries
- Rise in throughput for all terminals in all scenarios
- Potential for coal export up to 70 MTPA
- Potential for growth in agricultural sector, resulting in more export through Beira Port
- Fertilizer import for growth in agricultural sector

7.4 Threats

7.4.1 Location

- Typhoon hits Beira Port damaging port severely

7.4.2 Landside infrastructure

- Throughput demand higher than terminal areas can handle
- Insufficient quay length

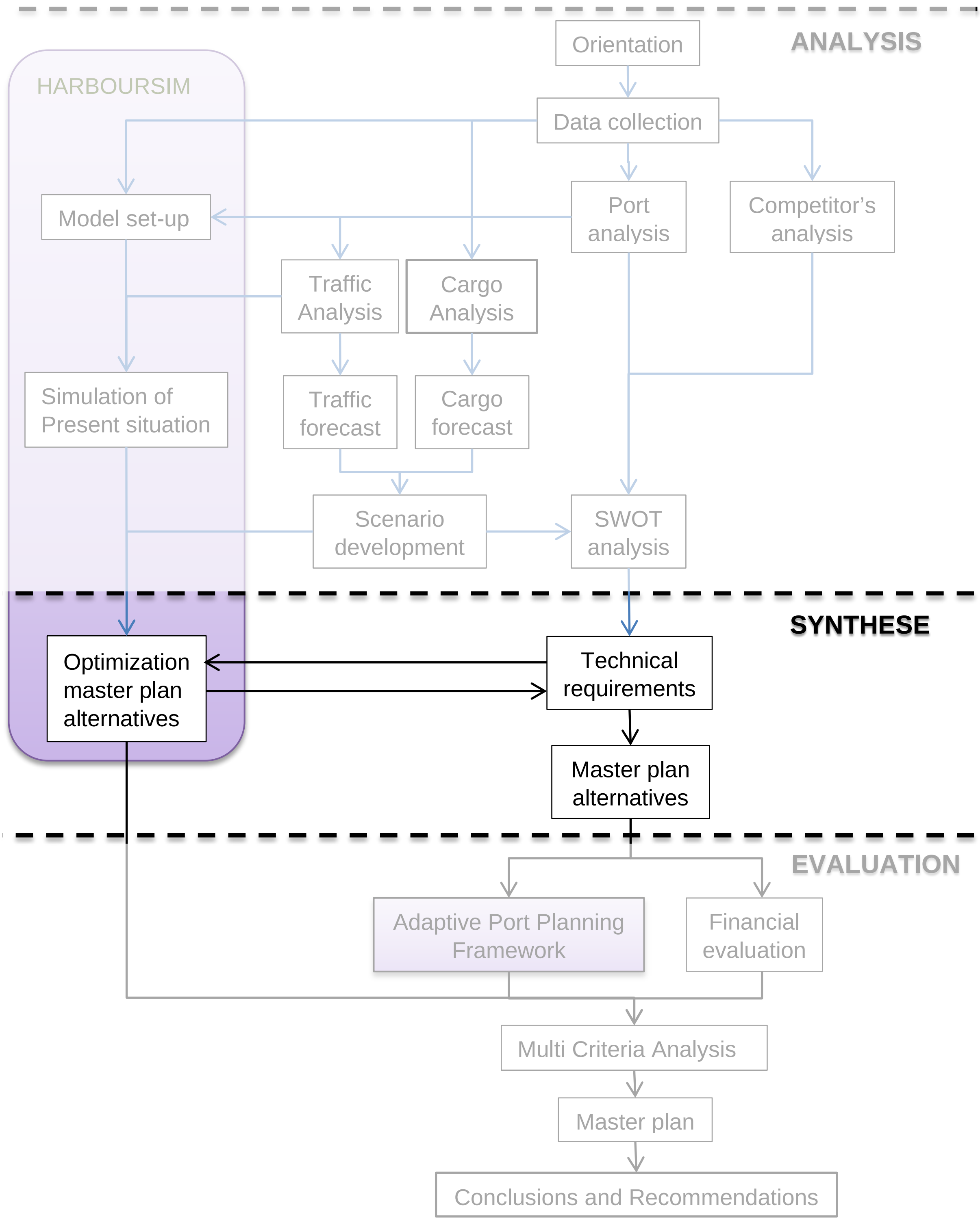
7.4.3 Wet infrastructure

- Ships with increasing dimensions cannot access Beira Port

7.4.4 Traffic

- Coal export largely dependent on railway expansion
- Large uncertainty about attracting coal export through Beira Port
- Expansion of railway line from coal reserves towards Nacala Port
- Initiatives to construct new ports along Mozambique coast for exporting coal

Part B: Synthesis



8 TECHNICAL REQUIREMENTS

This chapter aims at establishing a guideline for the development of the master plan alternatives. Rule of thumb formulae are used to calculate quantitative technical requirements for the land area, berths, access channel and the gates.

First, the cargo and traffic forecast are translated into terminal land area requirements. The required number of berths is calculated using the queuing theory and corresponding quay lengths and berth pocket depths are defined in paragraph 8.2 to 8.4.

The access channel widths are of importance to be able to estimate the dredge works required for a one- and two-way channel. Also the diameter of the turning circle in the port basin is calculated in the access channel requirements paragraph 8.5. No further channel dimensions are calculated, because these depend on the chosen depths resulting from the Harboursim simulations done in chapter 10.

To address the land-based traffic issues the modal split is determined in paragraph 8.6. This is directly used in the next paragraph to define the area requirements for the main and terminal gates.

The conclusions in the last paragraph are direct input for the concept master plan alternatives drawn in the next chapter.

8.1 Area requirements

The area requirements per terminal start by calculating the required cargo storage area. In literature, different formulas are found for different terminal types. In determining overall area requirements, allowance must be made for the ratio between the net area and the gross surface area of the terrain, including roads, strips for cables, etcetera. This will be added to the required storage area, to arrive at the total required terminal area.

8.1.1 Container

To calculate the required space for the container storage yard, the following formula is used (Ligteringen, 2007):

$$O = \frac{C_i * \overline{t_d} * F}{r * 365 * m_i}$$

In which:

O = area required [m^2]
C_i = number of TEUs per year per type of stack
$\overline{t_d}$ = average dwell time [days]
F = required area per TEU including equipment travelling lanes [m^2]
r = average stacking height / nominal stacking height
m_i = acceptable average occupancy rate

Containers remain in open-air storage areas for a few days until they are forwarded. The average dwell time for import and export are estimated at 8 days, for empties the dwell time is much longer: 20 days. The average dwell time is not expected to change in the three scenarios.

The factor F depends on the handling system and the nominal stacking height. In Table 8-1 an overview of typical values for the storage area per TEU depending on the used system and stacking height is given. For instance, with the current reach stackers and a nominal stacking height of three, F is 30 m^2/TEU. The handling system is not likely to change when throughputs increase, as highly qualified personnel is required for straddle carriers and gantry cranes (Ligteringen, 2007). Therefore, F=30 m^2/TEU in all scenarios.

Table 8-1 | Storage area per TEU for different equipment (Ligteringen, 2007)

System	Nominal stacking height	F [m^2/TEU]
Chassis	1	50-65
Straddle carrier	2 3	15-20 10-13
Gantry crane (RMG/RTG)	2 3 4 5	15-20 10-13 7.5-10 6-8
Forklift truck (FLT) or reach stacker	2 3	35-40 25-30

The nominal stacking height is high, but repositioning is cheap, because of cheap labour. Therefore, the factor r for import and export is estimated at 0.8. The factor r for empties must be higher, because these are all the same and do not have to be repositioned; 0.9 is chosen.

The factor m_i has to be introduced because the pattern of arrival and departures of containers to and from the terminal is stochastic by nature. The factor m_i is probably quite low because it is assumed that the arrival and departure of ships is not constant, a value of 0.6 is chosen.

In addition, area is reserved for the Container Freight Station (CFS), where stripping and stuffing takes place. No historic data is known for the percentage of containers that passes through the CFS in Beira Port. Therefore, no realistic calculation can be made. A benchmark was found in an example given in (Ligteringen, 2007). From this source, it is assumed that an additional 20% of the storage area is required for the CFS.

Moreover, 30% is required for the quay apron, equipment to manoeuvre, roads, parking, office, workshops, rail access, etcetera (DHV BV, 2012).

In Table 8-2 all parameters are given with resulting required terminal area in scenario low. The number of TEUs per year per type of stack is for each scenario different, but the other parameters remain the same. The result for scenario most likely and high is given in Table 8-3 and Table 8-4.

Table 8-2 | Required container terminal area for Scenario low

	Import	Export	Empties	Total
Ci	90,000	60,000	45,000	
td	8	8	20	
F	30	30	30	
r	0.8	0.8	0.9	
mi	0.6	0.6	0.6	
Storage area [m^2]	124,000	83,000	137,000	344,000
CFS area [m^2] (20%)				69,000
Additional area (30%)				104,000
Terminal area [m^2]				**517,000**

Table 8-3 | Required container terminal area for Scenario most likely

	Import	Export	Empties	Total
Ci	130,000	140,000	65,000	
Storage area	179,000	192,000	198,000	569,000
CFS area [m^2] (20%)				114,000
Additional area (30%)				171,000
Terminal area [m^2]				**854,000**

Table 8-4 | Required container terminal area for Scenario high

	Import	Export	Empties	Total
Ci	180,000	220,000	90,000	
Storage area	247,000	302,000	274,000	823,000
CFS area [m^2] (20%)				165,000
Additional area (30%)				247,000
Terminal area [m^2]				**1,235,000**

The current storage yard is 200,000 m^2 and is at its design capacity of 100,000 TEU per annum. In scenario low 448,000 m^2 is required, excluding the CFS, this corresponds relatively well to the fact that throughput in scenario low has doubled.

8.1.2 *General cargo*

The current general cargo terminal handles both general cargo and dry bulk. For the new master plan, the different cargo flows could be separated, because throughputs rise. Therefore, a distinction was already made between the general cargo and dry bulk throughputs in the scenario development. In this sub-paragraph, the general cargo flow is treated.

General cargo is stored in transit sheds. No data is available about the fraction of the total annual throughput that passes the sheds, but all cargo must be temporarily stored, open or covered. Space usage in sheds is done more efficient than on open grounds, because the covered storage is more expensive. The minimum terminal area requirement calculation is based on the assumption that all general cargo passes the sheds. For a transit shed, the required floor area O_{ts} can be calculated as follows: (Ligteringen, 2007).

$$O_{ts} = \frac{f_1 \cdot f_2 \cdot C_{ts} \cdot \bar{t}_d}{m_{ts} \cdot h \cdot \rho \cdot 365}$$

In which several assumptions are made (Ligteringen, 2007).

t_d = 10 days — average dwell time of the cargo in days
ρ = 0.6 t/m^3 — average relative density of the cargo as stowed in the ship
h = 2 m — average stacking height in the storage
f_1 = 1.5 — proportion gross/net surface in connection with traffic lanes
f_2 = 1.2 — bulking factor due to stripping and separately stacking
m_{ts} = 0.7 — average rate of occupation of the transit shed or storage
C_{ts} = — fraction of total annual throughput C_s which passes the transit shed.

The required floor area is multiplied by a factor 1.5, in order to be flexible for possible open storage. An additional 30% is required for the quay apron, equipment to manoeuvre, roads, parking, office, workshops, rail access, etcetera (DHV BV, 2012). The table below gives the resulting terminal area requirements.

Table 8-5 | Required terminal area for general cargo per scenario

	Scenario low	Scenario most likely	Scenario high
Import [tons]	450,000	600,000	750,000
Export [tons]	300,000	400,000	500,000
Storage area import [m²]	41,000	54,000	68,000
Storage area export [m²]	27,000	36,000	45,000
Additional area (30%) [m²]	21,000	27,000	34,000
Terminal area [m²]	**89,000**	**117,000**	**147,000**

Currently 15,000 m^2 of transit sheds is present on the 100,000 m^2 GC-DB terminal. In scenario low the present GC-DB terminal can be used for the expected throughput. However, then extra transit sheds must be built and the dry bulk transport allocated.

8.1.3 *Dry bulk*

In the past years, significant variation in dry bulk throughput has been experienced for instance in grain, maize, sugar, fertilizer, chrome ore, etc. (DVH BV, 2011d). Some commodities, like sugar and maize, need to be handled in covered storage sheds, where others, like dry bulk minerals, can be stored on open storage yards. Moreover, grain is currently stored in silos (DVH BV, 2011d). Therefore, these goods are currently transported over the GC-DB terminal.
A formula is adopted to calculate the required space for the dry bulk storage (Ligteringen, 2007):

$$O = \frac{C \cdot E_d \cdot f}{\bar{\rho} \cdot h \cdot 365 \cdot m_s}$$

In which:
O = area required [m^2]
C = design annual throughput [tons/year]
E_d = average dwell time of cargo [days]
f = factor accounting for difference between gross and net area [-]
ṗ = average cargo density [tons/m^3]
h = average stacking height [m]
m_s = storage occupancy [-]

The average dwell time, the gross/net factor and the storage occupancy are assumed equal to the general cargo, respectively 10 days, 1.5 and 0.7.

A list of cargo densities of known dry bulk commodities is given in Table 8-6. Fertilizer is the major cargo flow and the average of the given cargo densities is also close 1.0 tons/m^3.

Table 8-6 | Cargo densities of known dry bulk commodities

Commodity	Cargo density
Chrome ore	2.5 tons/m^3 (DVH BV, 2011d)
Grain	0.6 tons/m^3 (JCtrans, 2010)
Maize	0.6 tons/m^3 (JCtrans, 2010)
Fertilizer	1.0 tons/m^3 (JCtrans, 2010)
Sugar	0.6 tons/m^3 (JCtrans, 2010)

The average storage height depends on the bearing capacity of the ground, the characteristics of the material and on the outreach and height of handling equipment. An average stacking height of 2.5 m (DHV BV, 2008) is chosen.

An additional 30% is required for the quay apron, equipment to manoeuvre, roads, parking, office, workshops, rail access, etcetera (DHV BV, 2012). The table below gives the resulting terminal area requirements.

Table 8-7 | Required terminal area for general cargo per scenario

	Scenario low	Scenario most likely	Scenario high
Import [tons]	1,200,000	1,600,000	1,600,000
Export [tons]	575,000	400,000	1,600,000
Storage area import [m^2]	29,000	38,000	38,000
Storage area export [m^2]	14,000	10,000	38,000
Additional area (30%) [m^2]	13,000	15,000	23,000
Terminal area [m^2]	**56,000**	**63,000**	**99,000**

8.1.4 Coal

The required area for the coal export terminal is determined using figures from other large export terminals in South Africa and Australia. There appears to be a rather large variation in stockpile volume related to the annual throughput, which naturally has a large impact on the required terminal area. For Beira Port, it is assumed that the stockpile volume is averaged between the benchmarks, resulting in a stockpile volume of 6.5% of the annual throughput. The area requirement for the stockpile is rather constant for the benchmark terminals at about 30,000 tons/ha. Apart from the stockpile, the terminal area also requires space for the quay apron, equipment to manoeuvre, roads, parking, office, workshops, rail access, etc. In general, 30% of the terminal area is reserved for these other than storage aspects. (DHV BV, 2012)
Total terminal area requirements are given in Table 8-8.

Table 8-8 | Required coal terminal area per scenario

	Scenario low	Scenario most likely	Scenario high
Throughput [tons]	5,000,000	20,000,000	40,000,000
storage capacity [% of MTPA]	6.50%	6.50%	6.50%
[tons]	325,000	1,300,000	2,600,000
[t/ha]	30,000	30,000	30,000
storage area [m^2]	108,000	434,000	867,000
additional area [m^2]	32,000	130,000	260,000
terminal area [m^2]	**140,000**	**564,000**	**1,127,000**

8.1.5 Fuel

The size of storage areas for oil and liquid gas depends on the number and dimensions of the tanks and the distances between these tanks. Currently the tank farm covers an area of 360,000 m^2. Operational storage capacity is, generally, in the order of 1 month consumption (DHV BV, 2008). In addition there is a strategic storage.

Zimbabwe imports the majority of its fuels through Beira Port. The country relies heavily on the supply from Beira and does not have a strategic reserve inland. The strategic reserve for Zimbabwe is effectively located at Beira Port. Reserves in neighbouring countries are between 5 to 21 days, and globally up to 3 months consumption (Wikipedia, 2012). A reserve of one month average consumption should suffice, in case the supply to Beira Port is hampered or the pipeline to Zimbabwe is blocked and calling ships still have to be serviced.

In case of oil tanks, the distance between the tanks is mainly determined by the criterion that each tank has to be surrounded by a concrete or earth wall (bund) at such a distance and such a height that in the event of a collapse of a full tank the oil can be contained within the bund. For example a tank of 100,000 m^3 surrounded by a useful height of 4 m requires a surface of 25,000 m^2. (Ligteringen, 2007)

Seven storage units in Beira Port with a capacity of 77,000 m^3 were built on an area of 40,000 m^2 (macauhub, 2009). This area to storage capacity ratio of 2 is also found for other tank units in the port and therefore chosen for the area requirement calculation.

Space has to be added for pipe tracks, road, pumping stations, buildings, etc. This additional area requirement is again assumed at 30% of the storage area.

In the present situation there is storage space left, due to inefficient space usage by the numerous companies located at the farm. There is currently a surplus of storage capacity. The required storage space in each scenario is calculated using the assumptions above. In Table 8-9 the resulting area requirements are given.

Table 8-9 | Required fuel terminal area per scenario

	Present situation	Scenario low	Scenario most likely	Scenario high
Throughput [tons]	1,280,000	2,680,000	4,470,000	5,500,000
Throughput [m^3]	1,600,000	3,350,000	5,587,500	6,875,000
Operational storage [m^3]	133,000	279,000	466,000	573,000
Strategic storage [m^3]	133,000	279,000	466,000	573,000
Height of bunds [m]	2	2	2	2
Storage area [m^2]	133,000	279,000	466,000	573,000
Additional area (30%) [m^2]	40,000	84,000	140,000	172,000
Terminal area [m^2]	**173,000**	**363,000**	**606,000**	**745,000**

8.2 Number of berths

In the following sub-paragraphs, the required numbers of berths are calculated. The required numbers of berths are calculated using the queuing theory (Groenveld, 2001). Later, the number of berths is tested with the Harboursim model, because the queuing theory is a simplification of the occurring processes.

The total mean waiting time as a percentage of the service time is used as the port performance indicator. This ratio is widely used as a measure of the level of service provided by a terminal, as would seem logical, for ships that have less cargo to discharge cannot afford to wait as long as ships that have more. Tolerated waiting times in literature are around 0.05-0.2 (Ligteringen, 2007) and these will be used as guideline.

8.2.1 Container

To calculate the number of moves in TEUs, a TEU factor is required:

TEU factor = (# 20-feet container + # 40-feet container) / # of TEU.

As the proportion of 40-feet containers seems to be increasing, the TEU factor will rise, and in the near future it will be reasonable to assume a TEU factor of 1.6 (Verschoof, 2002).

With the newly ordered twin-lift ship-to-shore-cranes, it is possible to move two 20-feet containers at once or one 40-feet container. This increases the crane productivity for 20-feet containers, but not for 40-feet containers. Therefore a new factor is introduced, the Twin-lift TEU factor, or TT factor. The TT factor can be maximum 2, when only FEUs or two TEUs together are moved by the cranes. In Beira Port, the TEU factor is increased with 0.1 to arrive at the TT factor.

It is assumed in all scenarios that one crane per berth is available. All other input for the queuing theory calculation is given in Table 8-10.

Table 8-10 | Input for queuing theory calculation container terminal per scenario

Parameter	Unit	Scenario low	Scenario most likely	Scenario high
Throughput	TEU	195,000	335,000	490,000
Transhipment	TEU/call	350	400	500
# of calling ships	calls/year	558	838	980
Handling speed	moves/hr	20	20	20
TEU factor	-	1.6	1.6	1.6
TT factor		1.7	1.7	1.7
Throughput	moves	114,706	197,059	288,235
Transhipment	moves/call	206	235	294
Inter arrival time	minutes	940	630	540
Service time	minutes	798	886	1,062

Using the Kendal notation, an $M/E_5/n$ distribution table should be used for the waiting time calculation per berth. However, no such table could be found and therefore use is made of an $M/E_2/n$ table, resulting in lower calculated waiting times. The calculated waiting time is only due to the occupancy of the berths and all other factors are neglected. Therefore, the calculated waiting time with the queuing theory is the lower boundary of the occurring waiting time in reality.

The current three berths would suffice in scenario low and most likely as is shown in the results Table 8-11. In scenario high, four berths are required to keep tolerated waiting times.

Table 8-11 | Result queuing theory calculation; *M/E$_2$/n distribution table is used

	Scenario low		Scenario most likely		Scenario high	
	Occupancy	W* [ST]	Occupancy	W* [ST]	Occupancy	W* [ST]
1 berth	0.849	4.457	1.406	#N/A	1.967	#N/A
2 berths	0.424	0.174	0.703	0.744	0.984	#N/A
3 berths	**0.283**	**0.027**	**0.469**	**0.095**	0.656	0.314
4 berths			0.352	0.020	**0.492**	**0.067**
5 berths			0.281	0.000	0.393	0.019
6 berths					0.328	0.000

8.2.2 *General cargo*

For the general cargo terminal the same method is used as with the container terminal, with the difference that in this calculation the moves/hour of the cranes are not used, but the tons/hour. As dry bulk and general cargo are now split in two separate cargo flows, a new assumption for the handling speed must be done. Handling speeds of general cargo are normally much lower than dry bulk. From a master plan study done by DHV (DHV BV, 2008) a handling speed of 50 tons/hour is adopted. Transhipment per call is expected to be equal to the dry bulk goods, as was already stated in the scenario development. Table 8-12 gives an overview of the used input and Table 8-13 shows the result.

Currently 4 berths are available, which would suffice in all scenarios.

Table 8-12 | Input for queuing theory calculation general cargo per scenario

Parameter	Unit	Scenario low	Scenario most likely	Scenario high
Throughput	tons	750,000	1,000,000	1,250,000
Transhipment	tons/call	2,500	3,000	4,000
# of calling ships	calls/year	300	333	313
Handling speed	tons/hour	100	100	100
inter arrival time	minutes	1,750	1,580	1,680
service time	minutes	1,680	1,980	2,580

Table 8-13 | Result queuing theory calculation general cargo; *M/E$_2$/n distribution table is used

	Scenario low		Scenario most likely		Scenario high	
	Occupancy	W* [ST]	Occupancy	W* [ST]	Occupancy	W* [ST]
1 berth	0.960	#N/A	1.253	#N/A	1.536	#N/A
2 berths	0.480	0.236	0.627	0.494	0.768	1.096
3 berths	**0.320**	**0.034**	**0.418**	**0.067**	**0.512**	**0.130**
4 berths			0.313	0.013	0.384	0.027
5 berths					0.307	0.001

8.2.3 *Dry Bulk*

The same method as for the general cargo is used for the dry bulk cargo. The average handling speed is assumed 240 tons/hour. This corresponds to the earlier assumption for the GC-DB terminal and to a master plan study performed by DHV on a similar dry bulk terminal (DHV BV, 2008). See Table 8-14 for the input values and Table 8-15 for the result of the queuing theory calculation.

Table 8-14 | Input for queuing theory calculation dry bulk per scenario

Parameter	Unit	Scenario low	Scenario most likely	Scenario high
Throughput	tons	1,775,000	2,000,000	3,200,000
Transhipment	tons/call	2,500	3,000	4,000
# of calling ships	calls/year	710	667	800
Handling speed	tons/hour	240	240	240
inter arrival time	minutes	740	790	660
service time	minutes	810	930	1,180

Table 8-15 | Result queuing theory calculation dry bulk; *M/E$_2$/n distribution table is used

	Scenario low		Scenario most likely		Scenario high	
	Occupancy	**W* [ST]**	**Occupancy**	**W* [ST]**	**Occupancy**	**W* [ST]**
1 berth	1.095	#N/A	1.177	#N/A	1.788	#N/A
2 berths	0.547	0.326	0.589	0.407	0.894	3.002
3 berths	**0.365**	**0.046**	**0.392**	**0.057**	0.596	0.224
4 berths	0.274	0.005	0.294	0.009	**0.447**	**0.049**
5 berths					0.358	0.012

8.2.4 *Combined general cargo and dry bulk*

From the previous two sub-paragraphs it comes clear that at least two extra berths must be created, when the general cargo and dry bulk are handled at separate berths. Therefore, the two cargo flows are combined for another queuing theory calculation. The transhipment per call was already assumed equal and the handling speed is the average of the two cargo flows.

Table 8-16 | Input for queuing theory calculation combined general cargo and dry bulk per scenario

Parameter	Unit	Scenario low	Scenario most likely	Scenario high
Throughput	tons	2,525,000	3,000,000	4,450,000
Transhipment	tons/call	2,500	3,000	4,000
# of calling ships	calls/year	1,010	1,000	1,113
Handling speed	tons/hour	198	193	201
inter arrival time	minutes	520	530	470
service time	minutes	940	1,110	1,380

Table 8-17 | Result queuing theory calculation combined general cargo and dry bulk; *M/E$_2$/n distribution table is used

	Scenario low		Scenario most likely		Scenario high	
	Occupancy	**W* [ST]**	**Occupancy**	**W* [ST]**	**Occupancy**	**W* [ST]**
1 berth	1.808	#N/A	2.094	#N/A	2.936	#N/A
2 berths	0.904	3.140	1.047	#N/A	1.468	#N/A
3 berths	0.603	0.234	0.698	0.415	0.979	#N/A
4 berths	**0.452**	**0.051**	**0.524**	**0.084**	0.734	0.352
5 berths	0.362	0.012	0.419	0.024	**0.587**	**0.082**
					0.489	0.028

When the two cargo flows are combined, two berths less are required than with separate terminals. The throughput division between the two cargo flows is also unsure, as explained in chapter 6. Therefore, a combined general cargo and dry bulk terminal seems a better flexible alternative.

8.2.5 *Coal*

The same method as for the general cargo terminal is used for the coal terminal, see Table 8-18 for the input values. For the coal transport the Erlang 10 distribution for the service and inter-arrival times were assumed. A table for such distribution was only found for a single berth ($E_{10}/E_{10}/1$), for multiple berths a table with comparable results has to be used. The $E_2/E_2/n$ distribution table is used for higher values of n. It must be noted that the numbers found with the use of this table are higher than would be found using a table for $E_{10}/E_{10}/n$, but as stated before these numbers are the lower boundaries of the expected waiting times and only used to choose a number of berths, which are tested later on.
From Table 8-19 it follows that one berth indeed suffices in scenario low, as designed by Vale. Three berths are chosen for scenario most likely and four berths for scenario high.

Table 8-18 | Input for queuing theory calculation coal

Parameter	Unit	Scenario low	Scenario most likely	Scenario high
Throughput	tons	5,000,000	20,000,000	40,000,000
Transhipment	tons/call	30,000	40,000	70,000
# of calling ships	calls/year	167	500	571
Handling speed	tons/hour	1,700	1700	1,700
inter arrival time	minutes	3,150	1050	920
service time	minutes	1,240	1590	2650

Table 8-19 | Result queuing theory calculation coal; *$E_2/E_2/n$ distribution table is used

	Scenario low		Scenario most likely		Scenario high	
	Occupancy	W* [ST]	Occupancy	W* [ST]	Occupancy	W* [ST]
1 berth	**0.394**	**0.200**	1.514	#N/A	2.882	#N/A
2 berths	0.197	0.006	0.757	0.651	1.441	#N/A
3 berths			**0.505**	**0.054**	0.961	#N/A
4 berths			0.379	0.007	**0.720**	**0.182**
5 berths					0.576	0.034

8.2.6 *Fuel terminal*

For the fuel terminal the same method as for the general cargo terminal is used. Table 8-20 gives an overview of the used input and Table 8-21 shows the result. With 1 berth, the waiting times are excessive; therefore, a second berth is necessary.

Table 8-20 | Input for queuing theory calculation fuel

Parameter	Unit	Scenario low	Scenario most likely	Scenario high
Throughput	tons	2,680,000	4,470,000	5,500,000
Transhipment	tons/call	10,000	10,000	20,000
# of calling ships	calls/year	268	447	275
Handling speed	tons/hour	1,200	1,200	1,200
inter arrival time	minutes	1,960	1,180	1,910
service time	minutes	680	680	1,180

Table 8-21 | Result queuing theory calculation fuel; *M/E_2/n distribution table is used

	Scenario low		Scenario most likely		Scenario high	
	Occupancy	**W* [ST]**	**Occupancy**	**W* [ST]**	**Occupancy**	**W* [ST]**
1 berth	0.347	0.395	0.576	1.026	0.618	1.219
2 berths	**0.173**	**0.025**	**0.288**	**0.073**	**0.309**	**0.085**
3 berths	0.116	0.000	0.192	0.008	0.206	0.011

8.3 Quay lengths

With the attained number of berths, the required quay lengths are calculated. As the layout of the future terminals is yet unknown, the quay lengths for all possible configurations are given.
For a single berth the quay length is determined by the length of the largest vessel frequently calling at port, increased with 15 m extra length fore and aft for the mooring lines. For multiple berths in a straight continuous quay front, the quay length is based on the average vessel length as follows:

$$L_{quay} = 1.1 \cdot n \cdot (\overline{L}_{ship} + 15) + 15$$

In Table 8-22 to Table 8-24 the determined number of berths are summarized. Different configurations are possible for the quays, for instance the GC-DB terminal is at the moment divided in to two quays. The ship lengths are repeated in the tables, because they are used in the above formulae. In the last columns the required quay lengths for different number of berths are given. The new layout should make use of the tables to specify the new quay lengths.

Table 8-22 | Quay lengths for different number of berths for scenario low

Terminal	average ship LOA [m]	max ship LOA [m]	# of berths	1 [m]	2 [m]	3 [m]	4 [m]
Container	175	210	3	240	433	642	-
General cargo	136	151	3	181	347	513	-
Dry bulk	124	155	3	185	321	474	-
Combined DB/GC	136	155	4	181	347	513	680
Coal	194	194	1	224	-	-	-
Fuel	175	230	2	260	-	-	-

Table 8-23 | Quay lengths for different number of berths for scenario most likely

Terminal	average ship LOA [m]	max ship LOA [m]	# of berths	1 [m]	2 [m]	3 [m]	4 [m]
Container	210	235	3	265	510	758	-
General cargo	151	151	3	181	380	563	-
Dry bulk	138	155	3	185	352	520	-
Combined DB/GC	151	155	4	181	380	563	746
Coal	194	194	3	224	475	705	-
Fuel	175	230	2	260	-	-	-

Table 8-24 | Quay lengths for different number of berths for scenario high

Terminal	average ship LOA [m]	max ship LOA [m]	# of berths	1 [m]	2 [m]	3 [m]	4 [m]	5 [m]
Container	270	270	4	300	642	956	1,269	-
General cargo	172	188	3	218	426	632	-	-
Dry bulk	168	188	4	218	418	619	820	-
Combined DB/GC	172	188	5	218	426	632	838	1,044
Coal	230	230	4	260	554	824	1,093	-
Fuel	230	230	2	260	-	-	-	-

8.4 Depth of berth pockets

The water depth in front of the quays should be sufficient to harbour ships during all water levels. The gross under keel clearance consists of the following parameters as illustrated in paragraph 5.5.2 in chapter 5:

- Maximum sinkage due to trim: 0.5 m based on experience.
- Vertical motion due to wave response. Very mild wave climate and large ships: 0.5 m.
- Remaining safety margin for a sandy bottom: 0.5 m

The total gross under keel clearance is set at 1.5 m, and is added to design ships draughts determined in the scenario development; Table 8-25 shows the required berth pocket depths.

Table 8-25 | required berth pocket depths per scenario [m CD]

Ship type	Scenario low	Scenario most likely	Scenario high
Container	-12.3	-13.3	-14.0
General cargo	-10.8	-10.8	-13.2
Bulk	-10.5	-10.5	-12.5
Coal	-10.7	-12.5	-15.0
Fuel	-13.1	-13.1	-13.1

8.5 Access channel requirements

Beira Port has a long access channel due to the coasts mild slope. The wind and wave climate, discussed in chapter 4, do not require a protected channel. Therefore, the access channel length is sufficient for save sailing, slowing down, making fast and actual stopping. These are the requirements mentioned in literature (Ligteringen, 2007).

The depth of the access channel is not to be calculated, because of the large tidal differences. If the depth is increased, the tidal window will be longer, which results in shorter waiting times. In the next chapters depths will be chosen for the different master plan alternatives.

The access channel widths for a one-way and two-way channel are discussed below for the different design ships in the three scenarios. Thereafter the diameter of the turning circle in the port basin is calculated.

8.5.1 Access channel width

The PIANC Working Group has developed a method for concept design, which accounts for all manoeuvring aspects adding to the minimum access channel width. For straight one-way sections, the channel width is described by the following equation (Ligteringen, 2007):

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

For a two-way channel, the separation distance between the two lanes (W_P) is added and this expression becomes:

$$W = 2\left(W_{BM} + \sum W_i + W_B\right) + W_P$$

The numerical values of each of the parameters are shown in Table 8-26 , which are chosen from a condensation of the PIANC report (Ligteringen, 2007).

Table 8-26 | Channel width parameters in straight sections

	Condition	Width
Basic width (W_{BM})	d < 1,25 D	1.7 B
Additional width (W_i)		
Prevailing cross-winds	15 – 33 kn	0.4 B
Prevailing cross-current	0.2 – 0.5 kn	0.2 B
Prevailing long-current	1.5 – 3 kn	0.1 B
Prevailing wave height	1 – 3 m	1.0 B
Aids to navigation	good	0.1 B
Seabed characteristics	soft	0.1 B
Cargo hazards	Medium / high	0.5 / 1.0 B
Bank clearance (W_B)	sloping edge	0.5 B
Separation distance (W_P)	8-12 knots	1.6 B

In Table 8-27 the design ship widths per scenario are summarized. The cargo hazard for fuel ships is labelled as high and for the other ships medium. Resulting that in scenario low and most likely the fuel ships are normative, but in scenario high the coal ships. The required access channel widths per scenario are summarized in Table 8-28.

Table 8-27 | Design ship widths per scenario [m]

Ship type	Scenario low	Scenario most likely	Scenario high
Container	30.5	32.2	32.2
General cargo	22.2	22.2	26.9
Bulk	22.9	22.9	28.4
Coal	28.0	28.0	38.0
Fuel	31.1	31.1	31.1

Table 8-28 | Required access channel widths per scenario [m]

	Scenario low	Scenario most likely	Scenario high
One-way channel	174	174	194
Two-way channel	367	367	410

8.5.2 Turning circle

The minimum diameter of the turning circle is two times the longest ship (Ligteringen, 2007). However, the currents in the Pungue River can be up to 1.7 m/s and the turning ships are likely to drift along. Therefore, an ellipse is proposed of three times the ships length along the present quay (the direction of the river flow) and two times in the width:

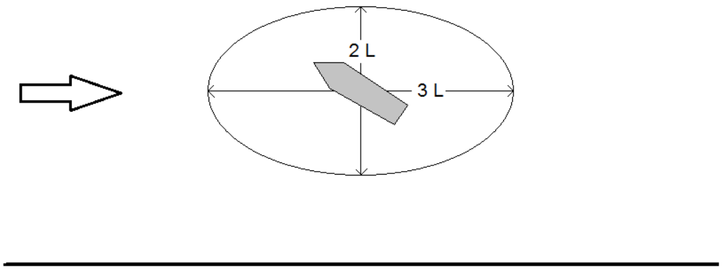


Table 8-29 | Required turning circle diameter per scenario [m]

	Scenario low	Scenario most likely	Scenario high
Design ship length [m]	230	235	270
Turning circle diameter [m]	690 x 460	700 x 470	810 x 540

8.6 Modal split

To design the layout alternatives it is important to know the modal split. As mentioned in paragraph 3.9 problems arise where transport links cross. It must therefore be known how the different terminals should be connected to the hinterland. Cargo flows for the different modalities per terminal should be known, to ensure that there is enough transport capacity. The modal split is used to calculate the required capacity of the road and rail

The Pungue River cannot be used for transportation, because of depth limitations. Throughput is transported by rail, road and pipeline. Currently all terminals are connected with the railway line. Container and general cargo throughput is dominantly transported by road. Fertilizer is known to be transported in 50 kg bags by trucks (DVH BV, 2011d). Other dry bulk is transported by road and rail, but the modal split is unknown. Coal arrives by train and no other realistic option exists. The fuel pipeline has a capacity of 1.28 million tons per annum for transportation to Zimbabwe. Within Mozambique, fuel is mostly transported by trucks. However, the rail connection is also used. The current modal split, based on the previous chapters and export opinion of DHV, is given in Table 8-30.

For the master plan development the same modal split is used for the three scenarios. There is no indication that the modal split will change.

Table 8-30 | Current modal split, based on expert opinion DHV

	rail	road	pipeline
container	1-10%	90-99%	
general cargo	1-10%	90-99%	
fertilizer	0%	100%	
Other dry bulk	30-70%	30-70%	
coal	100%	0%	
fuel	1-5%	19-25%	70-80%

8.7 Main and terminal gates

As described in paragraph 3.9, traffic jams occur at the main gate and the terminal entrances. The entrance is single lane and there are no parking spaces. When throughput is increased this will become a growing problem. Therefore, in the new master plan sufficient space should be reserved for entrance lanes with waiting areas.

At the current main entrance limited space is available, thus time-consuming checks should be done elsewhere. A system is proposed where the main gate only checks if you are allowed to go the designated terminal and at the terminal entrance all other time-consuming paper work is handled.

The following method is used to calculate the required number of truck gates at each terminal and if necessary, the area required for waiting. First, two methods are used to calculate the peak intensity in trucks per hour at the terminal gates. The accumulated intensities of the terminal gates are the peak intensity at the main gate. Thereafter the capacity of the gates is discussed. With the acquired intensity and capacity, the required number of gate lanes and the parking lots in front of the gate are calculated. Following design rules for traffic lane dimensions and parking area requirements, the required space at the gates is calculated.

8.7.1 Peak intensity

No data is available on the truck peak intensities at the gate, therefore it is tried to calculate them. In literature, one method was found, but with no further citations. Therefore, as validation, a second method is developed and the results will be compared.

In the method found in literature (AECOM, 2012) the annual terminal throughput is divided by the cargo per truck to result in an average number of trucks per day. By multiplying this by a peak day factor and a peak hour percentage, the peak intensity is acquired.

First, the number of trucks is calculated, using the cargo densities found in paragraph 8.1. An average truck volume is quoted from the AECOM reference. The peak day factor and peak hour percentage is found in the same source. By multiplying these with the average number of trucks per day, the peak intensity in trucks per hour is acquired. The calculation is shown in Table 8-31 for scenario low. As the chosen parameters are the same for the other scenarios, only the results are shown in Table 8-32 and Table 8-33.

Table 8-31| Peak intensity calculation in scenario low (AECOM, 2012)

	container	general cargo	dry bulk	fuel
terminal throughput [tons]*	90,000	450,000	1,200,000	2,500,000
cargo density [tons/m3]	-	0.6	1	1.25
truck volume [m3]	-	30	30	30
cargo per truck [tons]*	1	18	30	38
# of trucks/year	90,000	25,000	28,000	16,667
average # of trucks/day	247	68	77	46
peak day factor	1.5	1.5	1.5	1.5
peak hour percentage	10%	10%	10%	10%
peak intensity [trucks/hour]	**37**	**10**	**12**	**7**

*tons=TEU

Table 8-32| Peak intensity calculation in scenario most likely (AECOM, 2012)

	container	general cargo	dry bulk	fuel
terminal throughput [tons]*	140,000	600,000	1,600,000	3,750,000
# of trucks/year	140,000	33,333	37,333	25,000
average # of trucks/day	384	91	102	68
peak intensity [trucks/hour]	**58**	**14**	**15**	**10**

Table 8-33| peak intensity calculation in scenario high (AECOM, 2012)

	container	general cargo	dry bulk	fuel
terminal throughput [tons]*	220,000	750,000	1,600,000	5,500,000
# of trucks/year	220,000	41,667	37,333	36,667
average # of trucks/day	603	114	102	100
peak intensity [trucks/hour]	**90**	**17**	**15**	**15**

The first method uses many assumptions and therefore an alternative calculation is devised to compare the results.

The second method assumes there is a relation between the serviced ships and the further transport. In the second method, the maximum handling capacity at each berth is thought to be the required peak servicing rate of the trucks. When the maximum handling capacity of each terminal is divided by the average cargo per truck, the peak intensity is acquired. At the general cargo dry bulk terminal, general cargo ships are serviced slower than dry bulk ships and thus is the latter normative. It is assumed that each truck carries cargo in one direction and returns empty. The next tables show the calculation results of both methods.

Table 8-34| Alternative peak intensity calculation in scenario low and most likely

	container	GC DB	fuel
# of berths	3	4	2
handling capacity per berth [tons/hour]	20	240	1200
Max road modality [%]	100%	100%	25%
maximum handling capacity [tons/hour]	60	960	600
cargo per truck	1	30	37.5
peak intensity [trucks/hour]	**60**	**32**	**16**

Table 8-35| Alternative peak intensity calculation in scenario high

	container	GC DB	fuel
# of berths	4	5	2
maximum handling capacity [tons/hour]	80	1200	600
peak intensity [trucks/hour]	**80**	**40**	**16**

The two methods give similar results. The highest values for the peak intensity are chosen for further design. From the first method also the average number of trucks per hour can be read, by dividing the average number of trucks per day by 24. The average value is important as this is this is the bare minimum the gate capacity is required to be. In Table 8-36 the peak and average intensities are summarized.

Table 8-36 | Average and peak intensity [trucks/hour]

	scenario low		scenario most likely		scenario high	
	average	peak	average	peak	average	peak
Container	10	60	16	60	25	90
GC DB	6	32	8	32	9	40
Fuel	2	16	3	16	4	16
Total	**18**	**108**	**27**	**108**	**38**	**146**

8.7.2 *Gate capacity*

In Beira service is slow and checks at the main gate are extensive; the average service time is estimated to be about 6 minutes. Per checking point, this means a capacity of 10 trucks per hour. This is also the current average intensity, so it is logical that long waiting times occur during peak hours.

At the current main entrance limited space is available, thus time-consuming checks should be done elsewhere. A system is proposed where the main gate only checks if a truck is allowed to go the designated terminal and at the terminal entrance all other time-consuming paper work is handled. An automated gate would be able to serve 30 trucks per hour (AECOM, 2012).

8.7.3 *Gate dimensions*

With the previous calculated intensity and proposed automated gate check, the required number of gates can be calculated. For the main gate this results in the following:

Table 8-37 | Number of gates to handle average and peak intensities

	scenario low		scenario most likely		scenario high	
	average	peak	average	peak	average	Peak
Current operation	1.8	10.8	2.7	10.8	3.8	14.6
Proposed operation	0.6	3.6	0.9	3.6	1.3	4.9

For the current operation this implies many gates or parking lots. All the gates have to be operated by paid personnel, making it an expensive operation. A new automated gate system will require higher investment costs. However, less personnel and area is required, resulting in lower operational costs.

It can be chosen to implement a system without any waiting lots by building respectively four and five new automated gates. More cost effective would probably be to build one gate less and reserve some space for waiting. The total capacity will then be respectively 90 and 120 trucks per hour. For a peak intensity duration of one hour, the following gates and parking lots are required.

A typical truck is 17 m long (EVO Beheer) and in Figure 8-1 an example of typical gate dimensions are given. With this input the required gate area can be roughly dimensioned, see Table 8-38 and the resulting embedding in the current port layout in Figure 8-2.

It must be noted that a division of cargo flow can be made by introducing multiple port entrances. For instance when the reclamation site is used, a second entry would be logical, as the expansion is far from the current port.

Table 8-38 | Proposed dimensions of main gate

	Scenario low	Scenario most likely	Scenario high
# of gates	3	3	4
Total capacity [trucks/hour	90	90	120
Peak intensity	108	108	146
# of waiting lots	18	18	26
Width of gate	12 m	12 m	16 m
Width of waiting area	12 m	12 m	16 m
Length of waiting area	102 m	102 m	119 m

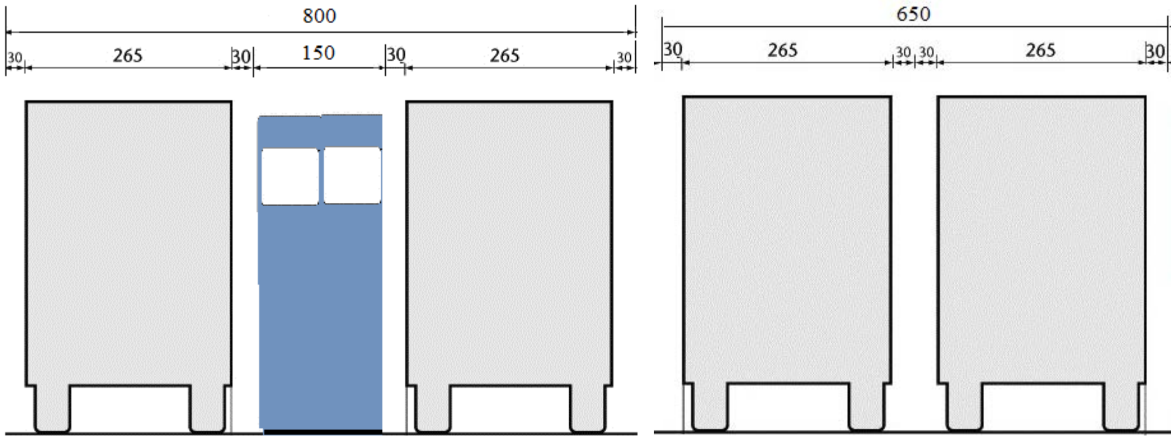


Figure 8-1 | Gate (left) and lane dimensions [mm] (right) (EVO Beheer)

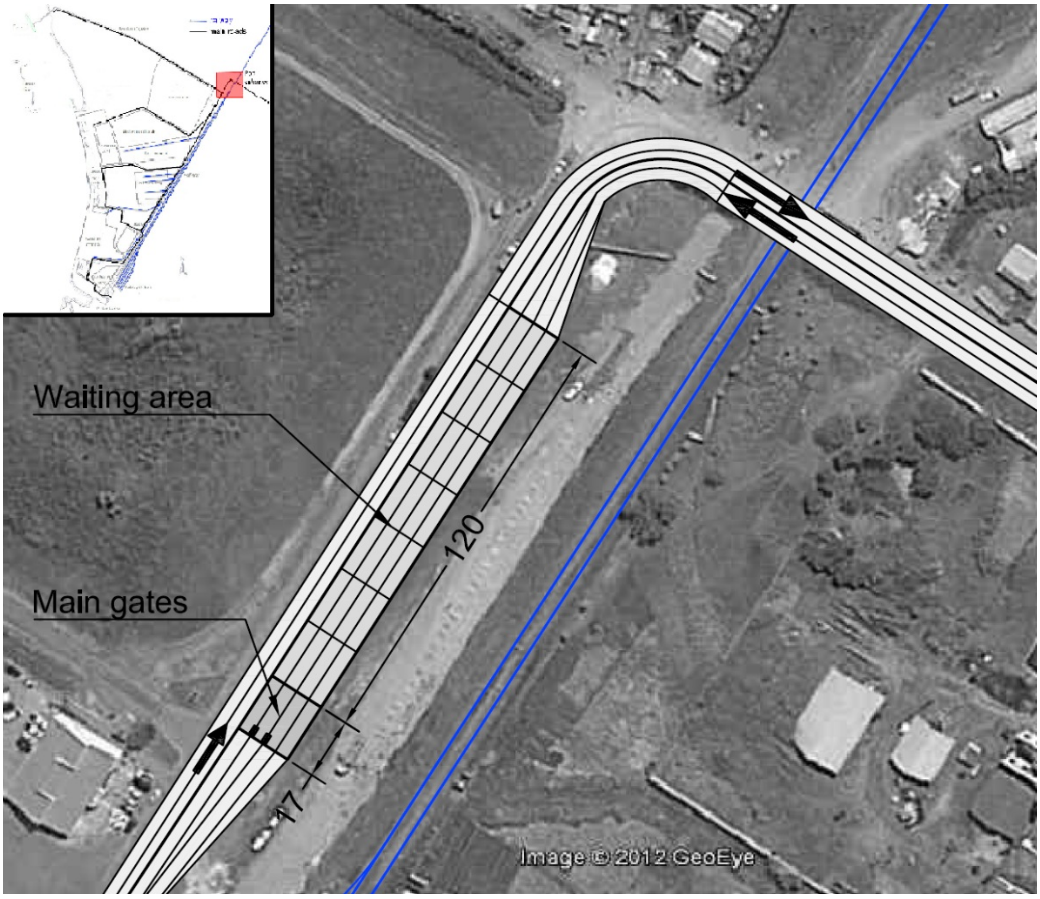


Figure 8-2 | Proposed layout of main entrance

8.8 Conclusions

The required terminal areas and the current terminal areas are summarized in Table 8-39. These figures are used to determine the layout for the master plan. As the quays for general cargo and bulk ships are combined, this is also done for the terminal area. It is concluded that all terminal areas are too small for future needs. In scenario low the additional required areas for coal, dry bulk and general cargo are small and can be found close by, noted in Figure 3-1 as undeveloped terrain. For the fuel terminal, free area can be found to the west of the current terminal. The container terminal needs an additional area of 317,000 m^2 and is fully surrounded by existing terminals.

Table 8-39 | Current and required terminal area's [m^2]

Terminal	Current area	Scenario low	Scenario most likely	Scenario high
Container	200,000	517,000	854,000	1,235,000
General cargo		89,000	117,000	147,000
Dry bulk		56,000	63,000	99,000
Combined DB/GC	100,000	145,000	180,000	246,000
Coal	120,000	140,000	564,000	1,127,000
Fuel	360,000	363,000	606,000	745,000

To be flexible for different sizes of calling ships, it is best to have one straight continuous quay per terminal. As Beira Port is located along a relatively straight river bank, this should be no problem for new quays. The current quay lengths are compared to the quay lengths required for one continuous quay in Table 8-40.

General cargo and dry bulk are best combined along one continuous quay in order to reduce the total quay length.

In scenario low, the current berth configuration can be used with one extra fuel berth. The spare length of the combined dry bulk and general cargo terminal can be used for the coal terminal, as is already done at present. For scenario most likely and high the current configuration does not suffice.

Table 8-40 | Quay lengths required for one continuous quay per scenario [m]

Terminal	Present	Scenario low	Scenario most likely	Scenario high
Container	646	642	758	1,269
General cargo		513	563	632
Dry bulk		474	520	820
Combined DB/GC	2 x 336	680 or 2 x 347	746 or 2 x 380	1,044
Coal	188	224	705	1,093
Fuel	264	433	433	554

The modal split asks for a road and rail connection to the container, general cargo, dry bulk and fuel terminal. Container and general cargo is mainly transported by trucks. If necessary, the rail connection towards the container and general cargo terminal may cross road connections in the port, as not much cargo is transported via rail.

The coal terminal has the largest throughput in all scenarios and receives all its cargo over the railway line. As already congestion takes place at railroad crossings, the new layout must foresee in a separated railway line towards the coal terminal.

The fertilizer is transported using trucks and could therefore be handled at an area without rail connection.

Table 8-41 compares the current depths in front of the quays with the required berth pocket depths per scenario. The depths were calculated compared to the lowest astronomical tide and with the design ship at limit state boundary conditions, thus very conservative. This implies that in scenario low only small adaptions to the current quay structures or no even no adaptions are foreseen. Nevertheless, in the higher scenarios large structural changes are unavoidable.

Table 8-41 | present and required berth pocket depths per scenario [m CD]

Ship type	Present	Scenario low	Scenario most likely	Scenario high
Container	-11	-12.3	-13.3	-14.0
General cargo	-10	-10.8	-10.8	-13.2
Bulk	-10	-10.5	-10.5	-12.5
Coal	-10	-10.7	-12.5	-15.0
Fuel	-12	-13.1	-13.1	-13.1

The current width of the channel ranges from 135 m to 160 m on outer sections. Following the design rules for safe navigation the access channel should be widened. Dredging operations for the implementation of a two-way channel will be costly, as the channel will become twice as large.

Table 8-42 | Required access channel widths per scenario [m]

	Present	Scenario low	Scenario most likely	Scenario high
One-way channel	135-160	174	174	194
Two-way channel		367	367	410

In order to handle the peak truck intensity at the main gate, a system is proposed where the main gate only checks if a truck is allowed to go the designated terminal and at the terminal entrance all other time-consuming paper work is handled. The required main gate fits in the port layout at the current location.

9 LAYOUT ALTERNATIVES

In this chapter layout alternatives for each of the scenarios are presented.

First a few basic notions are given, which form together with the previous requirements chapter the basis for the generation of port layout alternatives. Comments are made on the presented layout alternatives for the landside of the port in paragraph 9.2 to 9.4. The layouts are given in a plan view drawing in Appendix VII. It is advised to have this appendix at hand while reading the paragraphs. The appendix starts with a drawing of the current layout in the same format as the layout alternatives for easy comparison. For the explanation of the present layout, reference is made to chapter 3.

A total of eleven port layout alternatives are made. Each layout is based on a specific scenario, for which the technical requirements were determined in the previous chapter. Three alternatives are presented for scenario low. Four port layouts are developed for both scenario most likely and high, because in paragraph 8.8 it was concluded that in these scenarios the current port layout has to be altered extensively.

Adaptions to the wet layout are unavoidable as ship traffic and dimensions increase in all sketched scenarios. The wet layout options are discussed in paragraph 9.5, but not yet designed as their positive effect must first be proven, which is the subject of chapter 10.

9.1 Basic notions for the generation of alternatives

9.1.1 Scenarios

Three scenarios have been chosen for this master plan development. The scenarios have a large variation in throughputs. Especially in the coal forecast there is a large uncertainty. Because of the wide spread in area and berth requirements, it is chosen to make 3 alternatives per scenario. Although one scenario forms the basis for an alternative, the other two should not be neglected. Space will be reserved for future expansions.

9.1.2 Search area

First, one should look for open grounds inside the current port area to expand the current terminals. However, there must still be room for expansion of the terminals after 2032. Especially in the port layouts created for scenario low, where the higher scenarios must be kept in mind. Second, the open area between quay 10 and the fuel jetty could be used to lengthen the existing quay, following the proposal of Cornelder stated in paragraph 3.7. Third, the open grounds formed by the land reclamation in 2011 could be used to build an entirely new terminal. Last, new grounds could be created around the land reclamation. Eastern boundary is the existing railway line and to the south the fishery port.

9.1.3 Cut and fill

The optimum is to have a balance between “cut” and “fill” concerning land; in the case of the Port of Beira though, “cut” cannot be implemented due to lack of space in the land area. What can be done is to use the dredged soil from the access channel and port basin for land reclamation. This was already done with the capital dredging in 2011, where the open grounds north of the port were created. The dredged material should be used to be able to make a straight continuous quay instead of following the river bank contours.

9.1.4 Room for future expansion

The proposed expansion in this master plan development is just a part in the long history of Beira Port. Thus, it should be bared in mind that proposed expansions could be further extended after 2032.

9.1.5 Rectangular areas

The global trend concerning the shape of the terminals is towards large rectangular areas. This is especially true for the container terminals. Bends and incontinuities in berths hinder manoeuvring and make the implementation of automation harder.

9.1.6 Railroad crossings

Railroad crossings lead to congestion in the current layout of the terminal. In the new design, railroad crossings should be kept to a minimum. If crossings have to occur, overpasses should be created. An exception could be made for railroad crossing with low intensities.

9.1.7 Wind direction and wave attack

The prevailing wind and waves in the current port area do not hinder the ships, as stated in chapter 4. As our search area is further up the river, there will be no hindrance for ships in the expanded port area.

9.1.8 Location of second fuel berth

In all scenarios an additional fuel berth is required. To keep the required area, due to the safety requirements, at a minimum, the two berths must be located together. For the safety of the tanker and the tugboats, it is important that there is enough manoeuvring space provide for the tugboats around the tanker during its berthing and mooring. The safety distance between two moored tankers will depend upon the overall layout of the port, the number of tugboats assisting in the berthing or unberthing operation, the environmental conditions and the safety procedure at the terminal. The most realistic option is to create a second berth along the shoreline as shown in Figure 9-1. Tanker 1 is already berthed, while tanker 2 is berthing to berth 2 with tug assistance. The general principle is that tugs with radius RT shall not overlap the safety zone R1 for tanker 1. The distance d outside berth 2 is due to possible drift along the berth during the berthing and mooring situation. The safety distance may be found to vary between the following ranges. (Thoresen, 2010):

- The distance L3 between two moored fuel tankers may be from about 50 to 100 m.
- The distance between a moored fuel tanker L_4 and a passing ship may be over 150 m.

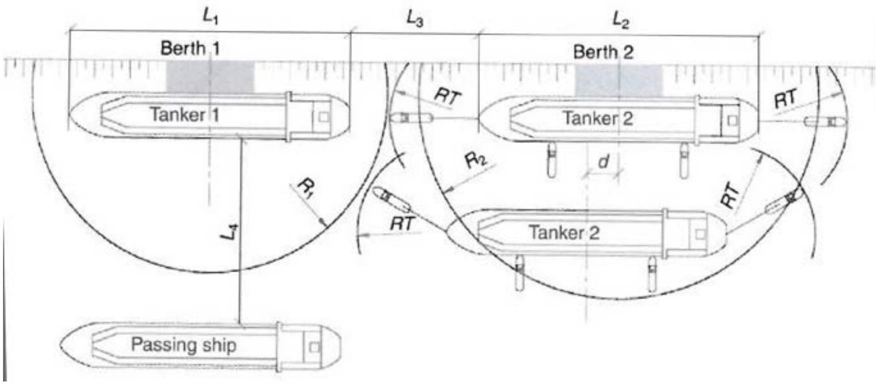


Figure 9-1 | Two tankers and a passing ship (Thoresen, 2010)

The layout of berthing structures for fuel tankers is different from the layout for the other ships. Loading and unloading occur through central manifold on the ship, placed more or less amidships. As a result, (un-)loading equipment does not have to be able to move alongside the ship to service the different holds thus no full-length marginal quay is required. For carrying the unloading arms and auxiliary equipment, a relatively small platform is generally sufficient.

9.1.9 *Expansion of tank farm*

Around the tank farm multiple plots in the west and north are free. These plots do not hinder other terminal area expansions and it does not matter which are used. The only remark on the expansion of the fuel terminal is that it is best placed further from the port entrance, to ensure enough space for port traffic and entrance gates.

9.1.10 *Dredging*

Capital dredging is an expensive operation. This means for the master planner that deepening and widening of the access channel should be kept to a minimum. Also creating an inner anchorage or passage points are costly because of the dredging operations.

Currently maintenance dredging is estimated at 2.5 million m^3 of sediment per annum. CFM ordered a ship with this capacity. Further research must be undertaken, to predict the new sedimentation volume after wet layout options are implemented. However, if the access channel dimensions are increased, the sedimentation rate is also likely to increase.

9.2 Layout alternatives for scenario low

Focus in these port layout alternatives will be on scenario low. Because this is the scenario with the lowest throughputs, the master plan focuses on small scale operations. Big investments are avoided, because they are not likely to be returned by an increase in income.

The port layout alternatives A1 to A3 are presented in a plan view drawing in Appendix VII, amongst other things, each port layout includes:

- The berth places
- The terminal areas
- Transport axles
- Hinterland connections

For scenario low one new fuel berth is needed. The coal terminal is in full operation and its berth should be lengthened to 224 m. All other terminals have enough quay capacity. However, due to the significant increase of required container terminal area, the current layout has to be adapted.

9.2.1 A1

In the first alternative, all current terminals and berths are kept at the same location. The expansions are found inside the current port area.

The container terminal needs an additional 320,000 m^2 compared to the present situation, which results in an inconvenient layout. Behind the container quays is not enough storage space, so it continuous north, far from the berths. The coal conveyor belt cuts through the terminal, hampering container handling operations.

The general cargo bulk terminal is surrounded by the container terminal. The road access is either in the north or through the container terminal. The rail connection is over the container terminal, thereby hindering container handling operations.
Quay 6-7 can accommodate two average ships with 330 m. There is no room left for the mooring lines of the coal ships at quay 8, which is current procedure.
General cargo and bulk ships can use the old berth structure of quay 11 for mooring. Thereby, the effective quay length is longer than 321 m and making it possible to berth two average ships.

The existing quay 8 is lengthened to the north by cutting a part of quay 9. Now the required 224 m is available for a moored coal ship.

The second fuel jetty is situated south of the existing berth structure. It is inside the current port area and connected by pipeline to the tank farm.

Table 9-1 | Terminal quay lengths and area alternative A1

Terminal	Quay length [m]	Area [m^2]
Container	646	520,000
General cargo / dry bulk	330 + 321	186,000
Coal	224	195,000
Fuel	264 + 264	360,000

9.2.2 *A2*

The second alternative strives to keep the container terminal area as a whole, without cuts by other terminal transport lines as in alternative A1.

The required 224 m quay length for the coal berth is gotten by acquiring 36 m from quay 7.
The rail line connection to the coal separates before the port entrance, whereby the road entrance is not crossed anymore. The busy railway line does not hinder traffic towards the container terminal.

Quay 6-7 is transformed in a new 300 m long container quay. The container terminal area is now conveniently located directly behind the corresponding quays. The terminal, enclosed by the railway workshop and the coal terminal, is sufficient for the container storage in scenario low.

The general cargo bulk terminal has four berths along one continuous quay. The present railway line towards the general cargo bulk terminal is no longer in use, because it would hinder container handling. A new line is built along the coal terminal and continuous over the full quay length, thereby serving all berths.

The second fuel jetty is situated north of the existing berth structure. Along the land reclamation it is not possible to build a quay over the full riverbank length anymore, as berthing ships have to go through the safety zone of the new fuel jetty. However, inside the port area more room exists for future expansion of the other quays.

Except the container terminal, which terminal grounds are fully enclosed, all terminals have room for future expansion.

Table 9-2 | Terminal quay lengths and area alternative A2

Terminal	Quay length [m]	Area [m^2]
Container	646 + 300	492,000
General cargo / dry bulk	680	175,000
Coal	224	192,000
Fuel	264 + 264	360,000

9.2.3 *A3*

This alternative for scenario low is similar to alternative A1, but with two major changes:

The container terminal is kept at the same location as in the present situation. The expansion of 320,000 m^2 is found by relocating the rail workshop away from the present port. In doing so, additional room is created for future expansion.

The coal terminal will be connected by new rail tracks. This rail connection does not cross the access road to the general cargo, dry bulk and container terminals. Fuel trucks still have to cross the rail line, but as stated in 8.6 most fuel is transported by pipeline.

Table 9-3 | Terminal quay lengths and area alternative A3

Terminal	Quay length [m]	Area [m^2]
Container	646	564,000
General cargo / dry bulk	330 + 321	186,000
Coal	224	195,000
Fuel	264 + 264	360,000

9.3 Layout alternatives for scenario most likely

In the next alternatives the area and berth requirements in scenario most likely are implemented.

The aim in the first three alternatives (B1 to B3) is to arrive at four separate terminals for each of the different cargo flows. Thereby the present layout had to be altered significantly. The coal terminal is in the first three alternatives relocated to the reclamation site, because the quay and terminal area requirements surpass the free area inside the current port. In the fourth alternative (B4), the present coal terminal is retained and a second terminal is constructed in the north.

9.3.1 B1

The huge rise in coal throughput asks for a new location of the coal terminal. It is placed north of the existing port area. With exception of the coal terminal, all current terminals and berths are kept at the same location. The expansions are found inside the current port area.

Quays 6 and 7 are altered to harbour container ships. The terminal has now two quays, where four average ships can berth. The current coal terminal area is reformed for container storage.

Quay 9-10 is lengthened northward to 710 m for general cargo and bulk ships. The terminal is connected by rail via the northern coal terminal.

The second fuel jetty is located north of the existing one, to ensure enough space for the general cargo bulk and container terminal is available inside the current port area.

The coal terminal is place further north than the reclamation area, because otherwise berthing ships would be in the safety zone of the second fuel jetty. The fuel terminal is expanded to the northeast.

The trucks have less hindrance on railroad crossings, because the rail line has only container and fuel traffic and trains for the workshop. The coal and general cargo trains are diverted north of the port.

Table 9-4 | Terminal quay lengths and area alternative B1

Terminal	Quay length [m]	Area [m^2]
Container	646 + 524	858,000
General cargo / dry bulk	746	228,000
Coal	705	564,000
Fuel	264 + 264	609,000

9.3.2 B2

In this alternative the fishery port is used for expansion of the current container quay. Doing so, the alterations to the present berth configuration are kept to a minimum.

The container terminal is expanded as in alternative A3 over the railway workshop and further north behind the general cargo terminal. This results in storage area far from the corresponding berths.

With the coal terminal in the north, the general cargo and bulk ships can berth along quay 6 to 10. The ships can make use of the old mooring facilities of quay 11 to increase the effective quay length. Quay 6-8 is 524 m long, which is only sufficient for two average calling ships to berth. However, three average dry bulk ships would fit along the quay. A system could be made, where the below average ships moor along quay 6-8 and the longer ships along quay 9-10.

For now, it is chosen to keep the rail current rail connection to the general cargo bulk terminal intact. It depends on the amount of rail traffic if another route has to be found, like in alternative B1.

The second fuel jetty is placed south of the existing one. Free plots north of the terminal are used for the area expansion.

The road access/exit to container terminal is in the northeast. The road traffic to the general cargo bulk terminal is diverted just south of the fuel terminal, thereby separating the two cargo flows.

Table 9-5 | Terminal quay lengths and area alternative B2

Terminal	Quay length [m]	Area [m^2]
Container	829	906,000
General cargo / dry bulk	524 + 352	211,000
Coal	705	564,000
Fuel	264 + 264	610,000

9.3.3 B3

In alternative B2 the container storage is far from the berths. An alternative berth configuration is proposed where the container terminal is directly behind its corresponding quays.

Quay 6 and 7 are changed into one container quay of 336 m. Because container ships are expected to grow in scenario most likely, only two ships can berth along the current quay 2-5. Thereby no extra crane has to be installed for ship-to-shore handling.
Container traffic is separated from the other traffic at the current port access/exit and the terminal entrance is at the northeast.

Quay 8 is now used for general cargo and bulk ships, requiring the same quay length as the current coal ships.

Quay 9-10 is expanded with 200 m extra quay length, where three average general cargo ships can berth.
The railway connection of the general cargo bulk is the same as in alternative A2, but now along the container terminal.

The coal terminal is north of the current jetty at the reclamation area. It is assumed that berthing is possible away from the safety zone of the jetty. The terminal is connected via the railway line, which splits north of the port.

The second fuel berth is again located south of the present one and the terminal expansion is towards the new jetty.

Table 9-6 | Terminal quay lengths and area alternative B3

Terminal	Quay length [m]	Area [m^2]
Container	646 + 336	960,000
General cargo / dry bulk	188 + 563	212,000
Coal	705	564,000
Fuel	264 + 264	610,000

9.3.4 B4

The recent investments in the coal terminal are significant and relocating it is a costly operation. In addition, it is possible that different coal exporting companies do not want to operate on the same terminal. In the following alternative the present coal terminal stays in place.
A second terminal is built on the land reclamation site. It is connected by rail from the north and by the existing road from the port entrance for the terminal personnel.

Along the present quays 2 to 5, just two average container ships are able to berth. The remaining 300 m of quay 6-7 is used to create a third container berth.
The terrain enclosed by the container quays, the port authority buildings, the railway and the coal terminal comes 60.000 m^2 short for the required container terminal area. However, an area on the other side of the coal terminal can be used for storage of empty containers with long dwell times, and then the coal terminal does not have to be crossed that often.
The container trucks no longer cross the busy railroad to the coal terminal, because the tracks are diverted in front of the port entrance. The trucks can go straight to the container terminal.

The general cargo terminal is situated along one continuous quay of 746 m. It has a railroad connection along the coal terminal. Trucks cross this railroad, which possibly causes traffic jams.

The second fuel berth is again located south of the present one. The tank farm expansion is similar to alternative B3.

Table 9-7 | Terminal quay lengths and area alternative B4

Terminal	Quay length [m]	Area [m^2]
Container	646 + 300	854,000
General cargo / dry bulk	746	240,000
Coal	224 + 475	572,000
Fuel	264 + 264	610,000

9.4 Layout alternatives for scenario high

In the last four alternatives the area and berth requirements in scenario high are implemented. The aim is to arrive at four terminals for the different cargo flows. Thereby the present layout had to be altered significantly and the expansion of the port has to go far north.

9.4.1 C1

In the first alternative the rail workshop is still present in the current port area. Therefore, it is not possible to keep both the container and general cargo bulk terminals in place, without dividing them in multiple terminals. The container throughput is quadrupled and it got priority over the other cargo flows in the present port area. General cargo, bulk and coal are handled at new terminal grounds in the north.

To ensure enough storage area is available behind the container quays, the complete current port area is converted into a container terminal. All quays are adapted for receiving Panamax container ships. There is room for a fifth berth further north along quay 10. The terminal can be accessed in the northeast via road; the rail access is not changed.

The coal terminal is located at the reclamation area, which is further increased. It is connected to the railway line, which is split from the current line northeast of the port.

The general cargo bulk terminal is placed further upstream the Pungue River. The terminal is connected to the railway line along the coal terminal. A viaduct should be built over the railway line, to enable a road connection to the general cargo bulk terminal.

The fuel terminal is expanded along the pipeline that connects the jetties. Hereby the container terminal has still room for future expansion of its terminal grounds.

Table 9-8 | Terminal quay lengths and area alternative C1

Terminal	Quay length [m]	Area [m^2]
Container	646 + 524 + 642	1,265,000
General cargo / dry bulk	1044	261,000
Coal	1093	1,235,000
Fuel	264 + 264	755,000

9.4.2 C2

The rail workshop is abandoned from the current port area and the container cargo is divided over two terminals. This results in little change to the current berth configuration.

Next to quay 10 an additional general cargo bulk berth is constructed. The land reclamation area behind the quay stretches until the current riverbank.

The storage area of the current container terminal is expanded behind the general cargo bulk terminal. The road traffic has no hindrance from the trains, because the railway is split just in front of the port entrance. Again, the container trucks enter the terminal area in the northeast.

It is assumed that the coal terminal is (partly) in operation before there is need for the second container terminal. Therefore, the second container terminal is located further upstream than the coal terminal. As this is an alternative for scenario high, there is no room reserved for expansion of the coal terminal and the container terminal is placed directly next to it.

The second fuel berth is again in the south and the tank farm grows close to the jetties.

Table 9-9 | Terminal quay lengths and area alternative C2

Terminal	Quay length [m]	Area [m^2]
Container	646 + 642	1,237,000
General cargo / dry bulk	524 + 626	296,000
Coal	1093	1,235,000
Fuel	264 + 264	750,000

9.4.3 C3

In alternative C3 the second fuel jetty is located north of the current one, thereby creating enough room in the port area for the general cargo bulk and container terminals. The land reclamation cannot be fully used for quay construction, because of the safety zone of the fuel jetties.

Quay 6 to 8 is lengthened further north to create space for two container berths. By relocating the rail workshop, the container terminal can be placed behind the quays.

The 1033 m long continuous quay for the general cargo bulk terminal is located next to the container quays. The quay ends 150 m before the fuel berths, so outside the safety zone.

The tank farm grows to the north and east, thereby leaving room for the general cargo terminal grounds to expand.

There only container trains crossing the port entrance. The coal trains are diverted north of the port. The general cargo bulk terminal is connected by rail via the new coal terminal.

Table 9-10 | Terminal quay lengths and area alternative C3

Terminal	Quay length [m]	Area [m^2]
Container	646 + 642	1,273,000
General cargo / dry bulk	1044	322,000
Coal	1093	1,235,000
Fuel	264 + 264	753,000

9.4.4 C4

In the last alternative the present coal terminal is still in operation. The reclamation site is expanded for a second coal terminal. The terminal is connected by rail and road from the northeast.

As in alternative B3, quay 6-7 is converted into a container berth. With the calling Panamax ships, this is just enough for one design container ship. North of the coal terminal all space is used for extra container storage. This area should be used for long container dwell times, because the reach stackers must cross the coal terminal and the railroad to the general cargo bulk terminal.
North of the fuel jetty, a second container terminal is constructed, with an area of 240,000 m^2. There is room for future expansion further north, as the world container market is expected to grow further. It is chosen to connect this terminal only by road, which is the main modality. Container trains can be serviced at the main container terminal in the south.

Quay 9-10 is extended to 632 m, enough for three general cargo bulk berths. A fourth berth would be in the safety zone of the fuel jetties. The terminal is connected by road, which crosses its railroad connection via the coal terminal.
To enable enough berth capacity, a 426 m long quay is constructed next to the northerly coal terminal. The general cargo bulk market growth is much less than for containers, thus less room for future expansion is needed and it is chosen to place the general cargo quay in between the

coal and container terminals. If required, the quay in the present port can be lengthened with over 100 m.

The second fuel berth is again located south of the existing jetty. The tank farm expansion is similar to alternative C3.

The port is effectively separated into two ports. The landside traffic is split far from the ports, where more space for the construction of a viaduct is. This will result in no railroad hindrance for the trucks calling the northerly container and general cargo bulk terminals.

Table 9-11 | Terminal quay lengths and area alternative C4

Terminal	Quay length [m]	Area [m^2]
Container	646 + 300 + 300	1,290,000
General cargo / dry bulk	632 + 426	261,000
Coal	224 + 824	1,263,000
Fuel	264 + 264	753,000

9.5 Wet layout options

In this paragraph different options are presented to increase the capacity of the wet layout. The options will be described qualitatively on their effect on the capacity. In the next chapter the port layout alternatives will be simulated in combination with these options.

9.5.1 24 hour sailing

The landside port operations continue day and night at Beira Port. However, the access channel and port basin are not allowed to be sailed without daylight. The influence of the night restriction was already simulated for the present situation in paragraph 5.7. Mean waiting times dropped significantly, for some fleets over 10 hours, when night sailing was permitted.

The port is examining the possibilities of 24 hour navigation by installing a complete buoyage system for the entire channel. When the buoys are in place, it is expected that 24 hour navigation can be safely done (ACIZ, 2008). The buoys should be well maintained. In high currents buoys have a tendency to drift. Especially when anchored in a sand bed, which is likely to drift with the river current, as is the case in the access channel of Beira.

For all master plan alternatives, it is chosen to directly implement 24 hour sailing in the access channel, because it is a cheap and effective solution to reduce the occurring waiting times.

9.5.2 Access channel depth

The depth of the access channel is literally a bottleneck for ships with large drafts. The tidal window depends on the depth of the access channel. Increasing the depth will lengthen the tidal window of the ships.

Increasing the access channel depth will mean extensive capital dredging. Maintenance dredging will increase because sediment will drift easier to the relative low channel. This is further elaborated in the cost estimate chapter 13.

9.5.3 Two way traffic

Currently only one way traffic is allowed in the access channel of Beira Port. With each tidal window, first a convoy of ships sails out of the port, thereafter arriving ships sail in convoy towards the berths. For large ships with short tidal windows, this could mean that in one tidal window only one ship can enter or leave the port. With two way traffic ships could pass each other, and as with the inner anchorage, the waiting times could significantly by reduced.

Allowing two way traffic means that the access channel should be widened. Extensive capital dredging is required and maintenance dredging will increase too, because the bottom area has been enlarged.

9.5.4 Passage points

It could also be chosen to allow two way traffic only at specified sections of the access channel. Arriving and leaving ships can pass each other at the designated sections. Timing will be hard to achieve, especially with the varying tidal currents.

Two locations are interesting: halfway the channel or just before the berths. When the passage point is located halfway the channel, a short tidal window can be used by departing and arriving ships. The berth is not occupied during the time that is used to sail towards the berth. The advantage of placing the passage point just before the berths is that the berth is only unoccupied during (de)berthing. The drawback is that a short tidal window cannot be used by both departing and incoming ships.

When ships continue to sail in convoy, the passage point must be able to facilitate passage for multiple ships from both sides. A method is devised to estimate the minimum required length of a passage point. First, the convoy length must be determined.

Convoy length = # ships * ship length + (# ships – 1) * distance between ships + safety distance

A safe distance between the ships is about 3 times the ships length. The safety distance consists of additional length for imperfect timing, early stirring or other external factors. It can be chosen to use the maximum number of ships for the convoy, e.g. the number of berths. Elsewise an average number of ships can be determined from the Harboursim model, which shows a graph of the number of ships in the access channel in time. This would be a more cost effective way, but then there remains the chance that passage is not possible when the convoy is too long.

The ends of zones having different widths should be joined by straight lines of length at least equal to the reach of the target vessel, but not less than a length/additional width ratio of 10:1 to provide a smoother change from the straight section to the widened cross section (TERMPOL CODE, 1977). If both convoys make an evasive manoeuvre, only 5 times the additional width is required for the transition zone.

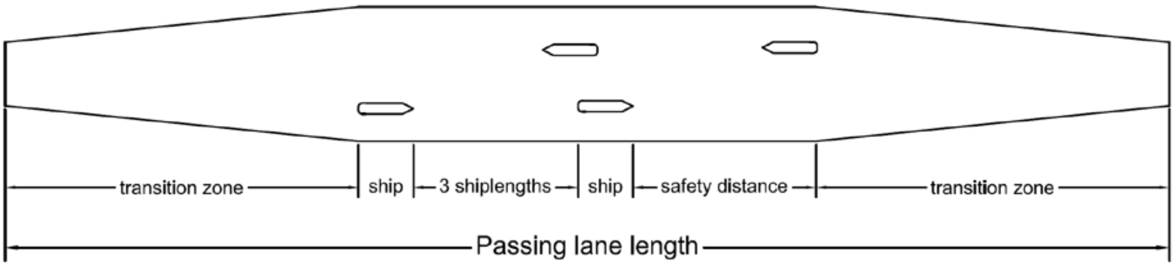


Figure 9-2 | Passing lane design

The above picture illustrates the passing lane design. For example, if a convoy would exist of only two ships of 150 m length and using the widths calculated in paragraph 8.5.1 for a one and two-way channel. We assume a 500 m safety distance, and then it follows:

Passing lane length = 2 * 150 + (2 – 1) * (3 * 150) + 500 + 2 * (367 - 174) * 5 = 3200m

9.5.5 *Inner anchorage*

An inner anchorage in the port of Beira could increase possible berth occupancy significantly. When a ship is serviced in the port, it first has to sail the access channel before the new arriving ship is allowed to enter the access channel and sail towards the berth.

An inner anchorage should be place close to the port basin. Waiting ship B could already sail towards the inner anchorage while ship A is still being serviced. When ship A is ready, it leaves the port basin and when it passes the inner anchorage ship B can proceed to the berth for servicing. It takes over 2 hours to sail the access channel, so waiting time reduction of more than 4 hours could be reached. Additionally the occupancy of the berth can be increased, because ships succeed each other faster.

A few factors are of importance for an inner anchorage:

- Dimensions: depends on the design ship and the maximum number of ships.
- Location: as close to the berths as possible. Anchoring ships should not hinder access channel traffic.
- Sedimentation: sedimentation rates will be high, because the inner anchorage is effectively a large pit in the estuary bottom, where flow velocities will be low and sediment will settle.

An alternative would be to use a waiting area, where ships moor along a fixed structure. This will decrease the required area, because the mooring space per ship is less. The fixed structure could be jetty or freestanding piles with fenders.

The inner anchorage will be implemented only for one terminal, when the mean waiting time of this terminal is much higher than the other terminals. It is assumed an expensive solution relative to adaptions to the access channel, because it requires a lot of space in the port basin and expensive structure.

9.6 Conclusions

For scenario low one new fuel berth is required, which is best placed next to the existing jetty. The coal berth should be lengthened to 224 m for safe mooring. The extension is made by cutting part of quay 9. All other terminals have enough quay capacity. However, due to the significant increase of required container terminal area, the current layout has to be adapted.

To be able to keep each cargo sector on one consecutive terminal in scenario most likely, adaptions have to be made to the current layout. By placing the coal terminal north of the current port boundaries, room is created for the other sectors. The location of the second fuel jetty determines how far the general cargo quay can be extended northwards.

The rail workshop occupies valuable area for expansion of the container terminal and should be relocated north of the port. The container quay can be extended over the current dilapidated fishery quay.

The trains are best diverted before the main gate, in order to reduce traffic congestion at railroad crossings, especially when the coal terminal stays at its current location. The railroad over the coal terminal is conveniently extended to the GC-DB terminal expansion.

In scenario high the alteration to the current layout will become too significant, if the cargo sectors each require one consecutive terminal area. By dividing the container terminal into two terminals, less severe alterations have to be made.

For all master plan alternatives, it is chosen to directly implement 24 hour sailing in the access channel, because it is a cheap and effective solution to reduce the occurring waiting times. Additionally the waiting times could be reduced by:

- Deepening the access channel to lengthen the tidal windows.
- Widening the access channel, to allow two-way traffic in the entire channel
- Widening a section of the access channel to allow in- and outgoing ships to pass
- Implement a mooring point in the port basin, where ships can wait for servicing.

Deepening and widening the channel will induce expensive capital and maintenance dredging costs, which should be further investigated.

10 HARBOURSIM SIMULATION OF ALTERNATIVES

As mentioned before the access to the port needs to be improved, therefore several solutions were suggested in the previous chapter. Harboursim is used to simulate the new port layouts presented in the previous chapter in their designated scenario. The Harboursim model of the present situation, developed in chapter 5, is adapted to the new port layout alternatives presented in chapter 9.

It is aimed in this chapter to find the best combination of port layout alternative and wet layout improvements, as discussed in the previous chapter. These combinations are necessary for the development of the master plan alternatives for the three scenarios.

Several capacity increasing wet layout adaptions were discussed in paragraph 9.5, which in the following Harboursim simulations are combined with the port layouts. Simulations will be done whereby the wet layouts will be varied. It is aimed to arrive at suitable combinations of wet and port layout alternatives for each of the three scenarios.

The set-up of the Harboursim models used in this chapter is similar to the model of the present situation. In order to keep this chapter brief and to the point, many cross-references are made to the more detailed discussion of the Harboursim model in chapter 5.

This chapter commences with a discussion of the first set of simulations. In paragraph 10.2, the foreseen output of the simulations is discussed. The physical schematization of all the port layouts is discussed in the next paragraph and reference is made to appendix IX-A for the drawings. The changes in port processes with respect to the simulation of the present situation are discussed in paragraph 10.4. The model input is discussed in paragraph 10.5 and presented in tables in appendix IX-B.
The results of the first set of simulations are discussed in paragraph 10.6. When the results imply that additional simulations are necessary, these will be conducted and discussed right after the first set of simulations. The final paragraph states the conclusions.

10.1 Simulations

In this chapter all alternatives are simulated in their designated scenario. As stated in paragraph 9.5, all simulations are done 24-hour sailing, because this is a cheap and effective solution. The wet layout is varied for the different simulations. The various options were discussed in paragraph 9.5.

It is chosen to do first a set of simulation with varying depth and one with two-way traffic. After the first simulations, it will be clear if further or different adaptions to the wet layout are necessary, like an inner anchorage or passage points.

In the present situation a -8 m CD channel did not suffice as was shown chapter 5. First, this is validated by combining the scenario low alternatives with the same channel. For scenario low it is aimed at low investments, thus an expensive two-way channel should be avoided. Therefore, the channel is lowered to -9 m CD and -10 m CD, which would increase the tidal window and make mean waiting times acceptable.

For the first set of simulations in scenario most likely it is assumed on beforehand that the channel has to be lowered to at least -10 m CD, due to the increase in ship drafts and vessel movements. In order to further lower the tidal window, the channel depth is lowered to -11 m and -12 m. As traffic increases, the need for a two-way channel will be more severe. For the first set of simulations it is chosen to do a simulation run with a two-way channel for 10 m channel depth.

In scenario high ship design size has increased to 17 m for the frequently calling coal ships. It is presumed that the channel depth has to increase accordingly to -13 m, -14 m or -15 m CD. Moreover, the increase in vessel movements in the channel presumably requires two-way traffic. What follows are the first set of simulations summarized in Table 10-1.

The results of the first simulations are discussed in paragraph 10.6. It will be concluded if additional simulations with varying depths and/or two-way traffic are necessary. Furthermore, a passing lane can be implemented as an intermediate solution between a one- and two-way channel.

Table 10-1 | First set of simulations

Alternative	Depth [-m CD]	One- or two-way
A1 - A3	8	One
	9	One
	10	One
B1 - B4	10	One
	11	One
	12	One
	10	Two
C1 - C4	13	One
	14	One
	15	One
	13	Two

The inner anchorage will be implemented only for one terminal, because it is assumed an expensive solution relative to adaptions to the access channel. It will be added to the model, when the mean waiting time based on the service time of only one terminal is higher than the desired value of 0.2. Therefore, it is only used in the second set of simulations.

10.2 Foreseen output of simulations

The goal of this simulation is to determine how well the combinations of port layout alternatives and maritime improvements perform. Their performance is measured on the mean waiting time in ratio to the service time for all the terminals. As mentioned in paragraph 8.2, the optimum is found at a ratio of 0.2.

The occupancy rate of all berths should be above 0.4 for a reasonable profit for the terminal operators (DHV BV, 2008). Logically, the occupancies should not be so high that waiting times become too long. This implies that when the occupancy rate of the berths is lower than 0.4 and the MWT [ST] is still higher than 0.2, solutions must be found in increasing the capacity of the wet layout. Conclusions on that matter will be done at the end of this paragraph.

10.3 Physical schematization

The physical schematization of the new models is similar to the present situation, given in chapter 5. In appendix IX-A the physical schematizations of each of the alternatives are given. Below some specific changes are explained:

It is aimed to keep the changes to the model of the present situation to a minimum. Thereby the section numbers towards the different terminals are kept the same, despite the changed berth configurations. The sailing time of the sections are adapted to fit the new berth layouts.

Alternative A1 and A3 can both be simulated by the same model, because their berth configuration is identical. In addition, alternative B3 and B4 can be combined, because the quay lengths result in exactly the same berth configuration in Harboursim. Thereby it must be noted that the short difference in sailing time between quay 8 and the new coal terminal (4 minutes) is neglected.

The passage points are modelled by dividing section 1, representing the access channel and shown in Figure 5-1, into three sections. In the middle one, two-way traffic will be allowed and it represents the passage point. The length of the passage point is represented by the sailing time added to this section. The sailing time is equal to the sailing speed multiplied by the length of the passage point in reality.

10.4 Port processes

Fleets are designated to their corresponding terminals similar as in the current situation. Below some specific changes are explained:

24 hour sailing is relatively cheap and easy to implement in the access channel to Beira Port. All simulations are done 24-hour sailing, the feature as described in paragraph 5.4.1 is therefore turned off.

Where two general cargo bulk quays are available, the longest is first checked for free quay length. This will result in lower occupancy rates for the shorter quay. In reality the ships are designated to a terminal depending on their cargo load. The real occupancy rates are in the range of the two occupancies.

The other quays are modelled as one continuous quay, with room for the same number of berths as in the port layout alternative. This can be done, because all calling ships per terminal have the same length in the model. This is the length of an average calling ship.

The inner anchorage cannot be modelled as an anchorage in Harboursim, because in the journey of a ship only an anchorage can be present at the start of a ship in the model. During the trip, a ship cannot be sent to an anchorage following the model processes. The inner anchorage is best modelled as a terminal arrival queue. When free quay length becomes available, the ship is directly allowed to moor. It must be noted that in reality the ship needs additional time to unmoor from the inner anchorage and sail to the quay. As this extra time is unknown and differs per terminal, it is not implemented in the model.

The coal processes as described in paragraph 5.3, are similar in scenario low and most likely. 2/3 of the total coal throughput is exported by Vale with transfer ships. In scenario most likely, the transfer ships do five trips of 40,000 ton to fill one OGV. For the port layout alternatives designed for scenario high, Panamax ships with a load of 70,000 tons are used for direct sailing over the ocean, the transfer ships are no longer in use.

10.5 Model Input

The port layout alternatives are modelled in a similar way as described in paragraph 5.5. The differences with the present situation are described below. A summary of the resulting input is given in appendix IX-B.

The average ships were described in paragraph 6.5.1 to 6.5.3 per scenario. The fleets are modelled as ships with the average ships' lengths and drafts. The general cargo and container ships are thus modelled as if they are always loaded to the maximum draft. This is an overestimate of the average ships draughts and resulting tidal windows are shorter than in reality.

The general cargo and dry bulk ships are combined in one fleet, because they call the same quays. The ships can be still be separately defined, but they have a combined inter arrival time. With the total number of calling ships, the inter arrival time is calculated for the fleet.

10.6 Results of simulations

In this paragraph, the results of the first set of simulations are discussed. Their performance is measured on the mean waiting time (MWT) in ratio to the service time [ST], which will be presented in clear charts.

The occupancy rate of all berths should be above 0.4 for a reasonable profit for the terminal operators (DHV BV, 2008). Logically, the occupancies should not be so high that waiting times become too long. This implies that when the occupancy rate of the berths is lower than 0.4 and the MWT [ST] is still higher than 0.2, solutions must be found in increasing the capacity of the wet layout.
The wet layout should provide acceptable mean waiting times for all terminals. However, if this means extreme measures for just one terminal, than a specific solution for that terminal should be found, for instance an extra berth or a terminal arrival queue.

The paragraph is divided in sub-paragraphs per scenario. For each of the scenarios it is started with analysing the results of the first set of simulations. When it is concluded that additional simulations are necessary, these are added to the second set of simulations, which are discussed directly thereafter.

10.6.1 Simulation results alternatives A1-A3

The mean waiting time expressed as percentage of service time per terminal is shown in Figure 10-1. It is clear that none of the simulated depths is satisfies to the required value of 0.2. Especially the coal waiting times are far too long.

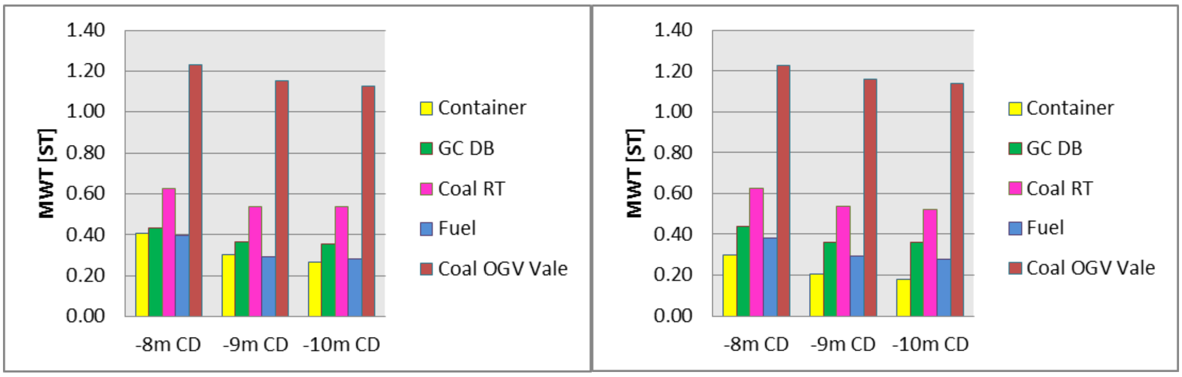


Figure 10-1 | MWT [ST] for alternative A1 & A3 (left) and A2 (right)

There is a clear improvement from 8 to 9 meters water depth for all calling ships. The waiting time is reduced by 10% to 25%. From 9 to 10 m there is no visible difference, thus deepening the access channel further than 9 m has no use.

The occupancy rate of all berths should be above 0.4 for a reasonable profit for the terminal operators (DHV BV, 2008). From Table 10-2 it is clear that the number of berths designed in alternative A1 and A3 should be used. Extra reduction of waiting times should be found in adaptions to the wet layout.

Table 10-2 | Occupancy rates based on service time for alternatives A1 & A3 and A2

	A1 & A3	A2
Container	0.247	0.18
GC DB	0.30 - 0.43	0.34
Coal 8	0.36	0.36
Fuel	0.13	0.13

The reduction of the waiting times for all ships can be produced by implementing a two-way channel or a passage point. These measures are likely to have a big influence on the waiting times and therefore simulated on the channel depth of -8 m CD in the second set of simulations.

As stated before, investment costs should be kept at a minimum in scenario low. Therefore, it could be decided by the port authorities to reduce the waiting time of only the coal ships, as the other sectors are relatively close to the desired waiting time. An inner anchorage will be simulated for only one coal ship.

The present coal terminal, maintained in the alternatives, was built for the simulated traffic. Therefore, it is likely that Vale and Rio Tinto are aware of the fact that waiting times will be long for their ships. It is foreseen that the coal sector takes the waiting for granted and the access channel for alternative A2 only has to be lowered to 9 meters.

Table 10-3 | Proposed second set of simulations scenario low

Alternative	Depth [-m CD]	One- or two-way	Passage point	Inner anchorage
A1 & A3	8	Two-way		
	9	One-way	Halfway	
	9	One-way	Close to berths	
	9	One-way		Coal

The proposed additional simulations are listed in Table 10-3. Figure 10-2 shows the mean waiting time results for the second set of simulations done for alternative A1 and A3 and as reference the results for a single -9 m CD channel.

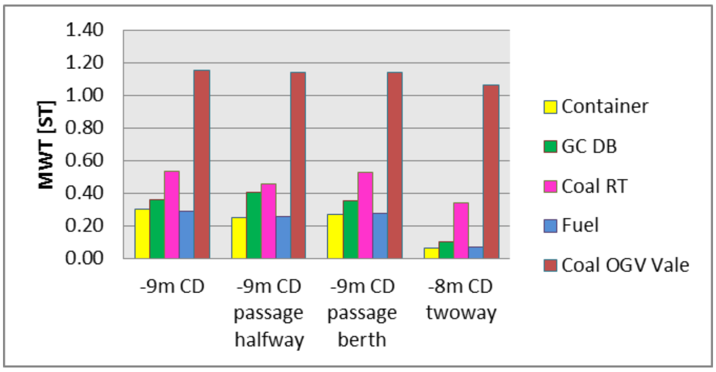


Figure 10-2 | MWT [ST] of alternative A1 & A3

The result for a -8m CD two-way channel shows that all, except the coal, mean waiting times are very low, but this is a large investment for scenario low. Therefore, the model is simulated with a passing lane. However, it must be noted that Harboursim does not use convoy sailing as is currently used in Beira Port. The results shown for the passing lanes are an overestimate of the occurring waiting times, because traffic could be regulated to make more efficient use of the passing lane.

A slight drop in waiting times can be seen for the passage points. If we take a closer look it can be seen that the deeper container ships are much more affected by passage halfway than by a passage close to the berths. This was expected, because the deeper ships benefit from the fact that shorter tidal windows can be used, as was stated in paragraph 9.5. The more shallow general cargo and dry bulk ships benefit as expected more from a passage point close to the berths. This model shows good results, with the consideration that the coal sector has settled with the longer waiting times. In consideration with the cost aspect of a full two-way channel, for alternative A1 and A3 a -9 m CD channel with passage close to the berths is chosen.

A solution for the coal sector would be to implement an inner anchorage or mooring site for the coal ships. Due to an unknown error, this simulation could not be done, but from other inner anchorage simulations, it is concluded that it would have a significant impact on the waiting times.

10.6.2 *Simulation results alternatives B1-B4*

Figure 10-3 summarizes the result of the simulations done for the scenario most likely alternatives.

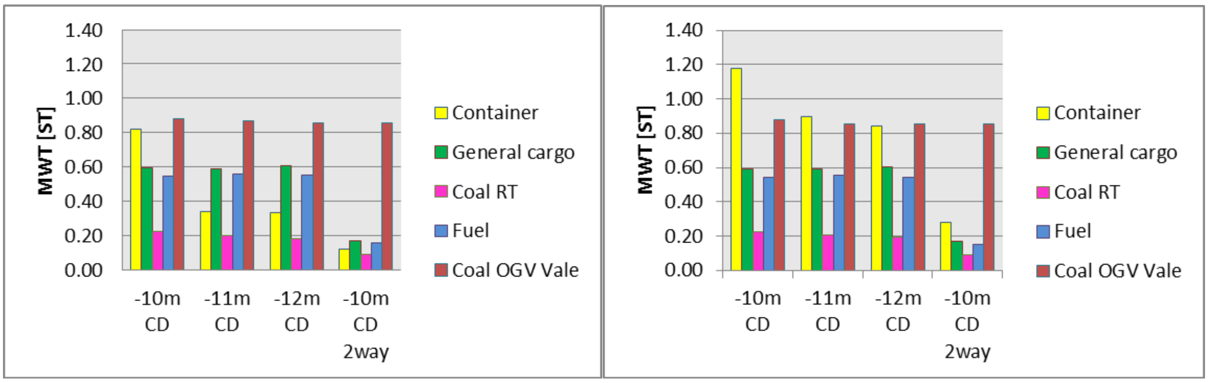


Figure 10-3 | MWT [ST] for alternative B1 (left) and B2 – B4 (right)

For alternative B2 to B4 the model results are identical. For B3 and B4 this is obvious, because the same model input could be used. However, alternative B2 has an additional general cargo bulk berth available, thus an improvement in waiting times for this terminal was expected. In the simulations for alternative B2, a 524 m long quay was used. Along this quay it would be possible for three dry bulk ships to moor, thus in theory a total of five ships could berth along the general cargo dry bulk quays, as shown in 9.3.2. However, the Harboursim results for this alternative are similar to B3, which has only room for four ships. Harboursim does not distinguish between ship sizes and when one average general cargo ship is placed along the 524 m long quay, there is not enough space left for two dry bulk ships. It is concluded from the results that 524 m is too short to berth three ships on regularly basis.

There is no improvement for the OGV of Vale for deepening the channel or allowing two-way traffic, as shown in Figure 10-3. This can be explained by the fact that the process is already at its optimum, due to the limiting loading rate at the coal quay. The ships are loaded with a rate of 1700 tons/hour at the quay, but unloaded at sea with a rate of 3000 tons/hour. Therefore, the service time of the OGV at sea is much shorter than the service time of the transfer ships at the quay. Hence, the OGV has to wait for the next transfer ship, which increases the total waiting time. Then the transfer ship has to sail to back and forth to the terminal quay. Last, the transfer ships have waiting time, due to occupation of the quay and turning basin, increasing the waiting time for the OGV further. Finally, this results in a mean waiting time of the OGV of about 70 hours. Still this is half of the current waiting time of the OGV's. Because the waiting times are caused by their own chosen operations, these are no longer considered in the choices for the wet layouts.

The waiting time for the Rio Tinto coal ships is a much better parameter to easily judge the performance of the access channel for the coal sector, because the ships sail directly to the coal quay. The charts show good results for all wet layout alternatives.

From Figure 10-3, it is clear that only for the container ships the depth increase to -11 m CD is useful. However, the waiting times are still far too long and a two-way channel is necessary. A -9 m CD two-way channel is simulated for all alternatives in the second set to see if this still suffices.

Table 10-4 | Occupancy rates for alternatives B1 and B2 – B4

	B1	B2 – B4
Container	0.304	0.371
GC DB	0.39	0.34 - 0.37
Coal 8	0.5	0.5
Fuel	0.27	0.27

Following the lower boundary of 0.4 for the occupancy rate, it is not advised to implement the extra container berth from alternative B1, see Table 10-4. However, the mean waiting time is still too long with a -10 m two way channel. With four container berths, all ships have a mean waiting time of less than 20% of the service time. A solution could be found in an inner anchorage or mooring site for one container ship, which is modelled in the second set of simulations discussed next.

Table 10-5 | Proposed second set of simulations scenario most likely

Alternative	Depth [-m CD]	One- or two-way	Passage point	Inner anchorage
B1	9	Two-way		
B2 – B4	9	Two-way		Container
	10	Two-way		Container

For alternative B1 the best option is a -9 m CD two-way channel, for which the mean waiting time results are shown in Figure 10-4. The results are almost perfect for all calling ships, except the OGV's which were already discussed above.

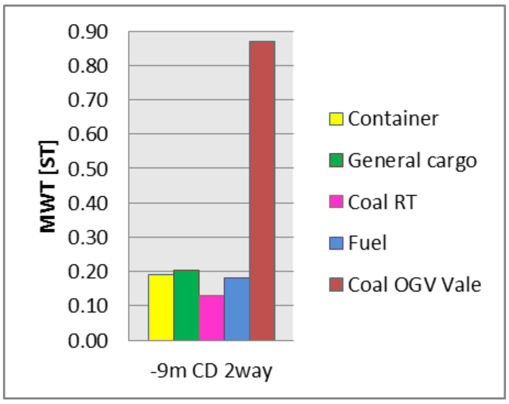


Figure 10-4 | MWT [ST] alternative B1

Alternative B2 to B4 are modelled with an inner anchorage for the container ships. The results are summarized in Figure 10-5 and compared to the results without inner anchorage. It reduces the waiting times significantly and even a -9m CD two-way channel satisfies. Constructing a mooring site for one container ship is more cost effective than an additional berth with handling equipment as in alternative B1.

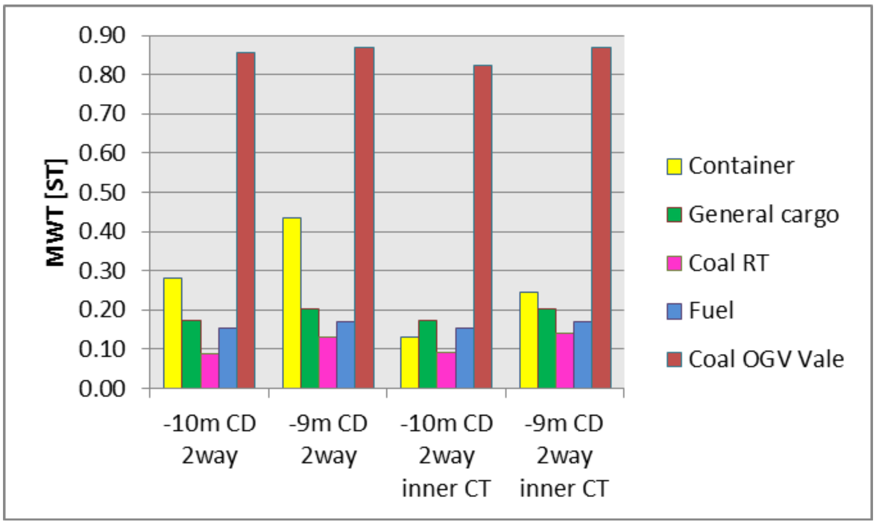


Figure 10-5 | MWT [ST] alternative B2 – B4

10.6.3 Simulation results alternatives C1-C4

The alternatives C1 to C3 have the same number of berths for all terminals, thus the results of the Harboursim model are similar. Alternative C4 has two coal terminals, the present terminal and the new terminal in the north. The transferring coal ships call the present terminal, while Panamax ships call the new terminal. For a single lane access channel, the maximum number of 20 ships at anchorage in the model was exceeded in alternative C4. The simulation ends at that moment and thus no results can be shown. However, when this happens it is sure that waiting times exceed the limit. The mean waiting times are summarized in the charts of Figure 10-6.

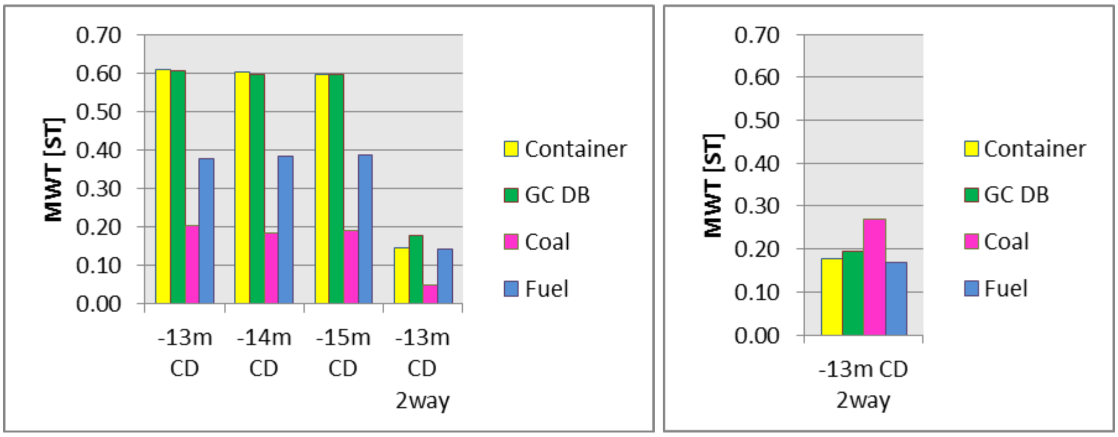


Figure 10-6 | MWT [ST] for alternative C1 – C3 (left) and C4 (right)

With a one-way access channel the waiting times of the container, GC DB and fuel berths are too high for alternative C1 to C3. However, the occupancies of the berths are low, shown in Table 10-6, thus it is advised to improve the capacity of the access channel.

Deepening the channel further than -13 m has no use. The improvement in waiting times is clearly visible for the two-way channel. In the second set of simulations, a -12 m CD two-way channel for alternative C1 to C3 should be checked.

It is clear a two-way channel is necessary in alternative C4, because the anchorage exceeded its limit of 20 ships in the simulations with a single lane channel. Alternative C4 is best combined with -13 m CD two-way channel, as waiting times are perfectly close to 20% of the service time.

Table 10-6 | Occupancy rates for alternatives C1 – C3 and C4

	C1 – C3	C4
Container	0.43	0.448
GC DB	0.45 - 0.54	0.48
Coal new	0.63	0.73
Coal 8		0.35
Fuel	0.26	0.34

The coal terminal for alternative C1 to C3 has very low waiting times, with a relatively high berth occupancy compared to the other terminals. An explanation could be found in the more scheduled arrivals for the coal sector, with an Erlang 10 distribution instead of the negative exponential distribution. A simulation is proposed with one coal berth less, to see if waiting times are still acceptable. Table 10-7 summarizes the second set of simulations for scenario high.

Table 10-7 | Proposed second set of simulations scenario high

Alternative	Depth [-m CD]	One- or two-way	Passage point	Inner anchorage
C1 – C3	12	Two-way		
C1 – C3	Only 3 coal berths			

Alternative C1 to C3 are modelled with a -12m CD two-way channel. The mean waiting times still meet the requirements for all berths. One less coal berth was also simulated for alternative C1 to C3, but this resulted in skyrocketed waiting time and berth occupancy of 84%. It is clear that 3 coal berths do not suffice, which is no surprise for a throughput of 40 million tons of coal.

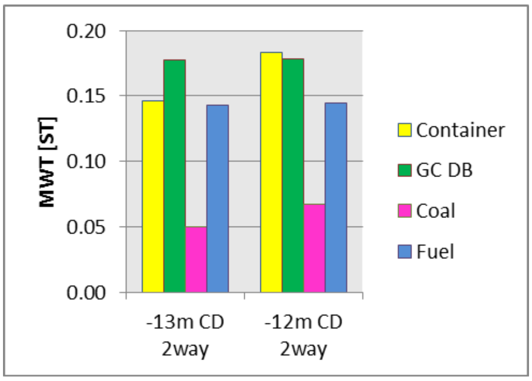


Figure 10-7 | MWT [ST] of alternatives C1 to C3 with a two-way channel

10.7 Conclusion

It is conclude that the coal sector takes the long waiting time for granted and the access channel for alternative A2 only has to be lowered to 9 meters. For alternative A1 and A3 a passing lane close to the berths is additionally constructed. Hereby the waiting times of over 20% of the service time are accepted, in order to reduce the capital and maintenance dredging cost.

For alternative B1 the preferred option is a -9 m CD two-way channel. Alternative B2 to B4 have one container berth less and should therefore be combined with an inner anchorage for the container ships. Otherwise, a -10 m CD two-way channel could be applied.

Alternative C1 to C3 should be combined with a -12m CD two-way channel and alternative C4 is accompanied by a -13 m CD two-way channel, due to the transferring coal ships. Table 10-8 summarizes the preferred wet layouts for all port layout alternatives.

Table 10-8 | Port layout alternatives with preferred wet layouts

Alternative	Depth	One- or two-way	Passage point	Inner anchorage
A1 & A3	-9 m CD	One-way	Close to berths	
A2	-9 m CD	One-way		
B1	-9 m CD	Two-way		
B2 – B4	-9 m CD	Two-way		Container
	-10 m CD	Two-way		
C1 – C3	-12 m CD	Two-way		
C4	-13 m CD	Two-way		

The waiting times of the OGV's of Vale are very long, due to sailing and service times at the coal terminal of the transferring ships. Because the waiting times are caused by their own chosen operations, these are not considered in the choices for the wet layouts.

11 FLEXIBLE MASTER PLAN ALTERNATIVES

In the previous chapters, the three scenarios formed the basis for the layout alternatives. In this master plan development study, it is aimed to develop a master plan flexible for all three scenarios. This implies that the final result should be a master plan feasible in scenario most likely, but is also applicable in scenario low and scenario high. In this chapter the layouts for the different scenarios are combined to form flexible master plan alternatives. For these master plan alternatives all three scenarios are taken into account.

The scenario most likely concept alternatives (B1-B4) developed in chapter 9 will be the basis for the flexible master plan alternatives. These will be expanded to be applicable in scenario high, for which concept alternatives C1-C4 are used. Furthermore, the flexible master plan alternatives can also be used in scenario low, using concept alternatives A1-A4. Thus, the results of the previous chapters are used to create two alternatives, which are flexible for implementation in each of the three scenarios. For each alternative, it is aimed to keep the alterations between the scenario layouts to a minimum.

Using the results of the Harboursim simulations of chapter 10, each alternative will be accompanied by the preferred wet layouts. The results of these simulations are thus also valid for the presented master plan alternatives in this chapter.

In consultation with DHV experts, the best port layout features from chapter 9 are chosen and two flexible layouts are designed. It is aimed to develop two alternatives with distinctive features. The main distinction between the alternatives is the relocation of the present coal terminal in alternative 1 and maintaining the current location in alternative 2. The advantage of relocating the coal terminal is that the thus created space can be used to expand the container and GC-DB terminals. One consecutive area and quay per terminal is the result. The disadvantage is off course the destruction of capital of the recently constructed coal terminal.

The second distinctive feature is location of the second fuel jetty. The new construction can be placed either north or south of the present jetty. By constructing the jetty in the north, more room is available in the present port boundaries for extending quay 10 northwards. However, no optimal use can be made of the land reclamation site, due to the safety zone of the new jetty.

Two drawings are presented per master plan alternative. The first drawing shows the port layout with quay lengths and the second drawing focuses on the port basin layout. The dark colours depict the areas that will be developed in all the scenarios. The lighter colours depict the necessary areas required for scenario most likely and high, indicated by respectively ML and H. The hatched ML areas change terminal user in scenario most likely and high. The areas inside the thick lines clearly show the most likely terminal boundaries.

Each paragraph in this chapter discusses one master plan alternative. The design choices are explained per scenario and the designed layouts can be found in the corresponding drawings at the end of each paragraph.

11.1 Alternative 1: Flexible master plan A3B2C2

The first flexible master plan alternative is roughly based on the alternatives A3, B2 and finally C2 The master plan is drawn in Figure 11-1. The rail workshop is for all scenarios relocated outside the port area boundaries, realizing space for the container terminal expansion. The coal terminal is relocated to the reclamation site, in order to facilitate the container cargo in scenario most likely on one interconnected storage site. In scenario high, no additional relocation takes place and all terminal expansions are found close to the terminals.

Table 11-1 summarizes the total terminal areas in the different scenarios. The highlights of the alternative are discussed first for scenario most likely and thereafter the alteration necessary for respectively scenario low and high. Further layout information can be found in Figure 11-1. The last paragraph discusses the port basin layout, which is presented in Figure 11-2 at the end of this paragraph.

Table 11-1 | Terminal area [m2] in different scenarios for alternative 1

Terminal	Low	Most likely	High
Container	563,000	908,000	1,254,000
General cargo / dry bulk	186,000	209,000	307,000
Coal	192,000	564,000	1,235,000
Fuel	412,000	609,000	749,000
Total	**1,353,000**	**2,290,000**	**3,545,000**

11.1.1 Scenario most likely

Alternative B2 forms the basis for this flexible alternative, only the railroads and tank farm expansion are changed.

The railroad is diverted in front of the main gate. This is done by extending the railroad towards and over the terminal. This reduces hindrance for container trucks crossing the current railroad line, which results in less congestion.

To facilitate the increased ship size demand, the current container quay is extended towards the fishery port over the full length of quay 1. As this quay is currently in deteriorated state, a new quay should be built. The maximum additional quay length of 182 m is constructed, in order to be already flexible for scenario high, or possible increasing ship sizes. Following the technical requirements, the container storage yard is expanded. To maintain one interconnected yard, the coal terminal has to be relocated.

The coal terminal is relocated to the reclamation site, thus enabling room for the other commodities. Quay 8 will again be used by GC-DB ships and increased to 227 m to accommodate three average general cargo ships. To extend quay 8 a cut is made in quay 9, reducing this quay length to 312 m, but as stated before the old quay 11 can be used for the mooring lines.

The reclamation sit is used for the new coal terminal. The current equipment can be reused at the new site. A big advantage of the relocation is that the coal trains will no longer hinder truck traffic in the port. The terminal personnel will use the current main gate, assuming that offices on the new coal terminal will be located on the south side.

The tank farm expands towards the fuel jetty, while a second fuel jetty is realized south of the existing one. In between the fuel, GC-DB and container terminal space is intentionally left free for future expansion of terminal grounds.

For the wet layout it is required to expand to a two-way access channel, as concluded in chapter 10. The choice is made to create a mooring point for container ships extending from quay 10. Due to the mooring point, the access channel can be limited to -9 m CD.

11.1.2 Scenario low

The scenario low layout is based in concept A3. In Figure 11-1 it is indicated by the darker terminal colours. The tank farm has enough space within its current boundaries, thus is not expanded. Furthermore, the current container quay suffices and due to the relocation of the rail workshop, the coal terminal can stay in place.

The railroad track diversion in front of the main gate is also preferred for scenario low, because the increased coal traffic will make use of this track.

The general cargo dry bulk terminal is kept in place, divided over quay 6-7 and quay 9-10. Quay 8 will primarily be used by the coal exporters.

The access channel is deepened to -9 m CD and a passing lane will be located just before entering the port basin. Thereby the waiting times will be acceptable for most terminals and the large investment for an entire two-way channel are postponed. It is assumed that the coal exporters continue to operate in the port and settle for the long waiting times.

11.1.3 Scenario high

In scenario high, the flexible alternative 1 will be expanded to an example of concept alternative C2. In scenario high even longer ships are expected. However, due to rearrangement and extensions of general cargo and dry bulk quays for scenario most likely, there is space left to be flexible for possible larger ships or multiple smaller ships in scenario high.

A second container terminal is created north of the expanded coal terminal, because two extra berths have to be created to handle the larger ships. There is still room left in the present port boundaries and this terminal remains flexible in the case the ships sizes do not increase as predicted in scenario high.

The northerly container terminal is connected to the road from the north, because the container terminal requires a good road connection. It is proposed to construct a viaduct outside the port boundaries, to cross the busy railroad towards the coal terminal.

Due to the relocation of the coal terminal, it is possible to extend the general cargo dry bulk quay further north, in order to accommodate three average ships. At the other GC-DB quay, three below average ships or two design ships can berth.

The fuel terminal grows northeast until the road which connects the coal terminal for personnel. It would be wise to locate the terminal offices at this side for easy access.

As concluded in chapter 10, concept alternative C2 requires an access channel of -12 m CD to be able to receive the large coal ships.

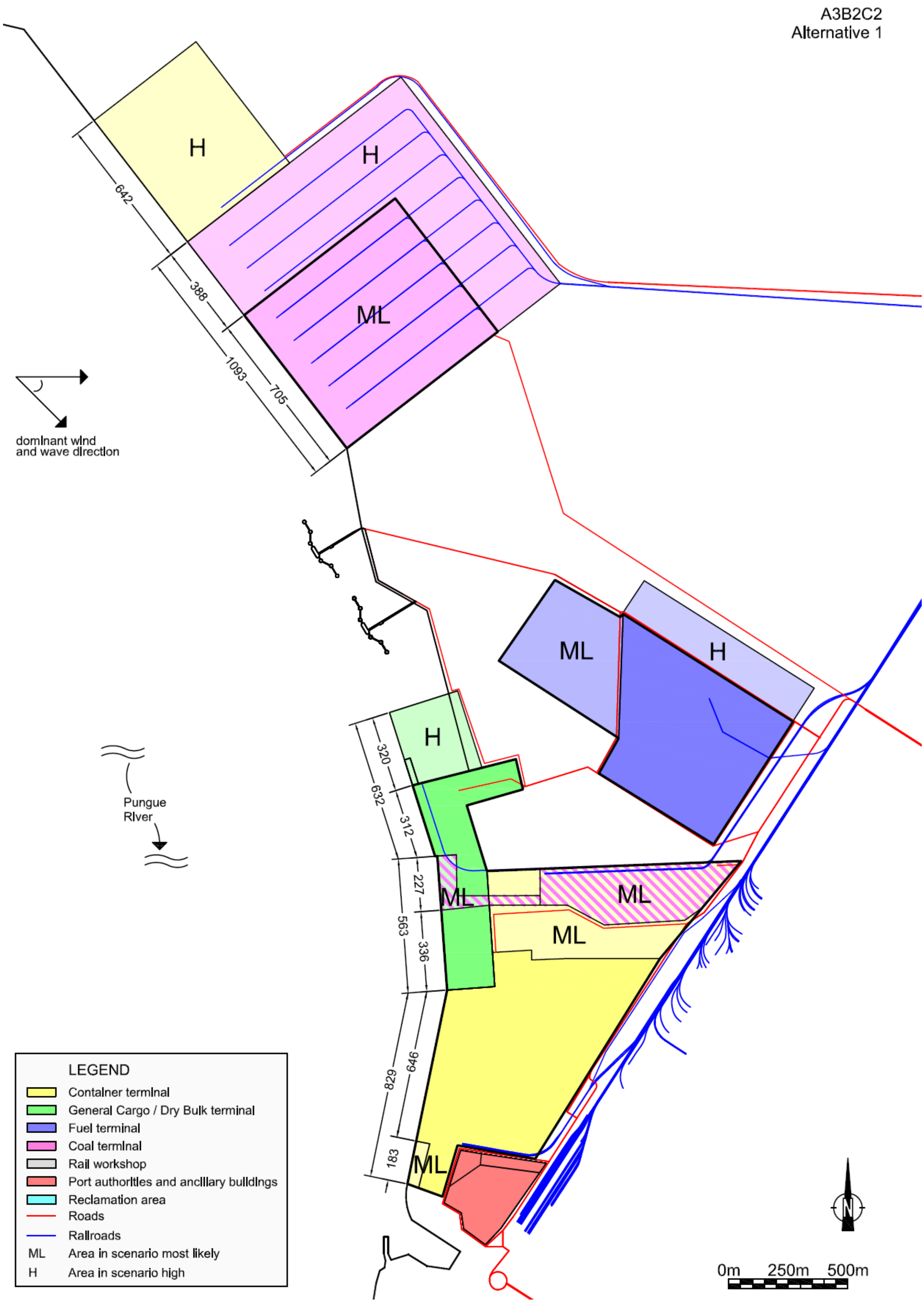


Figure 11-1 | Alternative 1: port layout

11.1.4 Port basin layout

Now that the landside of the port is known, the port basin layout is designed. The requirements of paragraph 8.4 and 8.5 form the basis for the dimensions in the layout in Figure 11-4. All scenarios are drawn in Figure 11-2, which shows the expansions. The depths were already discussed for the different scenarios and the slopes are not drawn, in order to keep the picture orderly. Mild underwater slopes of 1:5 are advised.

The turning basin dimensions for scenario low and most likely differ just 10 m, thus the basins will be dimensioned equally to fit both scenarios, e.g. an ellipse of 470 by 700 m. The ellipses will be enlarged to 540 by 810 for scenario high, to ensure the Panamax ships can turn.

The berth pockets are 1.5 B. The channel width for scenario most likely is 367 m and follows the eastern river bank to minimize the required dredging. In scenario high the width will be 410 m, but in scenario low only 174 m is needed, because of the single lane access.

The safety distance between a moored tanker and a passing ship may be from 200 to 250 m (Thoresen, 2010). This distance is kept by the ships passing the two fuel jetties and a safety radius is annotated in the picture.

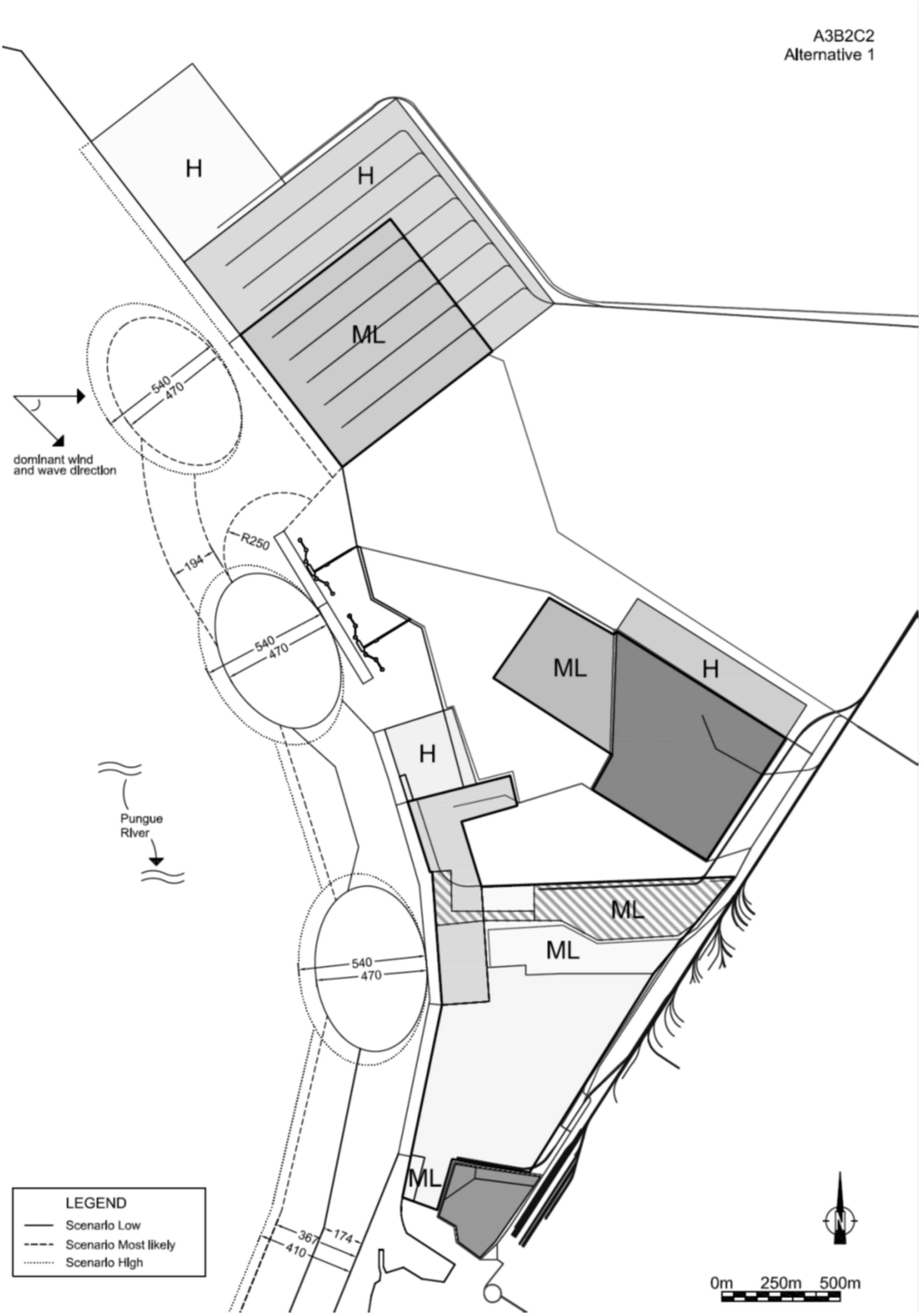


Figure 11-2 | Alternative 1: port basin layout

11.2 Alternative 2: Flexible master plan A2B4C4

The second flexible port layout is roughly based on the alternatives A2, B4 and C4. Quay 6-7 is transformed in a container quay to realize space for future needs in scenario most likely. There is now a clear division between the terminals and hinterland connections are better separated. The alternative needs little further investments, only the expansion of the container terminal requires relocating the rail workshop outside the port boundaries. For scenario high the GC-DB quay can be extended upstream, because the second fuel jetty is constructed in the north.

Table 11-2 summarizes the total terminal areas in the different scenarios. The highlights of the alternative are discussed first for scenario most likely and thereafter the alteration necessary for respectively scenario low and high. Further information can be found in the corresponding drawings in Figure 11-3 and Figure 11-4 at the end of this paragraph.

Table 11-2 | Terminal area [m2] in different scenarios for alternative 2

Terminal	Low	Most likely	High
Container	492,000	866,000	1,270,000
General cargo / dry bulk	240,000	240,000	330,000
Coal	192,000	571,000	1,180,000
Fuel	412,000	602,000	757,000
Total	**1,336,000**	**2,279,000**	**3,537,000**

11.2.1 Scenario most likely

Alternative B4 forms the basis for this master plan alternative. Alternately, the second fuel jetty is place north of the current one. Thereby the coal terminal is also placed further north, to keep a safe distance from the jetties. This results in more space inside the current port boundaries for quay extensions in scenario high.

Again, the railroad is diverted in front of the main gate. For the flexible layout the introduction of a railway entering the port from the northwest is not feasible, because the railroad track is not flexible for the other two scenarios.

The GC-DB terminal will have more flexibility, because quay 9-10 is lengthened to 746 m to form one continuous quay. The new construction requires just 66 m more quay length compared to requirements for scenario low and thus best implemented also for scenario low, with an eye on the future after 2032.

The rail workshop is relocated outside the port, thereby creating space for the expansion of the container terminal. More container yard room is acquired north of the existing coal terminal. A second advantage of the rail relocation is that the increased container truck traffic has no hindrance of any railroad crossing.

A second coal terminal is built north of the two jetties. It has a rail access for the cargo and a road access for personnel. The railroad diverts far north of the port, thereby not hindering truck traffic.
The access channel is expanded to a -10 m two-way channel. This is done with an eye on the future, where the channel will be lowered further.

11.2.2 Scenario low

In scenario low no expansion of the fuel terminal area is required. In addition, the relocation of the railway workshop can be delayed, because there is still enough room for the container yard.

In scenario low one additional container quay is available compared to the first alternative. Due to construction of the long general cargo quay, it is advised to keep additional costs for the improvement of the general cargo dry bulk terminal lower. Therefore, only the access channel will be lowered to -9 m CD and the terminal has to settle for the somewhat long waiting times.

11.2.3 Scenario high

In the highest scenario, the container terminal is further expanded over the free terrain in the current port boundaries. Additionally, a second container terminal is built north of the second coal terminal. This coal terminal is increased to accommodate three Panamax bulk ships. Between the two northern terminals, space is available for the construction for a future extra coal berth. Future expansion of the container terminal should be located further upstream.

The space realised by placing the fuel jetty further north will be used to lengthen the general cargo dry bulk quay with at least 298 m, in order to accommodate five average ships.

The tank farm grows further towards the jetties along the northern port boundary. Thereby leaving the area between the GC DB terminal and the fuel terminal free for future expansion.

To meet the waiting time requirements the channel has to be lowered to -13 m CD, as concluded in the previous chapter.

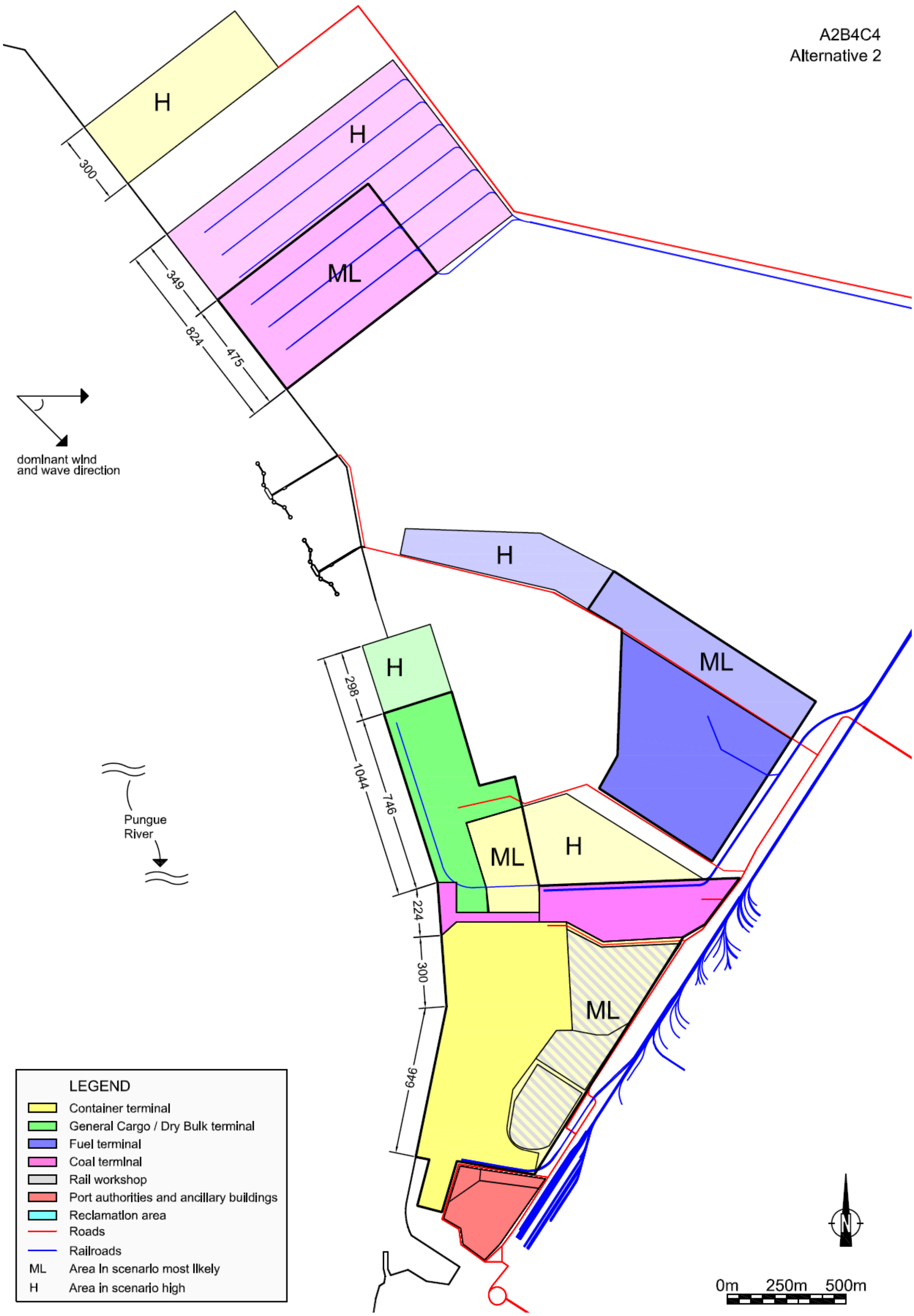


Figure 11-3 | Alternative 2: port layout

11.2.4 Port basin layout

In Figure 11-4 the flexible port basin layout is drawn. The same notions as stated in paragraph 11.1.4 are applicable.

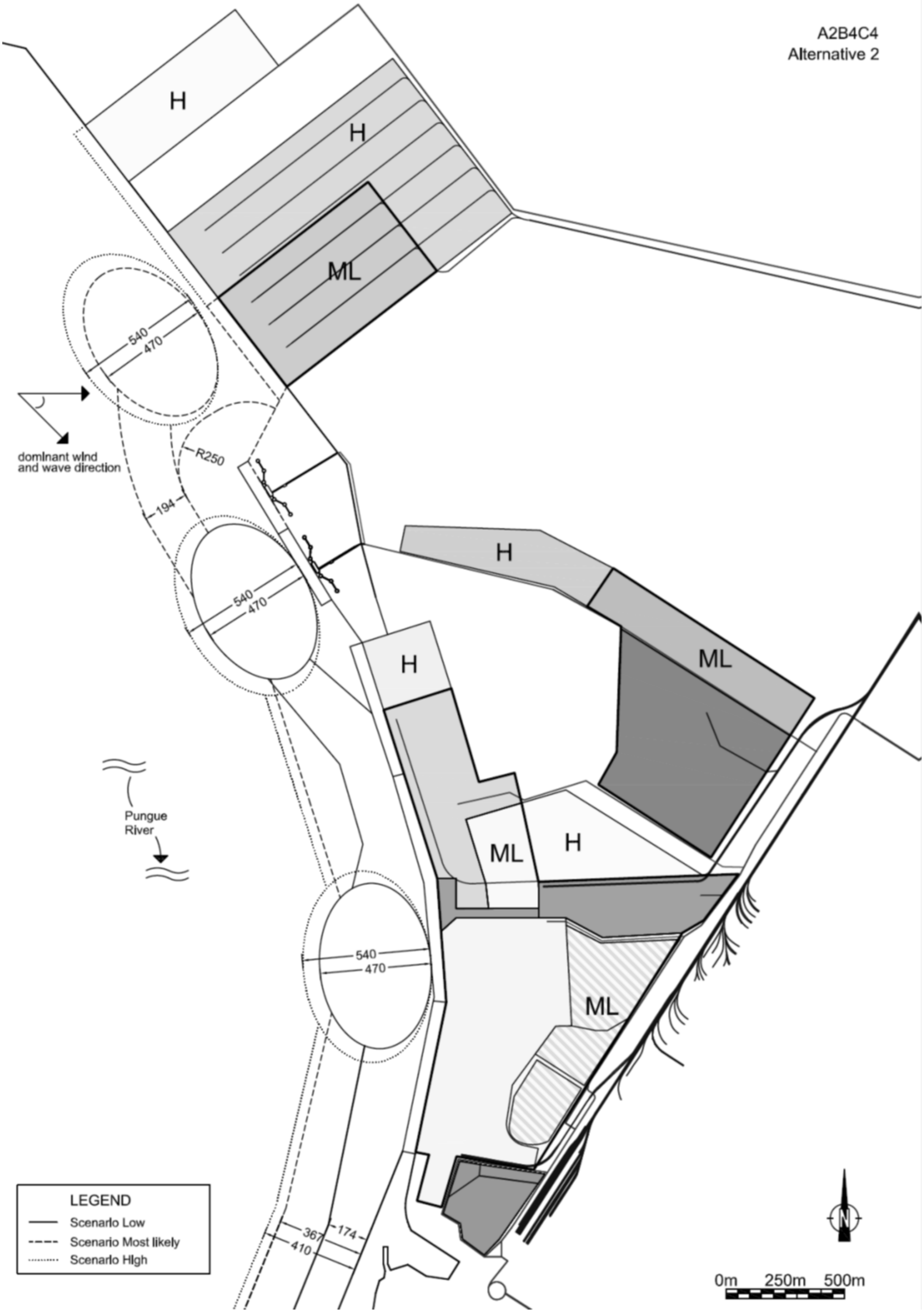
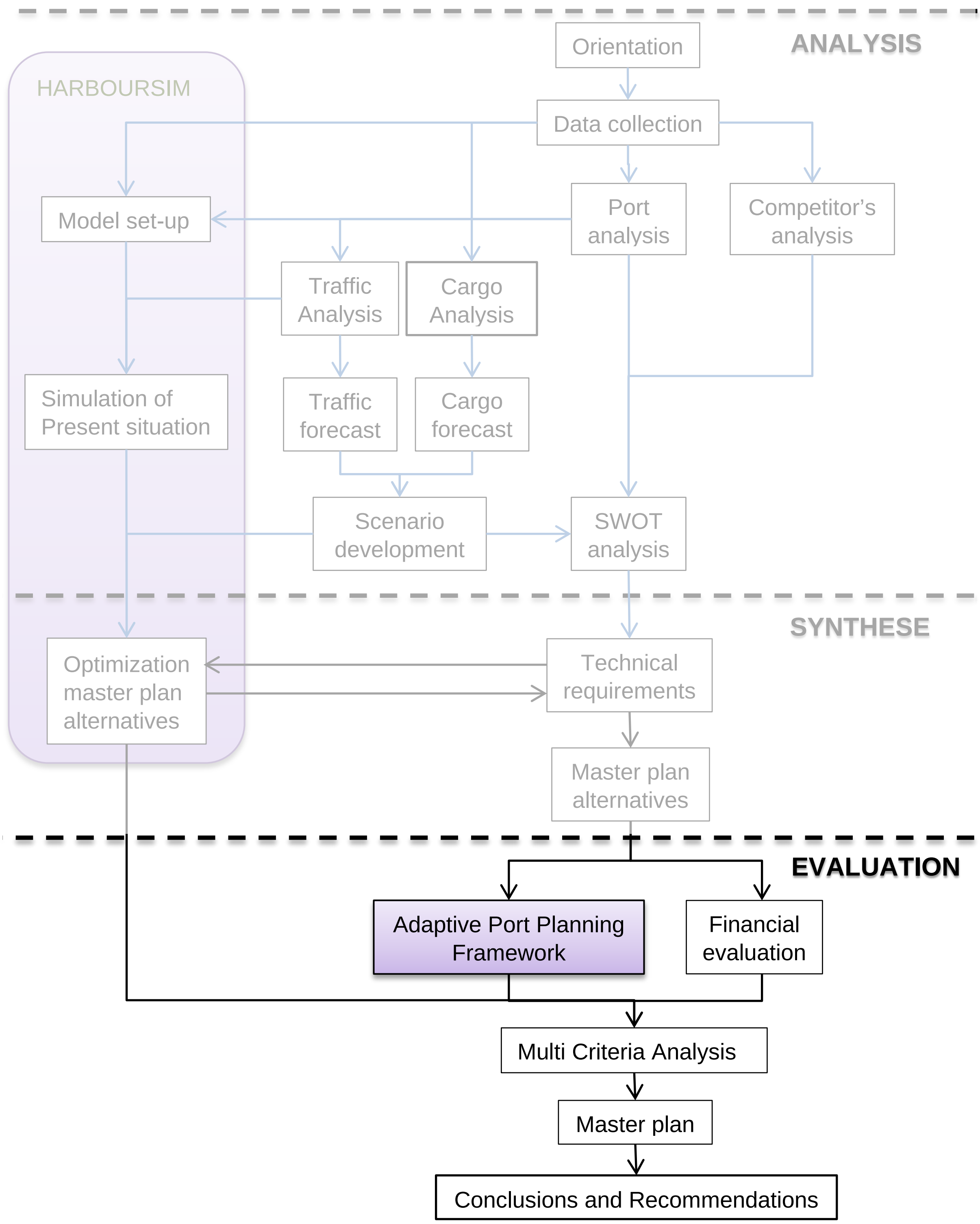


Figure 11-4 | Alternative 2: port basin layout

Part C: Evaluation



12 ADAPTIVE PORT PLANNING

In 2010 a new adaptive approach to port planning is developed, Adaptive Port Planning (APP), which combines elements of Assumption-Based Planning (ABP), developed in the early 1990s, and Adaptive Policymaking (APM), developed in 2001. The reason for the new approach is stated in Taneja (2010):

"A port master plan needs to be dynamic and responsive to all external developments during its lifetime. The existing master planning approach is static and as a result it is poorly equipped to deal with many uncertainties in the port and shipping industry."

The new adaptive approach identifies in a structured way the uncertainty in an existing plan, and subsequently improves its robustness and adaptability through taking actions either in the planning stage or by preparing actions in advance that can be taken as the uncertainties resolve themselves. The value of this proactive and dynamic approach lies in its manner of dealing with uncertainties. It leads planners to recognize vulnerabilities in a plan and incorporate strategies for dealing with them, adapting to new developments, and building in capacity for taking advantage of new opportunities. The objective of using this adaptive approach is to realize a master plan robust across many futures, so that the port can meet the requirements of its stakeholders during its entire lifetime.

The paper illustrates this approach by applying it to the plan of the Maasvlakte 2, but only on an abstract level. Recently funds have come available to apply APP in its full content for updating the current master plan (version 7) of the Maasvlakte 2. However, until now this framework has never been applied on a port master plan.

In this study, the adaptive port planning method is applied on the two alternatives for Port of Beira. The result will be used to map differences between the master plan alternatives robustness's. This will increase the insight in the robustness criterion for the selection of the best alternative. Furthermore, the robustness of the chosen alternative is increased, because actions for dealing with the vulnerabilities and opportunities associated with each alternative are determined.

Due to a time constraint in this study, the framework of APP is only applied on assumptions related to the expansion of the capacity of the Sena railway line. These particular assumptions are handled, because it is highly uncertain if and when these expansions will take place. Furthermore, the impacts on the master plan will be immense and presumably different for the two alternatives.

This chapter starts by explaining the method with help of the description of the steps cited from (Taneja, 2010). In the following paragraphs all steps are carried out. In paragraph 12.3 it is further explained why only a few assumptions are handled in the framework of APP. The chapter ends with conclusions on the robustness of both alternatives and conclusions on the APP framework.

12.1 Introduction to steps in adaptive port planning

The various steps to be followed in the proposed approach for port planning are illustrated in Figure 12-1 and explained in the following subparagraphs, quoted from the paper published by Taneja (2010).

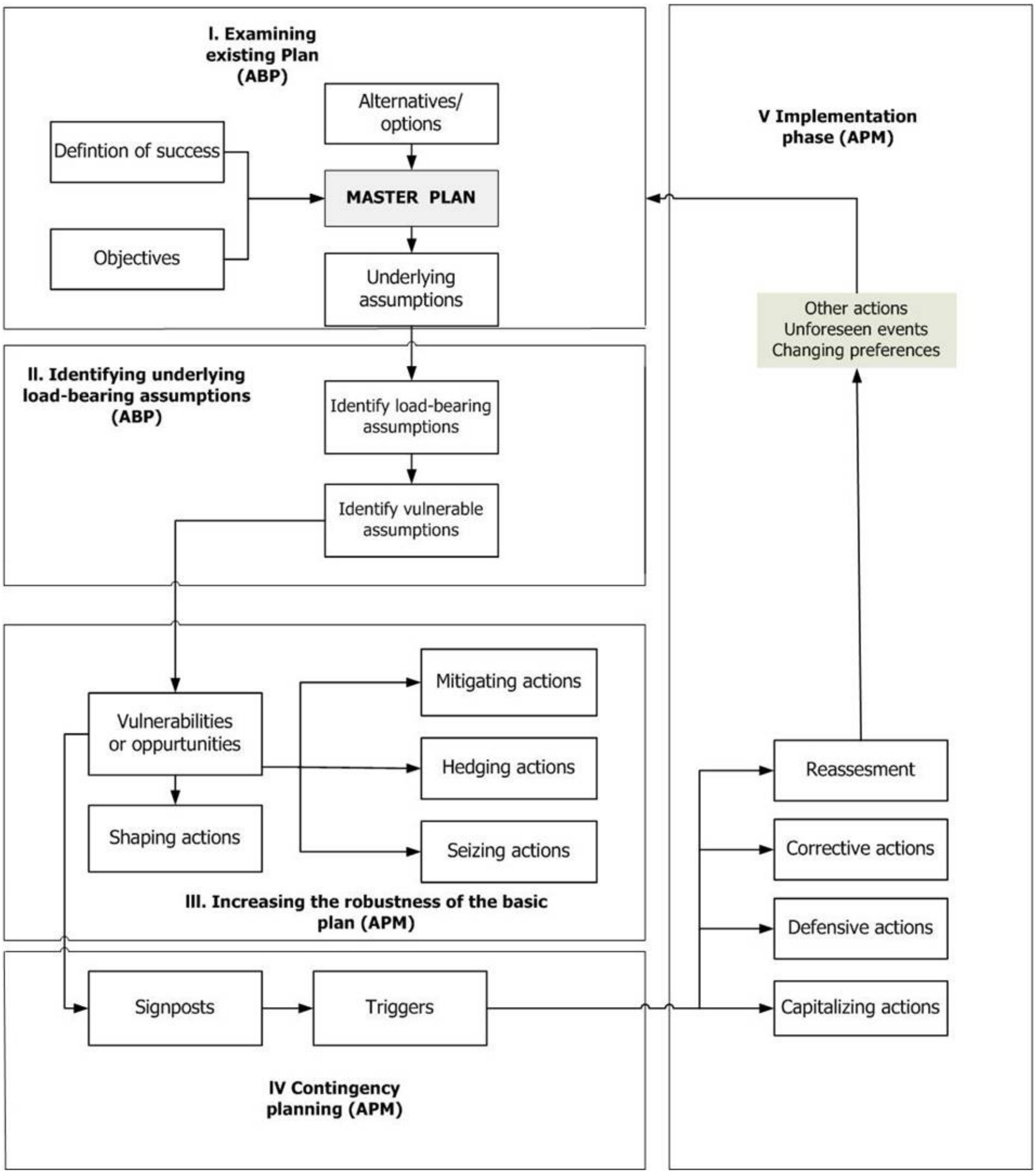


Figure 12-1 | Steps in Adaptive Port Planning (Taneja, 2012)

12.1.1 *Step I: Examining existing plan*

This step involves studying the existing Master Plan in order to identify the objectives of the organization, the definition of success of the plan, the various constraints or boundary conditions, the available options, and the underlying assumptions. Based on this, the definition of success can be given, in terms of the specification of desired outcomes. This is required in order to be able to decide when the plan needs to be changed.

12.1.2 Step II: Identify assumptions underlying basic alternatives

In step II, assumptions in the master plan alternatives are identified. A load bearing assumption is an assumption whose failure would mean that the plan would not meet its objective. Identification of load-bearing assumptions requires an assessment of the consequences of failure of an assumption. Identification of vulnerable assumptions involves thinking about the future and identifying plausible developments that could occur in the lifetime of a plan and, if they were to occur, would cause the plan to fail. If a development causes the plan to fail in its favour, it is called an opportunity. Otherwise, the development is called a vulnerability. These vulnerabilities and opportunities are dealt with in subsequent steps.

12.1.3 Step III: Devise actions to increase the robustness of each basic alternative

In the third step of the process, the robustness of the plan is increased. This step is based on specifying actions to be taken that are related to the vulnerabilities and opportunities identified in step II. A plan can be prepared for vulnerabilities and opportunities by specifying actions to be taken right away or that can be taken in the future if necessary. The latter is considered in step IV.

There are four different types of actions that can be taken in advance, in anticipation of specific contingencies or expected effects of a plan, in order to make it more robust:

- mitigating actions are taken now to reduce the certain adverse effects of a plan
- hedging actions spread or reduce the risk of uncertain adverse effects of a plan
- seizing actions are taken to seize available opportunities that are certain
- shaping actions are taken now and is intended to affect the vulnerability of a critical assumption, by either reducing it or changing its nature.

Mitigating actions and hedging actions prepare the master plan for potential adverse effects and in this way try to make the plan more robust. Seizing actions are actions taken now to change the plan in order to seize available opportunities. In contrast, shaping actions are pro-active and aim at affecting external forces in order to reduce the chances of negative outcomes or to increase the chances of positive outcomes.

12.1.4 Step IV: Set up monitoring system

Even with the actions taken in advance, there is still the need to monitor the performance of the plan and take action if some of the assumptions are failing. In the fourth step, the plan is further expanded via contingency planning, in which the plan is further enhanced by including adaptive elements. The first element of the contingency plan is the identification of signposts. Signposts specify information that should be monitored in order to determine whether the plan is on course to achieving success. The starting point for the identification of signposts is the set of vulnerabilities and opportunities specified in step III. Critical values of signpost variables (triggers) are specified, beyond which actions should be taken to ensure that a plan keeps moving the system in the right direction and at a proper speed. These actions are prepared for in advance; most represent changes to the basic plan. We can define four different types of actions that can be triggered by a signpost:

- defensive actions (DA) are taken after the fact to clarify the plan, preserve its benefits, or meet outside challenges in response to specific triggers that leave the basic plan unchanged
- corrective actions (CR) are adjustments to the basic plan in response to specific triggers
- capitalizing actions (CP) are taken after the fact to take advantage of opportunities that further improve the performance of the plan
- reassessment (RE) is a process to be initiated or restarted when the analysis and assumptions critical to the plan's success have clearly lost validity.

12.1.5 *Step V: Prepare trigger responses*

Once the Master Plan and additional actions are agreed upon, the final step involves implementing the entire plan. In this step, the actions to be taken immediately (from step III) are implemented and a monitoring system (from step IV) is established. After implementation of the initial mitigating, hedging, seizing, and shaping actions to make the plan robust, the adaptive planning process is suspended until a trigger event occurs. As long as the original plan objectives and constraints remain in place, the responses to a trigger event have a defensive or corrective character - that is, they are adjustments to the basic plan that preserve its benefits or meet outside challenges. Sometimes, opportunities are identified by the monitoring system, triggering the implementation of capitalizing actions. Under some circumstances, neither defensive nor corrective actions might be sufficient to save the plan. In that case, the entire plan might have to be reassessed and substantially changed or even abandoned. If so, however, the next plan deliberations would benefit from the previous experiences.

12.2 Define problem and strategy

Step I of Adaptive Port Planning starts with examining the master plan, for this reference is made to the entire report thus far. In this case study the two flexible master plan alternatives are examined. As the two plans are developed with the same main objective, also the definition of success is the same.

12.2.1 Main objective

The main objective of the port authorities is to facilitate the anticipated volume growth and meet port performance requirements in the five market sectors: general cargo, dry bulk, container, fuel and coal, while having a feasible business case with a positive return of investment.

"To facilitate the anticipated growth" means that the sufficient terminal areas, quays and access channel dimensions should be available as determined in the technical requirements, so that the forecasted throughputs can be reached.

"Port performance requirements" should be met in order to ensure user satisfaction. This requires the following:

- Solve current traffic congestion at railroad crossings and thereafter maintain good rail and road accessibility
- Reduce calling ship waiting times to 20% of the service time, while berth occupancy should not drop below 40%
- Provide safe maritime access for all calling ships

"A feasible business case" means that investments in expansions of the port, like quays, terminal terrains and access channel dimensions, should have users. Otherwise no additional revenue is made and investments are not returned.

12.2.2 Definition of success

Success of the master plan is based on meeting the above stated objective. This is directly coupled to the uncertainties, if and when they manifest themselves, being adequately dealt with.

12.3 Step II: Identify assumptions underlying the master plan alternatives

Many assumptions were made in the development of the master plan alternatives. First, a summary is given of the areas in which assumptions were made. Assumptions underlying the master plan alternatives are related to:

- The capacity of the rail connections to the hinterland
- The capacity of the road connections to the hinterland
- The modal split over the modalities road, rail and pipeline
- Well maintained maritime access
- The terminal handling operations; terminal equipment, the handled cargo load per ship and more specific the use of transfer ships for coal export
- Environmental boundary conditions: water levels, currents and sedimentation volumes
- Waiting time standards
- The anticipated throughput in the container, general cargo, dry bulk, coal and fuel market
- The ship dimensions
- Main and terminal gate capacity and peak intensity
- Area available for port expansion
- User requirements, e.g., multi-user or dedicated terminal, shared or individual rail, sharing of equipment or not, value added activities or not

In order to realize a master plan robust across many futures, so that the port can meet its objectives during its entire lifetime, all the assumptions should be handled in the framework of APP. However, this implies a master thesis project on itself. Therefore, for the purpose of illustrating the method, it is chosen to focus only on one of the above mentioned areas.

In the following paragraph it is explained why the expansion of the Sena railway line is chosen to be handled in the framework of APP. The load-bearing assumptions are identified and these implicate four vulnerabilities. The driving forces behind the failure of the assumptions are discussed. Moreover, the vulnerabilities are explained by listing their impacts on the master plan alternatives. The actions, which will be devised in the follow-up steps, should be aimed at the driving forces or the negative impacts.

12.3.1 *Major uncertainties related to the expansion of the Sena railway line*

Based on plans presented by CFM it is assumed that in the three scenarios the railroad will be upgraded. However, currently the capacity of the line is less than 3 million tons per annum (MTPA) and it is uncertain when expansion projects will be implemented. The coal export fully depends on the availability of enough railroad capacity from the Moatize mines to Beira Port. As the anticipated excessive throughput growth in the coal sector is only plausible when the Sena railway capacity is expanded, the underlying assumptions are of great importance to the master plan alternatives. Moreover, a major difference between the two master plan alternatives is made by relocating the coal terminal in alternative 2, while keeping it in place in alternative 1.

Therefore, to illustrate the various steps of Adaptive Port Planning it is chosen to handle the uncertainties that are related to the expansion of the Sena railway line to the Port of Beira. For the master plan alternatives, the following load-bearing-assumptions are present on the expansion of the Sena railway line:

1. The Sena railway line is expanded from a capacity of 3 million to 5 million tons coal per annum in scenario low
2. The Sena railway line is expanded from a capacity of 5 million to 20 million tons coal per annum in scenario most likely
3. The Sena railway line is expanded from a capacity of 20 million to 40 million tons coal per annum in scenario high
4. The Sena railway line transports at least 30% of the general cargo dry bulk terminal throughput
5. The Sena railway line transports at least 1% of the container terminal throughput
6. The Sena railway line transports at least 1% of the fuel terminal throughput

12.3.2 *Vulnerabilities for the master plan alternatives*

The first three assumptions show there is a clear distinction made between the scenarios in the alternatives. Basically, scenario low and high imply an altered master plan of the most likely scenario. Thus, these vulnerabilities are handled separately, despite they are all expansions of the same railway line. In the next steps, it comes clear that the vulnerabilities imply different impacts and thus need other actions. The fourth assumption implicates for all scenarios the same impact and is thus handled for all scenarios together. The last two assumptions do not lead to any positive or negative impacts. Finally, the failure of the first four assumptions can lead to the following vulnerabilities for the two master plan alternatives:

1. The Sena railway line is not expanded at all and the capacity remains 3 million tons coal per annum in scenario low
2. The Sena railway line is not expanded to a capacity over 5 million tons coal per annum in scenario most likely
3. The Sena railway line is not expanded to a capacity of over 20 million tons coal per annum in scenario high
4. The Sena railway line transports less than 30% of the general cargo dry bulk terminal throughput

We conclude that no opportunities for the master plan alternatives arise from failure of the assumptions. This was to be expected, because both alternatives rely heavily on the coal export, which arrives via the Sena railway line.

12.3.3 *Driving forces behind failure of assumption*

The driving forces behind failure of the assumptions are investigated, in order to determine if actions can be added to the master plan alternatives. The driving forces are:

- Local government does not want more rail traffic to Beira. It is foreseen that Beira City does not want to cooperate with the port, because of dust and noise pollution. Dust pollution, due to the fine coal particles taken by the wind to the city. Noise pollution, due to the 24-hour arrival of coal trains. The port is located directly next to the city and the railway line crosses land of the municipality. The port needs the support of the local government to expand the rail traffic.
- Concessionaire does not construct the railway line. In 2003, a tender was won be an Indian consortium (RICON) to completely rehabilitate the Sena line to be able to carry one million tonnes of cargo a year by the end of 2009. In fact, the line was only opened to coal traffic in August 2011, with freight running at just 27% of the initial target and with a cost overrun of over 50 million dollars (All Africa, 2012).
- Technical requirements are not met, which could lead to less capacity of the line than designed for. Also in the above mentioned rehabilitation works, the technical requirements were not met. The durability was thus affected and additional maintenance required, this causes congestion for trains and hence reduced capacity.
- CFM does not receive funding from central government for expansion of the railway line. As discussed paragraph 6.2, several other options exist to export the coal from Moatize; especially Nacala Port is a competitive port. The central government could decide to invest in other routes for the coal export.
- Due to the fiasco of the last concession of the railway line, it is likely that the World Bank, who was the main moneylender, will not finance further expansions. Without the funds, no expansion can be constructed.

12.3.4 *Impacts of less expansion of the Sena railway line than forecasted*

The <u>impact</u> of the above presented vulnerabilities is that the cargo transport to and from the port via rail is unknown, in particular the coal arrivals. This affects the dimensions of the coal terminals, but also the other terminal grounds and thereby the entire master plan. Next, all impacts on the master plan alternatives per vulnerability are listed. Impacts can either be on both alternatives or specific for one.

1. The Sena railway line is not expanded at all and the capacity remains 3 million tons coal per annum in scenario low

   Impacts on both alternatives
   - The coal export is less than 5 MTPA, which results in less revenue for the port authorities, because the port fee depends on the throughput.
   - Quay 8 has a low occupancy, because it is dedicated to the coal ships.
   - Road accessibility increases to general cargo dry bulk and fuel terminals, due to lower intensity on railroad crossings
   - Main gate intensity is larger than capacity, because forecasted rail cargo is transported by trucks. This impact presumes that the additional 2 million tons is transported by trucks to the port. These have to enter the port through the main gate, increasing peak intensity and thus leading possibly to road congestion.

2. The Sena railway line is not expanded to a capacity over 5 million tons coal per annum in scenario most likely

   Impacts on both alternatives
   - The coal export is less than 5 MTPA, which leads to less revenue for the port authorities. The alternatives are designed for 20 MTPA and the port fee depends on the realized throughput.

- The draft of coal ships calling Beira Port does not increase, because economies of scale are not applicable. With 5 MTPA, the same nautical operations will be used for the coal export.
- Less ship movements in port area. Waiting times for the container, general cargo, dry bulk and fuel ships will presumably decrease, due to the less used maritime access to Beira Port.

Impacts on alternative 1

- The coal exporters are not willing to leave their plot to make room for the container and general cargo dry bulk terminals. As the capacity of the current coal terminal plot is not exceeded, there is no incentive for the coal exporters to move their operations to the new northern terminal area.
- Expansions of the terminal areas and quays for the coal sector are just partly used. The new northern terminal is designed for 20 MTPA, thus space remains free for alternative use.

Impacts on alternative 2

- Expansions of the terminal areas and quays for the coal are not used. The capacity of the current terminal is sufficient to export all the coal. The prepared land in the north is left unused.
- The channel extension to the new coal terminal area is not used.

3. The Sena railway line is not expanded to a capacity over 20 million tons coal per annum in scenario high

   Impacts on both alternatives

   - The coal export is less than 20 MTPA, which leads to less revenue for the port authorities. The expansion for scenario high is designed for 40 MTPA and the port fee depends on the realized throughput.
   - The size of coal ships calling Beira Port does not increase to Panamax ships, because economies of scale are not applicable.
   - Expansions of the terminal areas and quays for the coal sector are not used

4. The Sena railway line transports less than 30% of the general cargo dry bulk terminal throughput

   Impacts on both alternatives

   - Main gate truck intensity is larger than capacity, because forecasted rail cargo is transported by trucks. This impact presumes that the same amount of cargo is transported through the port, only not by rail.
   - The general cargo and dry bulk throughput is less than forecasted. For this impact it is presumed that the goods transported by rail cannot by transported by trucks and thus this part of the market is lost.

12.4 Step III: Devise actions to increase robustness of the plan

In step III, we define actions that can be taken in the planning phase to make the plan robust. The plans are prepared for the vulnerabilities by specifying actions to be taken right away. All vulnerabilities in this case study are uncertain, because all certain vulnerabilities were already taken into account in the development of the alternatives. Two types of actions are applicable: hedging and shaping actions.

Hedging actions (HA) spread or reduce the risk of uncertain adverse effects of a plan; they prepare the master plan for potential adverse effects and in this way try to make the plan more robust. Shaping actions (SHA) are taken now and are intended to affect the vulnerability of a critical assumption, either by reducing it or changing its nature; they are pro-active and aim at affecting external forces in order to reduce the chances of negative outcomes or to increase the chances of positive outcomes.

12.4.1 The Sena railway line is not expanded at all and the capacity remains 3 million tons coal per annum in scenario low

- SHA: Invest in Sena railway line expansion. As the railway line is the lifeline of the port, the authorities (CFM) could invest themselves in the railway line, because the money will be returned due to acquired throughputs and thus port fee income.
- SHA: Promote investments by coal exporters in Sena railway line expansion. As the coal export sector will primarily benefit from the railroad line, they should take their responsibility and invest in the expansions. Moreover, the coal exporters are wealthy companies and have sufficient funds available, where the Mozambiquan government has to lend money.
- SHA: The port authorities should take a leading role in the management of the railroad expansion. In the recent rehabilitation project, the contractor had the leading role in the management. The project failed, because their primary interest was making money and not completing the railroad expansion.
- SHA: Use price strategies; internalize external costs in pricing of road transport to stimulate investments in rail.
- HA: Promote benefits of alternative modalities for the coal sector. This action helps to reach the coal throughput figures without the railroad capacity increase.
- HA: Promote new transport solutions from coal mine to port, like pipeline transport. The throughput could be reached by using innovative transportation means. The projected coal exports are of such a scale that a brand new transport system could be implemented.
- HA: Make agreements with the coal exporters to make alternative use of quay 8, due to the low berth occupancy. The general cargo and dry bulk sector could again make partly use of quay 8 if there is only 3 MTPA export through the coal terminal. This would decrease general cargo and dry bulk ship waiting times.

Changing to truck transport, will be introduce a new vulnerability, that is – road congestion due to the additional coal truck traffic.

- SHA: Invest in road accessibility to ensure total export of 5 million tons coal per annum can be reached
- HA: Increase main and terminal gate handling capacity for trucks, to be able to handle the promoted change in modality

12.4.2 *The Sena railway line is not expanded to a capacity over 5 million tons coal per annum in scenario most likely*

- HA and SHA: The same actions as mentioned for the first vulnerability are applicable for the second vulnerability. In addition, the following actions can be taken.
- HA: Invest in flexible infrastructure. The design of the new quay structures should be flexible or adaptable, to prepare the port for other cargos than coal. The same master plan alternatives can then be used, but the designated coal terminal areas will be used by other cargo flows.
- HA: Share risk of wet layout investments with coal exporters. One of the main cost drivers are the capital dredging activities, which will be mainly undertaken for the coal ships. By sharing the investment risks with the coal exporter, they have a driving force to make the master plan of the Port of Beira to a success. Additionally less money is lost if the project fails.
- SHA: Stimulate promotional and marketing activities by coal sector. To convince the Mozambiquan government and local actors of the necessity and benefits of the coal export, the port authorities can help with promotional and marketing activities of the coal sector.
- HA: Seek alternative use for the unused coal terminal areas and quays, by attracting new markets.

12.4.3 *The Sena railway line is not expanded to a capacity of over 20 million tons coal per annum in scenario high*

- HA and SHA: All the actions mentioned before can be applied to make the alternatives more robust.

12.4.4 *The Sena railway line transports less than 30% of the general cargo dry bulk terminal throughput*

- HA: Negotiate infrastructure investments with terminal operators. This induces that the risk of less throughput is spread with the terminal operators. The terminal operators should share in the investment cost, which will be returned when forecasted throughput is reached.
- HA: Promote benefits of alternative modalities for the general cargo and dry bulk sector. This action helps to reach the throughput figures in the different scenarios without using the railroad.

12.5 Step IV: Set up monitoring system

Now we have stated actions that can be taken on beforehand, but there is still the need to monitor the performance of the plan and take action if some of the assumptions are failing. We start out by identifying signposts, which specify information that should be monitored in order to determine whether the plan is on course to achieve success. For each vulnerability, the possible signposts are discussed.

Critical values of signposts variables (triggers) are specified, beyond which actions should be taken in order to reduce the negative impacts stated in paragraph 12.3.4 or induced by actions taken in step III. The numbers used as triggers are illustrative and need to be researched.

We see that some signposts can be used for multiple vulnerabilities, but the triggers are different and the accompanying actions will divert too. We set up a monitoring system, whereby four different types of actions can be triggered by a signpost:

- defensive actions (DA) are taken after the fact to clarify the plan, preserve its benefits, or meet outside challenges in response to specific triggers that leave the basic plan unchanged
- corrective actions (CR) are adjustments to the basic plan in response to specific triggers
- capitalizing actions (CP) are taken after the fact to take advantage of opportunities that further improve the performance of the plan
- reassessment (RE) is a process to be initiated or restarted when the analysis and assumptions critical to the plan's success have clearly lost validity.

In this final step, the differences between the two alternatives will influence the actions to be taken. We will see that that some triggers require different actions per alternative. After this step, conclusions can be made about the difference in robustness of the two plans for the assumption that the Sena railway line will be expanded.

Four monitoring systems were devised, which will be discussed in the following sub-paragraphs. Each section starts with an explanation of the monitoring system, followed by the determined triggers and ended with their accompanying actions.

12.5.1 Monitor Sena railway line expansion

The railroad construction is monitored to know how much throughput could be transported by rail. Corrective actions can be taken to reduce the negative impacts of the first three vulnerabilities. Furthermore, the throughput forecasts should be adapted to the expected capacity of the railway line due to the railway line expansions.

Triggers

- If no start is made with construction of railroad upgrade to over the present 3 million tons coal per annum, while implementing the master plan for scenario low, do RE1
- If no start is made with construction of railroad upgrade to over 5 million tons coal per annum, while implementing the master plan for scenario most likely, do RE1 and CR1
- If no start is made with construction of railroad upgrade over 20 million tons, while implementing the master plan for scenario high, do RE1 and CR2

Actions

CR1: Do not construct rail connection to expansion for the coal sector, because it will not be used.

CR2: Do not construct rail connection to scenario high expansion for the coal sector.

RE1: Reassess coal, dry bulk and general cargo throughput forecasts. New forecasts should be made, which take into account that there is no additional railway capacity.

12.5.2 *Monitor throughput forecast*

The throughput forecasts are based on the capacity of the railway line coming available in different scenarios. However, without the railway line capacity the throughput figures could still be reached by using different modalities. Therefore, the throughput forecast should be updated every year in order to know when corrective actions should be taken. Additionally a reassessment of a part or the entire master plan has to be taken when throughputs are below initially forecasted.

Triggers

- If coal export forecast is less than 3 MTPA, while other commodities are as in scenario low, do CR3
- If coal export forecast is less than 5 MTPA, while other commodities are as in scenario most likely, do CR4 and RE2 for alternative 2
- If coal export forecast is less than 5 MTPA, while other commodities are as in scenario most likely, do RE3 for alternative 1
- If coal export forecast is less than 20 MTPA, while other commodities are as in scenario high, do CR5, RE2 and RE4
- If general cargo and dry bulk throughput can be handled on the most likely quay and terminal area, do CR6

Actions

CR3: Assign quay 8 also to general cargo or dry bulk ships, thus not dedicated to coal ships only. It can be used by other ships, because the occupancy of the quay is low. Thereby the waiting times of the general cargo and dry bulk fleet are reduced.

CR4: Do not construct expansion for the coal sector, as this will not be used in alternative 2

CR5: Do not construct scenario high expansion for the coal sector

CR6: Do not construct scenario high expansion for the general cargo and dry bulk sector

RE2: Reassess wet layout dimensions, because the draft and the number of ships in the channel are much lower than initially designed for.

RE3: Reassess entire master plan, because relocating the coal terminal does not seem a logical option anymore, because the current capacity is sufficient. The other terminals are thus affected that an entire reassessment of the master plan alternatives is necessary.

RE4: Reassess location scenario high expansion for the container sector, because it can possibly be located closer to the rest of the port.

12.5.3 *Monitor ship size*

Due to economies of scale in the coal sector, it is forecasted that ship sizes will increase to Panamax dimensions in scenario high. The wet layout and quays are designed for these ships. Therefore, it is essential to monitor the ship size demand and reassess the master plan if necessary

Trigger

- If still only Handymax ships with a 40,000 DWT load are demanded in scenario high, do RE3

Action

RE3: Reassess entire master plan. The coal berths have to be redesigned, which affects the coal quays and terminal areas. The wet layout needs a reassessment, due to the changed ship sizes and accompanying ship movements in the access channel and port basin. Affectively the entire master plan has to be reassessed.

12.5.4 *Monitor truck delay*

Due to actions taken in advance to ensure the required throughput in the scenarios is reached, truck traffic will be more than forecasted. This could result in truck waiting times higher than the accepted standards. The truck delay is monitored and when the accepted standards are reached, actions should be taken. Small defensive actions should be taken preferably before the standards are exceeded.

What the accepted standards are currently should be investigated in cooperation with the terminal operators. Because it depends on many factors, it is outside the scope of this study and only percentages of the accepted standards are given as a guideline for the actions.

Triggers

- If delay is at 80% of accepted standard, do DA2
- If delay is at 100% of accepted standard, do CP1
- If delay is at 150% of accepted standard, do CR7 or CR8
- If delay is at 200% of accepted standard, do RE5

Actions

DA2: Invest in traffic control systems. These will increase the capacity of the implemented road network.

CP1: Increase road fee. The port authorities should make advantage of the large road demand by increasing the road fee. Moreover, the transporters are thus encouraged to invest in the rail network.

CR7: Invest in viaducts. When busy rail crossings are a source of congestion, these can be resolved by constructing viaducts.

CR8: Increase main gate capacity. By increasing the capacity, the waiting times will be reduced.

RE5: Reassess road plan. Now it is assumed that the proposed road network does not suffice anymore. The reassessment should focus on increasing road capacity, gate capacity and rerouting of truck traffic.

12.6 Step V: Implementation

In the implementation step, the mast plan alternatives are now expanded with the actions specified in Step III and the monitoring system specified in step IV. The actions specified in step IV, should be implemented when the accompanying triggers are reached. In appendix VIII a schedule is given, which summarize all the vulnerabilities, impacts, monitoring systems and actions.

Furthermore, this step is basically the implementation of the devised master plan with the devised monitoring system and actions, which is the follow-up step of this study.

12.7 Conclusions on the master plan alternatives

In the introduction to this chapter, two goals were determined for application of the APP framework in this study. First, the robustness of the master plan alternatives has to be increased for the uncertainty of the expansion of the Sena railway line. Secondly, it was aimed to map differences between the two alternatives.

The robustness for the expansion of the Sena railway line is increased, by devising actions for the determined vulnerabilities. No opportunities could be detected in this particular region of assumptions, which shows the importance of the expansion of the railway line for the Port of Beira.

The vulnerabilities for the coal sector were split for the three scenarios, because there is a clear distinction made between the scenarios. The three vulnerabilities imply different impacts and thus need other actions. Less expansion of the Sena railway line also implies a vulnerability for the general cargo and dry bulk sector. The impacts are the same for all the scenarios and thus in the framework of APP handled together.

By determining the driving forces behind the vulnerabilities many shaping actions could be devised that can be taken on beforehand, in order to reduce the risk of no or less expansion of the Sena railway line. Additionally hedging actions were devised in Step III to reduce the negative impacts of the vulnerabilities.

We can conclude from this APP study that securing public and private investments for the expansion of the port hinterland connection is essential for the port itself. Furthermore, the investment and constructions should be supervised by the port authorities to make sure the expansions are executed according to plan. Innovation in the coal transport sector should be stimulated, in order to be able to reach the proposed capacity of the coal terminals.

The coal sector depends largely on the expansion of the railway line. Solutions can be found in shifting modalities from rail to road. However, these actions result in an increase in truck traffic, with road congestion as a new vulnerability. When promoting truck traffic, care should be taken whether the master plans require correction or reassessment. Therefore, in step IV the truck delay is monitored and actions were devised.

If the rest of the port activities are considered, it can be concluded that the impacts are much less. Because the coal terminal is largely separated from the other cargo streams, corrective measures can be taken for only the coal terminal areas and quays. However, in the most likely scenario a distinction can be made between the alternatives, because in alternative 1 the present coal terminal has to make room for the expansion of the container terminal.

Table 12-1 summarizes the differences between the two alternatives for the vulnerability that the capacity of the Sena railway is not expanded to 5 million tons coal per annum in the most likely scenario. It is concluded that the relocation of the coal terminal in alternative 1 will become an issue, when the expansion is not as forecasted. No actions could be devised to prevent or reduce this impact. The only solution is to reassess the entire master plan, because the whole layout is affected.

Alternative 2 is made more robust for the above mentioned vulnerability. Still a corrective action and reassessment of the wet layout is necessary, but this is a smaller measure than an entire reassessment of master plan alternative 1. Measured on the robustness for the vulnerabilities linked to expansion of Sena railway line, alternative 2 is more robust.

Table 12-1 | Impact and action differences between master plan alternatives in scenario most likely

Alternative	Impact	Hedging (HA) and Shaping (SHA) actions	Monitoring	Actions Reassessment (RE) Corrective (CR)
1	Expansions of the terminal areas and quays for the coal sector are just partly used	HA: Seek alternate use for the unused coal terminal areas and quays	If coal export forecast is less than 5 MTPA	RE3: Reassess entire master plan
	The coal exporters are not willing to leave their plot to make room for of the container and general cargo dry bulk terminals			
2	Expansions of the terminal areas and quays for the coal are not used	HA: Seek alternative use for the unused coal terminal areas and quays	If coal export forecast is less than 5 MTPA	CR4: Do not construct expansion for the coal sector
	The channel extension to the new coal terminal area is not used			RE2: Reassess wet layout dimensions

12.8 Conclusions on the APP framework in general

This case study shows that APP is an effective tool to make a master plan robust among uncertain futures. Investing time in the early stage of the development of a project is normally considered as money well spent.

However, this case study also shows the extend of implementing the APP framework. In this study, just one region of assumptions was investigated, which already resulted in many actions. As shown in the introduction of paragraph 12.3, many more assumptions should be handled to fully realize a master plan robust across many futures.

Furthermore, by devising actions for the determined vulnerabilities, new vulnerabilities are created for which again actions should be devised. This is illustrated in this study by the increase in road congestion, due to the advertised shift in modality for the coal sector. Vulnerabilities induced by the proposed actions are currently not handled in the APP framework. All actions have a reaction, thus by devising more actions, also more reactions are triggered. The question remains where does the planning stop? The next step would be to weigh actions in a cost benefit analysis, to see whether a devised action should be taken or not.

13 COST ESTIMATE

One of the criteria of the multi criteria analysis in the next chapter is costs. In the framework of this study, a cost estimate will suffice as a financial criterion. Revenue of the two alternatives is assumed to be equal, because they are designed for the same throughputs and thus port fee income will be equivalent. A full economic study, including revenues, is recommended in follow-up research, but is outside the scope of this study.

The cost estimates for the alternatives are discussed for each scenario, to determine their flexibility for these futures. In this chapter, also some additional design decisions are made to complement the cost estimates. Only the costs for civil and marine works are taken into account. The terminal operators are responsible for further development of the quays and terrains.

The unit prices are determined using benchmark projects. Mostly projects inside the Port of Beira are used, because these represent the actual situation best. Where no benchmark project in the port could be found, the unit prices from the Port of Said master plan (DHV BV, 2008) are used.

This chapter starts with determining the various cost elements. The first four paragraphs all start with some additional design decisions, which act as input for the investment cost estimate. The paragraphs end with determining the maintenance cost. The first cost element that is discussed is the dredging cost, followed by the terminal areas, quays, jetties, roads and railroads. Paragraph 13.5 discusses some additional overall investment costs.

All investment and maintenance costs are summarized and accumulated in the net present value paragraph. To compare the costs of the two alternatives the values are discounted for the most likely scenario and the result is discussed in subparagraph 13.7.2, followed by a sensitivity analysis for scenario low and high and several major assumptions. Final conclusions on the cost estimate are made in the closing paragraph.

Not included is the operational cost of the port authorities: port administration, traffic regulation, security, customs and back-office. For a feasibility study, these must be incorporated together with the revenues.

13.1 Dredging

Dredging of the access channel can best be done with a trailing suction hopper dredger. These can operate in higher wave conditions than a cutter dredger and are easy to manoeuvre, which limits commercial traffic hindrance. In 2011, two suction hopper dredgers were used by van Oord to perform the emergency dredging of 9 million m^3. (DHV BV, 2011f)

13.1.1 Capital dredging

Van Oord has provided surveys of the channel before and after the dredging works. The channel cross sections were analysed and an average depth of the channel surroundings was determined: -5 m CD. The channel will be dredged as a trapezoid with slope angles of 1:6 (DHV BV, 2011f), illustrated by the picture below.

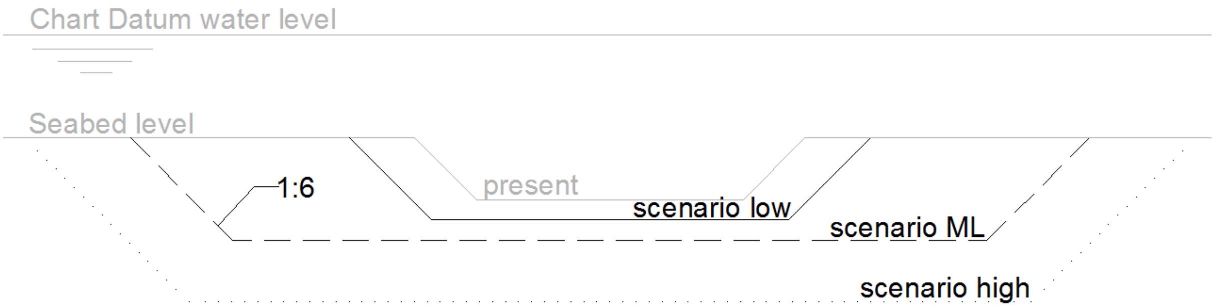


Figure 13-1 | sketch of cross-section access channel in different scenarios, (not on scale)

The unit rate for dredging is based on the quotation by Van Oord, which includes fuel consumption and mobilization/demobilization, leading to €5/m^3 (DHV BV, 2011f). It must be noted that the below is a very rough estimate of the capital dredging costs. The €/m^3 depends on several unknowns, as the fuel price, dump distance, used equipment, etcetera. More important the dredge volumes depend on the actual cross sections when starting the capital dredge project.

Table 13-1 and Table 13-2 show the capital dredging volume and cost calculations for the different scenarios in the master plans. The dredging works along the quay are neglected as these volumes are assumed negligible in comparison to the access channel dredging.

Table 13-1 | Capital dredging costs alternative 1

	Low	Most likely	High
Channel depth [m CD]	-9	-9	-12
Channel width [m]	174	367	410
Channel length [m]	35000	35000	35000
Slope	0.167	0.167	0.167
Average surrounding depth [m]	-5	-5	-5
Dredged volume [m^3]	12,180,000	39,200,000	95,200,000
Unit price [€/m$^{3]}$	5	5	5
Total costs [€]	**60,900,000**	**196,000,000**	**476,000,000**

Table 13-2 | Capital dredging costs alternative 2

	Low	Most likely	High
Channel depth [m CD]	-9	-10	-13
Channel width [m]	174	367	410
Channel length [m]	35000	35000	35000
Slope	0.167	0.167	0.167
Average surrounding depth [m]	-5	-5	-5
Dredged volume [m^3]	12,180,000	53,935,000	112,700,000
Unit price [€/m$^{3]}$	5	5	5
Total costs [€]	**60,900,000**	**269,675,000**	**563,500,000**

In scenario low of alternative 1, a passing lane is constructed. In paragraph 9.5.4 the design of the passing lane is explained. The maximum number of ships in the channel found in the Harboursim simulation is seven, as shown in Figure 13-2 below.

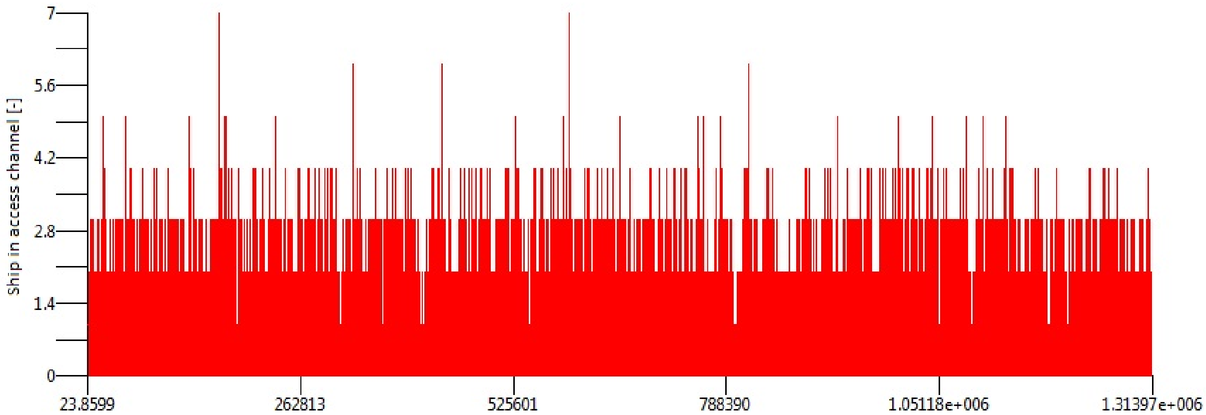


Figure 13-2 | Number of ships in the channel, from Harboursim simulation A1 & A3

The above will be used for the convoy length calculation. The widths were calculated in paragraph 8.5.1 and 500 m safety distance is chosen. The average ship length in scenario low is about 160 m, resulting in the following passing lane length:

*Convoy length = # ships * ship length + (# ships – 1) * distance between ships + safety distance*
*Passing lane length = Convoy length + 2 * 5 * (two-way width – single lane width) =*
*7 * 160 + (7 – 1) * (3 * 160) + 500 + 2 * 5 * (367 – 174) =*
6400 m

Table 13-3 show that the additional dredging cost is 20 million € for scenario low of alternative 1.

Table 13-3 | Capital dredging cost for passing lane

Passing lane depth [m CD]	-9
Passing lane width [m]	367
Passing lane length [m]	6400
Slope	0.167
Average surrounding depth [m]	-5
Dredged volume [m^3]	3,970,000
Unit price [€/m$^{3]}$	5
Total costs [€]	**19,900,000**

13.1.2 Maintenance dredging

The amount of maintenance dredging will increase with larger dimensions of the channel, because it will allow more sand to settle. DHV expert opinion is that doubling the channel width will increase the current sedimentation rate with a factor 1.5 to 2, for our calculation we use 1.5. Increasing the access channel depth is assumed to increase the sedimentation rate with 10% per meter added depth, again from DHV expert experience.

The passing lane in alternative 1 is implemented close to the port basin. Here, the sedimentation rates are high, indicated by the extensive shoal formation in this region. This is backed-up by an interview held with the director of the port's dredging contractor, in which he states that the maintenance dredging is concentrated in this region. Following the above facts it is assumed that widening the channel in this region has the same effect as widening the entire channel and the accompanying width factor for scenario low is determined at 1.5.

As stated in paragraph 4.5, the sedimentation processes are complicated and therefore further research is recommended to predict the sedimentation rates. In the net present value calculation, the sensitivity on this matter is checked by varying the annual dredged volume per scenario. For now, the following tables give the determined annual maintenance dredging costs:

Table 13-4 | Maintenance dredging costs alternative 1

	Present	Low	Most likely	High
Channel depth factor	1	1.1	1.1	1.4
Channel width factor	1	1.5	1.5	1.5
Annual dredged volume	2,700,000	4,500,000	4,500,000	5,700,000
€/m^3	5	5	5	5
Maintenance costs [€]	**13,500,000**	**22,300,000**	**22,300,000**	**28,400,000**

Table 13-5 | Maintenance dredging costs alternative 2

	Present	Low	Most likely	High
Channel depth	1	1.1	1.2	1.5
Channel width	1	1	1.5	1.5
Annual dredged volume	2,700,000	3,000,000	4,900,000	6,100,000
€/m^3	5	5	5	5
Maintenance costs [€]	**13,500,000**	**14,900,000**	**24,300,000**	**30,400,000**

13.2 Terminal areas

The terminal area costs are depicted by the reclamation cost, soil improvement and relocation of terminals. First, the new areas are determined from the master plan alternatives drawings, with which the required sand volume is determined for reclamation and soil improvement. It will be substantiated whether this results in investment costs. Next, the additional soil improvement costs are discussed and quantified. In the last section, assumptions are made on the relocation of terminals and rail workshop.

13.2.1 Reclamation

A 6 m thick sand layer is required to improve the soil conditions for the new terminal areas north of the present port area (DHV BV, 2011f). Inside the port area, the sand required for soil improvements is likely to be less. In Table 13-6 and Table 13-7 the terminal areas per scenario are given, calculated from the terminal areas stated in chapter 11.

Some new terminal grounds are already used for construction and thus need little or no improvement. These already prepared areas include: the terminal grounds that are switching user, the rail workshop and the present reclamation site.

Table 13-6 | Additional terminal area [m^2] in different scenarios of alternative 1

	Low	Most likely	High
Container	292,000	666,000	1,070,000
General cargo / dry bulk	140,000	140,000	230,000
Coal	72,000	451,000	1,060,000
Fuel	52,000	242,000	397,000
Subtotal	**556,000**	**1,499,000**	**2,757,000**
Already prepared	248,000	1,047,000	1,047,000
Total new area	**308,000**	**452,000**	**1,710,000**

Table 13-7 | Additional terminal area [m^2] in different scenarios of alternative 2

	Low	Most likely	High
Container	363,000	708,000	1,054,000
General cargo / dry bulk	86,000	109,000	207,000
Coal	72,000	444,000	1,115,000
Fuel	52,000	249,000	389,000
Subtotal	**573,000**	**1,510,000**	**2,765,000**
Already prepared	70,000	558,000	558,000
Total new area	**503,000**	**952,000**	**2,207,000**

If we multiply the new area requirements by the conservative 6 m, it can be safely said that the volume of dredged material to form the basin and access channel is much larger than the soil volume required for land reclamation and soil improvement. Only the sandy layers should be used for the soil improvement. All other dredged material is deposited at dump sites as close to the access channel as possible, without increasing sedimentation rates of the channel.

The hoppers dredging sand, while sailing towards the port basin, dump the sediment on the reclamation site. As for the opposite direction, the sediment is dumped outside the port area. With this dual operation less time is wasted with sailing, which results in lower costs. The assumption is made that the reclamation works will not result in extra costs, similar to the dredging works performed by Van Oord in 2011 (DHV BV, 2011f)

13.2.2 *Soil improvement*

For the terminal areas, it is assumed that these will be developed by the terminal operator. The land will be served ready for constructing and thus soil improvements are necessary. The new areas have to be preloaded with a sand bed. The temporary overloading thus created will ensure the soil is improved and ready for construction. The water overpressure induced by the weight of the sand will be released by vertical drains.

Costs for removing the surplus of sand and placing drainages are considered. The unit removal price of the sand is based on the Port of Said master plan benchmark project, the price is 1.5 €/m^3 (DHV BV, 2008). Using the same report it is determined that about 2 m of sand has to be removed, resulting in a sand removal price of 3.0 €/m^2. The drainage unit price is determined at 1.5 €/m^2, based on the reclamation works performed by van Oord in 2011 (DHV BV, 2011f).

Table 13-8 | Soil improvement costs for alternative 1

	Low	Most likely	High
Total new area [m^2]	308,000	452,000	1,710,000
Removal price [€/m^2]	3	3	3
Drainage price [€/m^2]	1.5	1.5	1.5
Drainage costs [€]	**1,386,000**	**2,034,000**	**7,695,000**

Table 13-9 | Soil improvement costs for alternative 2

	Low	Most likely	High
Total new area [m^2]	503,000	952,000	2,207,000
Removal price [€/m^2]	3	3	3
Drainage price [€/m^2]	1.5	1.5	1.5
Drainage costs [€]	**2,264,000**	**4,284,000**	**9,932,000**

As soil improvement takes time and better results are achieved when taking more time for consolidation, the areas to be improved are installed long before implementation of the rest of the plan. This will be further discussed in the paragraph on phased implementation.

13.2.3 *Relocation of terminals and rail workshop*

The relocation of the rail workshop will be a costly operation as new shunting tracks, workshop buildings, offices and more has to be constructed. As the size and content has yet to be determined, just an indicative lump sum of 8 million euro is estimated, using the port of Said master plan as a benchmark (DHV BV, 2008). This lump sum figure should be further investigated, because in alternative 1 it is implemented in an earlier stage than in alternative 2, thus has an important role in the NPV comparison.

There will be additional costs in alternative 1 for relocation of the coal terminal. The equipment can be used at the new terminal, but has to be dismantled, transported and rebuilt. A first estimate of the costs is 5 million euro. The relocation of part of the general cargo terminal in alternative 2 will be much less, as no dedicated handling systems are present, only some storage sheds have to be removed. The costs are estimated at € 500,000.

13.3 Quays and jetties

The quays are capital-intensive structures. Depending on the subsoil conditions, the water depth and the loading conditions, the quay can have various structural characteristics. For this study, benchmark figures are used, obtained from experience in other DHV projects.

First, the investment costs of the quay extensions are determined, followed by the construction costs of the new jetty. Thereafter, two quay adaptions are discussed. The paragraph is ended with the maintenance costs of the quays and jetties.

13.3.1 Quay extensions

The costs for quay extensions are found by determining a unit price per running meter quay length. The cost for every 10 meters additional quay length is found in a feasibility study for another coal terminal in Mozambique: €100,000 per m quay length (DHV BV, 2012). In the following tables, the additional quay lengths are depicted and by multiplying this with the unit price, the total costs are found in each scenario per alternative.

Table 13-10 | Quay construction costs of alternative 1

	Low	Most likely	High
Container terminal [m]	-	183	825
General cargo / dry bulk terminal [m]	-	-	320
Coal terminal [m]	-	705	1093
Fuel terminal [m]	NA	NA	NA
Total [m]	0	888	2,238
Unit price [€/m]	100,000	100,000	100,000
Total costs [€]	**-**	**88,800,000**	**223,800,000**

Table 13-11 | Quay construction costs of alternative 2

	Low	Most likely	High
Container terminal [m]	-	-	300
General cargo / dry bulk terminal [m]	410	410	708
Coal terminal [m]	-	475	824
Fuel terminal [m]	NA	NA	NA
Total [m]	410	885	1,832
Unit price [€/m]	100,000	100,000	100,000
Total costs [€]	**41,000,000**	**88,500,000**	**183,200,000**

13.3.2 New jetty

The new jetty is built in both the alternatives at the same time and the costs will be equal, because only the location slightly differs. Consequently, the cost for the jetty will have no impact on the comparison of the alternatives.

The costs for the new jetty are estimated by using a benchmark project in Kamchatka where a similar jetty was built. This jetty was built for roughly €30,000,000 (DHV BV, 2010). This figure will also be used in this study.

13.3.3 Quay adaptions for new use

It shall be considered that the general cargo dry bulk quay 6-7 will be used for container handling in alternative 2. The container ships are serviced using container STS cranes, positioned on rails, which results in a different weight distribution over the quay structure. The additional costs for adapting the quay for container terminal use are estimated at € 3,000,000, using a reference project with a quay of 300 m (DHV BV, 2011e).

In alternative 1 quay 8 is extended by cutting 27 m of quay 9. The works consist of demolishing part of quay 9 and thereafter constructing a new quay structure of 27 m. The major cost factor will be the construction of the new quay, wherefore the earlier introduced unit price of € 100,000/m is used. Adding the demolition costs, a total lump sum of 3 million euro is estimated.

In the most likely scenario of alternative 1, a mooring site for container ships is located next to quay 10. The old quay construction of quay 11 can partly be used. The design ship is larger than this present construction, thus an additional breasting dolphin should be constructed. A first rough indication of the construction cost is 2 million, based on DHV expert opinion.

13.3.4 Maintenance costs

The annual maintenance costs are expressed as a percentage of the investment costs; 2% in the case of infrastructure (DHV BV, 2012), thus maintenance cost are € 2,000 per meter. As the present maintenance costs for infrastructure are unknown, these will be calculated using the same assumption. The total current quay length is 1770 m, resulting in 3.5 million euro per annum. The additional maintenance costs, due to implementation of the master plan alternatives are added to the present maintenance costs, see Table 13-12.

Table 13-12 | Quays and jetties maintenance costs

	Present	Low	Most likely	High
Alternative 1	3,540,000	3,540,000	5,316,000	8,016,000
Alternative 2	3,540,000	4,360,000	5,310,000	7,204,000

13.4 Roads and railroads

The last costs encompass the main roads and railroads to connect the terminals in the port. First, the investment costs of the new roads and railroads are determined. Thereafter the maintenance costs are covered.

13.4.1 Investment costs

To calculate the road and railroad investment costs a fixed unit price per running meter single lane is assumed from various previous studies.

The unit price per running meter railroad is €700, based on a reference project in Mozambique (DHV BV, 2012). This includes all works, like earthworks, tracks, ballast, signs, etcetera.

The unit price per running meter single lane road is €300, based on a study of 115 road projects done in sub-Saharan countries to road cost prices, quoted in (Grontmij, 2011). This includes all works, like earthworks, pavement, lining, curbs, road signs, etcetera. It is further assumed that all roads are constructed with two lanes in each direction. The directions will be physically separated, to ensure truck drivers stay on their own side. The railroad lines are for now assumed to have double tracks.

From the drawings of the alternatives, the additional length in each scenario per alternative is determined, which results in the following cost tables:

Table 13-13 | New roads and railroads in alternative 1

	Low	Most likely	High
Roads [m]	14,000	22,000	30,000
Unit price [€/m]	300	300	300
Road costs [€]	4,200,000	6,600,000	9,000,000
Railroads [m]	5,000	11,600	16,200
Unit price [€/m]	700	700	700
Railroad costs [€]	**3,500,000**	**8,120,000**	**11,340,000**
Total costs [€]	**7,700,000**	**14,720,000**	**20,340,000**

Table 13-14 | New roads and railroads in alternative 2

	Low	Most likely	High
Roads [m]	14,000	24,000	30,000
Unit price [€/m]	300	300	300
Road costs [€]	4,200,000	7,200,000	9,000,000
Railroads [m]	5,600	11,600	11,600
Unit price [€/m]	700	700	700
Railroad costs [€]	**3,920,000**	**8,120,000**	**8,120,000**
Total costs [€]	**8,120,000**	**15,320,000**	**17,120,000**

The cost of constructing the main gate to the port will consist of additional road, waiting lots and the automatic gate system. The total system is estimated at 1 million euro and will be added to the initial investment cost. For scenario high the system is expanded from three to four gates, this will require an additional € 330,000 (1/3 of the initial investment costs.)

13.4.2 Maintenance costs

As with the quays and jetties, the annual maintenance costs are expressed as 2% of the investment costs (DHV BV, 2012). This results in maintenance costs for respectively roads and railroads of € 4 and € 14 per running meter. As the present maintenance costs for infrastructure are unknown, these will be calculated using the same assumption. The total length of current road system is about 20 km and the railway system in the port is about 5 km, which results in respectively € 120,000 and € 70,000 per annum. The additional maintenance costs are added to the present maintenance costs, see the following tables.

Table 13-15 | Road and railroad maintenance costs in alternative 1

	Present	Low	Most likely	High
Roads[€]	120,000	204,000	252,000	300,000
Railroads[€]	70,000	140,000	232,400	296,800

Table 13-16 | Road and railroad maintenance costs in alternative 2

	Present	Low	Most likely	High
Roads[€]	120,000	204,000	264,000	300,000
Railroads[€]	70,000	148,400	232,400	232,400

13.5 Additional overall investment costs

Two additional overall investment costs are estimated as a fixed percentage of the capital costs. The costs cover pre-construction and contingencies for the entire master plan alternative and therefore, treated here separately. The percentages are found in two benchmark projects of DHV.

The pre-construction costs of the works are estimated at 5% of the accumulated costs (DHV BV, 2008). Included are detailed engineering, soil investigation and other recommended research.

Uncertainties with respect to estimates of the project's construction cost are incorporated in the contingency costs. It covers the undefined uncertainties that cannot directly be linked to the design and construction of the master plan alternatives. The contingencies are estimated as a fixed percentage of 10% the capital costs (DHV BV, 2011e).

13.6 Total cost per alternative in each scenario

This paragraph is a summary of the previous paragraphs, where the differences of the two alternatives are discussed. First, the investment costs are summarized from the previous paragraphs, followed by the annual maintenance costs.

13.6.1 Investment cost per scenario

The estimated investment cost for each scenario are summarized in Table 13-17 for alternative 1 and Table 13-18 for alternative 2. The total costs are an accumulation of all costs without discounting and is based on the calculated costs given in this chapter.

Table 13-17 | Summary of investment cost [€] per scenario in alternative 1

	Low	Most likely	High
Capital dredging	60,900,000	196,000,000	476,000,000
Passing lane	19,855,000		
Quay extension	0	88,800,000	223,800,000
Soil improvement	1,386,000	2,034,000	7,695,000
Jetty	30,000,000	30,000,000	30,000,000
Breasting dolphin		2,000,000	2,000,000
Relocation of rail workshop	8,000,000	8,000,000	8,000,000
Relocation of coal terminal		5,000,000	5,000,000
Quay 8 extension construction	3,000,000	3,000,000	3,000,000
Roads and railroads	4,400,000	10,520,000	16,140,000
Main gate	1,000,000	1,000,000	1,330,000
Pre-construction cost (5%)	6,427,000	17,318,000	38,648,000
Contingencies (10%)	12,854,000	34,635,000	77,297,000
Total	**147,822,000**	**398,307,000**	**888,910,000**

Table 13-18 | Summary of investment cost [€] per scenario in alternative 2

	Low	Most likely	High
Capital dredging	60,900,000	269,675,000	563,500,000
Quay extension	41,000,000	88,500,000	183,200,000
Soil improvement	2,264,000	4,284,000	9,932,000
Jetty	30,000,000	30,000,000	30,000,000
Relocation of rail workshop		8,000,000	8,000,000
Relocation of GC DB terminal	500,000	500,000	500,000
Adaption of quay 6-7 to CT terminal	3,000,000	3,000,000	3,000,000
Roads and railroads	3,920,000	10,520,000	11,720,000
Main gate	1,000,000	1,000,000	1,330,000
Pre-construction cost (5%)	7,129,000	20,774,000	40,559,000
Contingencies (10%)	14,258,000	41,548,000	81,118,000
Total	**163,971,000**	**477,801,000**	**932,859,000**

The total accumulated investment costs of alternative 1 are for each scenario at least 10% less than for alternative 2. From the tables it is concluded that the capital dredging and quay extension costs are the main cost drivers. In all scenarios, these are an order 10 higher than the other cost factors.

The most likely scenario has lower total investment cost for alternative 1. The capital dredging costs are much higher in alternative 2. The total cost of scenario low in alternative 1 is lower than in alternative 2. The quay extension costs for alternative 2 make the major difference between the two. In addition, the relocation of the rail workshop adds to the higher investment cost. In scenario high, the major difference is made by the capital dredging costs, favouring alternative 1 again. Despite the fact that the quay extension costs in alternative 1 are 40 million euro higher than in alternative 2.

13.6.2 Maintenance cost per scenario

The estimated maintenance costs at present and after implementation in each scenario, are summarized in Table 13-19 and Table 13-20. The total cost per annum are an accumulation of all the calculated costs per scenario presented in this chapter. 'Present' means the estimated currently occurring annual maintenance cost until realisation of the master plan.

Table 13-19 | Summary of maintenance costs [€] in alternative 1

	Present	Low	Most likely	High
Maintenance dredging	13,500,000	22,275,000	22,275,000	28,350,000
Quays	3,540,000	3,540,000	5,316,000	8,016,000
Structures	600,000	1,200,000	1,200,000	1,200,000
Roads	132,000	150,000	180,000	228,000
Railroads	70,000	140,000	232,400	296,800
Contingencies (10%)	1,784,000	2,731,000	2,920,000	3,809,000
Total	**19,626,000**	**30,036,000**	**32,123,000**	**41,900,000**

Table 13-20 | Summary of maintenance costs [€] in alternative 2

	Present	Low	Most likely	High
Maintenance dredging	13,500,000	14,850,000	24,300,000	30,375,000
Quays	3,540,000	4,360,000	5,310,000	7,204,000
Structures	600,000	1,200,000	1,200,000	1,200,000
Roads	132,000	132,000	180,000	204,000
Railroads	70,000	148,400	232,400	232,400
Contingencies (10%)	1,784,000	2,069,000	3,122,000	3,922,000
Total	**19,626,000**	**22,759,000**	**34,344,000**	**43,137,000**

The dredging cost is the driving maintenance cost factor in both alternatives. The quay maintenance costs are also of influence, but there is little differentiation between the alternatives. Due to the passing lane of alternative 1, the maintenance dredging costs are 50% higher than in alternative 2, which results in a 30% higher total annual maintenance cost in scenario low. The other two scenarios imply near equal annual costs.

13.7 Net present value

The series of annual cash outflows can be expressed in a single value using the time value of money; this value is based on the use that can be made of the money to generate a return. Using this time value the future cash outflows at different points in time can be discounted to the present. The net present value (NPV) of the cost estimate is defined as the sum of the discounted annual cash outflows during the lifetime of the project. Since only costs are taken into account, the NPV will be a negative value for both alternatives.

First, the phasing of the implementation of the master plan alternatives is discussed. The phases are discussed in detail in appendix X-A. In the next paragraph, the net present value of the alternatives in scenario most likely is discussed. Last, the sensitivity of the NPV results will be checked in paragraph 13.7.3.

13.7.1 Phased development of port

Until this paragraph, no phasing has been applied in the master plan alternatives. However, it is foreseen that the port master plan will be implemented in phases. For the NPV calculation, investment should be done when the terminal operators are ready to develop and thus when the throughput demand is sufficient.

In this paragraph, two phases are proposed per scenario per alternative. The phases are developed with a qualitative approach, because further investigation on the throughput demand should be done to make substantiated decisions on the phases. The proposed phases serve as a first guide line for the implementation and are in no way fixed.

As discussed in paragraph 13.2 the soil improvement takes and better results are achieved when taking more time for consolidation. Therefore, the areas to be improved for phase II are installed in phase I. The areas for phase I should be installed as soon as possible and are thus incorporated in the ‘Present’ costs.

The current occurring problems at the main gate should be solved as soon as possible. The implementation of the new main gate is a relatively cheap and effective solution and thus should be constructed as soon as possible. Together with the soil improvements for phase I, it is constitutes the ‘Present’ costs.

In appendix X-A the phases are discussed per scenario for the two alternatives. The appendix gives a description of the phases and presents the related costs.

For the net present value calculation, construction years must be coupled to the phases. The terminal operators do need time to develop the plots and thus the implementation of the master plan is planned to be ready 5 years before full operations. As the growth trend lines in chapter 6 are straight lines and Phase I foresees in about half of the foreseen throughput, it is chosen to implement phase I in 2017. Phase II is designed on the scenario being valid in 2032 and thus implemented in 2027. The realisation years were on purpose not discussed before, because these require further investigation and are not fixed for the master plan alternatives. The sensitivity on the realization years in the NPV’s is checked in paragraph 13.7.3.

13.7.2 Net present value result

The net present value (NPV) of the cost estimate is defined as the sum of the discounted annual cash outflows during the lifetime of the project. For this purpose, a rate of discount must be selected. In this financial analysis, this rate of discount will reflect the financial conditions for obtaining cash and the likely return on alternative financial investment open to the port authorities. Given that the World Bank Group was a primary investor in recent infrastructure projects in Mozambique, their typical discount rate of 10 percent is used in this calculation. Since the discount rate will be a point of discussion and has to be further investigated, the sensitivity on the NPV will be checked in paragraph 13.7.3.

Since only costs are taken into account, the NPV will be a negative value for both alternatives. The value cannot be used to consider the feasibility of the master plan, only to compare the two alternatives and as an indication of the discounted cost of the project.

It must be noted that the investments will be spread over multiple construction years. Agreements on the phased payments can be made with the contractors and banks, which naturally will influence the NPV. However, further studies must reveal how the costs are actually divided over the years. In this study, the investment costs are accounted as one lump sum, which is funded at completion of each phase of the master plan alternatives.

An economic analysis requires a project life span. The net present values of the master plan alternatives are calculated and judged on a life span of 30 year, using the Port of Said master plan as an example (DHV BV, 2008).

In appendix IX the full net present value calculation input and result for both alternatives is given. Table 13-21 shows the total investment cost, maintenance cost and NPV results for both alternatives. The table indicates that alternative 1 is cheaper at all aspects and thus the NPV is in favour of alternative 1. The maintenance costs of the last phase are 3 million euro lower for alternative 1 and thus a longer project span would also favour alternative 1. Figure 13-3 shows the NPV of both alternatives during the project span. It is concluded that alternative 1 is the cheapest during the entire project span.

Table 13-21 | Total investment, maintenance cost and NPV for both alternatives in million euro

	Present	Phase I	Phase II
Year	2012	2017	2027
Investment Alternative 1	2	157	244
Investment Alternative 2	4	164	316
Maintenance Alternative 1	20	22	32
Maintenance Alternative 2	20	23	35
NPV Alternative 1	-364		
NPV Alternative 2	-391		

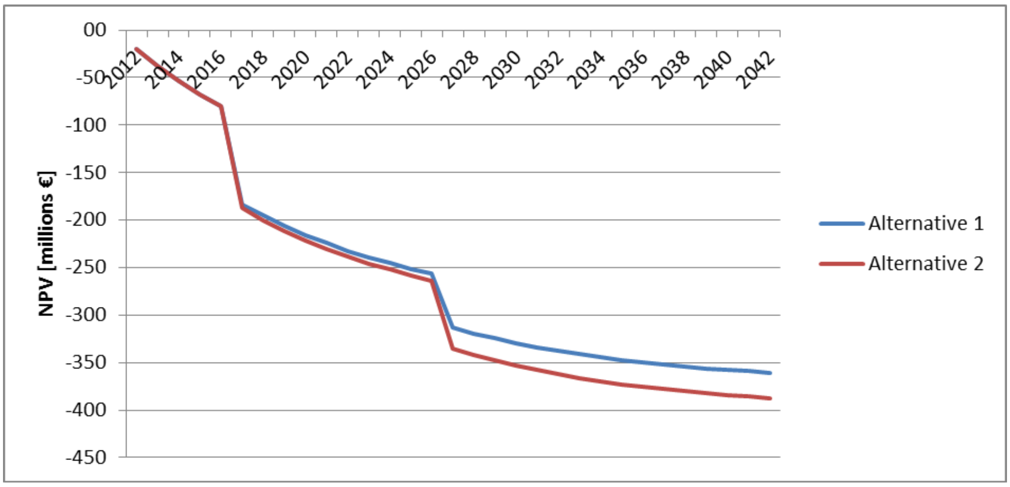


Figure 13-3 | NPV of both alternatives during project span in most likely scenario

13.7.3 *Sensitivity analysis*

As mentioned along this chapter a sensitivity analysis will be conducted on several influential uncertain factors. This paragraph describes the applied changes and their origin. Table 13-22 shows the resulting NPV's and the differences between the alternatives. When the difference is positive alternative 1 has a lower NPV and vice versa. The relative difference refers to the absolute difference as a percentage of the NPV of alternative 1.

First, the sensitivity is checked for the two other scenarios. In appendix IX phases are described for scenario low and high. The resulting NPV's are given in Table 13-22 and it is concluded the result is sensitive for both scenarios. In scenario low, the NPV is still in favour of alternative 1. However, in scenario high both alternatives give near equal result and thus

The sensitivity is checked on the assumed discount rate. The discount rate is varied between 7% and 13%. This results of course in big changes in the NPV's of both alternatives, but the relative difference is still in favour of alternative 1.

The implementation years of the different phases are highly uncertain. It depends on the demand growth and the realized hinterland connections. First, it was assumed that every 10 years a new phase is reached, with 2017 for phase I. For the sensitivity analysis, this is changed to every 5 years. The NPV's are higher, because the costs are fewer years discounted, which results in a larger difference between the alternatives.

The capital dredging costs are varied, due to the uncertainty of the calculated volumes. In paragraph 13.1.1 it was discussed that the current and future bottom profile is uncertain and a simple assumption was made. The sensitivity on the matter is checked by varying the dredging cost with 30%. The results show that both alternatives are equally affected and sensitivity is low.

Now the quay extension costs are varied. The quay construction costs are a major cost factor and thus its sensitivity on the NPV is checked. In paragraph 13.3 a rough estimate was made on the extension cost per running meter quay length, which is now varied with 20%. The results show that both alternatives are equally affected, thus sensitivity is low.

Last, the NPV is calculated without taking the current maintenance costs into account. Both alternatives are thus subtracted by the same amount per year and the NPV of implementation of the project is basically calculated. The relative difference now better shows that master plan alternative 1 is preferred over alternative 2.

Table 13-22 | NPV sensitivity analysis results in million euro

	NPV Alt. 1	NPV Alt. 2	Absolute difference	Relative difference
Base case	-364	-391	27	7%
Scenario Low	-239	-268	29	12%
Scenario High	-639	-646	7	1%
Discount rate 13%	-276	-294	17	6%
Discount rate 7%	-498	-542	43	9%
Phase I: 2017 Phase II: 2022	-412	-453	40	10%
Capital dredging cost 30% higher	-383	-415	32	8%
Capital dredging cost 30% lower	-339	-360	22	6%
Quay extension cost 30% higher	-388	-416	29	7%
Quay extension cost 30% lower	-334	-359	25	8%
Without current maintenance cost	-175	-202	27	16%

13.8 Conclusions

The cost estimate gives insight in the investment costs per scenario. The total accumulated investment costs of alternative 1 are for each scenario at least 10% less than for alternative 2. Alternative 1 has lower investment and maintenance costs in scenario most likely, primarily due to the capital dredging costs, which are much higher in alternative 2.

The capital dredging and quay extension costs are the main cost drivers. In all scenarios, these are an order 10 higher than the other cost factors.

The dredging cost is the driving maintenance cost factor in both alternatives. Due to the passing lane of alternative 1, the maintenance costs are 30% higher than in alternative 2 in scenario low. The annual maintenance cost in scenario most likely and high differ 2 million in favour of alternative 1.

The implementation of the new main gate is a relatively cheap and effective solution and thus should be constructed as soon as possible. Also the soil improvements for phase I should be implemented as soon as possible, because the sand requires time to settle.

Based on the NPV, alternative 1 is the preferred master plan. The absolute NPV difference is 27 million euro and the relative difference is 7% when the current maintenance costs are considered. The relative difference for the project implementation alone is 16%, which substantiates the preference for alternative 1.

The sensitivity analysis showed that alternative 1 is cheaper in all cases. Only in scenario high, there is little difference in NPV between the two alternatives and

14 MULTI CRITERIA ANALYSIS

The alternatives for a port layout entail many parameters that should be taken into account when deciding for the optimum. In order to deal with all these affecting parameters a Multi-Criteria Analysis (MCA) is applied.

In the previous chapters, all the criteria for the master plan have been discussed extensively. In this chapter, the alternatives will be judged on the main criteria. By using a comparison method for the two alternatives, the resulting valuation matrix presents the best alternative. Moreover, it shows directly for which criteria improvements can be found in the 'losing' master plan.

First, the mentioned decisive criteria will be presented and the relative importance of each of them explained. At the end of the first paragraph a certain weighing factor, ranging between 1 to 5 is used to express the preferences. Next, a comparison method will be used in order to score the alternatives. In the valuation matrix, the weighing factors and scores are multiplied and the accumulated results per alternative are compared. Due to the great subjectivity of the MCA, the chapter ends with a sensitivity check in order to validate the results.

14.1 Criteria and weighing factors

In this paragraph, the main criteria are summarized and sub-criteria are determined. The sub-criteria make it easier to judge the alternatives. By giving weighs to different criteria, the relative importance of one criterion with respect to the other one can be expressed. This weighing factor, in combination with the score of the alterative on the criteria, results in a final score for each layout.

First, the six main criteria are explained and the sub-criteria presented, additionally the importance is explained per criterion. In the last section, the criteria are accompanied by weighing factors.

14.1.1 Internal landside port traffic

In both alternatives, solutions have been found to solve the current traffic congestion in the port and at the main gate. The main gate dimensions were determined and implemented in the alternative layouts. In the two alternatives, some differences have been made in the internal road and railroad plan. The criterion for the alternatives is the road and railroad accessibility per terminal and at the main gate, because that is where the traffic is heading. The alternatives will be judged on the following sub-criteria:

a. Road and railroad accessibility of container terminal
b. Road and railroad accessibility of general cargo dry bulk terminal
c. Road and railroad accessibility of coal terminal
d. Road and railroad accessibility of fuel terminal
e. Road and railroad accessibility of main gate

The port authorities have stated (DHV BV, 2011a) that they want to solve the congestion issues and thus this criterion will be given a relative high weighing factor. All traffic is affected by the accessibility of the main gate; therefore, this sub-criterion requires a higher weighing factor than the other sub-criteria.

14.1.2 Room for future expansion

When developing the layouts this criterion was discussed in the basic notions of chapter 9. The proposed expansion in this master plan is just a part in the long history of Beira Port. Thus, it should be bared in mind that the proposed master plan alternatives could be further extended in the future.

Again, the alternatives will be judged per terminal. This will lead to the following sub-criteria:

a. Room for expansion of container terminal
b. Room for expansion of general cargo dry bulk terminal
c. Room for expansion of coal terminal
d. Room for expansion of fuel terminal

The success of the port primarily depends on implementation of the master plan. At the moment, it is more important that the proposed expansions be executed in the best way possible. The future for the port and possible expansions is of secondary importance. Therefore, this criterion has a low ranking.

14.1.3 Robustness and adaptability

In the adaptive port planning chapter already a list was given were assumptions in the plan related to. This criterion tests the robustness of the alternatives for these uncertainties. Some major differences in the alternatives are discussed and there robustness to get the required result. In the APP chapter, the capacity of the railway line has been treated in detail in chapter 12. The drawn conclusions for both alternatives will add to the score for this criterion.

The alternatives will be judged on the following sub-criteria:

a. Robustness and adaptability for expansion of the Sena railway line
b. Robustness of wet layout
c. Robustness of landside port layout

Focus in this master plan development has been on robustness and adaptability. Various scenarios were developed, phases applied and the APP framework tested on the alternatives. As already mentioned many assumptions were made in the development of the master plan alternatives, thus it is likely that the robustness will in fact be tested. Therefore, the robustness criterion requires a high weighing factor.

14.1.4 Port maritime capacity performance

The capacity of the wet layout is important for the port as it dictates the maritime throughput that could be obtained. As the waiting time is an important parameter for ship owners to choose a certain port. Waiting time is lost time and therefore lost money. In chapter 10, the alternatives were accompanied by wet layouts and capacity simulations resulted in predicted mean waiting times and berth occupancies for the different cargo sectors. The terminal operators are interested in high berth occupancies and the shipping companies in low mean waiting times. The criterion for the master plan alternatives is high berth occupancies and low mean waiting times.

The alternatives will be judged on the following sub-criteria:

a. Mean waiting times of the calling ships
b. Berth occupancies of the terminals

The maritime capacity of the Port of Beira has been a bottleneck for the port in the past years. The water depth was unreliable, as explained paragraph in 4.5, and too shallow, underpinned by the simulations from chapter 5. In order to receive the forecasted throughput it is essential for the Port of Beira that the maritime capacity is at least close to standards. Moreover, Beira Port has the potential to grow in the coal export significantly, as presented in paragraph 6.2.2, but exporters are already examining the possibility to transport through Nacala Port, mainly because of its maritime capacity. Therefore, the maritime capacity criterion receives a high weighing factor.

14.1.5 Costs

In the framework of this study only cost will suffice as a financial criterion. Revenue of the two alternatives is assumed to be equal, because they are designed for the same throughputs for each scenario and thus port fee income will be equivalent. In chapter 13 a cost estimate was made for both alternatives. The net present value of both alternatives was calculated for the whole project life span of 30 years. Furthermore, the sensitivity analysis is used to judge the alternatives on their costs.

The alternatives will be judged on the following sub-criteria:

a. Net present value of the estimated project costs
b. Sensitivity of the estimated net present value

Costs are very important for the Port of Beira, where funding is limited. Despite the enormous macro-economic growth in recent years, presented in paragraph 6.1, Mozambique is still a third world country. The best argument that the cost criterion requires the highest weighing factor is that there is currently no money available to assign Royal HaskoningDHV to design a new port master plan.

14.1.6 *Environmental impact*

All the dredging works have a negative impact on the Pungue River delta life. Species are endangered in their natural habitat. The sub-criterion “environmental impact of dredge works” will be judged by comparing the sand volumes to be dredged in the project life span.

Due to the increase of the port area, less room remains for the municipality of the city of Beira. Furthermore, the natural environment of the land north of the current port is destroyed by the new land use. The sub-criterion “environmental impact new port land” is judged by comparing the areas of new port land required outside the current port boundaries for the two alternatives.

The social impacts, for instance increase of employment, are for both alternatives equal, because the same throughput is realized with similar handling operations. Thus, the alternatives will be judged on the following sub-criteria:

a. environmental impact of dredge works
b. environmental impact new port land

Currently, it is standard to accompany the master plan development with research on the environmental impacts of the alternatives. These investigations should be worked out in an Environmental Impact Assessment (EIA), which is outside the scope of this study. Because insight in this criterion is currently minimal, it will receive a low ranking.

14.1.7 *Weighing factors*

In the previous sub-paragraphs, notions were made on the weighing factors. For all criteria, a weighing factor is determined. The most important criteria are given a high weighing (5) and the least important criteria a low weighing factor (1). The alternatives are judged on the specified sub-criteria. The added weighs of the sub-criteria count to the overall weighing factor of the criterion. In a criterion, all sub-criteria are equally weighed. One exception is the accessibility of the main gate, as discussed in paragraph 14.1.1.

Criteria	Weighing factor
1. Internal landside port traffic	**4**
f. Road and railroad accessibility of container terminal	½
g. Road and railroad accessibility of general cargo dry bulk terminal	½
h. Road and railroad accessibility of coal terminal	½
i. Road and railroad accessibility of fuel terminal	½
j. Road and railroad accessibility of main gate	2
2. Room for future expansion	**1**
a. Room for expansion of container terminal and quay	¼
b. Room for expansion of general cargo dry bulk terminal	¼
c. Room for expansion of coal terminal	¼
d. Room for expansion of fuel terminal	¼
3. Robustness and adaptability	**4**
a. Robustness and adaptability for expansion of the Sena railway line	2
b. Robustness of wet layout	1
c. Robustness of landside port layout	1
4. Port maritime capacity performance	**4**
a. Mean waiting times of the calling ships	2
b. Berth occupancies of the terminals	2
5. Costs	**5**
a. Net present value of the estimated project costs	2 ½
b. Sensitivity of the estimated net present value	2 ½
6. Environmental impact	**1**
a. environmental impact of dredge works	½
b. environmental impact new port land	½

14.2 Scores of the alternatives

Because only two alternatives are discussed, a comparison method is used. The alternatives are compared by confronting the two alternatives with each other for each criterion and decide which is best. The alternative that 'dominates' most, according to the comparison is the best alternative (Verhaeghe, 2009). Furthermore, this method directly shows for which criterion improvements could possibly be found in the other alternative, thus improving the best alternative. This is input to improve the recommended master plan.

The different alternatives are scored for each sub-criterion. The scoring will be done based on a grading system: worse (0), equal (1) and best (2). The sub-criterion will be multiplied by the adjoining weighing factor. The results are summed to get a total score for each criterion. The cumulative score of all the criteria is the total for each alternative. This way, the best alternative receives the highest total score.

14.2.1 Internal landside port traffic

The modal split is taken into account in judging the sub-criteria, by balancing the accessibility demand with the designed roads and railroads.

The container terminal can be reached by railroad, which is sufficient for both alternatives, as most container traffic is transported by truck. The road accessibility of the container terminal is for alternative 1 best, because in scenario most likely and high the coal terminal does not have to be crossed as in alternative 2.

The accessibility for the GC-DB terminal is better in alternative 1, because the coal trains no longer hinder general cargo and dry bulk traffic.

The coal terminal is better accessed in alternative 1, because all coal traffic is separated, by placing all coal activities north of the current port. The fuel terminal has the same access in both the alternatives, thus is equally ranked.

The main gate accessibility is equal for both alternatives. For both alternatives a new main gate is designed, which is capable of processing all the road traffic. The railroad traffic for the port is diverted in front of the main gate.

14.2.2 Room for future expansion

Room for expansion of the container sector is found aside the northern terminal, thus equal for both alternatives.
The GC-DB terminal has free area behind the current quays, but the quays cannot not be extended, due to the close proximity of the fuel jetties. As the alternatives are equal on this sub-criterion, both score 1.
The coal quay can only be extended in alternative 2, thus better than the other alternative, where a new terminal has to be built.
The fuel terminal area can be expanded in both alternatives equally. There is still room to expand toward the jetties.

14.2.3 Robustness

Table 12-1 summarizes the differences between the two alternatives for the vulnerability that the capacity of the Sena railway is not expanded over 5 million tons coal per annum. It is concluded that the relocation of the coal terminal in alternative 1 will become an issue, when the expansion is not as forecasted. For alternative 2 actions could be devised to make the plan more robust for the above mentioned vulnerability. Still a corrective action and reassessment of the wet layout is necessary, but this is a smaller measure than an entire reassessment for master plan alternative

1. Measured on the robustness for the vulnerabilities linked to expansion of Sena railway line, alternative 2 is more robust.

The robustness of the wet layout of alternative 1 is worse than for alternative 2. The effect of the passing lane implemented in scenario low is not substantiated. The convoy sailing currently used in Beira Port is not simulated, thus waiting times could differ. Moreover, the passing lane increases the chance of ship collision. Next, the inner container waiting berth results in additional ship movements in the port, with risks attached. The wet layouts in alternative 2 are straight forward and do not use complicated solutions, which increase risk, especially in undeveloped countries.

The robustness of the landside is in this preliminary stage assumed to be equal for both alternatives. As addressed in chapter 12, further research is necessary to make more detailed conclusions on this matter.

14.2.4 *Port maritime capacity performance*

The Harboursim simulations resulted in waiting times and berth occupancies, which are quantitative figures. In Figure 14-1 the mean waiting times in the different scenarios are summarized, according to the simulations of chapter 10. The mean waiting times of the coal sector are judged on the Rio Tinto ships and not on the ocean going vessels of Vale, because no substantiated judgment can be done on these waiting times, as the opinion of Vale is unknown.

As a comparison method is used, the best alternative is sought. The mean waiting times in scenario high of the coal ships are lower in alternative 1. The other waiting times are similar, thus alternative 1 is 'dominating'.

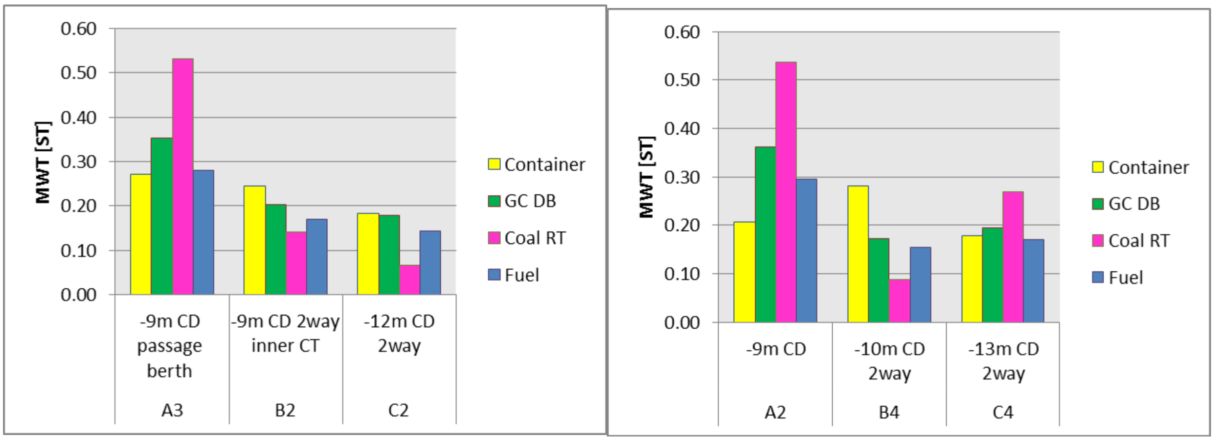


Figure 14-1 | Mean waiting times [ST] of the calling ships for the two alternatives

The berth occupancies should be above 40%, which is the presented standard from paragraph 10.2. In Figure 14-2 the occupancy rates of the terminals are summarized, according to the simulations of chapter 10. In both alternatives the occupancy rates are mostly below 40%, thus they are both insufficient. Furthermore there is no indication that one of the alternatives is better than the other, thus both a score 1.

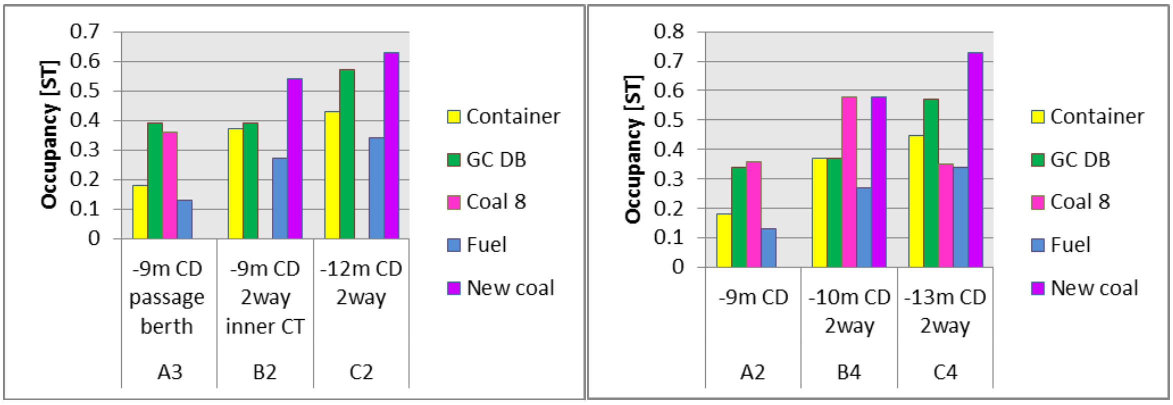


Figure 14-2 | Occupancy rates [ST] of the terminal berths for the two alternatives

14.2.5 Costs

The net present values are in favour of alternative 1. The maintenance costs are 3 million euro lower for alternative 1 and thus a longer project span would favour alternative 1. Furthermore, the sensitivity analysis showed that alternative 1 is cheaper in all cases, except one. Thus alternative 1 scores better on both sub-criteria.

14.2.6 Environmental impact

From the determined dredging volumes in paragraph 13.1 it is clear that the capital dredging volumes are less in alternative 1. Moreover, Figure 14-3 shows the cumulative dredging volumes including the maintenance works. Again, alternative 1 has the best result.

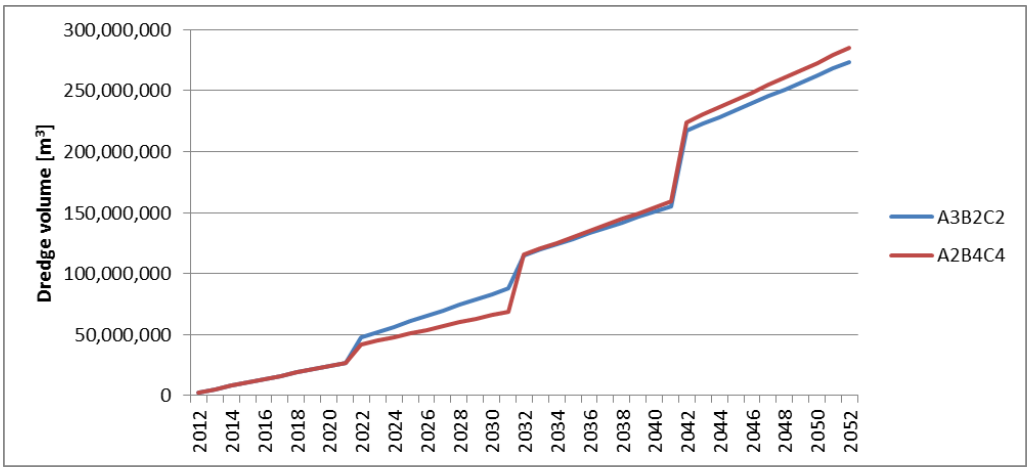


Figure 14-3 | Cumulative dredging volumes for both alternatives

The land claim outside the current port boundaries is more severe in alternative 1 as shown by the layout drawings of chapter 11, thus alternative 2 scores best on this alternative.

14.3 Valuation matrix

The weighs of the criteria are accompanied by the scores and summarized in Table 14-1. This results in the next valuation matrix shown in Table 14-2. Alternative 1 has a total score of almost twice the score of alternative 2. The four sub-criterion for which alternative 1 scores less should be investigated to see whether improvement of the plan could be made.

Table 14-1 | Summary of weighs and scores for the MCA

Criterion	Weighing factor	Score Alt. 1	Score Alt. 2
1. Internal landside port traffic	**4**		
a. Road and railroad accessibility of container terminal	½	2	0
b. Road and railroad accessibility of general cargo dry bulk terminal	½	2	0
c. Road and railroad accessibility of coal terminal	½	2	0
d. Road and railroad accessibility of fuel terminal	½	1	1
e. Road and railroad accessibility of main gate	2	1	1
2. Room for future expansion	**1**		
a. Room for expansion of container terminal and quay	¼	1	1
b. Room for expansion of general cargo dry bulk terminal	¼	1	1
c. Room for expansion of coal terminal	¼	0	2
d. Room for expansion of fuel terminal	¼	1	1
3. Robustness and adaptability	**4**		
a. Robustness and adaptability for expansion of the Sena railway line	2	0	2
b. Robustness of wet layout	1	0	2
c. Robustness of landside port layout	1	1	1
4. Port maritime capacity performance	**4**		
a. Mean waiting times of the calling ships	2	2	0
b. Berth occupancies of the terminals	2	1	1
5. Costs	**5**		
a. Net present value of the estimated project costs	2 ½	2	0
b. Sensitivity of the estimated net present value	2 ½	2	0
6. Environmental impact	**1**		
a. environmental impact of dredge works	½	2	0
b. environmental impact new port land	½	0	2

Table 14-2 | Valuation matrix for the MCA

Criterion	Alternative 1	Alternative 2
1. Internal landside port traffic	5 ½	2 ½
2. Room for future expansion	¾	1 ¼
3. Robustness and adaptability	1	7
4. Port maritime capacity performance	6	2
5. Costs	10	0
6. Environmental impact	1	1
Total Score	**24.25**	**13.75**

14.4 Sensitivity analysis

Due to the great subjectivity of the weighings in the MCA, a sensitivity check is made in order to validate the results. Several other weightings are considered and the results will be discussed after.

Currently the waiting times at Beira Port are known to be longer than the standards, as substantiated by the simulations of chapter 5. This could indicate that shipping lines accept the high waiting times as Beira is the only port in the region. Beira Port has little competitive hinterland, effectively only for the Moatize coal, as shown in paragraph 2.5. Moreover, the coal sector currently takes the long waiting times for granted, indicated by the present operations. Therefore, despite all the capacity simulations, the weighing factor is chosen to be 1.

To check whether assessing the robustness and adaptability of the alternatives has influenced the MCA results significantly, it is left out of the equation.

In literature, many MCA's leave the cost aspect out of the equation and judge the alternatives in a complementary monetary analysis. Furthermore, further investigation should be done to investigate whether revenues of the two alternatives are really the same. As the NPV's of the two alternatives are based on rough information, it is chosen to leave the cost criterion out of the equation and check the sensitivity.

Table 14-3 shows the result of the sensitivity analysis. It is concluded that alternative 1 has the best papers for all the checks.

Table 14-3 | result of MCA sensitivity analysis

	Score alternative 1	Score alternative 2
Low maritime capacity performance	19.75	12.25
No robustness	23.25	6.75
No costs	14.25	13.75

15 CONCLUSIONS

Three main objectives were identified:
1. Develop a master plan for the Port of Beira
2. Add the 'Adaptive Port Planning' framework to the master plan alternatives evaluation
3. Simulate the maritime traffic of the Port of Beira in the present situation and the master plan alternatives in developed scenarios. If necessary, improve the current Harboursim model for future users.

In this chapter, the conclusions on each of the main objectives are discussed in separate paragraphs in the above presented order.

15.1 Master plan development

It is concluded that the present terminal areas and quays are too small for future needs. In scenario low, the additional required areas for coal, dry bulk and general cargo are small and room is available next to the present terminals. However, the container terminal expansion requires adaptions to the current layout. In scenario most likely and high, the port layout has to be adapted significantly to realize expansions of the terminals.

In scenario low, the current berth configuration can be used with one extra fuel berth. The spare length of the combined dry bulk and general cargo terminal can be used for the coal terminal, as is already done at present. For scenario most likely and high, the current configuration does not suffice and has to be altered significantly.

The coal terminal has the largest throughput in all scenarios and receives all its cargo over the railway line. As already congestion takes place at railroad crossings, the new layout must foresee in a separated railway line towards the coal terminal.

In order to handle the peak truck intensity at the main gate, it is concluded that a system is necessary where the main gate only checks if a truck is allowed to go to the designated terminal and at the terminal entrance all other time-consuming paper work is handled. The required main gate fits at the current location in the port layout.

Following the results of the multi criteria analysis, the preferred master plan is alternative 1. It scores best at most criteria and the accumulated weighted score is twice the score of alternative 2. Moreover, a sensitivity analysis shows that it remains the preferred alternative if the weighing of the scores is changed.

One of the deciding criteria is the estimated cost. The absolute net present value in 2042 including the current maintenance cost is 27 million euro higher for alternative 1 than for alternative 2 and the relative difference is 7%. The relative difference for the project implementation alone is 16%, which substantiates the preference for alternative 1.

The capital dredging and quay extension costs are the main cost drivers of the master plan. In all scenarios, these are an order 10 higher than the other cost factors. The implementation of the new main gate is a relatively cheap and effective solution and thus should be constructed as soon as possible. Also the soil improvements for phase I should be implemented as soon as possible, because the sand requires time to settle.

From the Harboursim simulations, it is concluded that in the master plan for scenario most likely and high all ships have acceptable mean waiting times. In scenario low, the waiting times are higher than standards, but much improved compared to the current situation. Further improvements would require investments, which are not likely to be returned in this scenario.

15.2 Adaptive Port Planning

Two goals were determined for application of the APP framework in this study. First, the robustness of the master plan alternatives has to be increased, by taking into account the uncertainty of the expansion of the Sena railway line. Secondly, it was aimed to map differences between the two alternatives.

Due to a time constraint in this study, the framework of APP is only applied on assumptions related to the expansion of the capacity of the Sena railway line. The robustness for the expansion of the Sena railway line is increased, by devising actions for the determined vulnerabilities. No opportunities could be detected in this particular region of assumptions, which substantiates the importance of the expansion of the railway line for the Port of Beira.

The vulnerabilities for the coal sector were split for the three scenarios, because there is a clear distinction made between the scenarios. Less expansion of the Sena railway line additionally implies a vulnerability for the general cargo and dry bulk sector. These impacts are the same for all the scenarios and thus in the framework of APP handled together.

We can conclude from this APP study that securing public and private investments for the expansion of the port hinterland connection is essential for the port itself. Furthermore, the investment and constructions should be supervised by the port authorities to make sure the expansions are executed according to plan.

This case study shows that APP is an effective tool to make a master plan that can cope with future uncertainties. By determining the driving forces behind the vulnerabilities many shaping actions could be devised that can be taken on beforehand, in order to reduce the risk. Additionally hedging actions were devised to reduce the negative impacts of the vulnerabilities.

The extend of implementing the APP framework is shown by this case study. In this study just one region of assumptions was investigated. All the assumptions should be handled in the APP framework to fully realize a master plan robust across many futures.

15.3 Harboursim model

The present situation of the Port of Beira and the master plan alternatives are simulated with a Harboursim model. Additional model processes are added to the Harboursim model code to improve model performances. The adaptions are made generally applicable for all future Harboursim users. The following additional features were written for the model:

- Daylight window
- Terminal arrival and departure queue for offshore berth
- Erlang k distribution as service time distribution
- Dwell time in the model per fleet
- Making Harboursim compatible with excel

The following errors in the Harboursim code are fixed and made generically applicable for future users of this improved Harboursim model:

- The tidal window calculation is oversimplified in Harboursim
- The required quay length per berthed ship does not use the accepted design rule
- The water level calculation uses only the depth of one section

Furthermore, the created spread sheets will reduce analysing time of the results.

The accuracy of all relevant model predictions of the Harboursim models is below 20%. It is concluded that the model gives relatively accurate results compared to the uncertainties of the acquired input data.

16 RECOMMENDATIONS

In the first paragraph recommendation on additional research is done, to validate the many assumptions. In paragraph 16.2 recommendations are done regarding the preferred master plan. Paragraph 16.3 discusses the further implementation of the Harboursim model. Finally, in paragraph 16.4 recommendations on the APP framework are discussed.

16.1 Additional research

Geotechnical data
To be able to make a detailed assessment of the construction costs and suitability of a location, more information on the soil characteristics is required. Geotechnical data was not available during this research project. This aspect does have a large influence on the soil improvement investment cost.

Sedimentation processes
The sedimentation processes are complicated and have proven to be unpredictable. To maintain the access channel dimensions more insight is required on the present sedimentation processes. Research is recommended on the occurring processes and the implication of the proposed channel expansions.

Bathymetry
The bathymetry has a big influence on the required amount of dredging. The lion's share of the investment cost is depicted by the capital dredge cost, thus with a more detailed bathymetry a better cost estimate can be done. The bathymetry depends largely on the sedimentation processes, thus these two studies can be combined.

Throughput forecast
This study aimed at establishing a master plan flexible for three scenarios. In order to define the future scenarios, forecasts were conducted until 2032. These scenarios should be treated very carefully. One reason is that the duration of 20 years is a very long period to make predictions. Another is that the three scenarios were developed based on forecasts made with limited data. In order to cope with the mentioned deficiencies, the forecasts will require regular update and will have to be constantly checked with the actual throughput handled at the port. This updating and checking procedure is considered to be crucial because otherwise this Master plan will not respond to reality.

Average cargo
The number of container, general cargo and dry bulk ships and service times of these ships is based on a rough assumption of the average cargo per call. For 2032, the average cargo per call is adapted to the forecasted cargo flows in these years. This is an arbitrary assumption and deserves a closer investigation. In cooperation with the terminal operators, better insight in the average cargo per call can be acquired.

Stakeholder analysis
In this study no stakeholder analysis was performed, because no contact with the stakeholders was possible. It is recommended to perform a stakeholder analysis to assess the attitudes regarding the potential changes. Moreover, the users of the port should be used in the master plan development, in order to design a master plan suited to their needs. For example regarding the acceptable waiting times of the ships.

16.2 Preferred master plan

Develop phases based on the improved throughput forecasts
The proposed phases serve as a first guideline for the implementation and are in no way fixed. It is recommended to investigate the phased implementation of the plan, depending on the above mentioned additional research on the throughput forecasts. A full economic study, including revenues, is recommended in follow-up research, in order to make a substantiated decision on the project feasibility for the phased implementation.

Improve the preferred master plan on the four sub criterion it scored less
The preferred master plan could be improved on ‘the room for expansion of the coal terminal’ criterion, by locating the second container terminal further north in scenario high.
The ‘adaptability for the expansion of the Sena railway line’ and the ‘environmental impact of new port land’ criteria can be improved by retaining the present coal terminal in all scenarios. However, this is the main distinction between the two alternatives and all the positive effects of relocating the terminal will be negated. Thus, it is recommended to investigate other options to improve the master plan on these criteria.
The passing lane and inner container waiting berth are such distinctive features of the preferred master plan. These cannot be adapted to the straight forward wet layouts of alternative 2, to increase the score on the’ robustness of wet layout’ criterion. However, research is recommended on safe navigation and the effectiveness of the passing lane.

Investigate the mooring requirements for coal ships at quay 8
It should be investigated if the present coal quay 8 suffices for berthing the calling ships, without having the required quay length available. Current procedure is that the mooring lines use boulders of quay 7 and 9. It should be investigated if a cut in quay 7 is necessary for the preferred master plan.

16.3 Harboursim model

Discard the original Harboursim model or improve the manual
The Harboursim model is written with little explanations and the manual contains errors. Therefore, it was hard to understand the model code and build the improvements for the model. It is recommended that the original Harboursim model will no longer be used or that the manual is adapted to the found errors. Especially the error in the depth calculation and the quay length rule should be mentioned for future users of the ‘old’ model.

Use the Harboursim version developed in this study
In this research, improvements to the model code were made and it is recommended that future users of Harboursim use this new version. It must be noted that due to the found errors in the model code, the suspicion has risen that the model has more errors; hence, it is recommended that the model code is checked thoroughly by an experienced programmer.

Construct a new Harboursim model
The Harboursim model is written in the software package Prosim. Currently more user friendly software is on the market to build a new simulation model. It is recommended to use the Harboursim model as a basis to construct a new model in another software package. For new users it would then be easier to adapt the model to their specific needs.

16.4 Adaptive port planning

Involve a diverse group of people
It proved challenging to generate vulnerabilities, driving forces, impacts and actions in the adaptive port planning method. Moreover, the master planner has likely a tunnelled vision, which leads to a one-sided subjective result. By involving a more diverse group of people, the result is less subjective. Brainstorm sessions are recommended where the steps of the APP framework are worked out together.

Weigh the actions in a cost benefit analysis
By devising actions for the determined vulnerabilities, new vulnerabilities are created for which again actions should be devised. It is recommended that vulnerabilities induced by the proposed actions will also be handled in the APP framework from step II. The framework results in many actions; it is recommended to weigh the actions in a cost benefit analysis, to see whether a devised action should be taken or not.

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LIST OF APPENDICES

I DESCRIPTION OF HARBOURSIM

I-A Introduction

To check whether a new port or an extension of an existing port satisfies the design requirements Delft University of Technology developed a simulation tool, Harboursim, to estimate the capacity and to assess safety of the port. Harboursim is a simulation model developed in the simulation software Prosim. A simulation run in Prosim does not simulate every minute, but the state of the model changes at a discrete point of time. This type of modelling reduces the total runtime considerably. Harboursim covers the wet infrastructure of a system built up by ports and waterways. It simulates the vessel and port processes within the model boundaries. In general, the capacity of a waterway system is dependent on the dimensions of the area, tidal conditions, traffic intensities, navigation rules and terminal facilities.
Below a brief description of the model is given, for a complete explanation reference is made to the Harboursim manual (Groenveld, 2004).

I-B Components in Harboursim

The model Harboursim is built up by modules that describe the behaviour of various components. Components are parts of the model to which specific characteristics can be attached for instance a ship, quay or traffic rules. Characteristics are defined in the input files and macros under laying the components. Components can be permanent, temporary, single or multiple. Permanent components are present during the whole simulation. Temporary components are generated, exist for a certain period in the model and in the end are terminated. Single components are components of which more than one can be present. E.g. a ship is a temporary multiple component; more than one exist with various characteristics. They are generated to sail a certain path and terminated afterwards.
The following components are written in Harboursim.

Component Main
The process of the component Main initialises the model with all the components and corresponding attributes. For this purpose, all the required data are read from different input files. The component Main starts each simulation run. After all runs have been carried out, Main cares for the output of the model.

Component Generator
The component Generator is activated by the component Main. An inter arrival time is generated by using statistical functions specified for each fleet in the input files. The generator waits during this inter arrival time and subsequently a new ship is generated. All attributes of the ship are assigned, including the service time at the designated quay. At last, a window object is created to show the position of this ship in animation.

Component Ship
The component Ship is generated and activated by the component Generator. It determines what each ship should do in the model. It activates the component Quay Master and VTS.

Component Quay Master
The task of the Quay Master is to find a berth for a ship. Wave conditions in front of the berth and the available free quay length are checked.

Component VTS
The component VTS checks the currents, water levels and traffic situation for every generated ship requesting to sail a combination of sections. Traffic situation holds rules with respect to

overtaking, encounters, problems in turning basins and night-time sailing. If all conditions are true then the ship is activated to proceed.

Component Terminal Operator
The process of the terminal operator is started on arrival of a ship at the quay and on departure from the quay. If the Generator does not determine the service time per fleet, the Terminal Operator sets the service time per terminal. On departure of a ship, the availability of a departure queue is checked, the occupied length of the quay is released and the Quay Master is activated.

Component Tidal Conditions
In the component Tidal Conditions at a regular basis the currents and water levels are stored to check whether the model correctly generates currents and water levels.

Component Show Process
The component Show Process shows windows of the number of ships handled per fleet, the occupancy of the different quays and the waiting times of ships on arrival.

I-C Harboursim logic

Harboursim generates at a defined rate various numbers of ships, each ship with its own characteristics. When a ship enters the system, it is place in the 'Arrival queue' and the model checks the availability of its destination quay(s). If at the ships destination a suitable berth is available, the ship is placed in the queue 'waterway'. The channel sections to the destination quay are checked on availability in accordance with the navigation rules and tidal window. If the ship is not allowed to sail to its destination quay, it has to wait in the anchorage and the next ship in the queue 'waterway' is checked, because this ship may have different navigation rules.

After a ship has received green light to sail toward its destination quay the model makes reservations for the different sections in which the waterway is divided for the time the ship will occupy each section. At its destination, the ship waits a defined service time and is placed in the queue 'departure'. When placed in this list the model again checks whether access can be granted to sail to its next destination. This is repeated for all destinations of the ship until it leaves the model. When a ship leaves the model, the waiting times are registered and added to the results of the simulation run.

The main procedure executed by Harboursim can be shown by the flow chart in Figure 0-1. In addition, Figure 0-2 shows a more detailed scheme on the process of a ship through the model. If a ship is scheduled to visit more than one berth, steps will be repeated as shown by the loop-arrow.

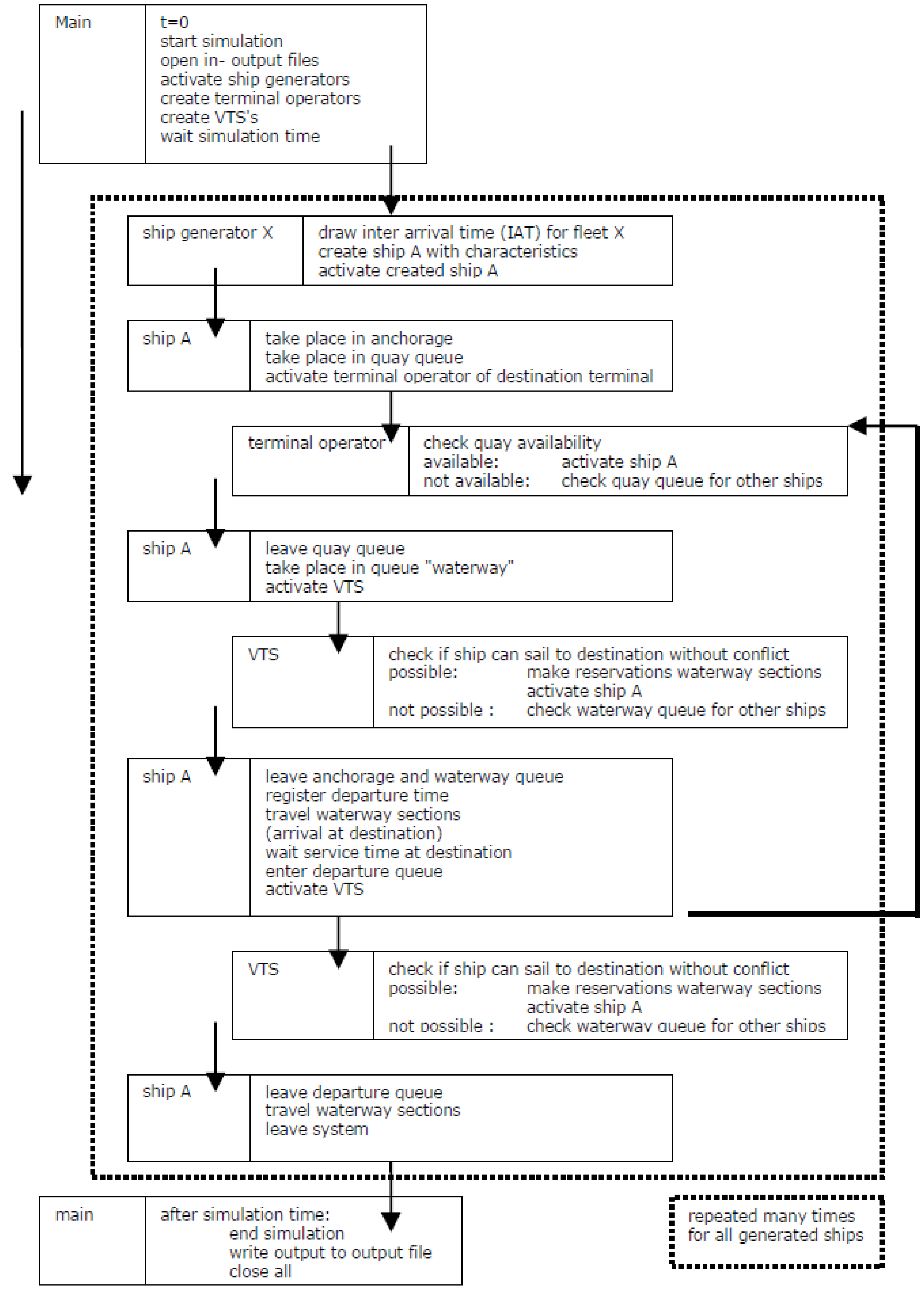


Figure 0-1 | Flow Chart Harboursim (Smits, 2006)

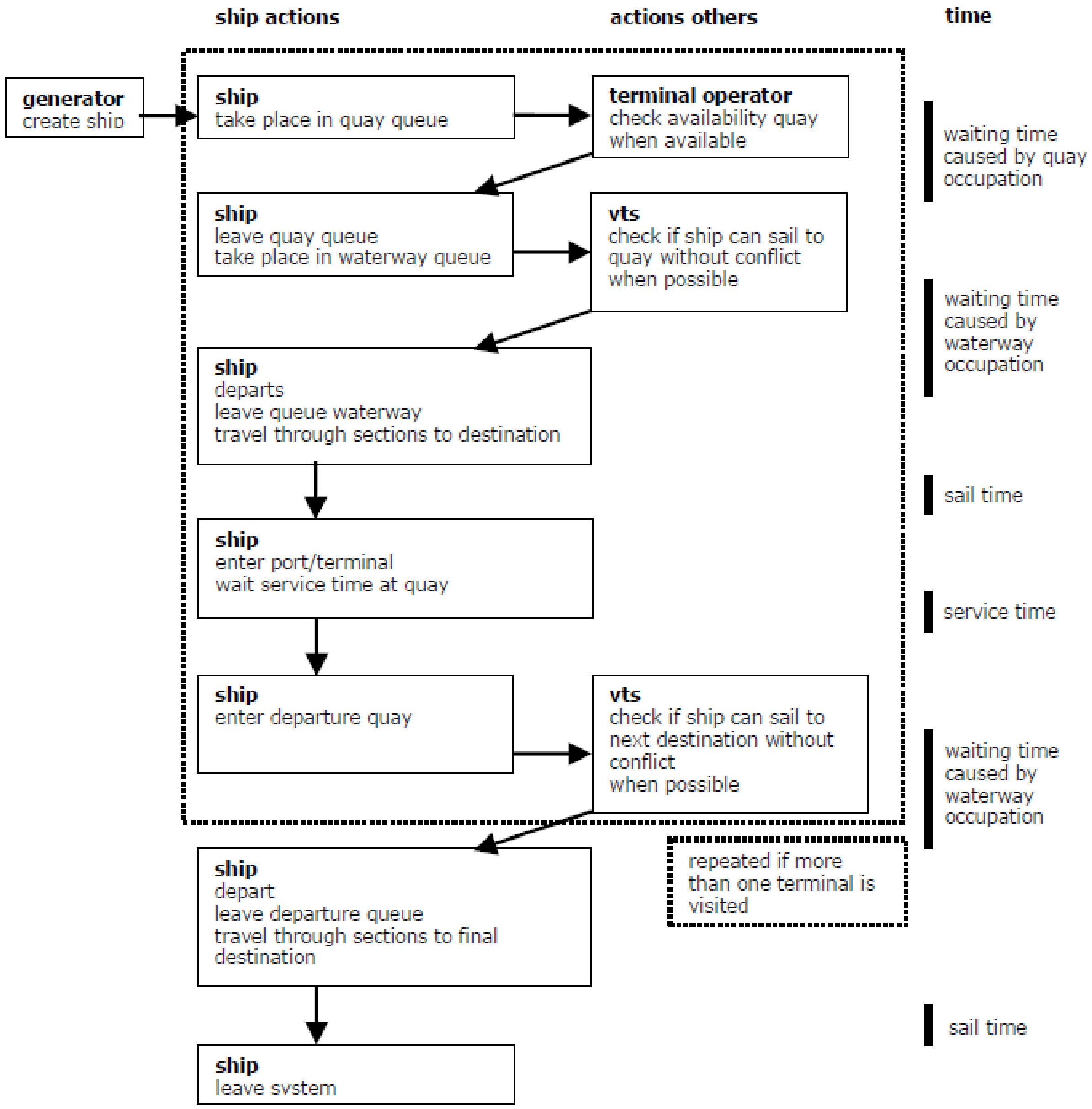


Figure 0-2 | Flow Chart Ship (Smits, 2006)

I-D Harboursim interface and visualization

After opening a Harboursim model, the user can choose to use a fixed tidal window or to let simulate a tidal window. Furthermore, the lengths of each quay can be changed. During the simulation, ships are shown at the different quays and anchorages. Per quay, incoming and outgoing ships are shown. Windows of the number of ships handled per fleet, the occupancy of the different quays and the waiting times of ships on arrival are shown. Figure 0-3 shows an example of the Harboursim simulation

Figure 0-3 | Example of the Harboursim animation

I-E Input

Several input files are used to define the models port, ships, traffic rules, currents and water levels.

Port data
This file is used to describe all points where ships can be serviced in the model. The names of all quays are specified as well as the length of different quays. The wave periods are specified for each quay to model good and bad weather. The number and capacity of anchorages are specified. From this file, the model also reads the duration of a simulation run and how many runs are to be carried out.

Ship data
Similar types of ships are bundled in a fleet. All fleet characteristics to be generated are defined in this file such as: ship dimensions, quays to be visited and service times at quays. The file determines how many ships belonging to a fleet are generated. It prescribes in what rate ships are generated and how the inter arrival time distribution is defined.

Traffic rules
This file describes for each fleet, which stretches are to be sailed per track and how long each stretch is occupied in minutes. For each stretch, the rules of encounter or overtaking between the different fleets are set.

Tidal data
Two files are used to specify the tidal data for the model. One can choose a fixed tidal window or a variable depending on maximum current velocities and draught limitations due to fluctuating water levels. To describe the tidal conditions only the curves during spring tide and neap tide must be defined. The actual current velocities are determined by interpolating.

I-F Output

In the first part of the output file the results of the individual runs are given. It shows the following output:

- The mean waiting times per fleet in anchorages and at the quays.
- The total number of ships generated and passed through the port per fleet.
- The occupation of the anchorage, specified by the total amount of minutes all ships stayed.

In the second part, the results of all the runs are summarized by the following output:

- The mean waiting times of all ships per run on arrival.
- The mean waiting times of all ships per run on departure.
- The mean waiting times over all runs at quays per ship type
- The berth occupancy of all quays over all runs
- The number of quay meter hours of all quays over all runs

II HARBOURSIM IMPROVEMENTS

This appendix serves as an extension of the Harboursim manual (Groenveld, 2004). The model has significantly been improved and the input and output files are changed to fit the users' needs. The model has been changed for general use, so improvements are made for all users of Harboursim.

While modelling the Port of Beira in Harboursim, problems arose. Limitations of the original Harboursim model made it impossible to make a good representation of the Port of Beira processes. To find out what caused the problems, a closer look was required in the model processes. While tracing the steps the model takes, errors where found. Now insight in the model was gotten, the errors and limitation were possible to repair. The following processes were fixed:

- Tidal window in Harboursim
- Quay length required for a ship
- Water level calculation

For Beira Port and ports around the world, processes should be added to the Harboursim model to make a good representation of the reality. All the model additions are generally applicable. The following additional features were written for the model:

- Daylight window
- Terminal arrival queue for offshore berth
- Terminal departure queue for offshore berth
- Erlang k distribution as service time distribution
- Dwell time in the model per fleet
- Making Harboursim compatible with excel

In the following chapters details about the changes in Harboursim are given. Herein the changes in the input files are given, so that future users can use the improved Harboursim model. A spread sheet is created to ease model inputs; this is explained in paragraph II-C. The additions to the results.txt output file are explained. Before recommendations are made in the last chapter, the use of the excel file is explained for future users.

II-A Fixed processes in Harboursim

II-A.a. Tidal window in Harboursim

A large error is found where Harboursim checks the currents and water levels for the ships. Harboursim only checks the water level and current at one point in time, instead of during the entire sail time of the ship.

In Figure 0-4 three ships ask to sail an access channel, all with the same tidal window. In reality, ship 1 should wait for the tidal window and ship 2 would be granted access immediately. Ship 3 should wait for the next tidal window, because it is too shallow during its sailing time. However, Harboursim would let the ship sail through and the tidal window is incorrectly lengthened with, at maximum, the ships sailing time. For further proof of the error, reference is made to the example shown in Appendix III.

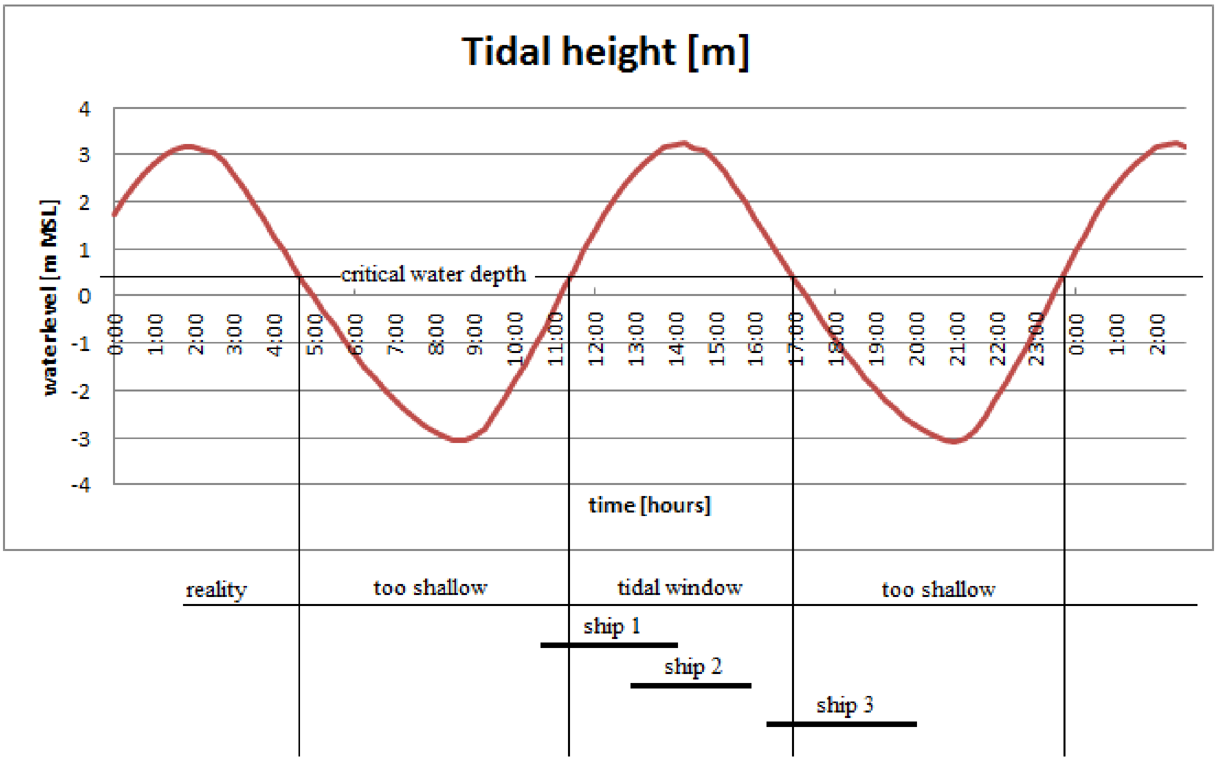


Figure 0-4 | Ships sailing times in relation to tidal window

The following changes have been made to Harboursim to solve the problem. The currents and water levels are now checked when the ship requests to sail its track for the actual time and for the end of its sailing time. Still it is possible that a ship gets into trouble when a tidal downtime is shorter than the ships sailing time. At the beginning and end time, it can be deep enough, but in between the depth can be less. Tidal limitations shorter than 30 minutes do not arise often because of neap and spring tide variations. Also the tidal variation in 30 minutes is generally not much around the minimums. This process is visualized in Figure 0-5. The model is expanded to check the depth with an interval of 30 minutes during the sailing time of the ship. If it is deep enough at every moment, the ship is granted permission to sail its section.

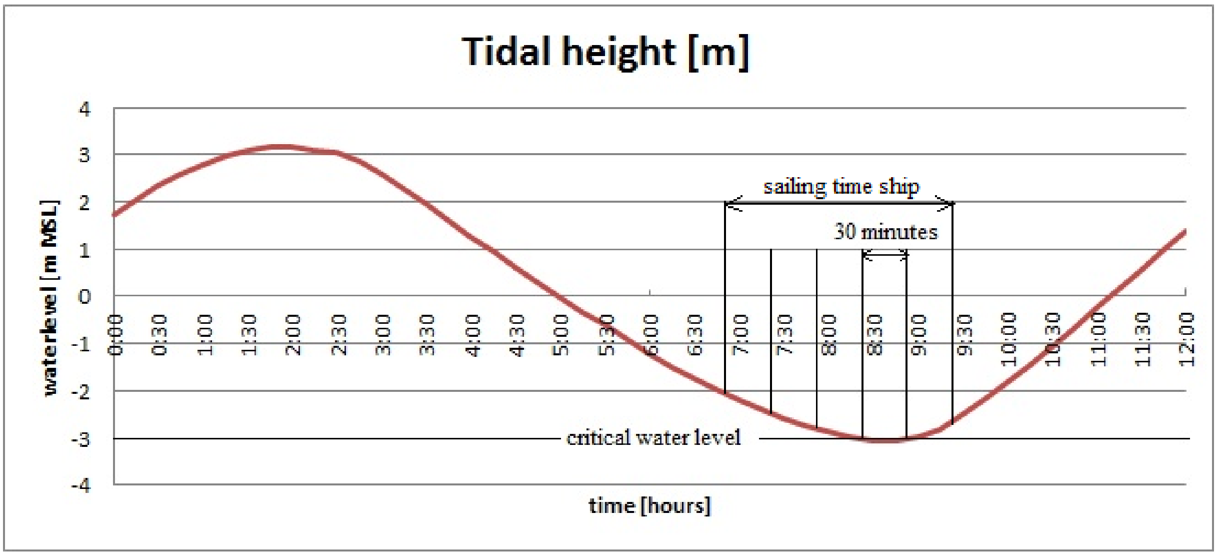
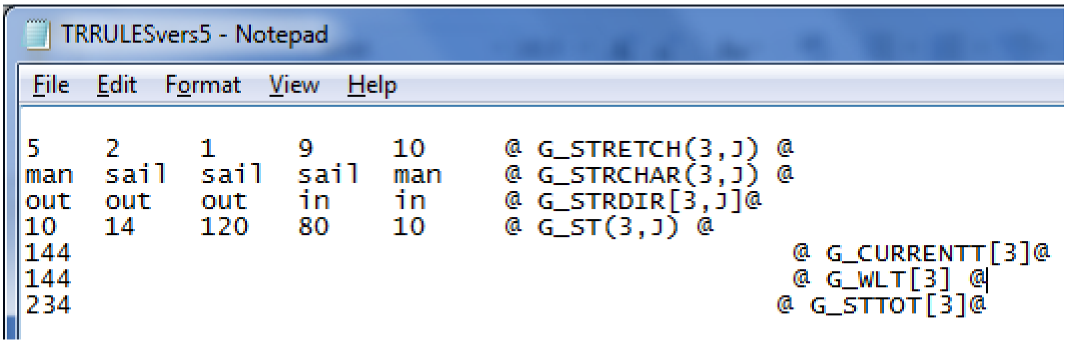


Figure 0-5 | Visualisation tidal window calculation in Harboursim

If a tidal window is only applied to the first part of the section the ship is requesting to sail, this can now also be added to the model. The end time of the sailing time through the tidal window part can be entered in the traffic rules input file, see Figure 0-6:

@ G_CURRENTT[3] @	Time for which currents should be checked
@ G_WLT[3] @	Time for which water level should be checked
@ G_STTOT[3] @	Total sailing time of track



```
TRRULESvers5 - Notepad
File Edit Format View Help

5     2     1     9     10    @ G_STRETCH(3,J) @
man   sail  sail  sail  man   @ G_STRCHAR(3,J) @
out   out   out   in    in    @ G_STRDIR[3,J]@
10    14    120   80    10    @ G_ST(3,J) @
144                                    @ G_CURRENTT[3]@
144                                    @ G_WLT[3] @
234                                   @ G_STTOT[3]@
```

Figure 0-6 | Track specification in TRRULESvers5.txt input file

II-A.b. Quay length required for a ship

For multiple berths in a straight continuous quay front, the quay length is based on the average ship length as follows (Ligteringen, 2007):

$$L_{quay} = 1.1 \cdot n \cdot \left(\overline{L}_{ship} + 15\right) + 15$$

This allows for a berthing gap of 15 m between the ships moored next to each other and an additional 15 m at the two outer berths. The factor 1.1 corrects for additional waiting time due to simultaneous berthing of several above-average vessels. (Ligteringen, 2007)

In the Harboursim model the length of each berthing ship is subtracted from the free quay length and no additional length is reserved. To ensure the effect of the quay length is correctly modelled, the above mentioned formula is added to the model. The free quay length is now calculated as follows:

$$L_{free,1} = L_{free,0} - 1.1 \cdot (L_{ship} + 15)$$

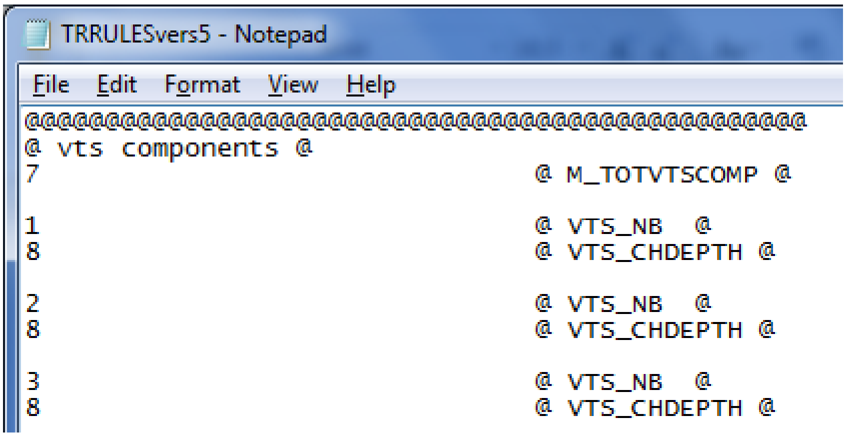
The additional 15 m for the two outer berths is subtracted from the total quay length of each terminal.

For a single berth the necessary quay length is the length of the largest vessel frequently calling at port, increased with 15 m extra length fore and aft for the mooring lines. However, Harboursim does not distinguish between single and multiple berths, because only quay lengths are input. The free quay length rule is used for single berths too. The quay lengths of single berths must therefore be adapted to ensure that all calling vessels can berth at the quay. Their model quay length must be at least:

$$L_{quay} = 1.1 \cdot (L_{\max\ ship} + 15)$$

II-A.c. *Water level calculation*

In the traffic rules input file TRRULESvers5.txt the depth of a VTS component can be entered, see Figure 0-7. A VTS component consists of the sections the ship sails to its next destination, also known as a track. However, Harboursim only uses the depth of VTS 1 to calculate the actual water level. Therefore, if for instance, your model has two access channels with different depths, it calculates the water level only correctly for access channel 1. All tidal window calculations for VTS 2 to i are done with the depth of VTS 1.
This mistake is probably deliberately made, because the water level calculation is also used to create a water level graph. With input from multiple tracks with different depths, this would create a wrong graph. A solution is found by separating the two processes of the water level depth calculation for the tidal window calculation and for the water level graph creation.


TRRULESvers5 - Notepad

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```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@ vts components @
7                      @ M_TOTVTSCOMP @

1                      @ VTS_NB   @
8                      @ VTS_CHDEPTH @

2                      @ VTS_NB   @
8                      @ VTS_CHDEPTH @

3                      @ VTS_NB   @
8                      @ VTS_CHDEPTH @
```

Figure 0-7 | VTS depth specification in TRRULESvers5.txt input file

II-B Added processes to Harboursim

II-B.a. Daylight window

In the original Harboursim model ships sail 24 hours a day. Sailing during the night is not everywhere possible. As with Beira Port, some ports have a daylight window in which it is permitted to sail the access channel and port area. In order to see the effect of allowing night traffic, a feature is added to Harboursim to toggle night sailing on/off.

First, a clock must be added to Harboursim that monitors the day and night cycle, which is naturally 24 hours. Then a daylight window must be specified. It is chosen to make a feature for a fixed window only, as this is the case close to the equator. A fixed begin and end time is specified in the Harboursim. It is recommended to make an addition to the port specification input file, where the daylight times can be specified. The traffic control checks for the begin and end time of the sailing time if there is daylight. Generally, night time is longer than the sailing time, so the daylight does not have to be checked on an interval as with the tidal window.
As with the tidal window, the feature can be toggled on/off in the starting input screen of Harboursim, as is shown in Figure 0-8

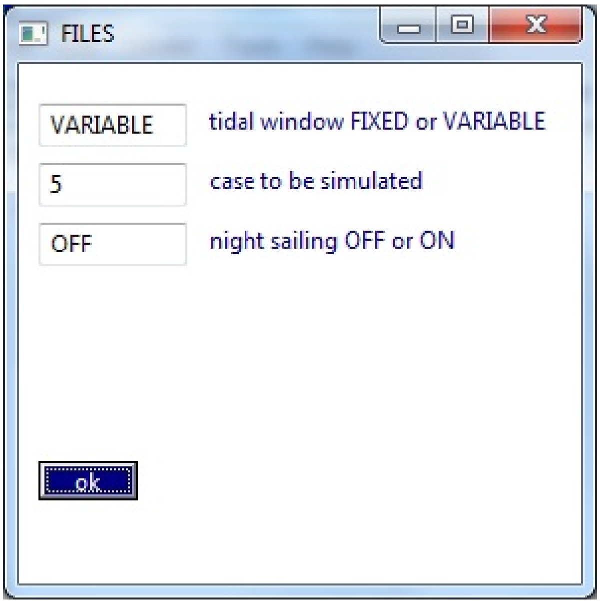

Figure 0-8 | starting input screen Harboursim

II-B.b. Terminal arrival queue for offshore berth

A 'terminal departure queue' is added as an option for terminals in Harboursim. This addition makes it possible for ships to sail to their designated terminal even if there is no free quay length. A terminal arrival queue can be added if there is additional mooring space at the quay or close to the quay. At this spot, a ship can wait to be serviced.
The ship reserves a spot in the arrival queue and set sail towards the terminal. On arrival, the free quay length is checked again for space for the ship. Until the required quay length becomes available, the ship waits in the arrival queue. As with an anchorage place, there is limited space in the arrival queue. This place is expressed as a maximum allowable amount of ships in the queue. In the port specification input file, the terminal arrival queue can be toggled on/off and a maximum number of ships can be set, see Figure 0-9.

@ AVTQ @	availability of terminal queue [1=yes, 0=no]
@ MAXDEPQ @	maximum amount of ships in departure queue
@ MAXARRQ @	maximum amount of ships in arrival queue

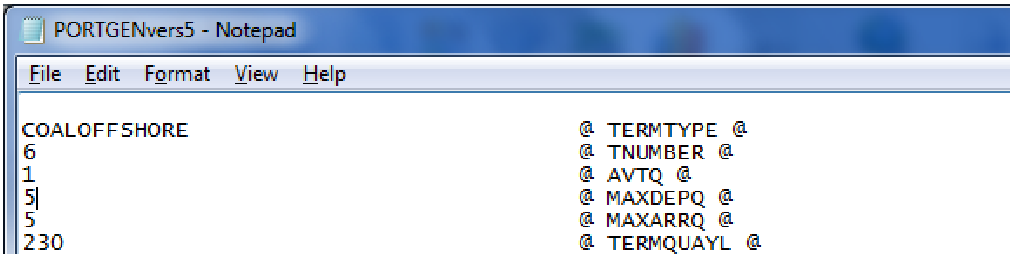

Figure 0-9 | Terminal specification in PORTGENvers5.txt input file

II-B.c. *Terminal departure queue for offshore berth*

A ‘terminal departure queue’ is added as an option for terminals in Harboursim. Similar to the arrival queue this is a place for ships to wait next to the terminal, only this time after the ship has been serviced. The ship waits in the departure queue until it can sail through to its next destination. This waiting time is monitored and added to the waiting time on departure. In the meantime, the quay is already made free for the next ship to be serviced. In the port specification input file, the terminal departure queue can be toggled on/off and a maximum number of ships can be set, see Figure 0-9. It must be noted that the Harboursim manual (Groenveld, 2004) makes reference to a terminal departure queue, but it was not present in the model.

II-B.d. *Erlang k distribution as service time distribution*

The Erlang k distribution is the most used distribution for service times. In Harboursim the Erlang k distribution could only be used as inter arrival time distribution. A macro is added to the model to make use of the Erlang k distribution as service time distribution. In the Harboursim manual is explained how samples are taken from the Erlang k distribution (Groenveld, 2004).

II-B.e. *Dwell time in the model per fleet*

The dwell time of a ship in the model represents the time the ship is present in the port area. For transport planning purposes, it can be useful to know this parameter. In our Harboursim model the mean dwell time per ship type is required to calculate the occupancy and the mean waiting time based on the service time of the OGV of Vale, further explained in paragraph 5.3.
When a ship leaves the model the time is monitored and subtracted from the starting time of the ship, this is the dwell time of the ship. The average of the dwell times per fleet is the mean dwell time per fleet. A feature is added to Harboursim to add it to the results.txt file, see Figure 0-10.

Results - Notepad

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'MEAN MODEL TIME PER SHIPTYPE OVER ALL RUNS'

'SHIPTYPE'	'RUN 1'	'RUN 2'	'RUN 3'	'RUN 4'	'RUN 5'	'RUN 6'	'RUN 7'	'RUN 8'	'RUN 9'	'RUN10'
CONTAINER	1579	1624	1642	1646	1524	1613	1760	1634	1517	1624
GENCARGO	1840	2292	1841	1852	1921	2265	1774	2231	2558	1920
COALVALE1	14116	14037	14509	14335	16678	13340	15794	13478	17308	15019
COALVALE2	11865	11858	12950	12837	13878	11611	13318	11487	14324	13388
COALRT	2412	2653	2839	2709	3103	2630	3196	2382	2986	2446
FUEL	1735	1877	1619	2533	2340	2135	2059	2019	2098	3217

Figure 0-10 | Mean model time per ship type in results.txt output file

II-B.f. *Making Harboursim compatible with excel*

Harboursim creates results.txt as the output file. For master planning use, these results must be analysed and compared to other simulation results. The output text file cannot be read by other programs. The text files are very user unfriendly and time consuming to use. Harboursim is reworked to create results.txt files that are compatible with excel. Now for further analysis of the results the Microsoft office program excel can be used.

II-C Using Excel to create input files

Once a port is specified in Harboursim, simulation will be done for different scenarios. To ease the process of filling in the fleet specification input file the software excel is used. The tables that have to be filled in are shown in Figure 0-11, Figure 0-12 and Figure 0-13. The yellow tables are calculated by excel. All relevant data is automatically copied to a spread sheet, which is saved as the SHIPPAOvers5.txt input file.

Fleet	Load*	Draught in [m]	Draught out [m]	LOA [m]
Container	300	9.5	9.5	154
General cargo	2000	10	10	113
Coal Vale 1	30000	7	10.7	194
Coal Vale 2	30000	7	10.7	194
Coal Rio Tinto	30000	7	10.7	185
Fuel	10000	11.5	8.5	130

Figure 0-11 | Average ship specification in excel

Fleet	Import*	Export*	Empties*	# of vessels	inter arrvial time [min]	k value
Container	90,000	60,000	45,000	375	1,752	1
General cargo	900,000	875,000		450	1,168	1
Coal Vale 1		3,000,000		100	5,256	10
Coal Vale 2		3,000,000		100	5,256	10
Coal Rio Tinto		3,000,000		100	5,256	10
Fuel	2,500,000	180,000		268	2,102	1

Figure 0-12 | Throughput specification in excel

Terminal	handling speed	service time**	k value
container	40	794	5
general cargo 6-7	240	694	5
Coal quay 8	1700	1133	10
general cargo 9-11	240	694	5
Fuel	1200	680	5
Coal offshore	3000	800	10

Figure 0-13 | Terminal operation specification in excel

II-D Conversion of model results with Excel

Results.txt gives a lot of detailed information on the model simulation results. We would like to compare different simulation results; therefore, the relevant results must be filtered and put into tables. We consider the following as relevant information for comparison, as explained in paragraph 5.1:

- The mean occupancy per terminal
- The mean waiting time per ship type over all runs on arrival
- The mean waiting time per ship type over all runs on departure
- The total mean waiting time per ship type over all runs
- The accuracy of the above mentioned parameters

II-D.a. A worksheet per simulation with detailed results

A macro is written in excel which reads the results.txt file and calculates means and standard deviations of the results over all runs. With this, the accuracy of the model predictions is calculated. The following steps are made in the macro:

- A results.txt file is loaded into a new worksheet and layout is improved for easy reading
- The mean waiting time per ship type over all runs on arrival is calculated in minutes
- The mean waiting time per ship type over all runs on departure is calculated in minutes
- The total mean waiting time per ship type over all runs is calculated in minutes
- The total mean waiting time per ship type over all runs is calculated as a percentage of the mean service time
- The standard deviation of the mean waiting time per ship type over all runs is calculated in minutes and as a percentage of the mean service time
- The means of the occupancy parameters per terminal over all runs are calculated
- The standard deviations of the occupancy parameters per terminal over all runs are calculated
- The mean of the waiting times over all runs of the OGV of Vale is calculated
- The accuracy of the mean waiting times in minutes and as a percentage of the mean is calculated per ship type
- The accuracy of the mean occupancy per terminal

II-D.b. Results of simulations filtered for comparison

In the worksheet per simulation now detailed results can be found. In the worksheet ‘results’ the most important results of different simulations are collected so they can be compared, an example of the ‘results’ spread sheet is shown in Figure 0-14. The following steps are added to the macro to create the spread sheet:

- The mean occupancy per terminal over all runs is copied to the worksheet ‘results’
- The mean waiting time per ship type over all runs on arrival and on departure in hours is written to the worksheet ‘results’
- The total mean waiting time per ship type over all runs in hours and as a percentage of the service time is written to the worksheet ‘results’
- A column chart is created with the occupancy rates over all runs per terminal
- A stacked column chart is created with the mean waiting times over all runs per ship type on arrival and departure is created

Occ:	Occ: 10.4			Occ: 10.3		
	OCC[ST]	OCC[ST+W]	OCC[ST+W+R]	OCC[ST]	OCC[ST+W]	OCC[ST+W+R]
Container	0.059	0.104	0.122	0.058	0.104	0.119
GenCargo67	0.15	0.22	0.26	0.15	0.23	0.26
Coal 8	0.4	0.49	0.55	0.33	0.4	0.45
Gen Cargo 911	0.13	0.2	0.23	0.09	0.14	0.16
Fuel	0.12	0.18	0.2	0.09	0.14	0.16
Offshore	0.19	0.41	0.45	0.23	0.59	0.64
Coal OGV	0.38			0.38		

MWT:	MWT: 10.4				MWT: 10.3			
	MWT on arrival	MWT on departure	TMWT [hours]	TMWT [ST]	MWT on arrival	MWT on departure	TMWT [hours]	TMWT [ST]
Container	6.8	7.8	14.6	1.52	5.9	7.9	13.8	1.43
General cargo	13.3	6.3	19.6	1.62	6.8	6.6	13.3	1.11
Coal Vale 1	3.6	11.7	15.3	0.75	2.9	12.8	15.8	0.82
Coal vale 2	9.8	13.6	23.4	0.94	8.7	15.4	24.1	1.05
Coal RT	19.0	4.5	23.6	1.25	18.4	4.8	23.2	1.23
Fuel	16.1	6.2	22.3	1.97	9.7	6.2	15.9	1.40
Coal OGV Vale			131.7	1.57			134.5	1.60

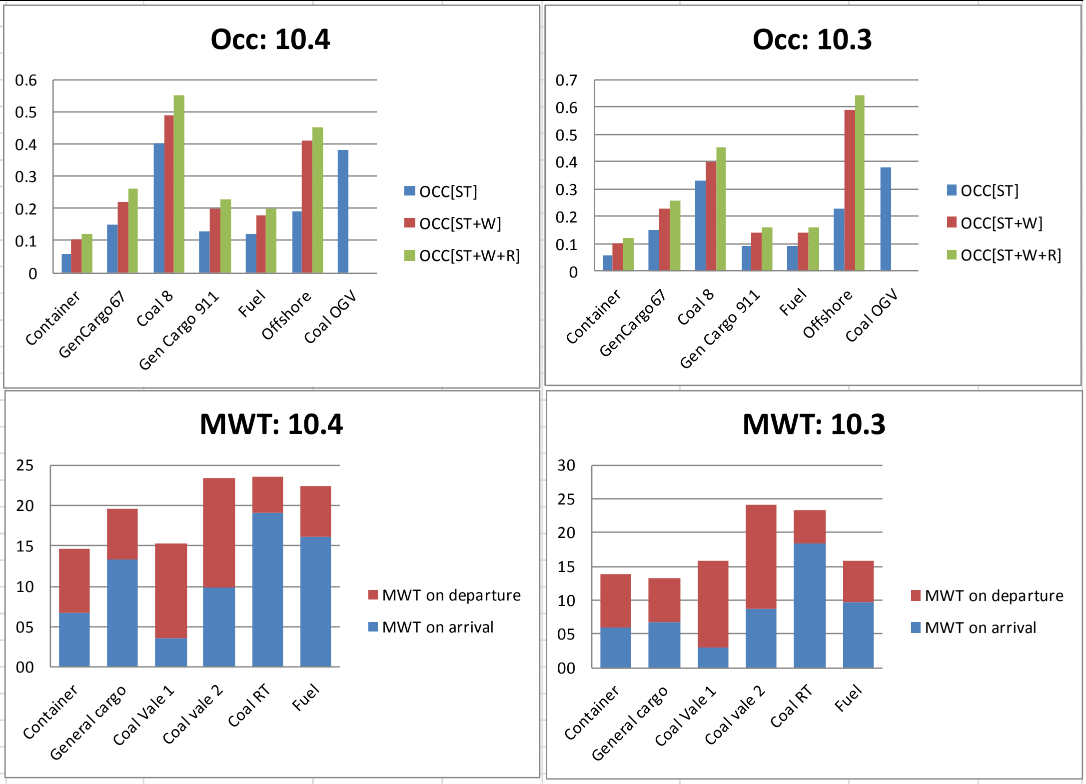


Figure 0-14 | Results spread sheet for fast comparison of results

II-D.c. *Calculation of the accuracy of the model predictions*

To calculate the acquired accuracy of the model results, the standard deviation of the runs has to be determined. This done with the help of the following formula:

$$s = \sqrt{\left(\frac{1}{N-1}\right)[(x_1-\mu)^2+(x_2-\mu)^2+(x_3-\mu)^2]} \quad ; \quad with\ \mu = \frac{1}{N}(x_1+x_2+x_3)$$

s is an approximation of the standard deviation for a sample of a population. x_1 to x_i are the model results. The factor N-1 is known as Bessel's correction, where N is the number of runs. With the estimated standard deviation, the accuracy d [minutes] of the results will be determined using the next formula:

$$d = \frac{s \cdot Z}{\sqrt{n}}$$

Where a probability ($Z_{\alpha/2}$) of 95% will suffice and with the help of a table for the area under the standard normal curve, Z is 1.96. The Harboursim model takes about ten minutes to run. The maximum of 10 runs is chosen for all simulations and used in the output macro in Excel, so n=10

The above formulae are added to the Excel macro. This is done for the occupancy, the mean waiting time on departure, arrival and total mean waiting time. The accuracy is given in minutes and as a percentage of the mean over all runs.

II-E Recommendations

Currently the daylight time is fixed in the model from 5:30 to 18:00. In reality, this is different around the globe. In the port specification input file, the daylight time should be possible to specify. Beira is located near the equator and therefore daily variations in daylight time are not significant. Further from the equator, this variation becomes more and more important. A longest and shortest day should be possible to specify in an input file. Even more realistic would be to make an additional input file comparable to the water level input file, where a curve for the daylight time could be specified. Here users should be able to choose for one, two or more specified daylight times divided over the year.

The additional 15 m for the two outer berths should be subtracted from the total quay length of each terminal. To avoid mistakes made by users who forget to subtract the 15 m, this subtraction should be added to the model process. Then users just have to enter the real quay length in the port specification input file.

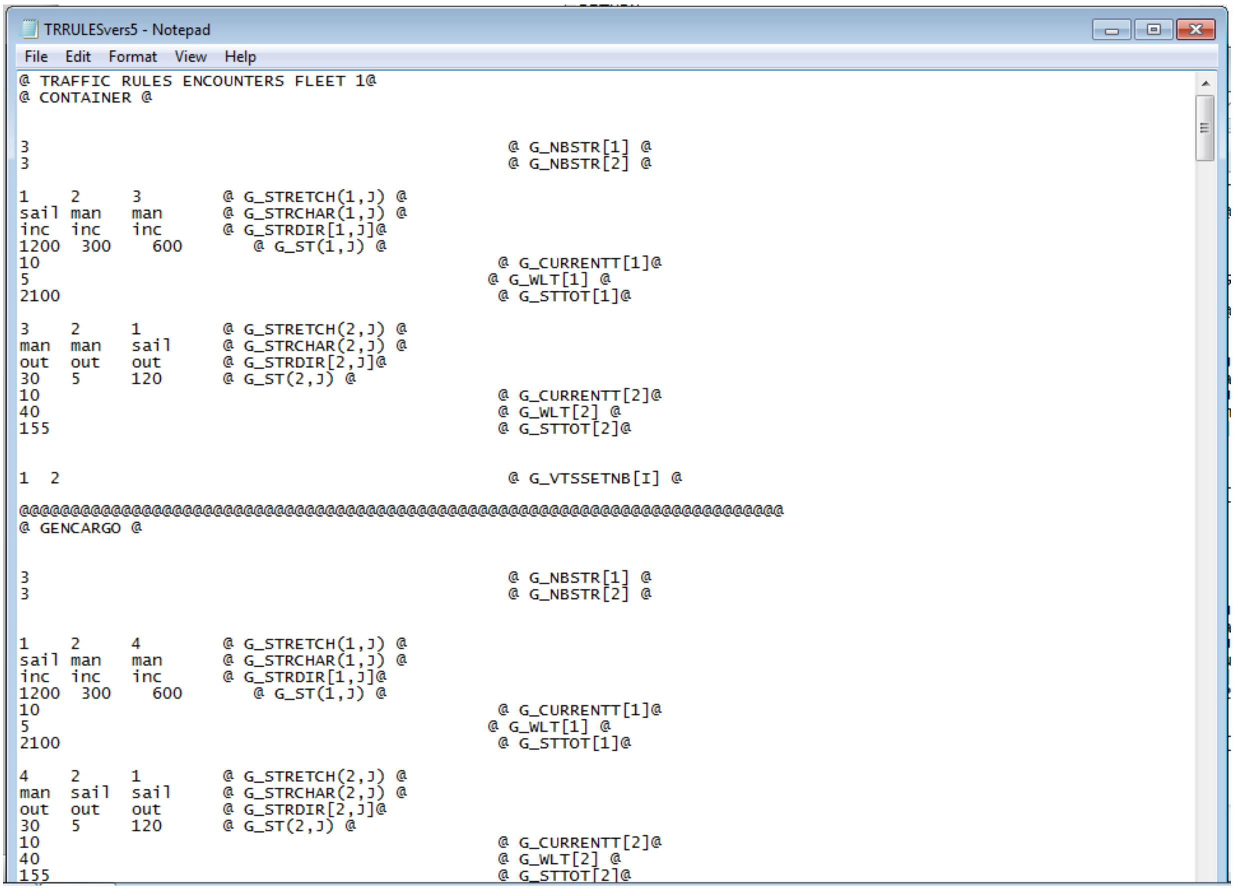
In the Harboursim manual no reference is made to the under keel clearance. However, the influence on the draught input is significant. As the keel clearance depends on several parameters, it is not advisable to implement in the Harboursim code. However, the manual should mention clearly that the under keel clearance has to be added to the draught.

The Harboursim model is used with the maximum of 10 runs per simulation. Also for the excel macro this number is fixed. The Harboursim model should be enhanced with the possibility to do more model runs per simulation. This will increase the accuracy of the model predictions if necessary.

III TIDAL WINDOW ERROR IN HARBOURSIM

During test simulation runs, the suspicion is risen that Harboursim only checks the waterdepth on the moment a ships requests permission to sail a certain section. It does not check the waterdepth for the time the ship sails the section. This way the tidal window in the model becomes much longer than in reality, especially with the long sailing times in the access channel. Below a test is described to check whether the suspicion is right. In the example the test is done with my own Harboursim model. For completeness is the same test done with the original Harboursim model, with comparable results.

In the input file TRRULESvers5.txt the sailing times for the first section are set at 1200 minutes. The total sailing time is also set at 2100 minutes. A tidal cycle is 745 minutes, so if a tidal window is checked for the entire sailing time the ships would be put in the anchorage.


TRRULESvers5 - Notepad
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```
@ TRAFFIC RULES ENCOUNTERS FLEET 1@
@ CONTAINER @

3                                               @ G_NBSTR[1] @
3                                               @ G_NBSTR[2] @

1    2     3          @ G_STRETCH(1,J) @
sail man   man        @ G_STRCHAR(1,J) @
inc  inc   inc        @ G_STRDIR[1,J]@
1200  300    600         @ G_ST(1,J) @
10                                             @ G_CURRENTT[1]@
5                                            @ G_WLT[1] @
2100                                           @ G_STTOT[1]@

3    2     1          @ G_STRETCH(2,J) @
man  man   sail       @ G_STRCHAR(2,J) @
out  out   out        @ G_STRDIR[2,J]@
30   5     120        @ G_ST(2,J) @
10                                             @ G_CURRENTT[2]@
40                                             @ G_WLT[2] @
155                                            @ G_STTOT[2]@

1  2                                            @ G_VTSSETNB[I] @

@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@ GENCARGO @

3                                               @ G_NBSTR[1] @
3                                               @ G_NBSTR[2] @

1    2     4          @ G_STRETCH(1,J) @
sail man   man        @ G_STRCHAR(1,J) @
inc  inc   inc        @ G_STRDIR[1,J]@
1200  300    600         @ G_ST(1,J) @
10                                             @ G_CURRENTT[1]@
5                                            @ G_WLT[1] @
2100                                           @ G_STTOT[1]@

4    2     1          @ G_STRETCH(2,J) @
man  sail  sail       @ G_STRCHAR(2,J) @
out  out   out        @ G_STRDIR[2,J]@
30   5     120        @ G_ST(2,J) @
10                                             @ G_CURRENTT[2]@
40                                             @ G_WLT[2] @
155                                            @ G_STTOT[2]@
```

Figure 0-15 | TRULESvers5.txt with sailing times of 1200 minutes

However, the depth is only compared to the draught at the moment a ship wants to enter the access channel and not for the entire sailing time. The container and general cargo ships are permitted to sail the access channel, as can be seen in Figure 0-16. In the animation, two container ships and one general cargo ship can be seen in the access channel. In the state analysis can also be seen that the ships are in the access channel. In Figure 0-17, is with help of the trace module the actual water depth of 6.78 m shown, while it should be at least 7 m for the ships.

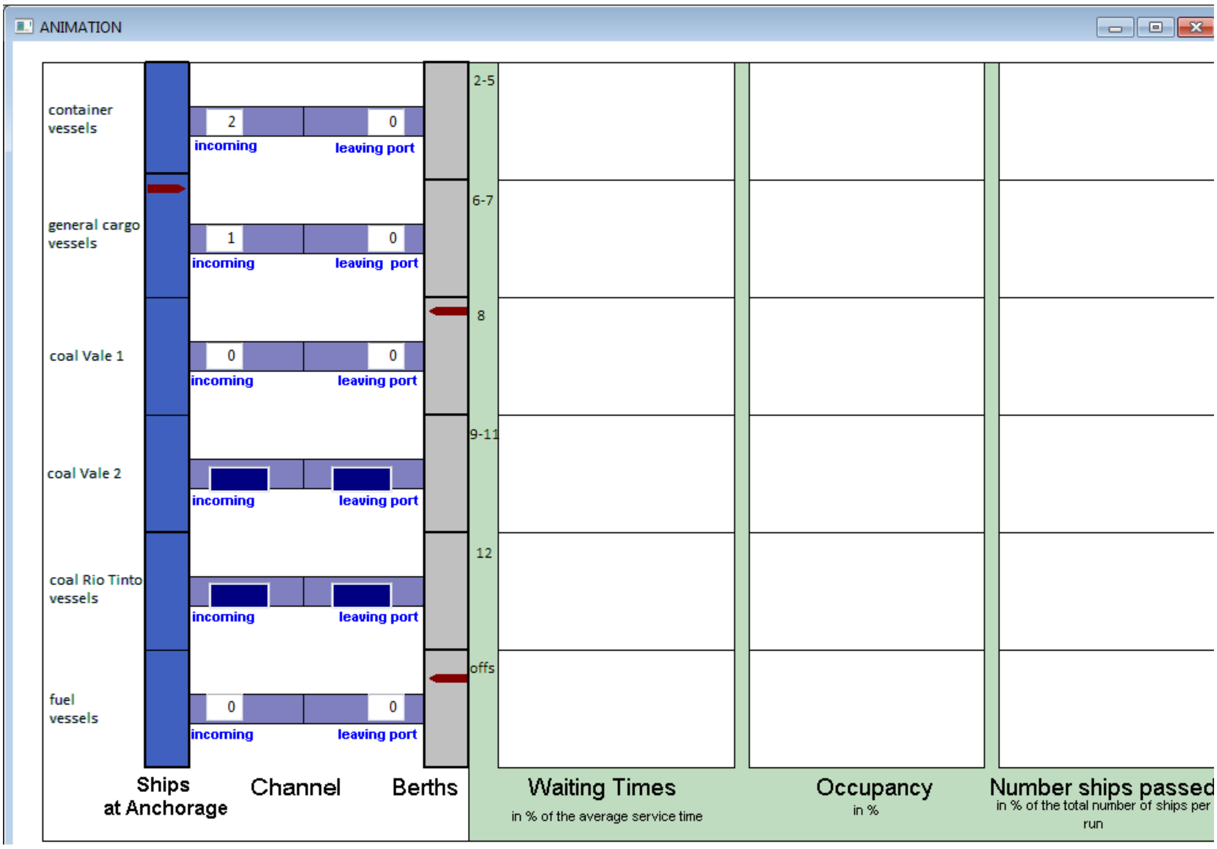


Figure 0-16 | Animation in Harboursim when depth is 6.78 m

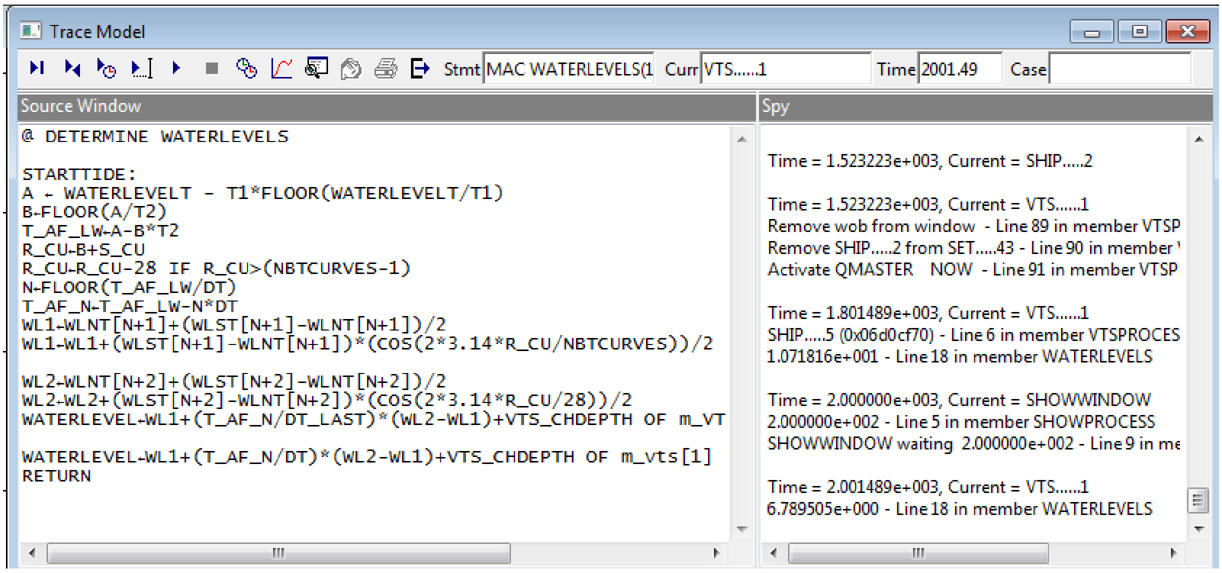


Figure 0-17 | Trace window: in the last line on the right the water depth is given: 6.78 m

IV COAL VESSELS IDEAL SCHEDULE

OGV	Coal Vale 1	Duration	Coal Vale 2	Duration	Cumulative
berthing		90		90	0
	start in model	0	start model	0	90
	berthing at OGV	60	wait at arrival queue of offshore berth	0	90
cargo 1 is loaded	**service time at OGV**	630			150
	deberth from OGV	30			780
	sail from OGV to anchorage	80	berthing at OGV	60	810
cargo 2 is loaded			**service time at OGV**	630	870
	sail from anchorage to quay 8	154			890
	berth at quay 8	60			1044
	service time at quay 8	1043			1104
			deberth from OGV	30	1500
			sail from OGV to anchorage	80	1530
			waiting at anchorage	**711**	1610
	deberth from quay 8	30			2147
	sail from quay 8 to anchorage	144			2177
	sail from anchorage to OGV	80	sail from anchorage to quay 8	154	2321
	berthing at OGV	60			2401
cargo 3 is loaded	**service time at OGV**	630			2461
			berth at quay 8	60	2475
			service time at quay 8	1043	2535
	deberth from OGV	30			3091
	sail from OGV to anchorage	80			3121
	waiting at anchorage	**551**			3201
			deberth from quay 8	30	3578
			sail from quay 8 to anchorage	144	3608
	sail from anchorage to quay 8	154	sail from anchorage to OGV	80	3752
			berthing at OGV	60	3832
cargo 4 is loaded			**service time at OGV**	630	3892
	berth at quay 8	60			3906
	service time at quay 8	1043			3966
			deberth from OGV	30	4522
			sail from OGV to anchorage	80	4552
			waiting at anchorage	**551**	4632
	deberth from quay 8	30			5009
	sail from quay 8 to anchorage	144			5039
	sail from anchorage to OGV	80	sail from anchorage to quay 8	154	5183
	berthing at OGV	60			5263
cargo 5 is loaded	**service time at OGV**	630			5323
			berth at quay 8	60	5337
			service time at quay 8	1043	5397
	deberth from OGV	30			5953

	sail from OGV to anchorage	80			5983
	waiting at anchorage	**551**			6063
			deberth from quay 8	30	6440
			sail from quay 8 to anchorage	144	6470
	sail from anchorage to quay 8	154	sail from anchorage to OGV	80	6614
			berthing at OGV	60	6694
cargo 6 is loaded			**service time at OGV**	630	6754
	berth at quay 8	60			6768
	service time at quay 8	1043			6828
			deberth from OGV	30	7384
			sail from OGV to anchorage	80	7414
			waiting at anchorage	**551**	7494
	deberth from quay 8	30			7871
	sail from quay 8 to anchorage	144			7901
	sail from anchorage to OGV	80	sail from anchorage to quay 8	154	8045
	berthing at OGV	60			8125
cargo 7 is loaded	**service time at OGV**	630			8185
			berth at quay 8	60	8199
			service time at quay 8	1043	8259
	deberth from OGV	30			8815
deberth	sail from OGV to anchorage	80			**8845**
	waiting at anchorage	**551**			8925
			deberth from quay 8	30	9302
			sail from quay 8 to anchorage	144	9332
	sail from anchorage to quay 8	154	sail from anchorage to OGV	80	9476
			Leave model		**9556**
	berth at quay 8	60			9630
	service time at quay 8	1043			9690
	deberth from quay 8	30			10733
	sail from quay 8 to anchorage	144			10763
	sail from anchorage to OGV	80			10907
	Leave model				**10987**
	Total model time [minutes]	**10987**	**Total model time [minutes]**		**9556**
	Total model time [hours]	**183.1**	**Total model time [hours]**		**159.3**
	Total model time [days]	**7.6**	**Total model time [days]**		**6.6**
	Total waiting time	**1653**	**Total waiting time**		**1813**

V GROSS DOMESTIC PRODUCT GROWTH

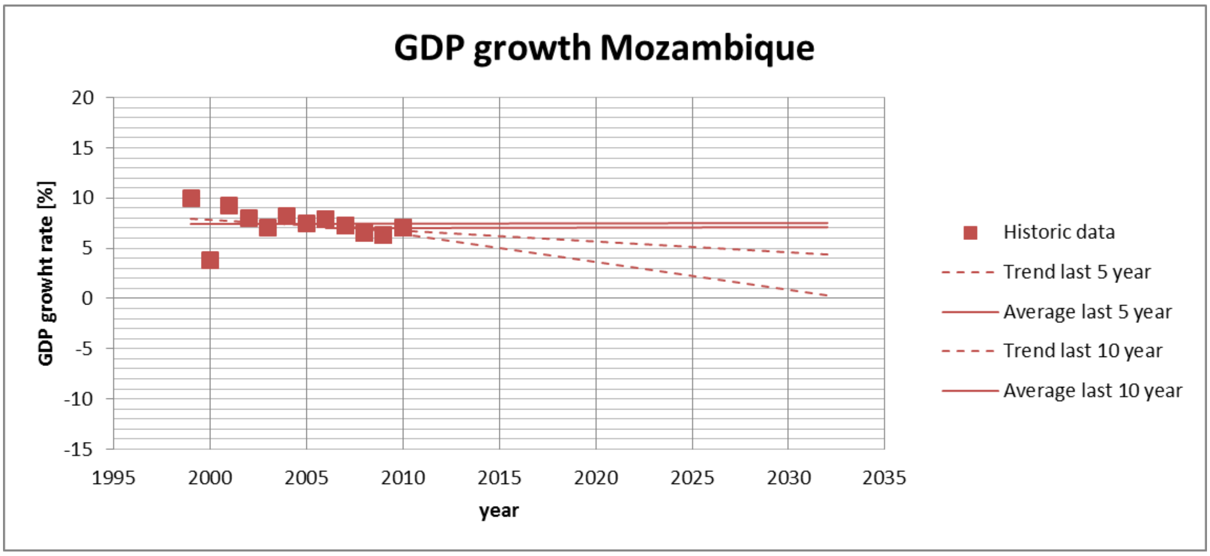


Figure 0-18 | GDP growth Mozambique with trend line and average over last 10 year

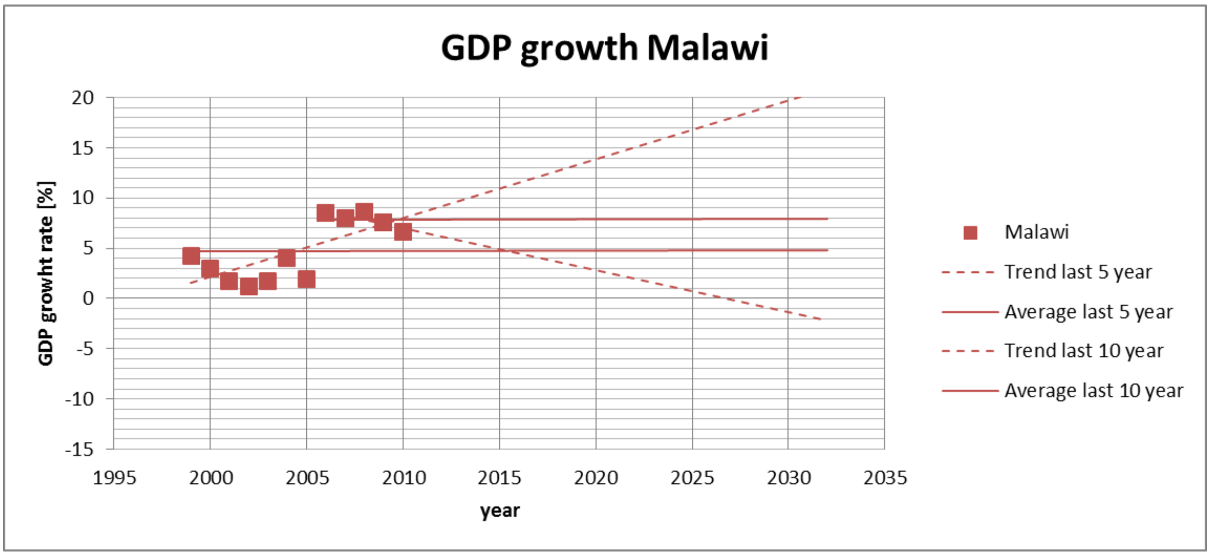


Figure 0-19 | GDP growth Malawi with trend lines and averages

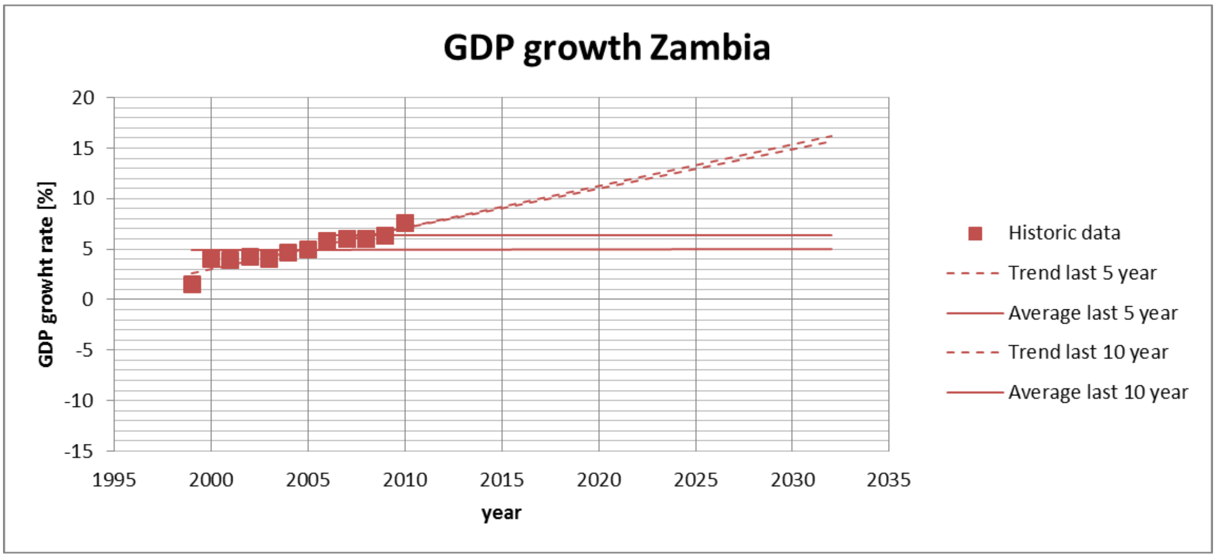


Figure 0-20 | GDP growth Zambia with trend lines and averages

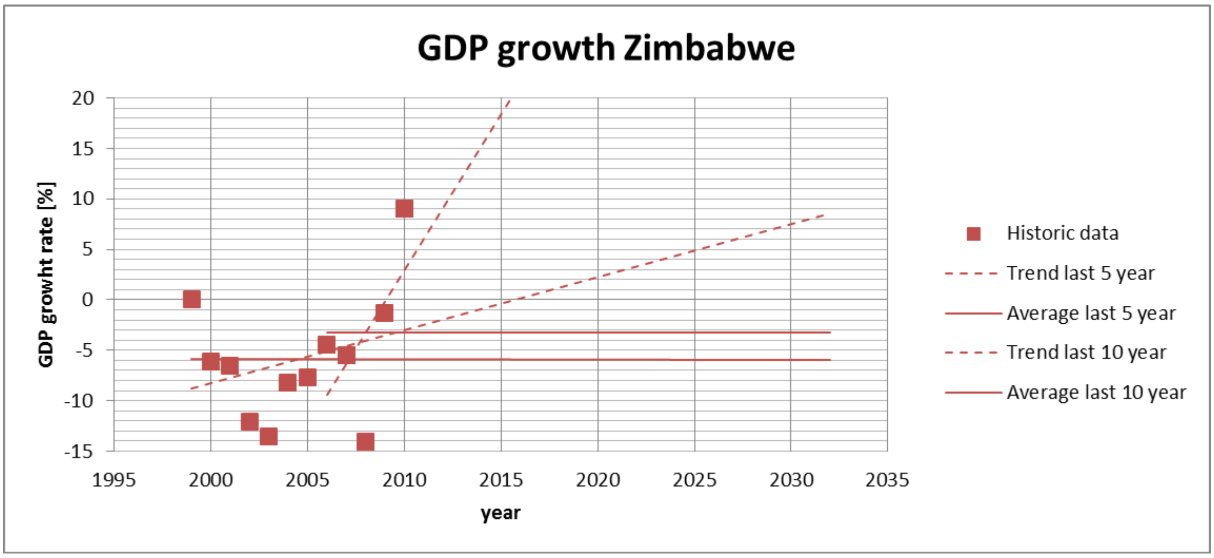


Figure 0-21 | GDP growth Zimbabwe with trend lines and averages

VI IMPORTS AND EXPORTS GROWTH

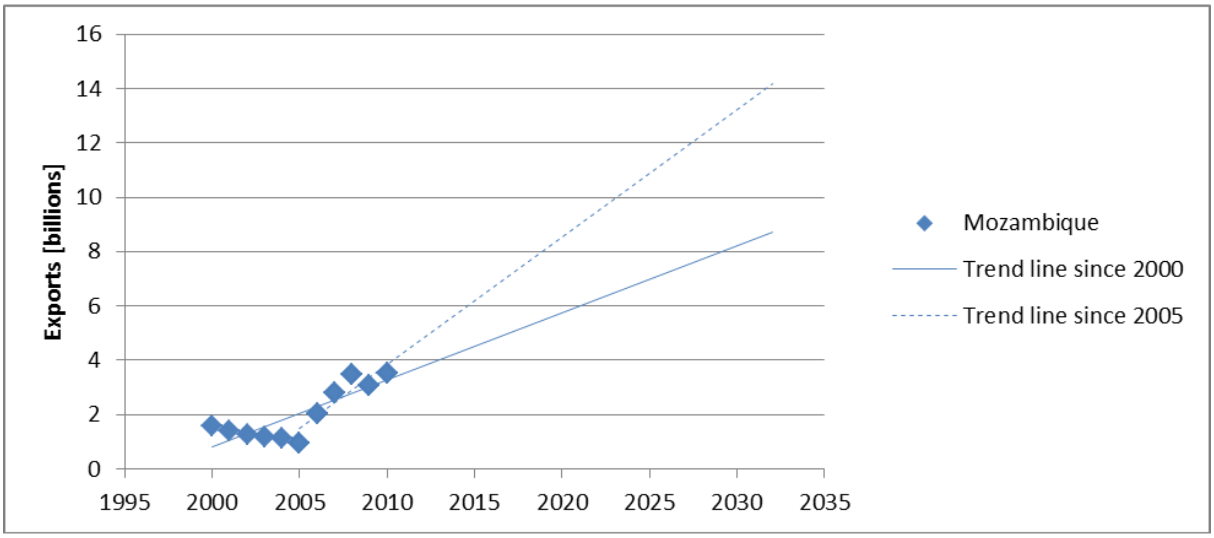


Figure 0-22 | Mozambique import with trend lines

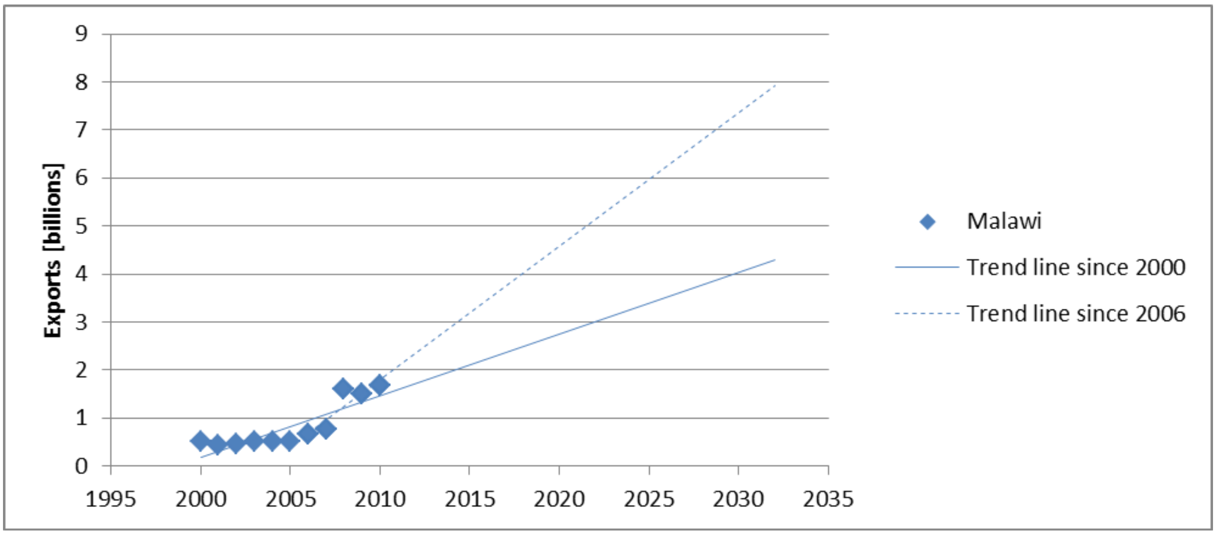


Figure 0-23 | Malawi import with trend lines

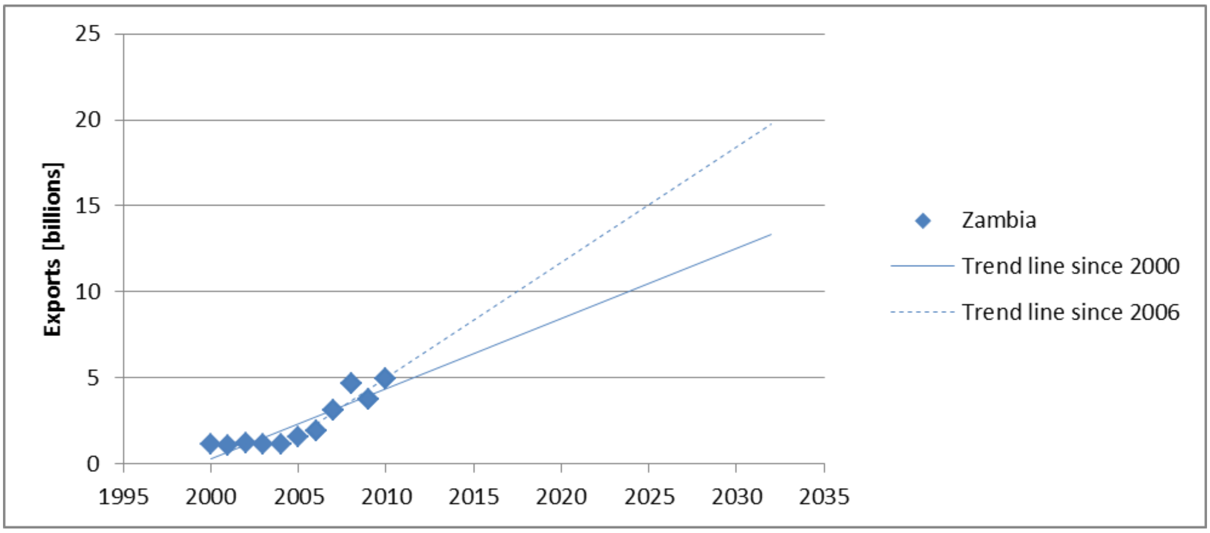


Figure 0-24 | Zambia import with trend lines

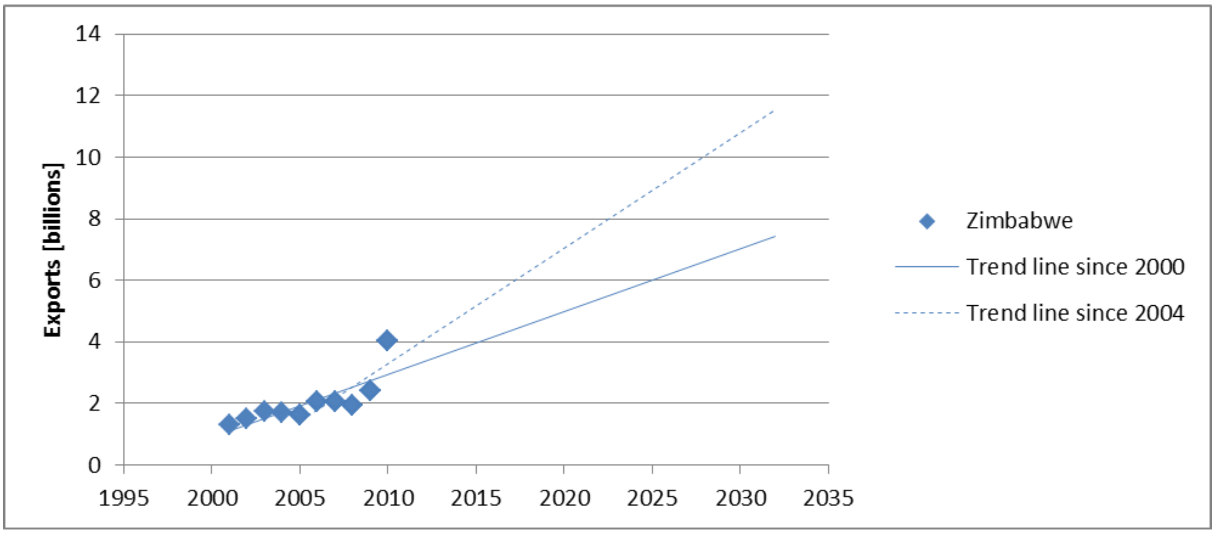


Figure 0-25 | Zimbabwe import with trend lines

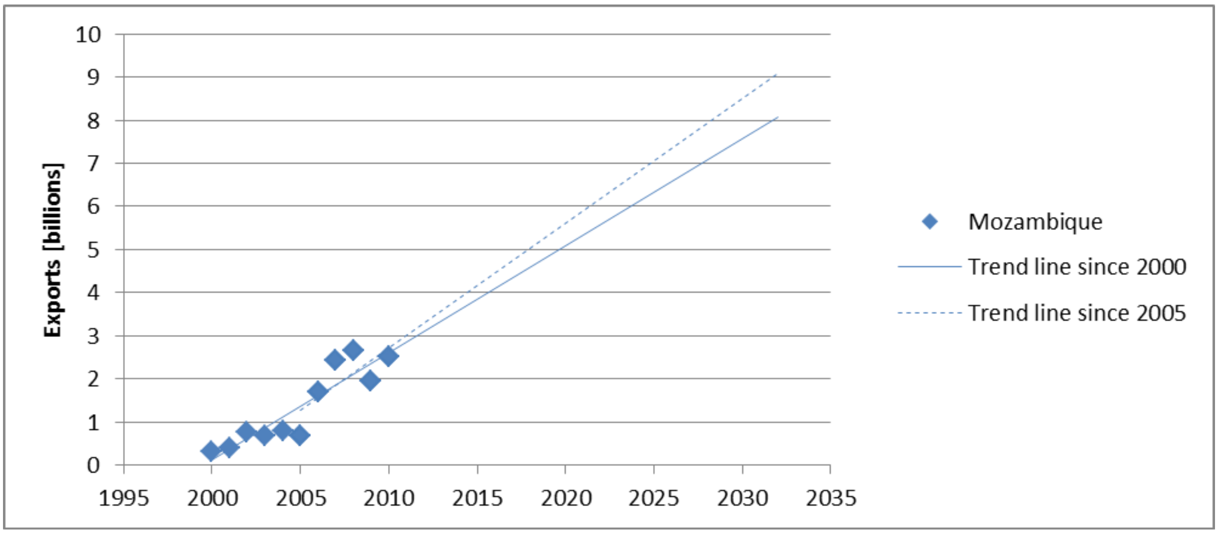


Figure 0-26 | Mozambique export with trend lines

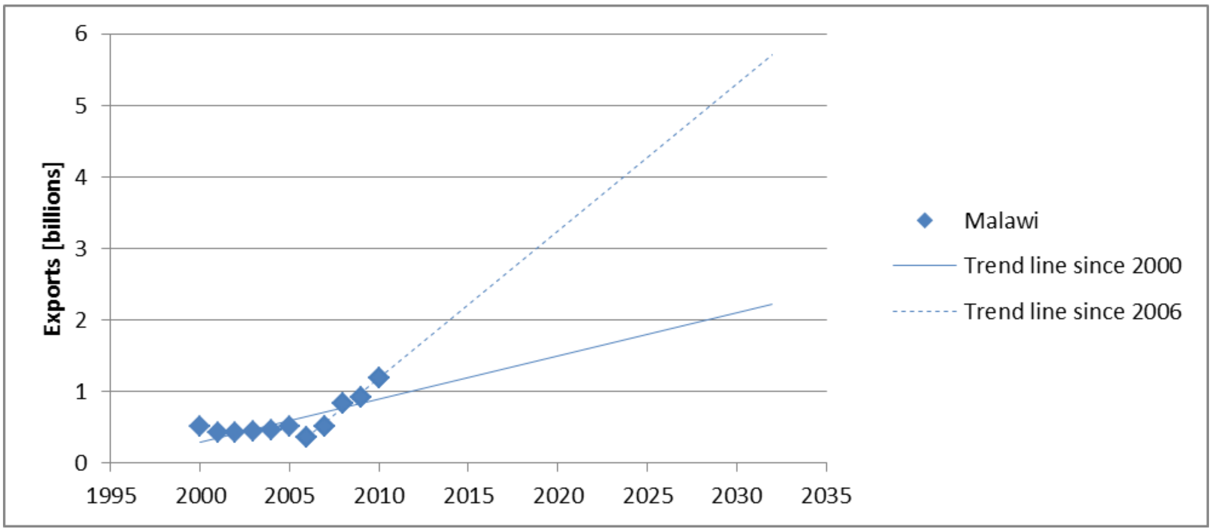


Figure 0-27 | Malawi export with trend lines

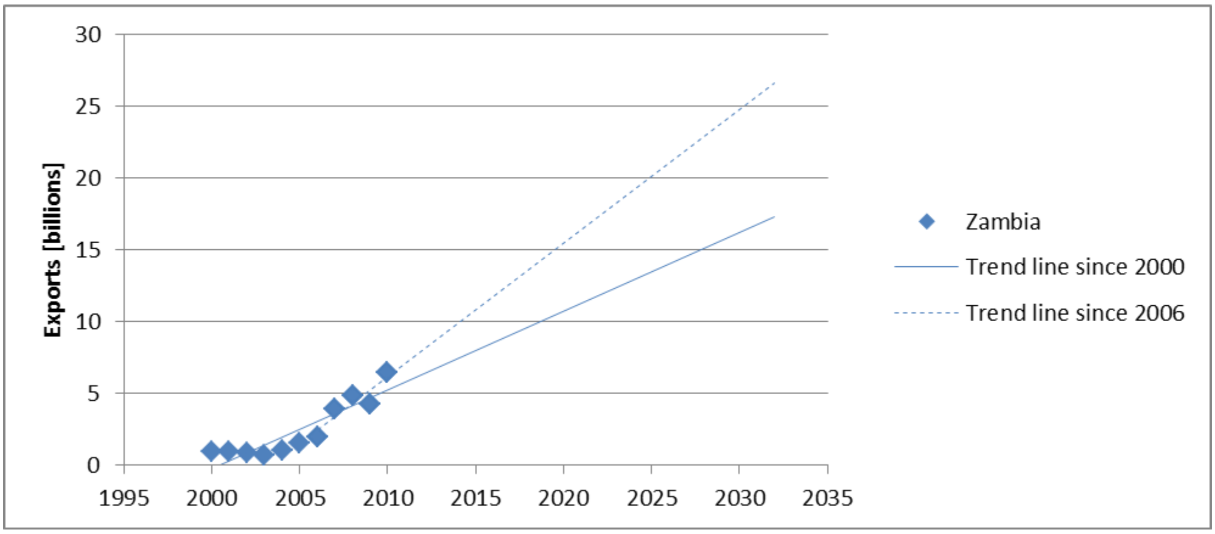


Figure 0-28 | Zambia export with trend lines

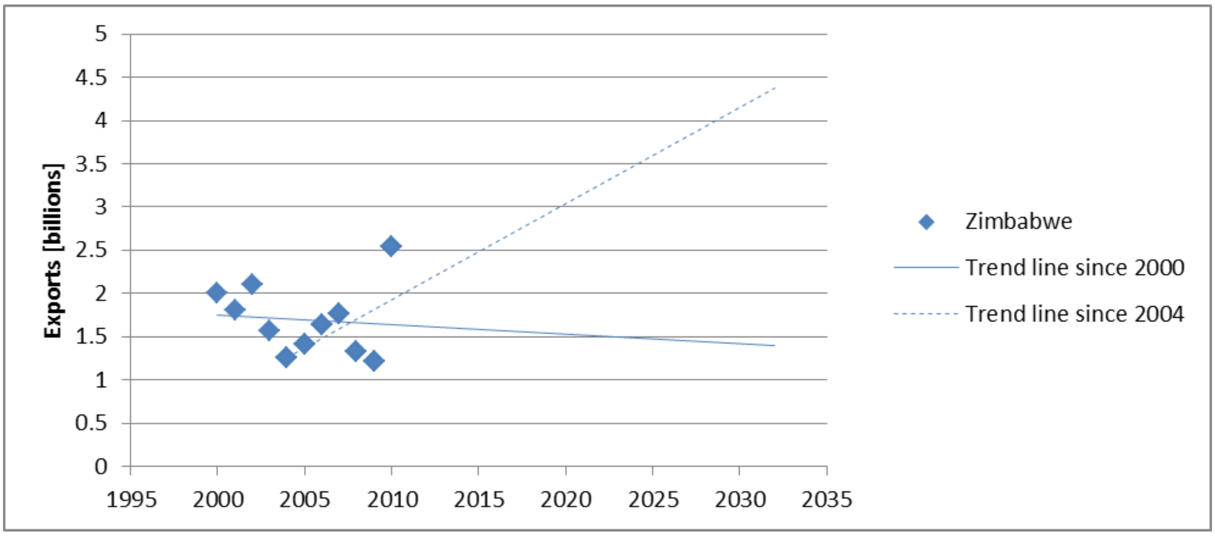
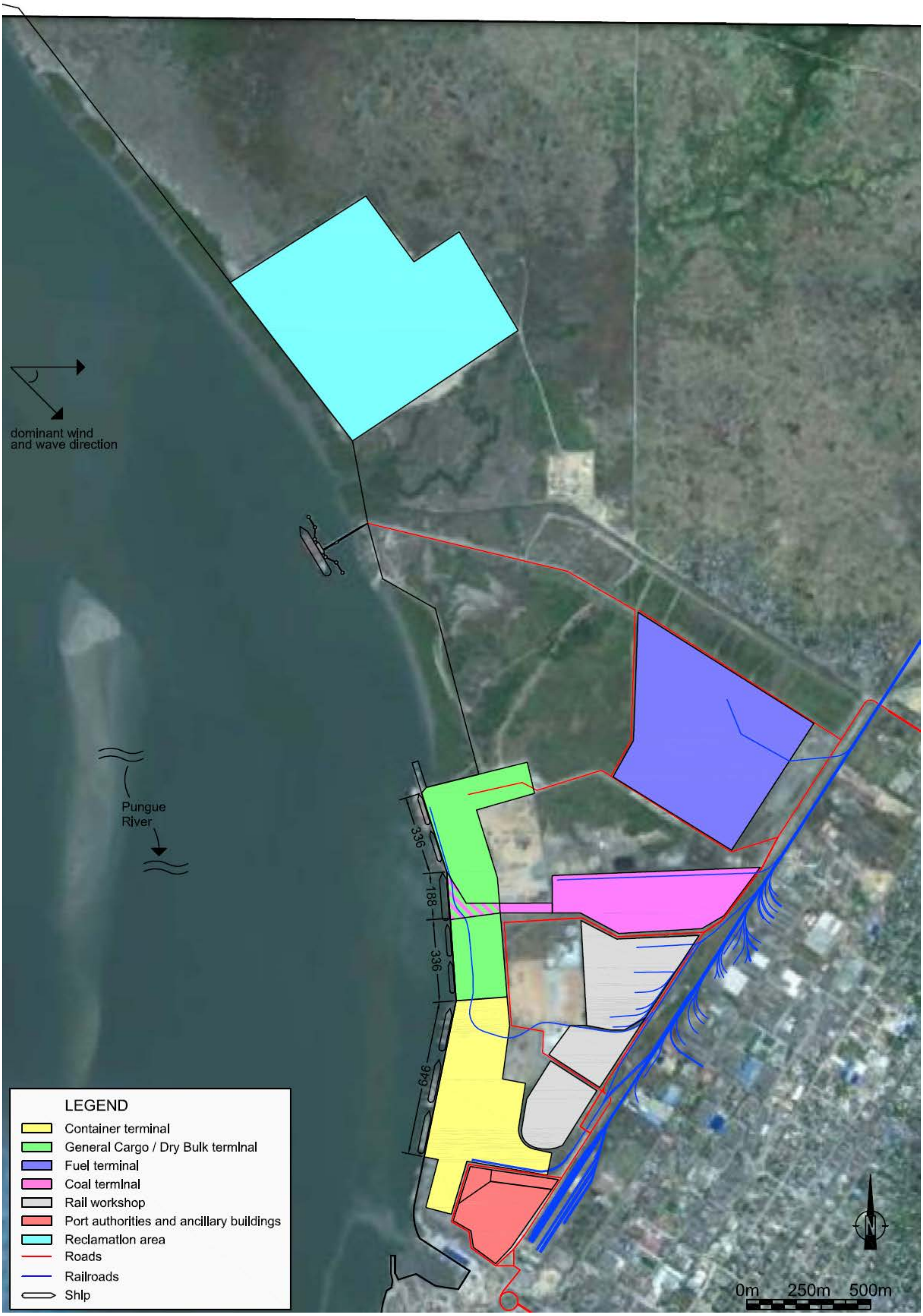
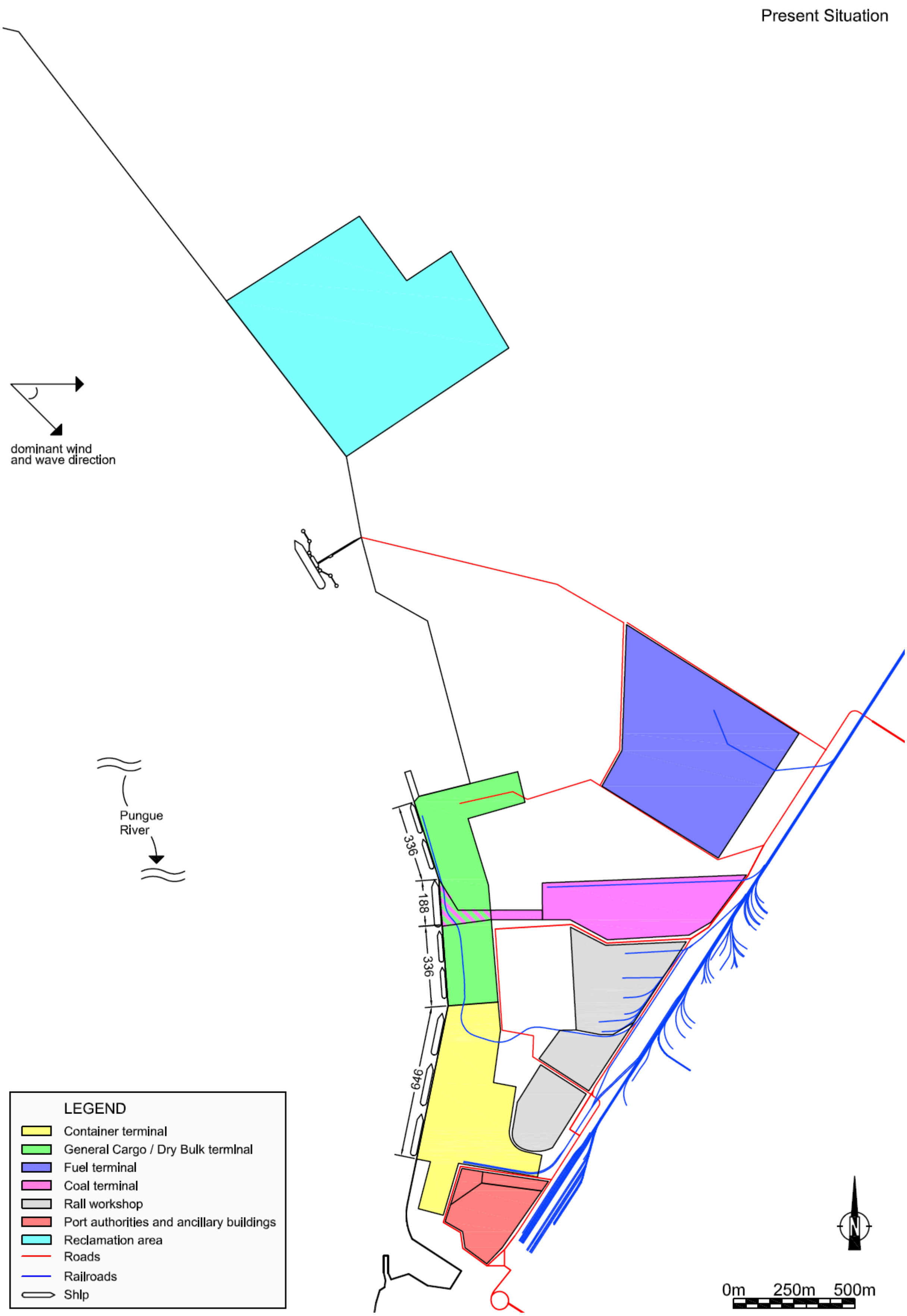


Figure 0-29 | Zimbabwe export with trend lines

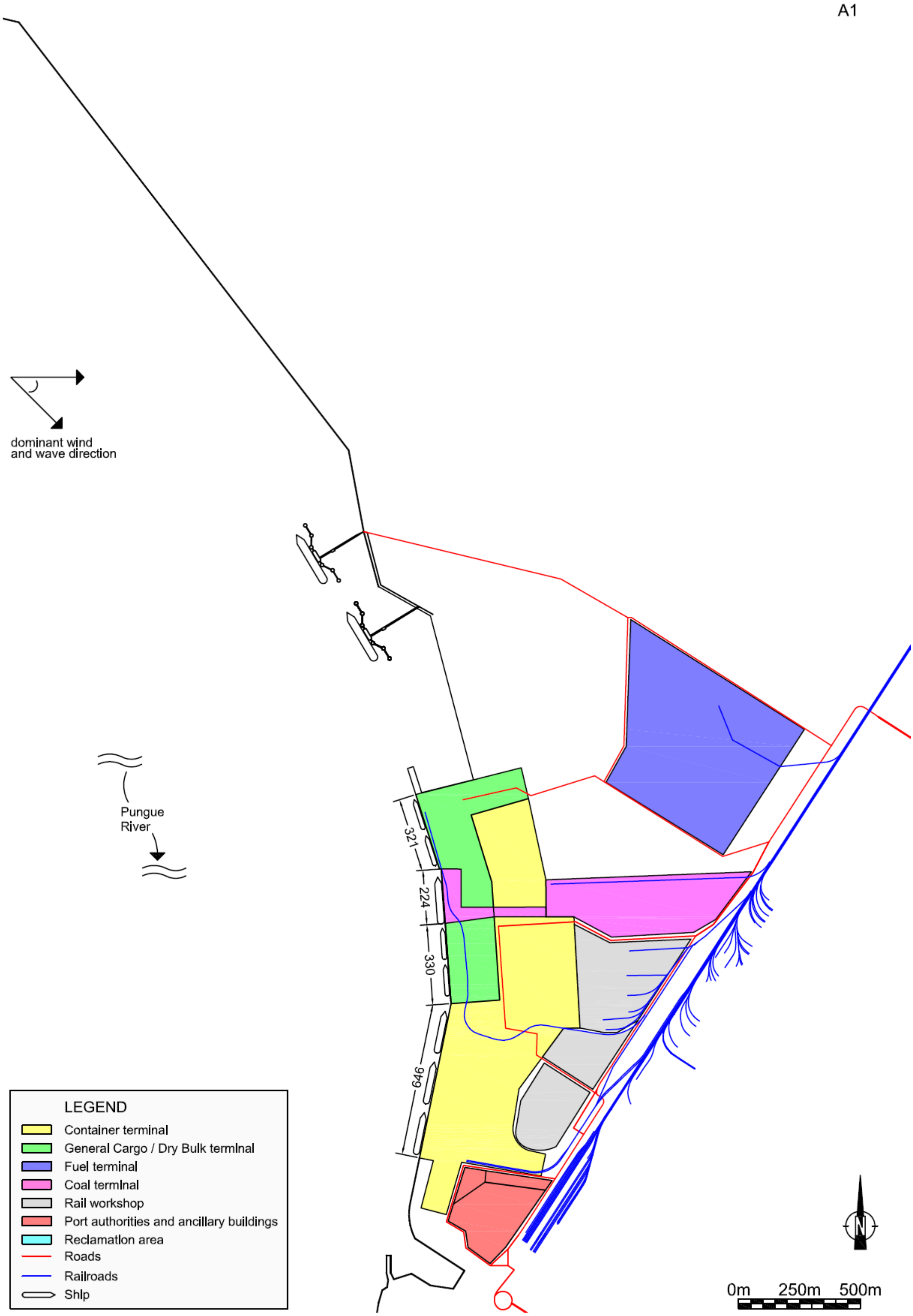
VII LAYOUT ALTERNATIVES

Present Situation

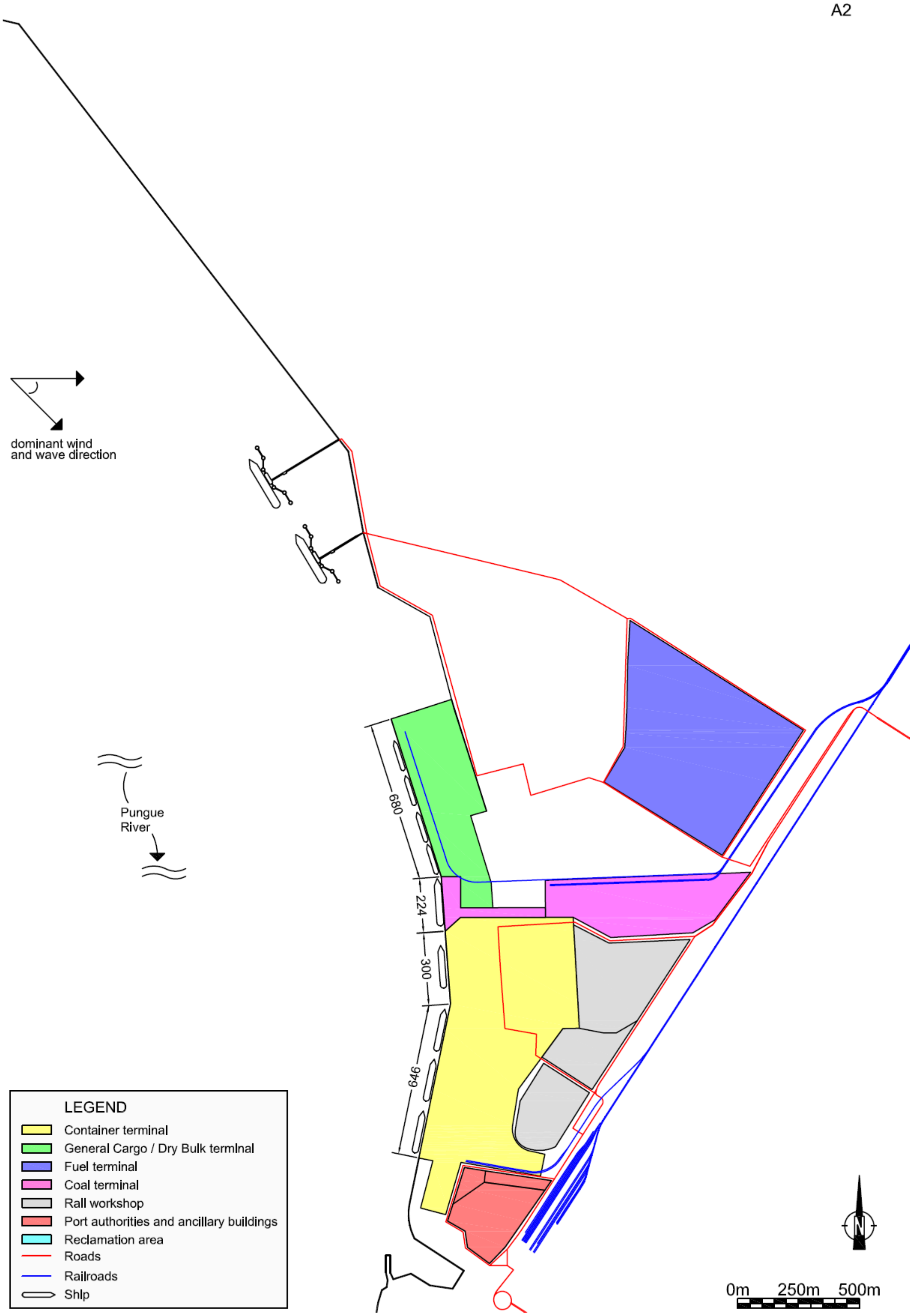



Present Situation
dominant wind
and wave direction
Pungue
River
336
188
336
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m

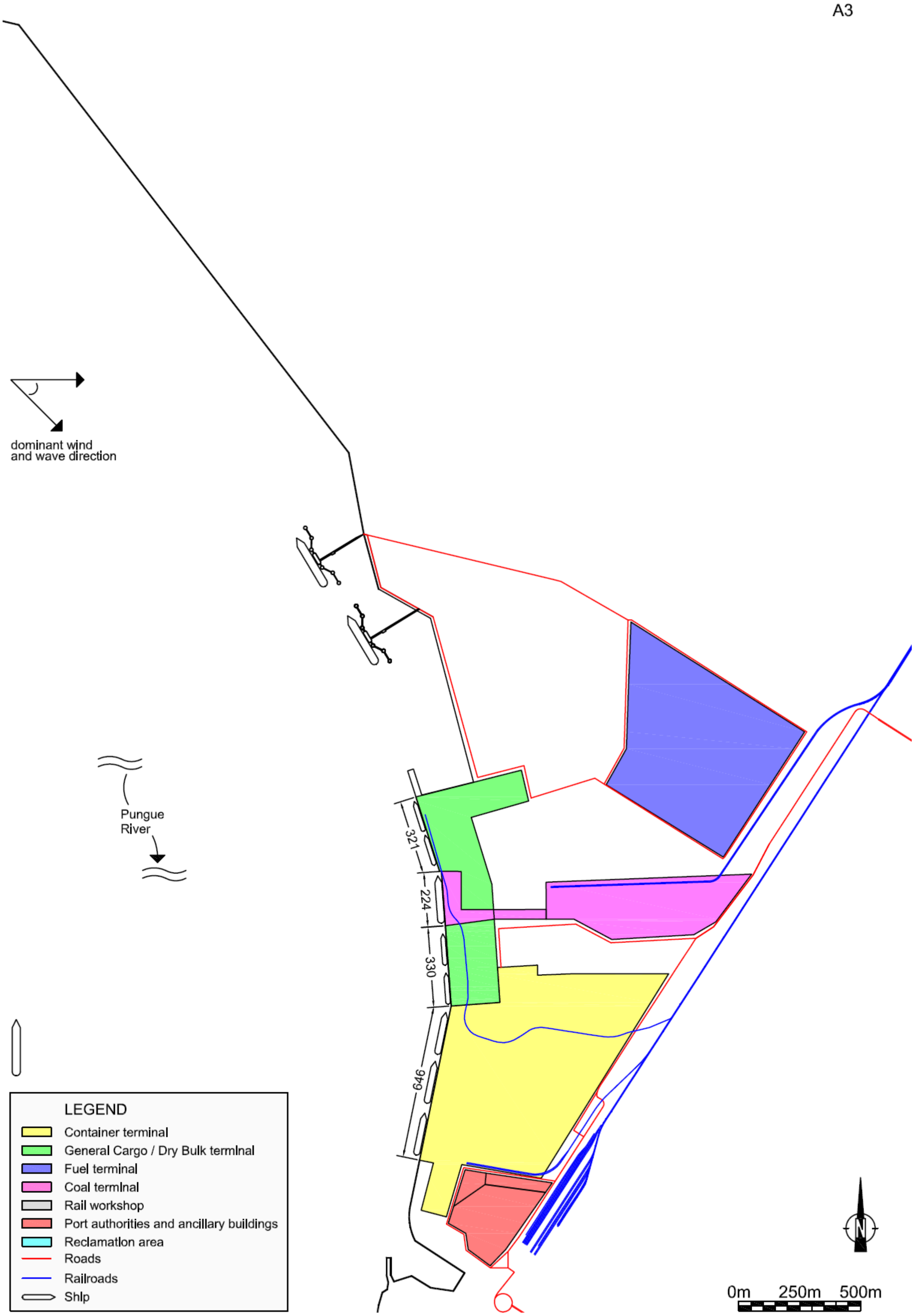
A1

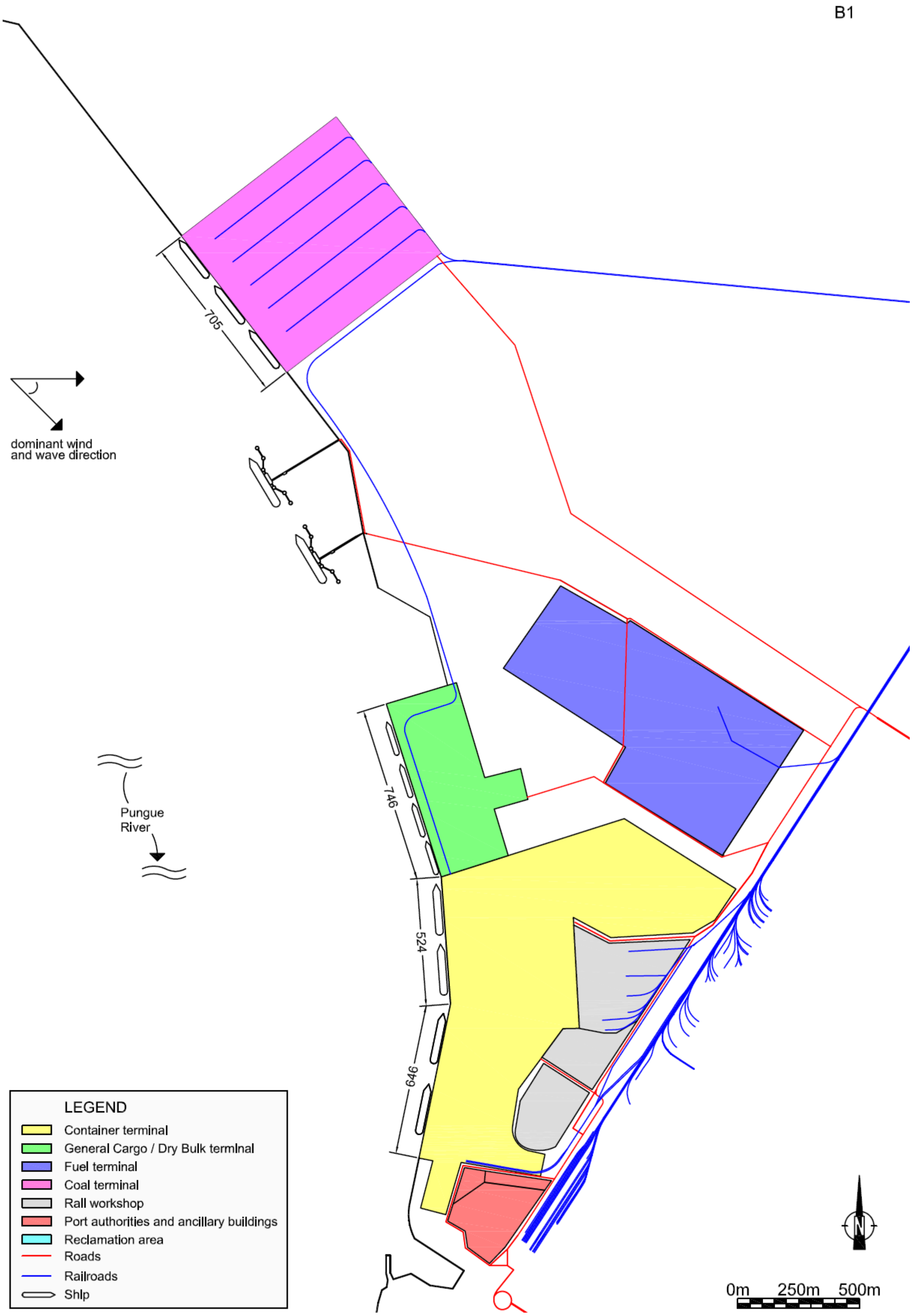

dominant wind
and wave direction
Pungue
River
321
224
330
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
0m 250m 500m

A2

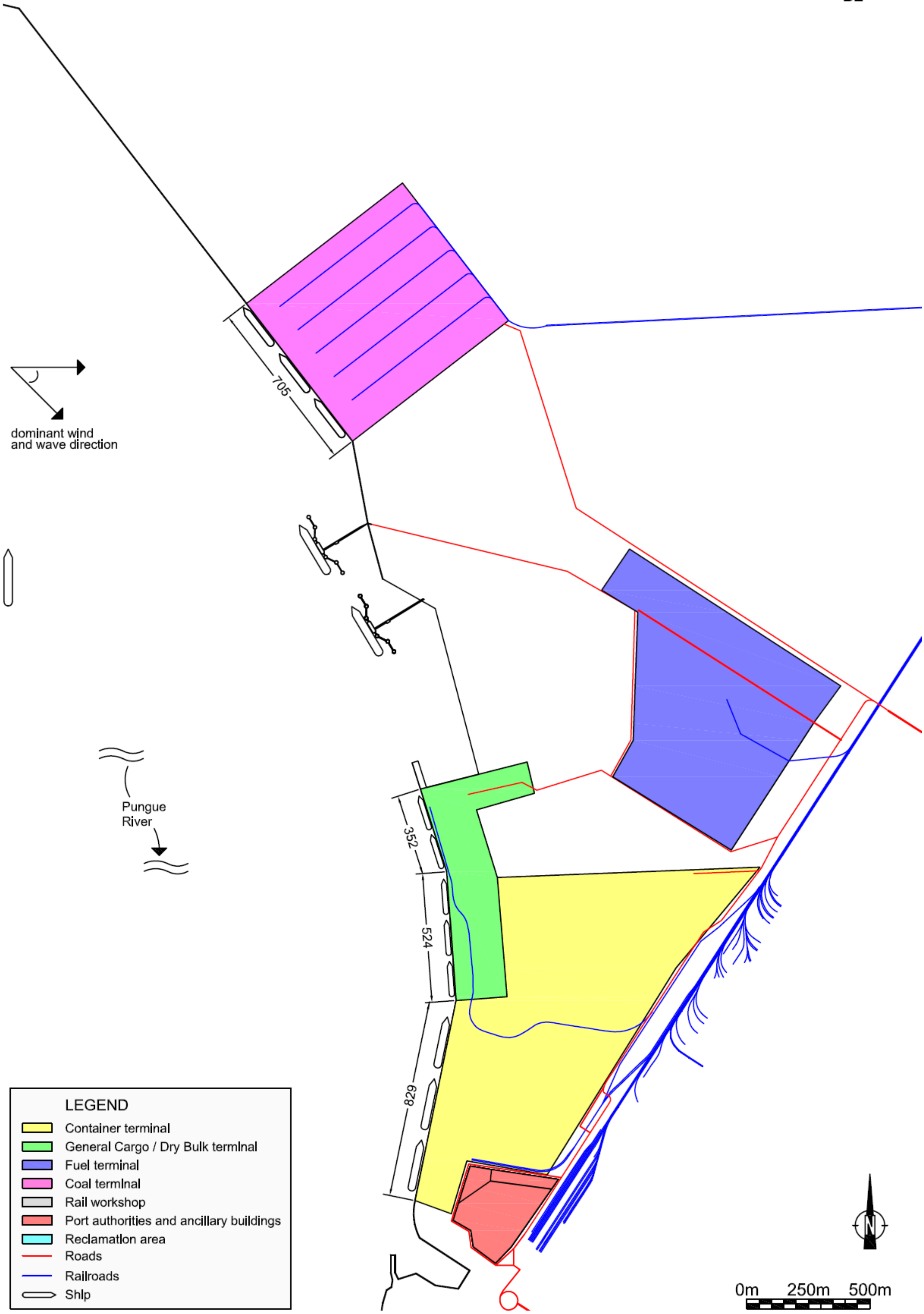

dominant wind
and wave direction
Pungue
River
680
224
300
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
0m 250m 500m

A3

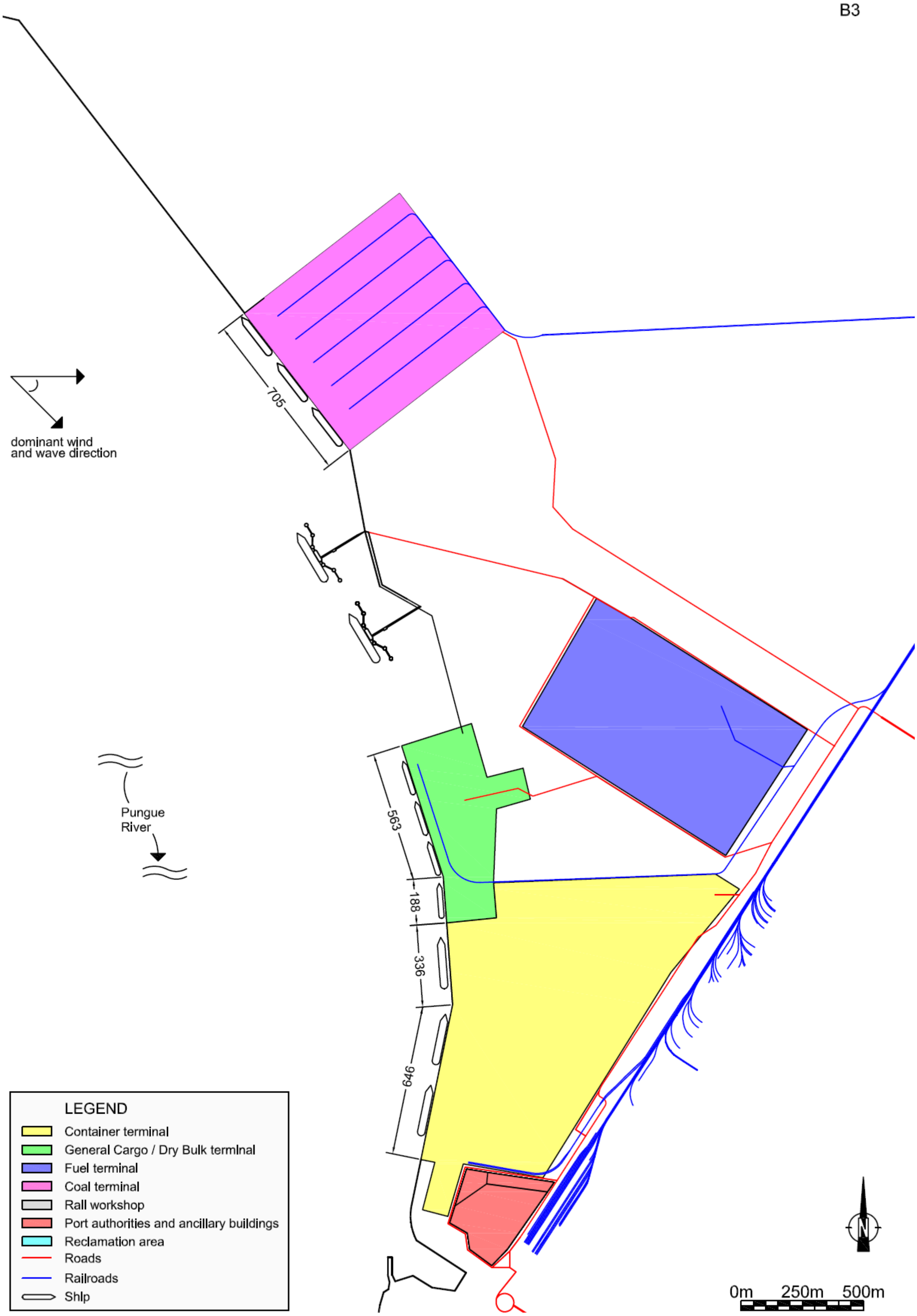

dominant wind
and wave direction
Pungue
River
321
224
330
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
0m 250m 500m


B1
705
dominant wind and wave direction
746
Pungue River
524
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m

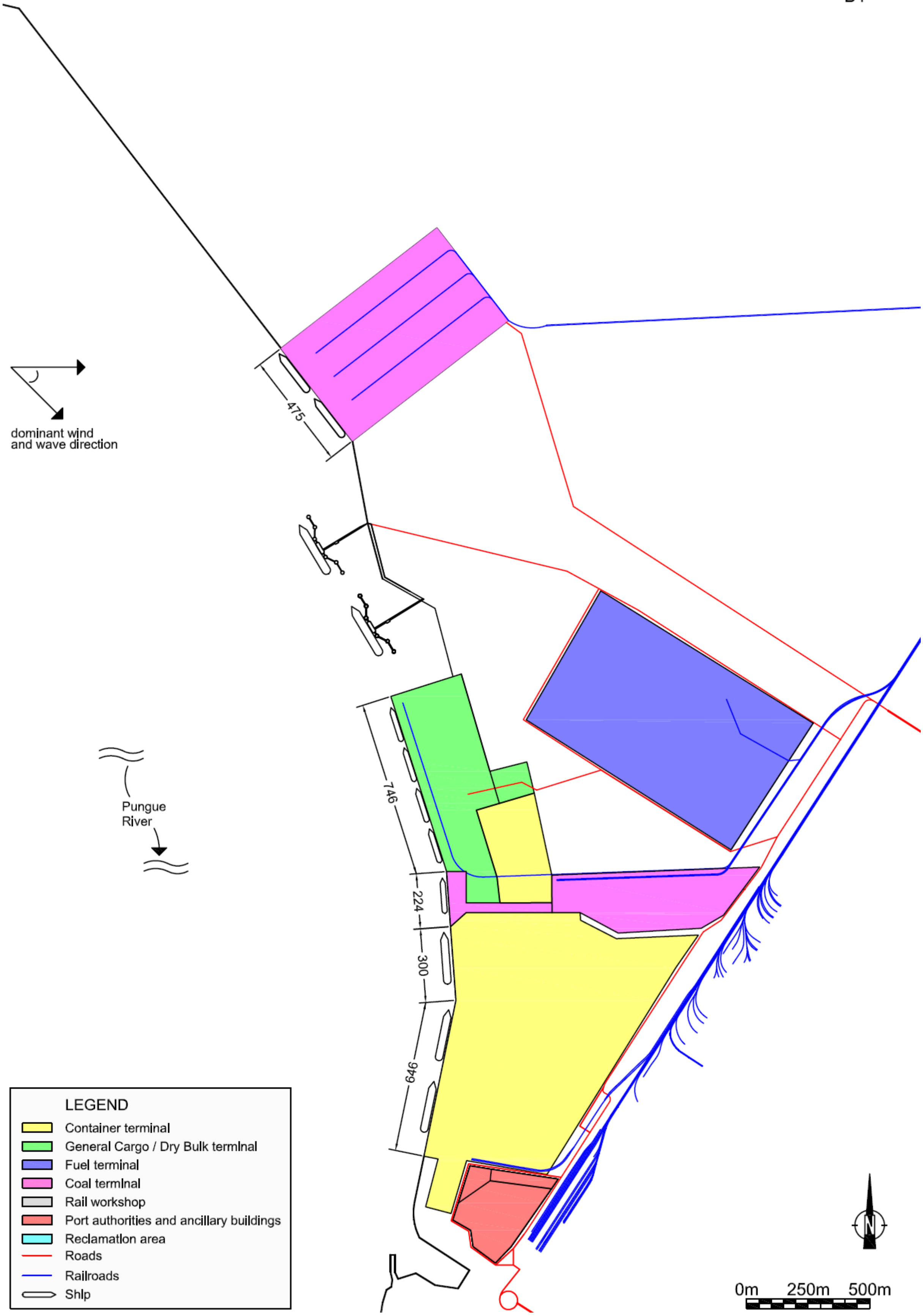
B2


705
dominant wind
and wave direction
Pungue
River
352
524
829
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m

B3

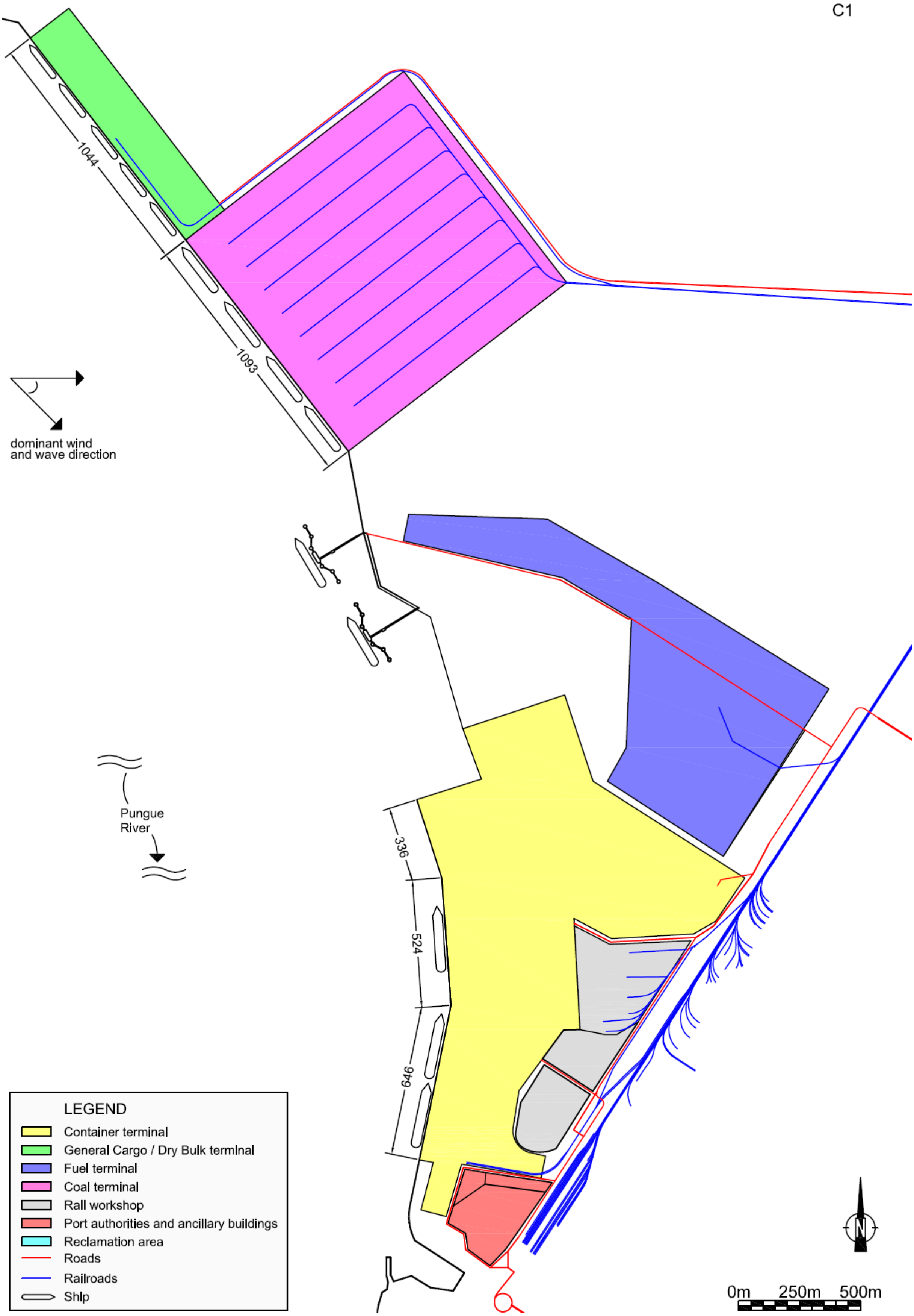

705
dominant wind and wave direction
Pungue River
563
188
336
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m

B4

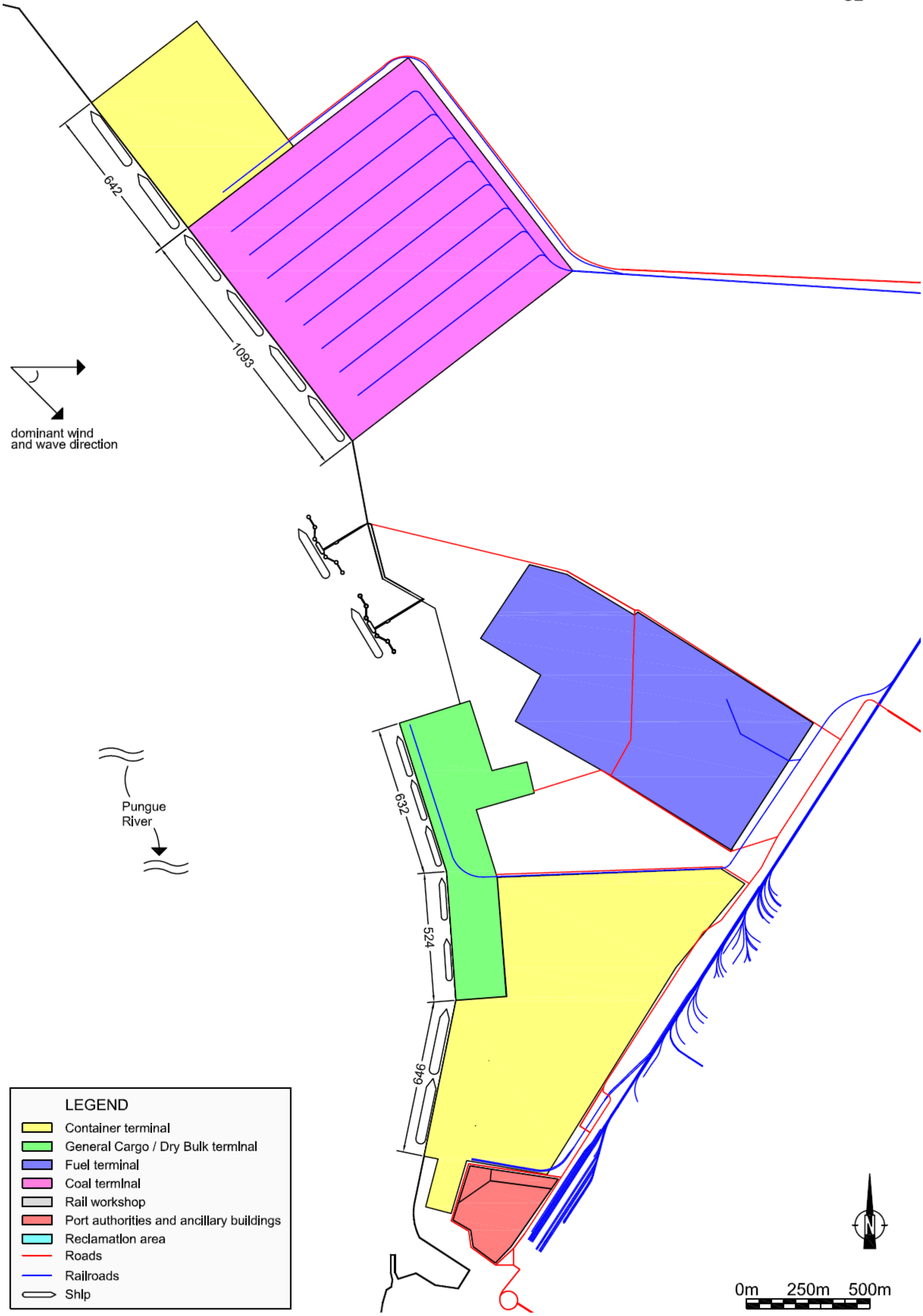


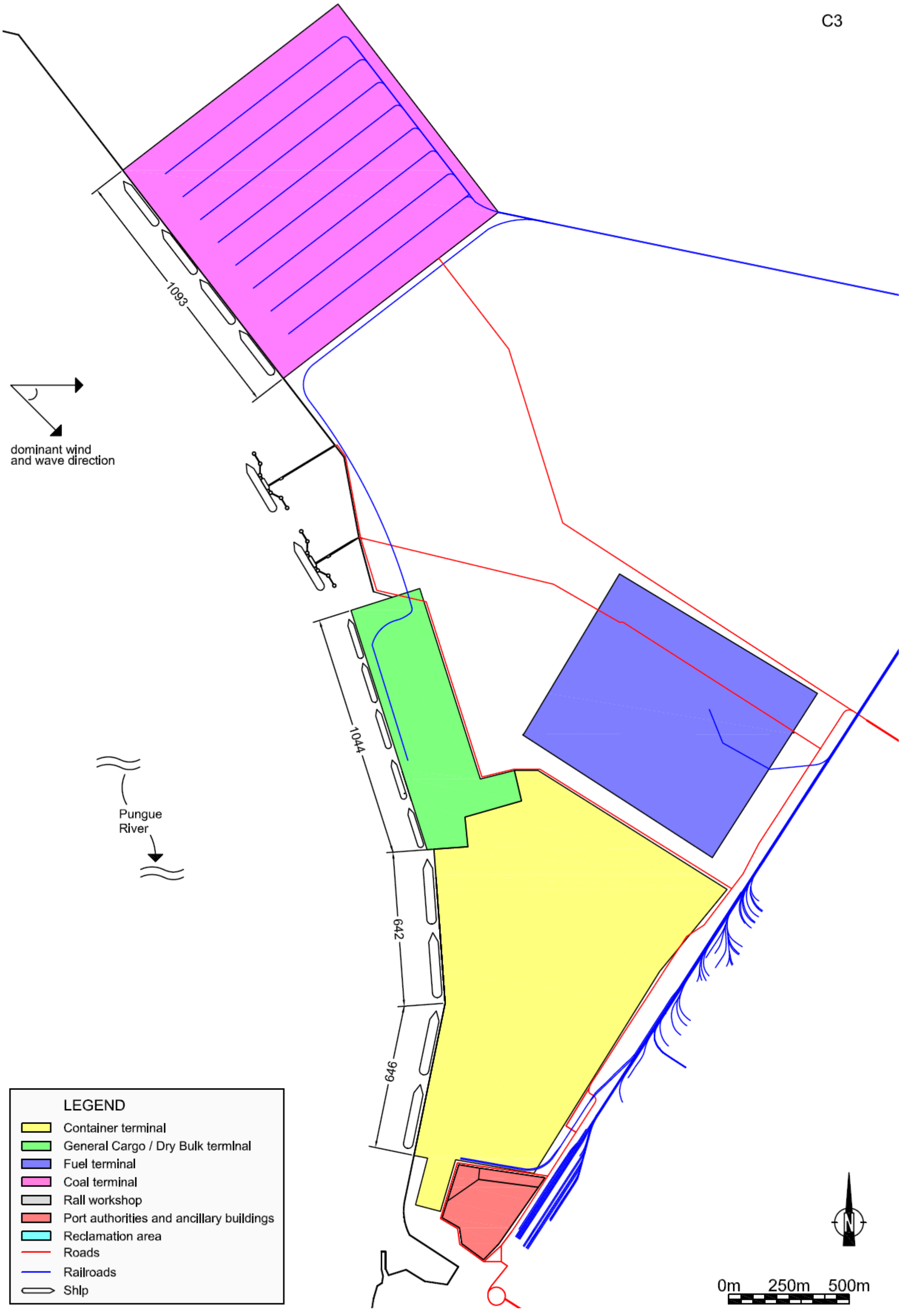
dominant wind
and wave direction
475
746
224
300
646
Pungue
River
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m

C1

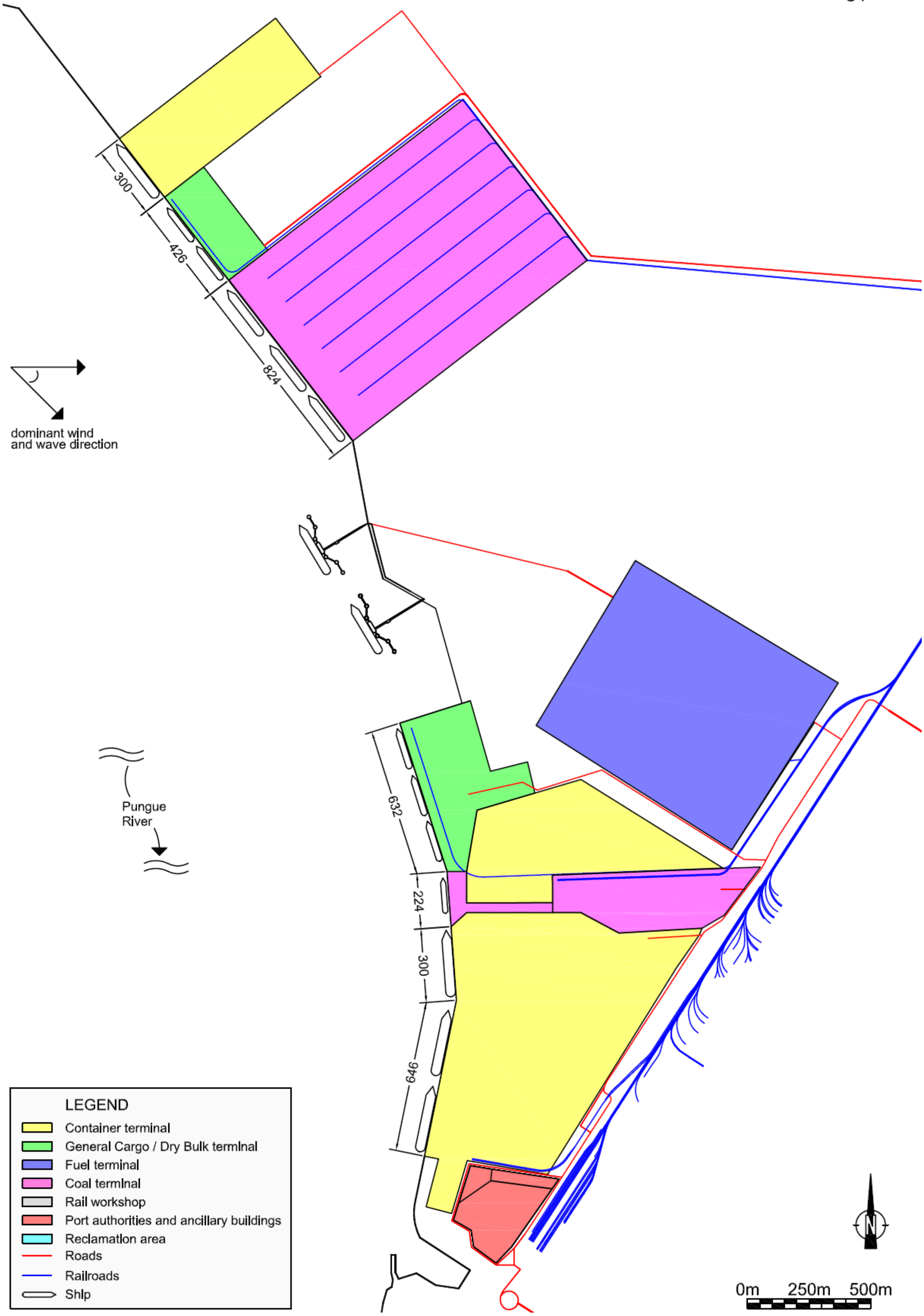

1044
1093
dominant wind
and wave direction
Pungue
River
336
524
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m

C2


642
1093
dominant wind
and wave direction
Pungue
River
632
524
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m


C3
1093
1044
642
646
dominant wind
and wave direction
Pungue
River
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m
250m
500m

C4


300
426
824
dominant wind
and wave direction
Pungue
River
632
224
300
646
LEGEND
Container terminal
General Cargo / Dry Bulk terminal
Fuel terminal
Coal terminal
Rail workshop
Port authorities and ancillary buildings
Reclamation area
Roads
Railroads
Ship
N
0m 250m 500m

VIII ADAPTIVE PORT PLANNING RESULT

IX HARBOURSIM SIMULATION OF ALTERNATIVES

IX-A Physical schematizations

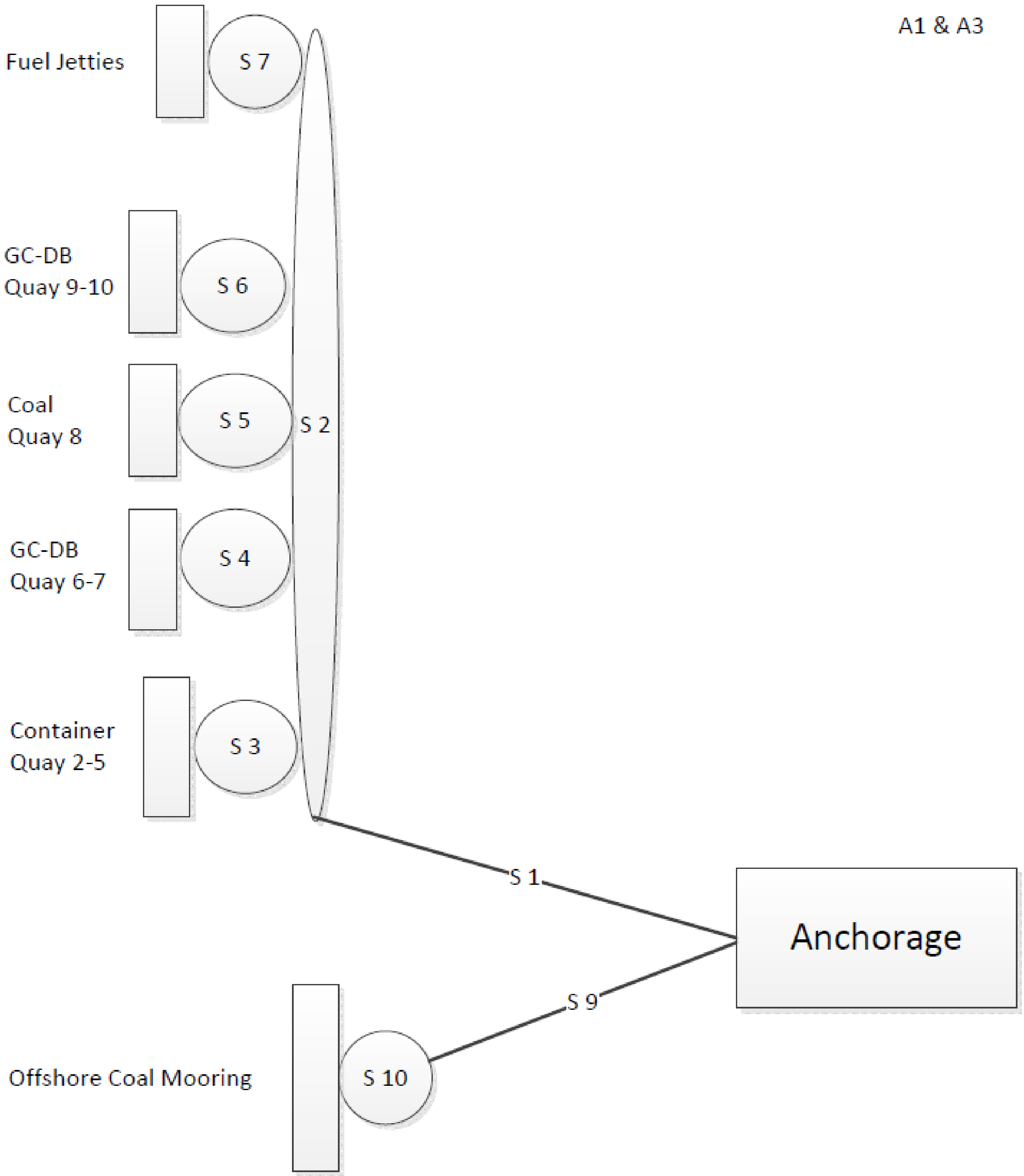


Figure 0-30 | Physical schematization alternative A1 & A3

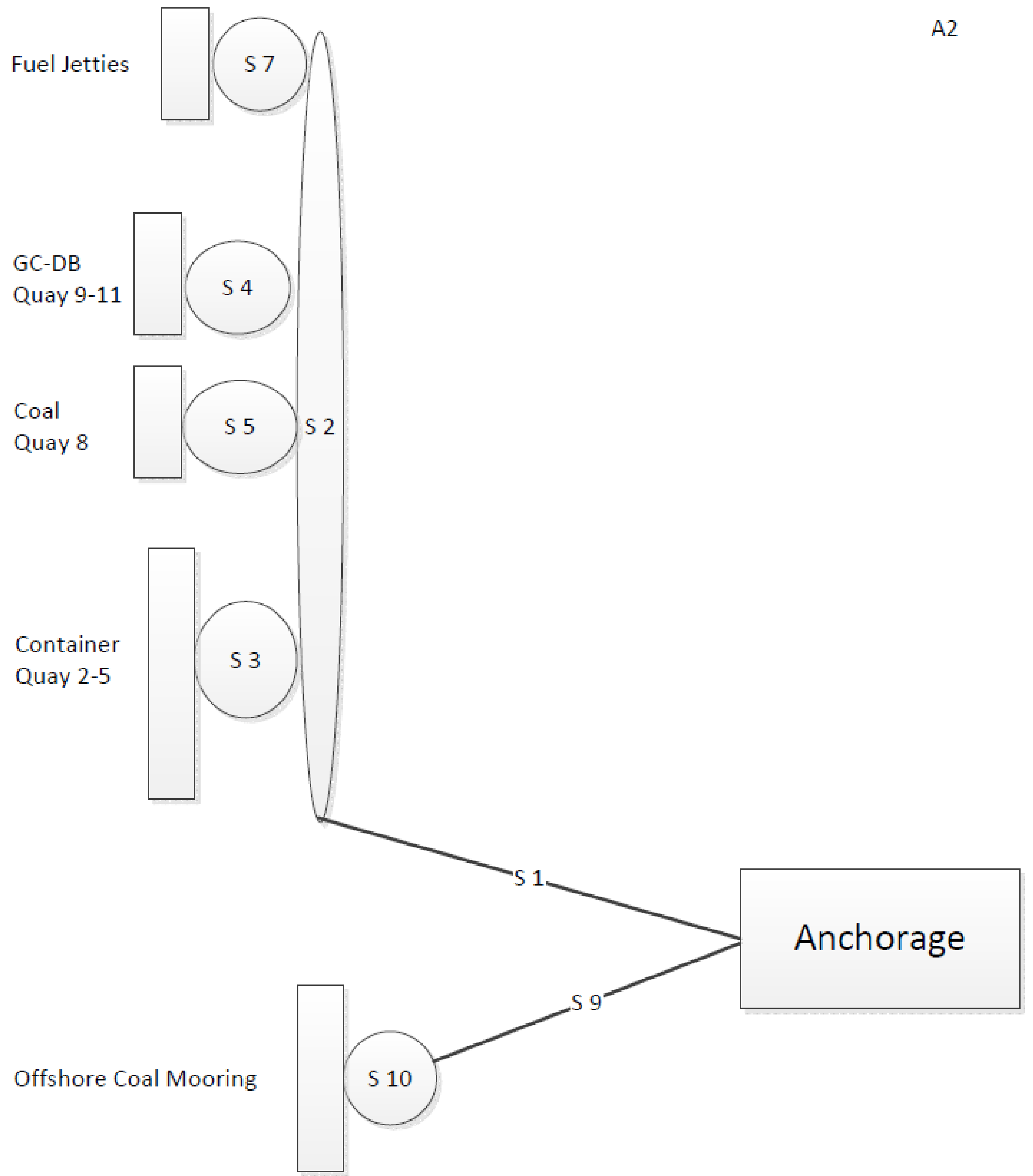


Figure 0-31 | Physical schematization alternative A2

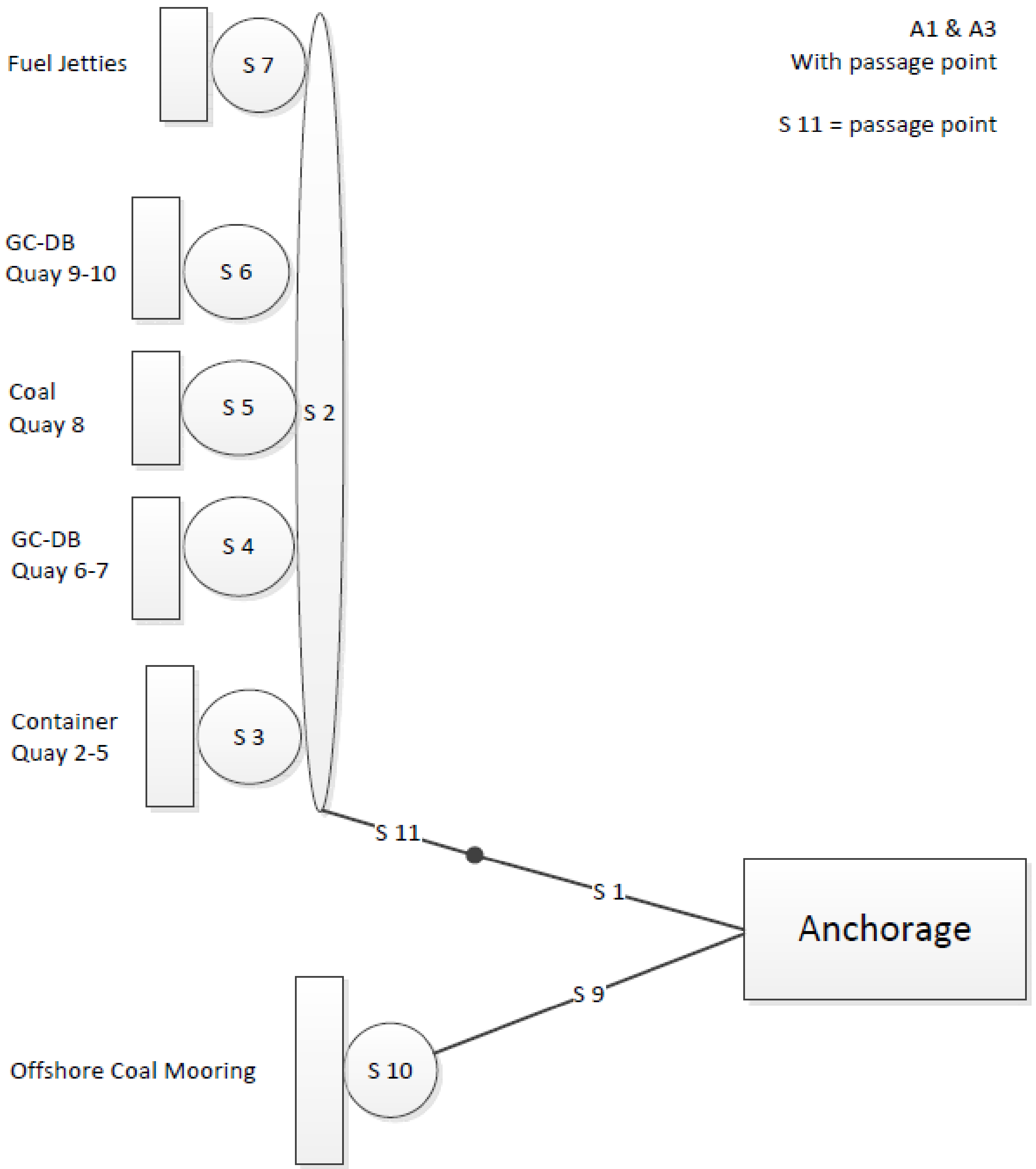


Figure 0-32 | Physical schematization alternative A1 & A3 with passage point berth

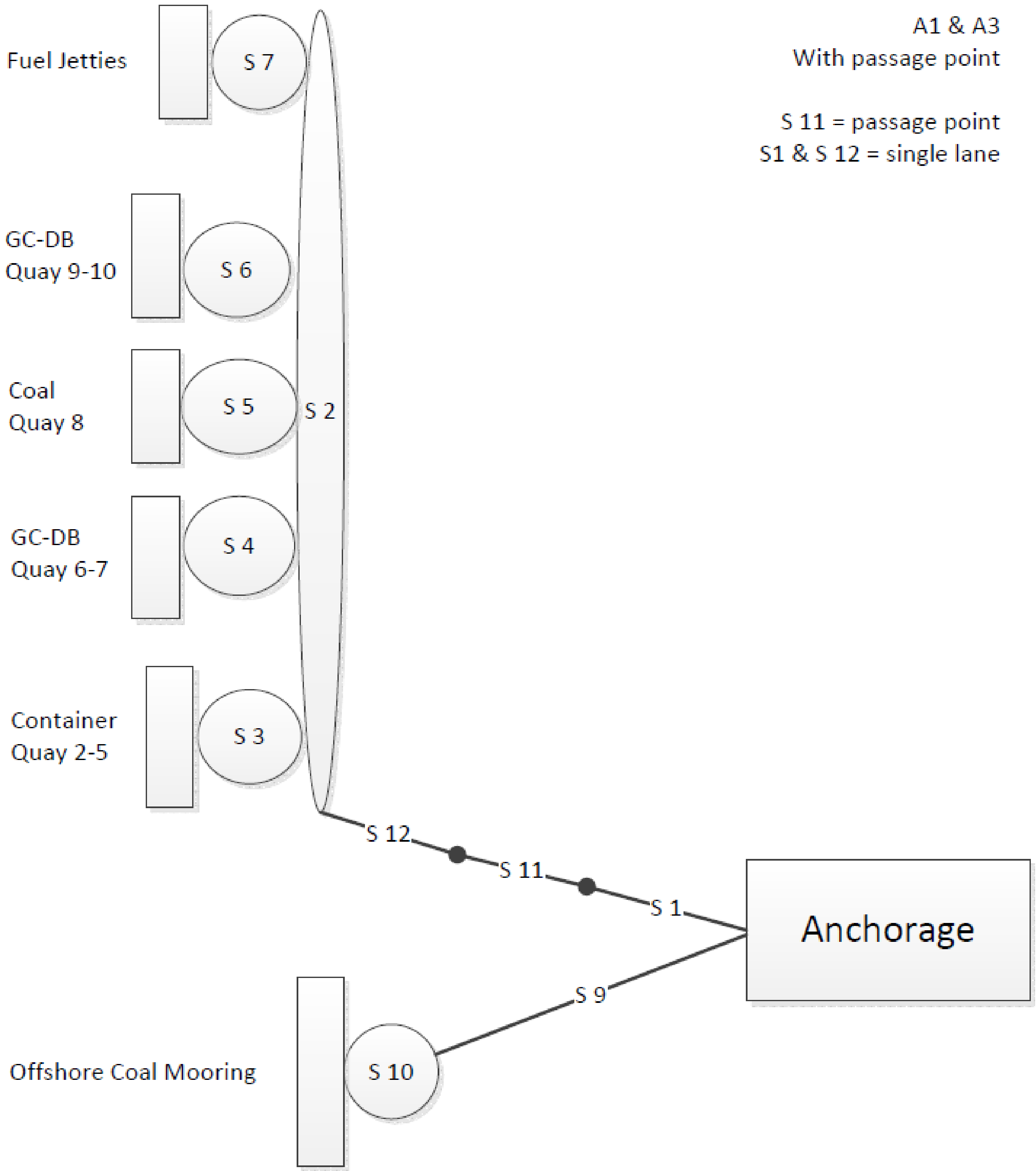


Figure 0-33 | Physical schematization alternative A1 & A3 with passage point halfway

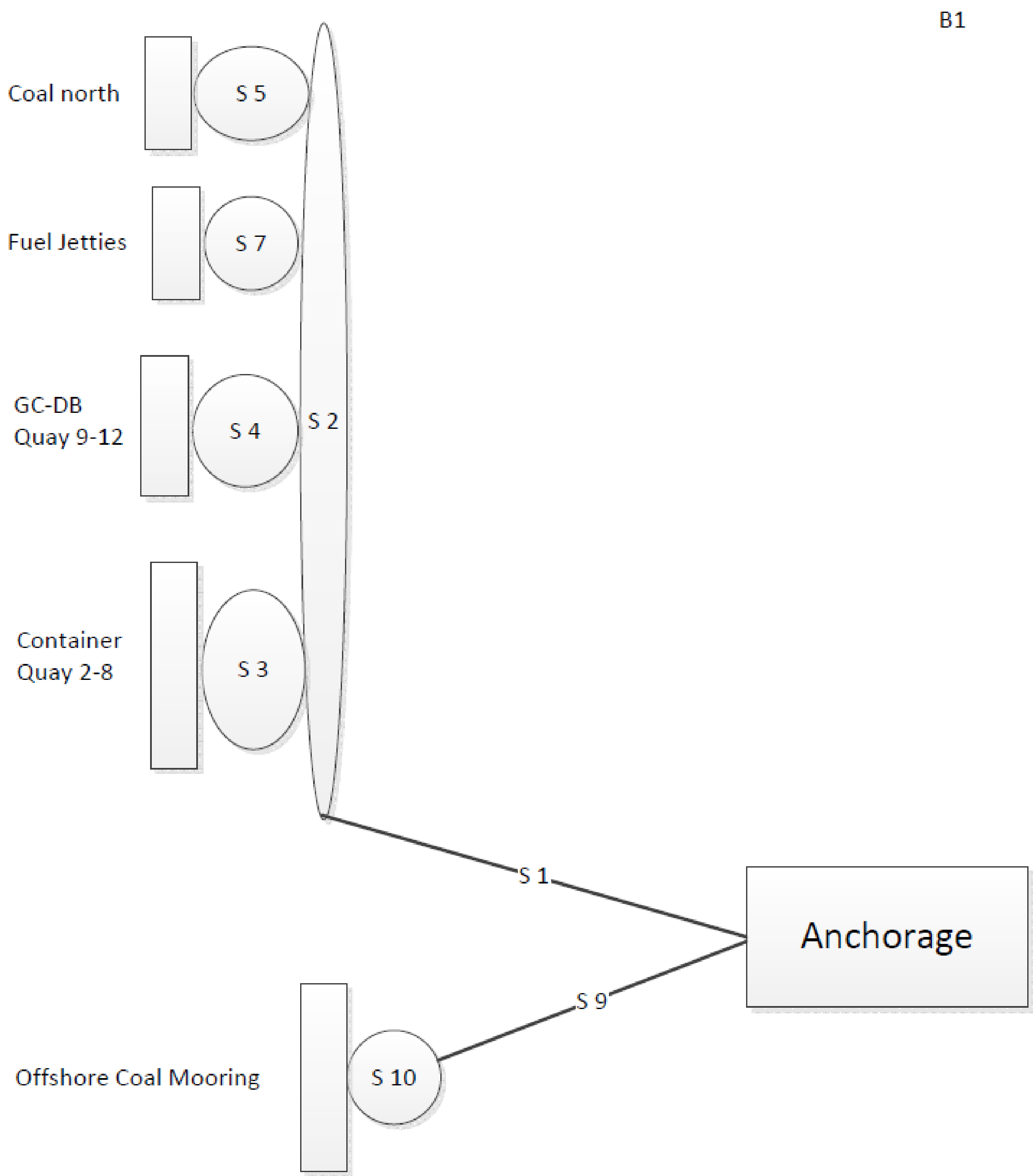


Figure 0-34 | Physical schematization alternative B1

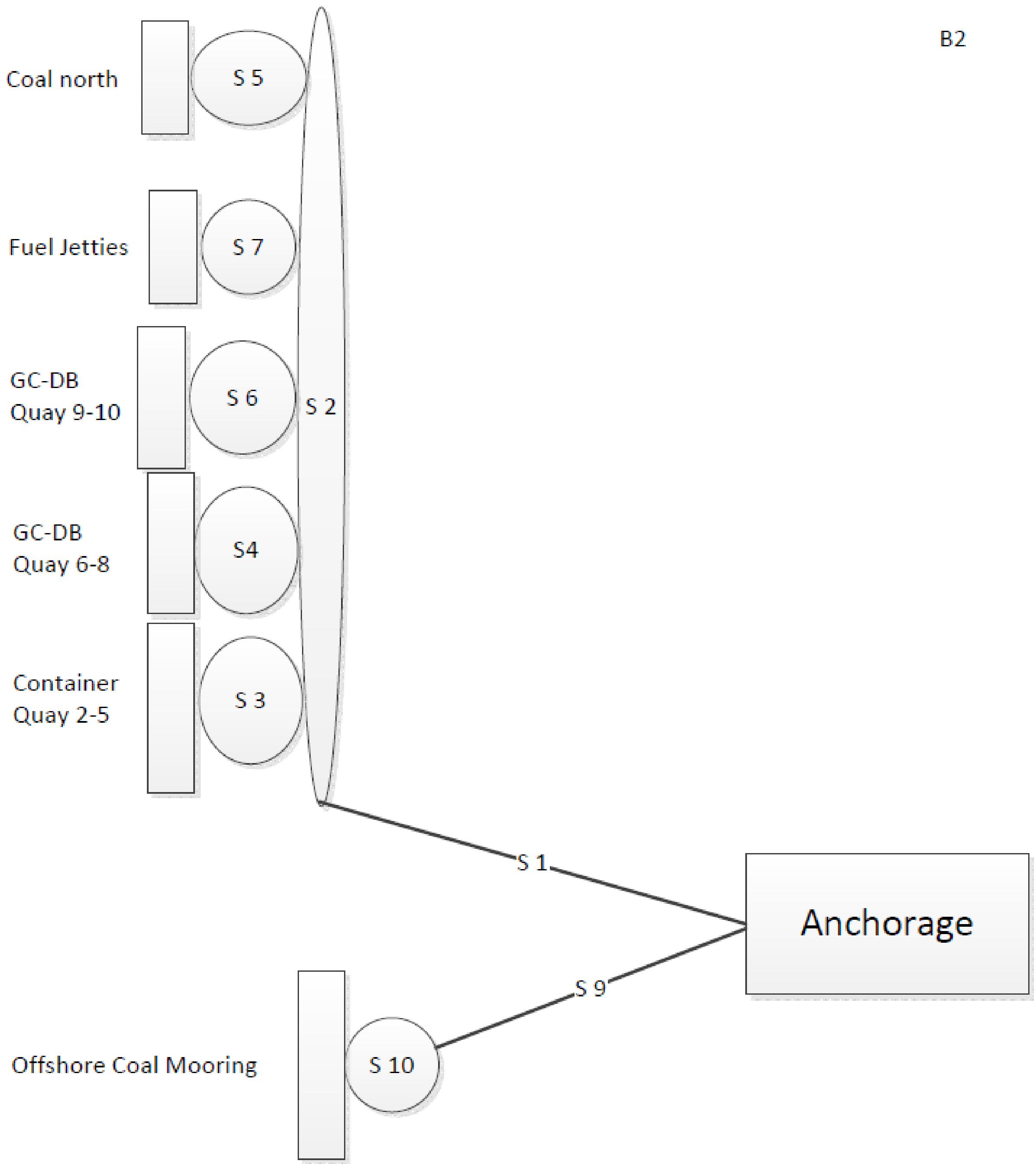


Figure 0-35 | Physical schematization alternative B2

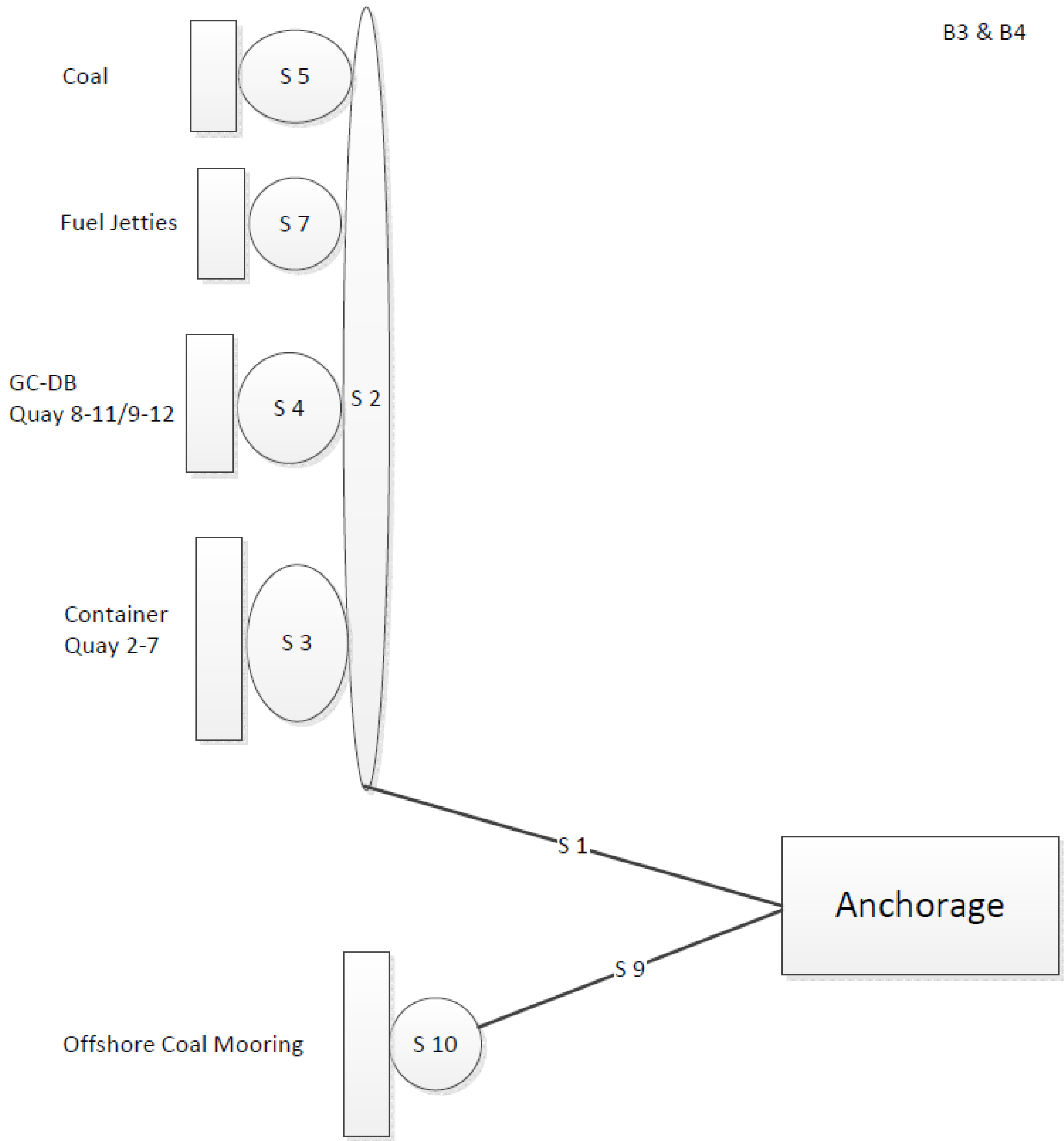


Figure 0-36 | Physical schematization alternative B3 & B4

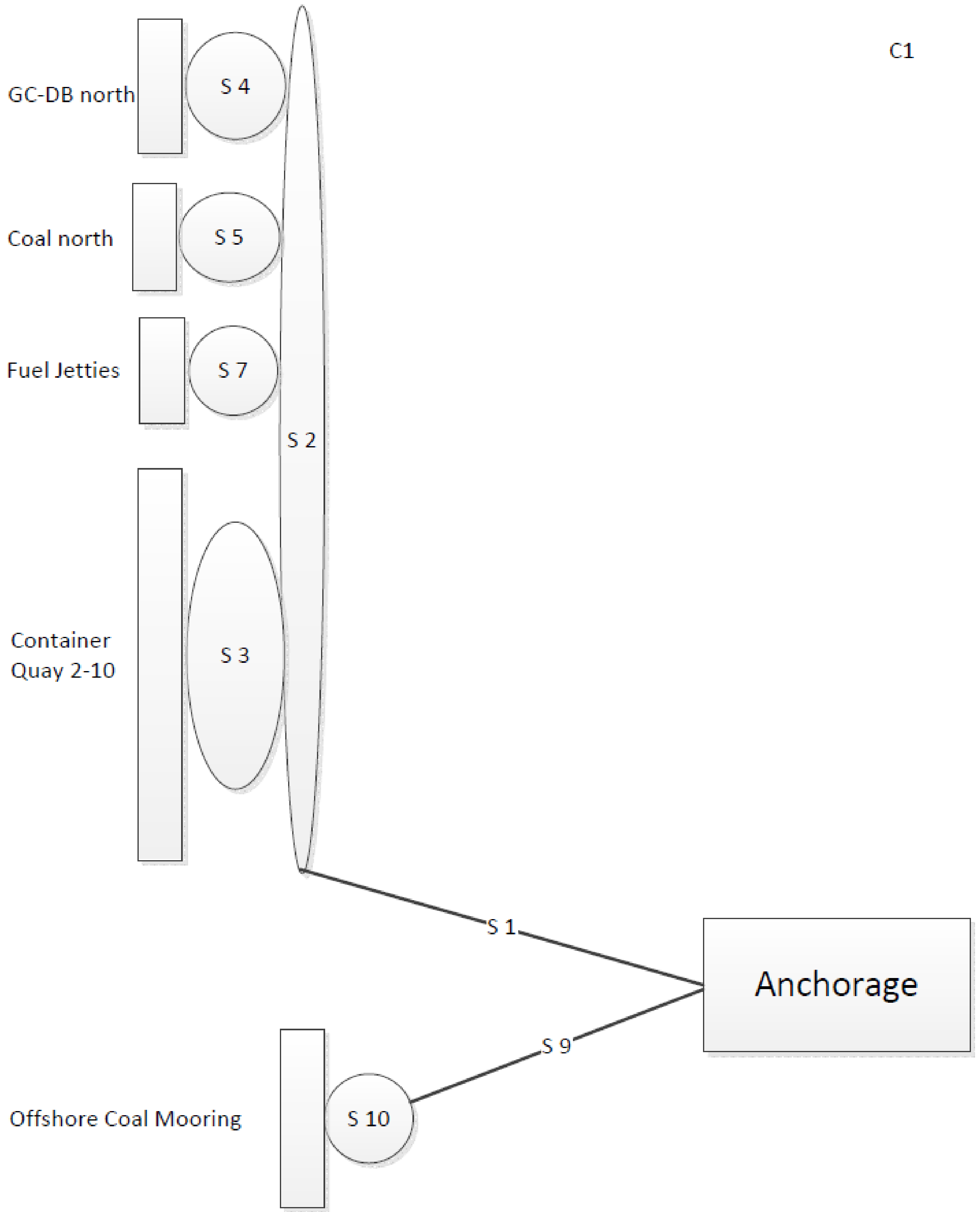


Figure 0-37 | Physical schematization alternative C1

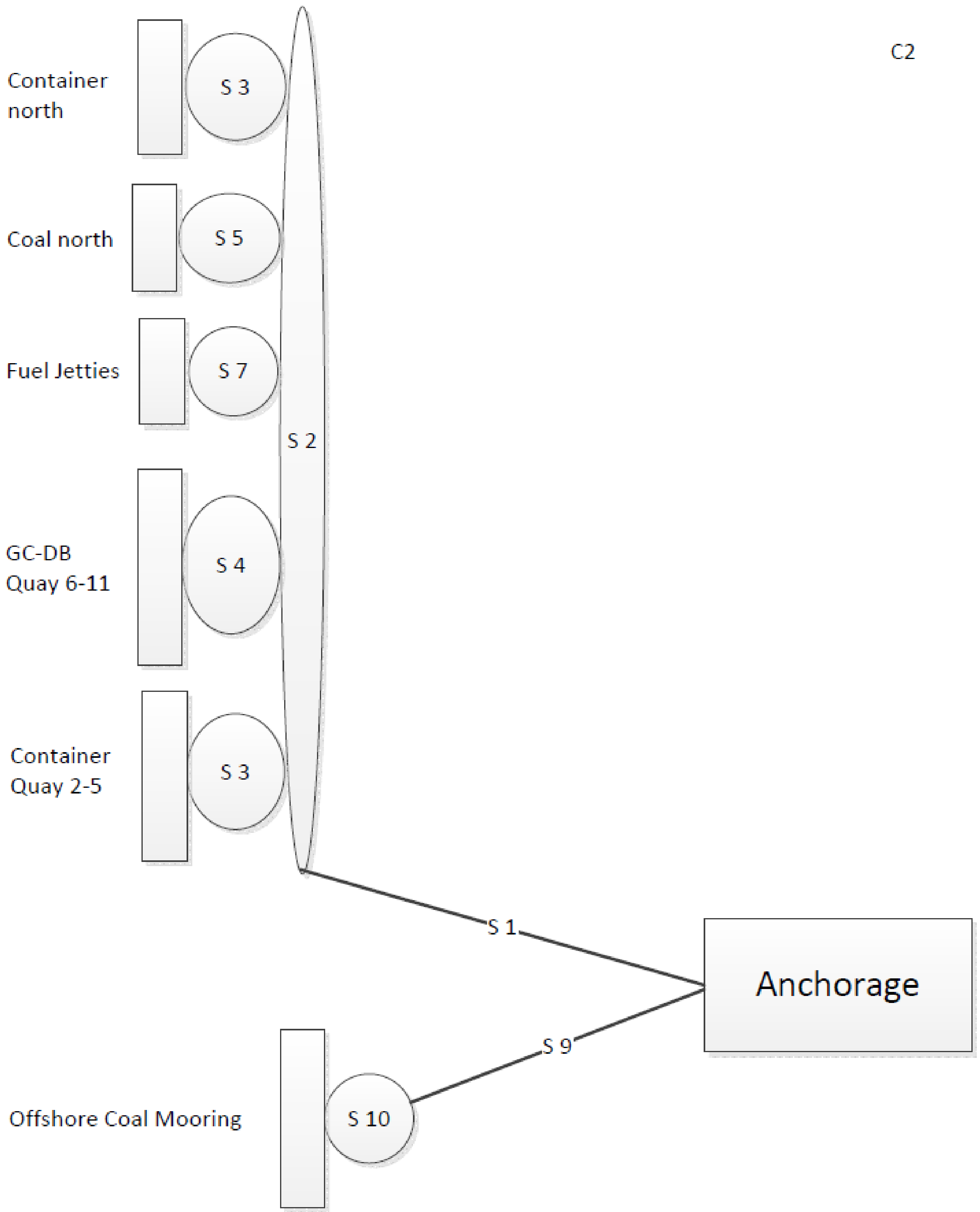


Figure 0-38 | Physical schematization alternative C2

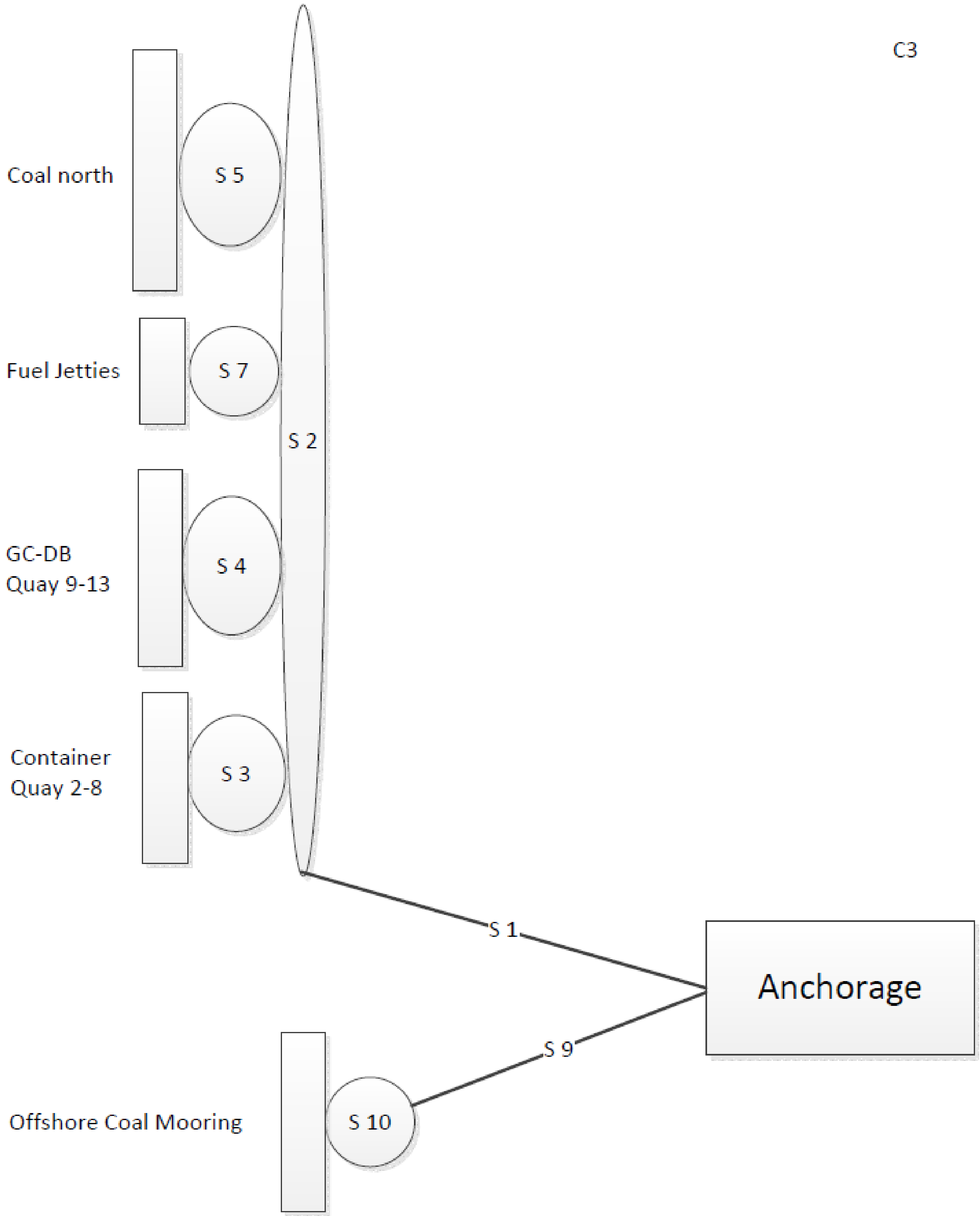


Figure 0-39 | Physical schematization alternative C3

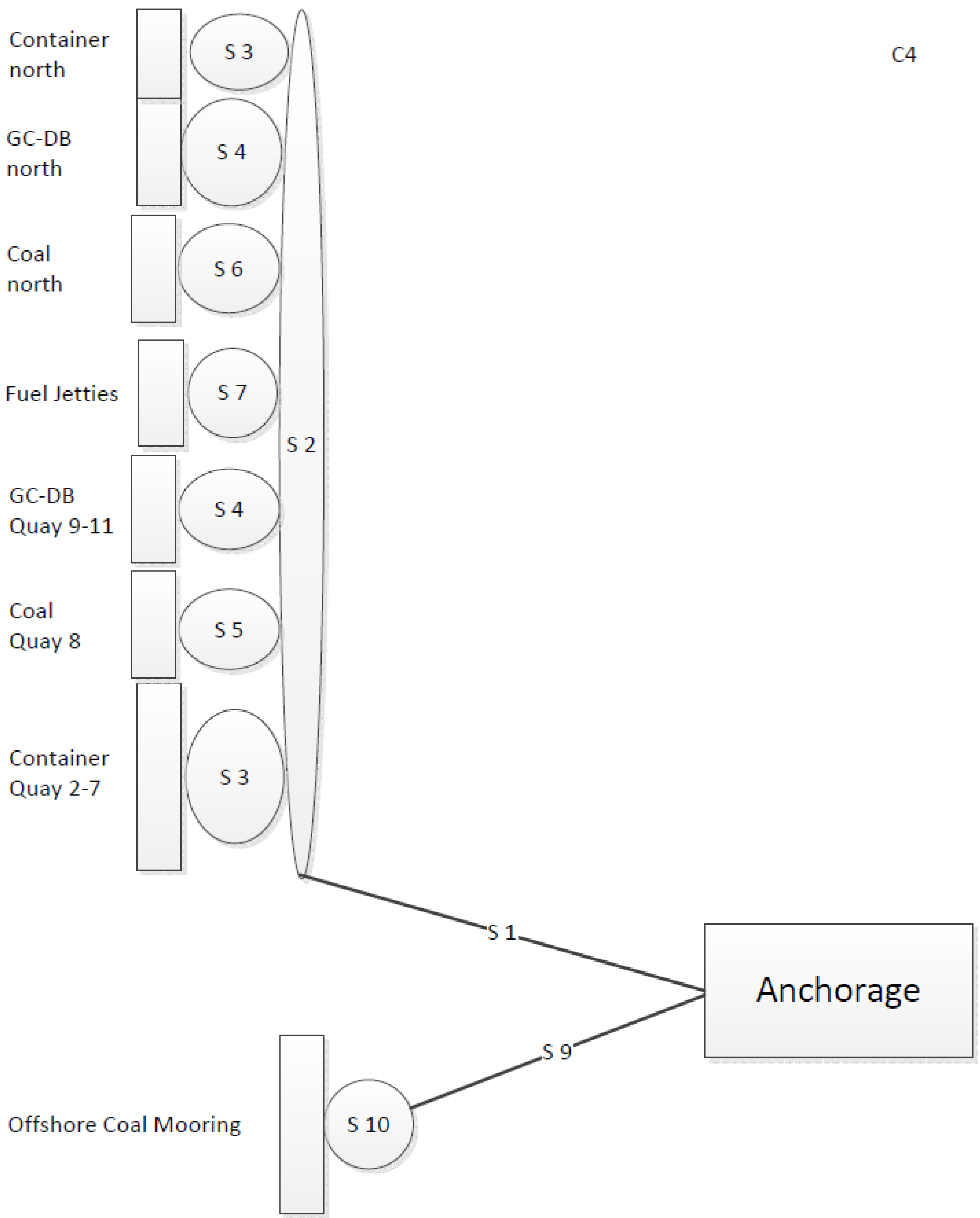


Figure 0-40 | Physical schematization alternative C4

IX-B Input in tables

Table 0-1 | Throughput through scenario low, in tons, except for containers in TEUs

Fleet	Import	Export	Empties
Container	90,000	60,000	45,000
General cargo	450,000	300,000	
Dry bulk	1,200,000	575,000	
Coal Vale		3,400,000	
Coal Rio Tinto		1,600,000	
Fuel	2,500,000	180,000	

Table 0-2 | Fleet input specification for alternatives in scenario low

Fleet	Load [tons]	d in [m]	d out [m]	LOA [m]	# of vessels	inter arrival time [min]	Erlang distr.
Container	350 [TEU]	10.5	10.5	175	557	940	1
General cargo	2,500	9.8	9.8	136	300	1,750	1
Dry bulk	2,500	8.7	8.7	124	710	740	1
Coal Vale 1	4 x 27,000	7.0	10.7	194	21	24,730	10
Coal Vale 2	3 x 27,000	7.0	10.7	194	21	24,730	10
Coal Rio Tinto	30,000	7.0	10.7	194	53	9,860	10
Fuel	10,000	10.7	9.5	175	268	1,960	1

Table 0-3 | Terminal specification for alternatives in scenario low

Terminal	handling speed	service time	Erlang distr.
Container	34	798	5
GC DB	198	938	5
Coal in port	1700	1133	10
Fuel	1200	680	5
Coal offshore	3000	800	10

Table 0-4 | Throughput through scenario most likely, in tons, except for containers in TEUs

Fleet	Import	Export	Empties
Container	130,000	140,000	65,000
General cargo	600,000	400,000	
Dry bulk	1,600,000	400,000	
Coal Vale 1		13,400,000	
Coal Vale 2		13,400,000	
Coal Rio Tinto		6,600,000	
Fuel	3,750,000	720,000	

Table 0-5 | Fleet input specification for alternatives in scenario most likely

Fleet	Load [tons]	d in [m]	d out [m]	LOA [m]	# of vessels	inter arrival time [min]	Erlang distr.
Container	400	12.3	12.3	210	838	627	1
General cargo	3000	10.8	10.8	151	333	1,576	1

Dry bulk	3000	9.5	9.5	138	667	788	1
Coal Vale 1	3 x 40,000	7.0	12.5	194	84	6,275	10
Coal Vale 2	2 x 40,000	7.0	12.5	194	84	6,275	10
Coal Rio Tinto	40000	7.0	12.5	194	165	3,185	10
Fuel	10000	10.7	9.5	175	447	1,175	1

Table 0-6 | Terminal specification for alternatives in scenario most likely

Terminal	handling speed	service time	Erlang distr.
Container	34	886	5
GC DB	193	1113	5
Coal in port	1700	1592	10
Fuel	1200	680	5
Coal offshore	3000	1060	10

Table 0-7 | Throughput through scenario high [tons, except for containers in TEUs]

Fleet	Import	Export	Empties
Container	180,000	220,000	90,000
General cargo	750,000	500,000	
Dry bulk	1,600,000	1,600,000	
Coal		40,000,000	
Fuel	5,500,000		

Table 0-8 | Fleet input specification for alternatives in scenario high

Fleet	Load [tons]	d in [m]	d out [m]	LOA [m]	# of vessels	inter arrival time [min]	Erlang distr.
Container	500	14.0	14.0	270	980	536	1
General cargo	4000	12.2	12.2	172	313	1,681	1
Dry bulk	4000	11.3	11.3	168	800	657	1
Coal	70000	10.0	15.0	230	571	919	10
Fuel	20000	13.1	10.0	230	275	1,911	1

Table 0-9 | Terminal specification for alternatives in scenario high

Terminal	handling speed	service time	Erlang distr.
Container	34	1062	5
GC DB	193	1424	5
Coal in port	1700	2651	10
Fuel	1200	1180	5

X NET PRESENT VALUE CALCULATION

X-A Phased development of alternatives

X-A.a. Scenario low

Alternative 1
In this first phase some small adaptions to the port layout are done, to address the current bottlenecks. The coal quay 8 is extended to ensure safe berthing, following the discussed design rules. The road and railroad infrastructure is improved to four lanes, in order to address the current congestion problems. The container terminal is expanded, but without relocating the rail workshop. The management of the fuel jetty is improved in order to use the spare berth capacity, which was shown in the Harboursim results of the present situation in chapter 5. The channel is designed to the required width for safe navigation, but remains at -8 m CD.

In the second phase, the rail workshop is relocated to make the required area free for the container terminal expansion and the passing lane is implemented.

Table 0-10 | Phased investments alternative 1 in scenario low

	Present	Phase I	Phase II
Capital dredging		€ 23,100,000	€ 37,800,000
Passing lane dredging			€ 19,855,000
Quay extension		€ -	€ -
Soil improvement	€ 693,000	€ 693,000	€ -
Jetty			€ 30,000,000
Relocation of rail workshop			€ 8,000,000
Quay 8 extension construction		€ 3,000,000	
Roads and railroads		€ 7,700,000	€ -
Main gate	€ 1,000,000		
Engineering	€ 85,000	€ 1,725,000	€ 4,783,000
Contingencies	€ 169,000	€ 3,449,000	€ 9,566,000
Total	**€ 1,947,000**	**€ 39,667,000**	**€ 110,004,000**

Alternative 2
Phase I is similar to alternative 1: coal quay 8 is extended, the road and railroad infrastructure is expanded to four lanes, the container terminal is expanded, and the channel width is increased.

In phase II, quay 10 is extended first and thereafter quay 6-7 is converted for container handling. The second fuel jetty is build, to get the capacity required for scenario low and the channel is lowered to -9 m CD.

Table 0-11 | Phased investments alternative 2 in scenario low

	Present	Phase I	Phase II
Capital dredging		€ 23,100,000	€ 37,800,000
Quay extension		€ -	€ 41,000,000
Soil improvement	€ 1,130,000	€ 1,134,000	€ -
Jetty			€ 30,000,000
Relocation of GC DB terminal		€ 500,000	
Adaption of quay 6-7 to container terminal		€ 3,000,000	
Roads and railroads		€ 8,120,000	€ -
Main gate	€ 1,000,000		
Engineering	€ 107,000	€ 1,793,000	€ 5,440,000
Contingencies	€ 213,000	€ 3,585,000	€ 10,880,000
Total	**€ 2,450,000**	**€ 41,232,000**	**€ 125,120,000**

X-A.b. Scenario most likely

Alternative 1

In phase I, it is aimed to facilitate about half the growth of the port throughput. The coal quay 8 is extended and the coal terminal behind the quay remains in place. One berth is created for coal at the reclamation site. The road and railroad infrastructure is expanded to four lanes. The container terminal is expanded, for which the rail workshop is relocated and quay 1 is rehabilitated for container handling. The channel is lowered to -9 m CD and widened to 174 m for safe one-way traffic.

In phase II, the coal terminal behind quay 8 is relocated and the quay converted for general cargo and dry bulk use. The coal terminal in the north is fully realized. The released coal terminal area is prepared for the container terminal expansion. The second fuel jetty is constructed and the fuel terminal expansion can be implemented, because the soil, prepared in phase I, is settled sufficiently. The channel is widened to 367 m and the mooring point for the container ships is implemented next to quay 10.

Table 0-12 | Phased investments alternative 1 in scenario most likely

	Present	Phase I	Phase II
Capital dredging		€ 60,900,000	€ 135,100,000
quay extension		€ 53,500,000	€ 35,300,000
Soil improvement	€ 1,017,000	€ 1,017,000	€ -
Jetty			€ 30,000,000
mooring point			€ 2,000,000
Relocation of rail workshop		€ 8,000,000	
Relocation of coal terminal			€ 5,000,000
Quay 8 extension construction		€ 3,000,000	
Roads and railroads		€ 10,100,000	€ 4,620,000
Main gate	€ 1,000,000		
Engineering	€ 101,000	€ 6,826,000	€ 10,601,000
Contingencies	€ 202,000	€ 13,652,000	€ 21,202,000
Total	**€ 2,320,000**	**€ 156,995,000**	**€ 243,823,000**

Alternative 2

In phase I, coal quay 8 is extended and a second coal terminal with one berth is constructed at the reclamation site. Quay 10 is extended first and thereafter quay 6-7 is converted for container handling. The road and railroad infrastructure is expanded to four lanes. The channel is lowered to -9 m CD and widened to 174 m for safe one-way traffic.

The rail workshop is relocated in phase II, in order to expand the container terminal further. The northern coal terminal is expanded to two berths. The fuel terminal expansion, with the second jetty is implemented. The access channel is lowered to -10 m CD and widened to 367 m to enable two-way traffic.

Table 0-13 | Phased investments alternative 2 in scenario most likely

	Present	Phase I	Phase II
Capital dredging		€ 60,900,000	€ 208,775,000
quay extension		€ 64,700,000	€ 23,800,000
Soil improvement	€ 2,142,000	€ 2,142,000	€ -
Jetty			€ 30,000,000
Relocation of rail workshop			€ 8,000,000
Relocation of GC DB terminal		€ 500,000	
Adaption of quay 6-7 to container terminal		€ 3,000,000	
Roads and railroads		€ 11,120,000	€ 4,200,000
Main gate	€ 1,000,000		
Engineering	€ 157,000	€ 7,118,000	€ 13,739,000
Contingencies	€ 314,000	€ 14,236,000	€ 27,478,000
Total	**€ 3,613,000**	**€ 163,716,000**	**€ 315,992,000**

X-A.c. Scenario High

Alternative 1

In phase I, it is aimed to facilitate about half the growth of the port throughput. The coal quay 8 is extended and the coal terminal behind the quay remains in place. Two berths are created for coal at the reclamation site, where operations as in scenario most likely are foreseen. The container terminal is expanded, for which the rail workshop is relocated and quay 1 is rehabilitated for container handling. The road and railroad infrastructure is expanded to four lanes. The channel is lowered to -10 m CD and widened to 367 m for two-way traffic.

The coal terminal is relocated in phase II, thus enabling room for expansion of the container terminal. A second container terminal is prepared in the north. The northern coal terminal is fully expanded. The second fuel jetty is implemented with the accompanying terminal expansions. The general quay is extended north of quay 10. The channel is dredged to -12 m CD and widened to 410 m for safe navigation of the Panamax ships.

Table 0-14 | Phased investments alternative 1 in scenario High

	Present	Phase I	Phase II
Capital dredging		€ 269,675,000	€ 206,325,000
quay extension		€ 88,800,000	€ 135,000,000
Soil improvement	€ 3,848,000	€ 3,848,000	€ -
Jetty			€ 30,000,000
mooring point		€ 2,000,000	
Relocation of rail workshop		€ 8,000,000	
Relocation of coal terminal			€ 5,000,000
Quay 8 extension construction		€ 3,000,000	
Roads and railroads		€ 14,120,000	€ 6,220,000
Main gate	€ 1,000,000		€ 330,000
Engineering	€ 242,000	€ 19,472,000	€ 19,144,000
Contingencies	€ 485,000	€ 38,944,000	€ 38,288,000
Total	**€ 5,575,000**	**€ 447,859,000**	**€ 440,307,000**

Alternative 2

In phase I, coal quay 8 is extended and a second coal terminal with two berths is constructed at the reclamation site. Quay 10 is extended first and thereafter quay 6-7 is converted for container handling. The container terminal is expanded until the boundary of the present coal terminal; therefore, the rail workshop is relocated. The road and railroad infrastructure is expanded to four lanes. The channel is lowered to -10 m CD and widened to 367 m for two-way traffic.

In phase II, the coal terminal is expanded beyond the coal terminal and a second coal terminal with one berth is constructed in the north. The second coal terminal is expanded to three berths. The second fuel jetty is implemented with the accompanying terminal expansions. The general quay is extended further northwards. The channel is dredged to -13 m CD and widened to 410 m.

Table 0-15 | Phased investments alternative 1 in scenario High

	Present	Phase I	Phase II
Capital dredging		€ 269,675,000	€ 293,825,000
quay extension		€ 88,500,000	€ 94,700,000
Soil improvement	€ 4,964,000	€ 4,968,000	€ -
Jetty			€ 30,000,000
Relocation of rail workshop		€ 8,000,000	
Relocation of GC DB terminal		€ 500,000	
Adaption of quay 6-7 to container terminal		€ 3,000,000	
Roads and railroads		€ 14,120,000	€ 3,000,000
Main gate	€ 1,000,000		€ 330,000
Engineering	€ 298,000	€ 19,438,000	€ 21,093,000
Contingencies	€ 596,000	€ 38,876,000	€ 42,186,000
Total	€ 6,858,000	€ 447,077,000	€ 485,134,000

X-B Net present value calculation and results

Table 0-16 | Summary of costs per phase for alternative 1 in scenario most likely

	Present	Phase I	Phase II
capital dredging			
Channel depth [m CD]	-8	-9	-9
Channel width [m]	130	174	367
Dredged volume [m³]	15,540,000	12,180,000	27,020,000
Unit price [€/m³]		5	5
Total costs [€]		€ 60,900,000	€ 135,100,000
Quay extension			
Container terminal [m]		183	
General cargo / dry bulk terminal [m]		-	
Coal terminal [m]		352	353
Fuel terminal [m]		NA	NA
Unit price [€/m]		100,000	100,000
Total costs [€]		€ 53,500,000	€ 35,300,000
Soil improvement			
Total new area [m²]	226,000	226,000	
Sand removal unit price [€/m2]	3	3	
Drainage unit price [€/m²]	1.5	1.5	
Total costs [€]	€ 1,017,000	€ 1,017,000	
Infrastructure			
Roads [m]		22,000	
Unit price [€/m]		300	
Rails [m]		5,000	6,600
Unit price [€/m]		700	700
Total costs [€]		€ 10,100,000	€ 4,620,000
Jetty			€ 30,000,000
mooring point			€ 2,000,000
Relocation of rail workshop		€ 8,000,000	
Relocation of coal terminal			€ 5,000,000
Quay 8 extension construction		€ 3,000,000	
Main gate	€ 1,000,000		
Subtotal	€ 2,017,000	€ 136,517,000	€ 212,020,000
Engineering	€ 101,000	€ 6,826,000	€ 10,601,000
Contingencies	€ 202,000	€ 13,652,000	€ 21,202,000
Total	€ 2,320,000	€ 156,995,000	€ 243,823,000

Table 0-17 | Summary of costs per phase for alternative 2 in scenario most likely

	Present	Phase I	Phase II
Capital dredging			
Channel depth [m CD]	-8	-9	-10
Channel width [m]	130	174	367
Dredged volume [m3]	15,540,000	12,180,000	41,755,000
Unit price [€/m3]		5	5
Total costs [€]		€ 60,900,000	€ 208,775,000
Quay extension			
Container terminal [m]		-	-
General cargo / dry bulk terminal [m]		410	-
Coal terminal [m]		237	238
Fuel terminal [m]		NA	NA
Total [m]		647	238
Unit price [€/m]		100,000	100,000
Total costs [€]		€ 64,700,000	€ 23,800,000
Land reclamation			
Total new area	476,000	476,000	
Sand removal unit price [€/m2]	3	3	3
Drainage unit price [€/m2]	1.5	1.5	1.5
Total costs [€]	€ 2,142,000	€ 2,142,000	€ -
Infrastructure			
Roads		24,000	
Road cost		300	
Rails		5,600	6,000
Railroad cost		3,920,000	4,200,000
Jetty			€ 30,000,000
Relocation of rail workshop			€ 8,000,000
Relocation of GC DB terminal		€ 500,000	
Adaption of quay 6-7 to container terminal		€ 3,000,000	
Main gate	€ 1,000,000		
Subtotal	€ 3,142,000	€ 142,362,000	€ 274,775,000
Engineering	€ 157,000	€ 7,118,000	€ 13,739,000
Contingencies	€ 314,000	€ 14,236,000	€ 27,478,000
Total	€ 3,613,000	€ 163,716,000	€ 315,992,000

Table 0-18 | Net present value calculation results for both alternatives in scenario most likely

	Present	Phase I	Phase II
Year	2012	2017	2027
Investment Alt. 1	€ 2,320,000	€ 156,995,000	€ 243,823,000
Investment Alt. 2	€ 3,613,000	€ 163,716,000	€ 315,992,000
Maintenance Alt. 1	€ 19,613,000	€ 22,497,000	€ 32,203,000
Maintenance Alt. 2	€ 19,613,000	€ 23,426,000	€ 35,097,000
NPV alternative 1	€ 363,762,394		
NPV alternative 2	€ 391,017,327		
Absolute difference	€ -27,254,933		
Relative difference	7%		

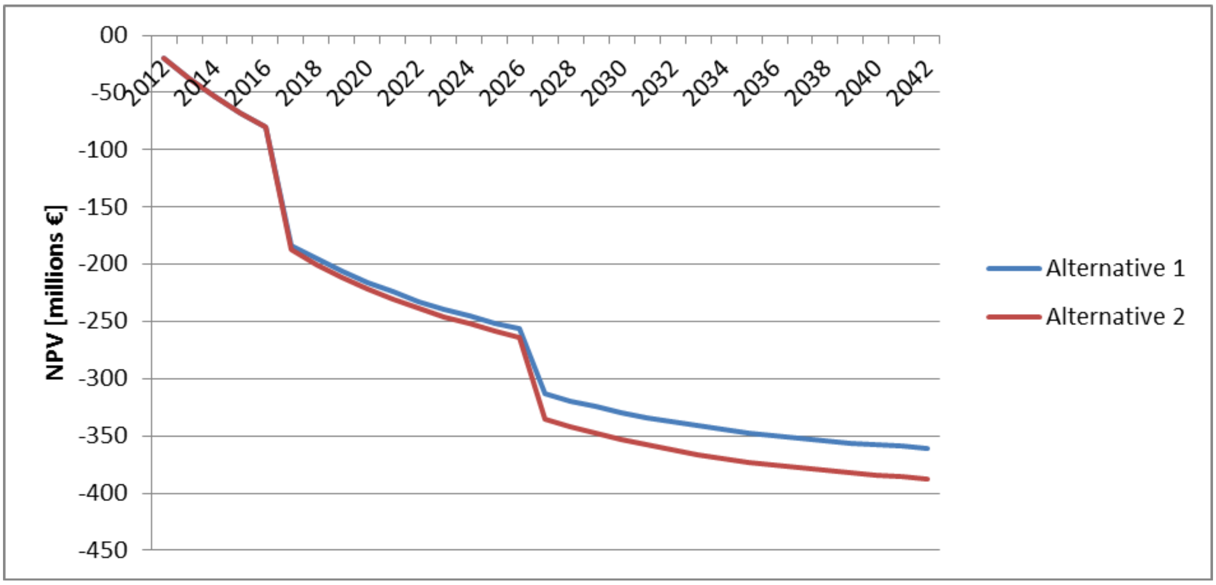


Figure 0-41 | Net present value of both alternatives during project span in most likely scenario