Container Port Development
A Port Choice Model for the European Mainland

M.A. Mueller
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M.A. (Michiel) Mueller
1275461
michielmueller@gmail.com
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Master Program Transport, Infrastructure & Logistics
Delft University of Technology

Graduation Committee:
Prof. dr. R.A. Zuidwijk
Faculty of Civil Engineering and Geosciences, Department Transport & Planning
Dr. B.W. Wiegmans
Faculty of Civil Engineering and Geosciences, Department Transport & Planning
Dr. J.H.R. Van Duin
Faculty of Technology, Policy and Management, Department Transport & Logistics
Dr. S.J. Veldman
Ecorys, Maritime Economist
Drs. E.H. Bückmann
Ecorys, Senior Consultant
PREFACE

This thesis concludes my master degree in Transport, Infrastructure and Logistics at the Delft University of Technology. For this thesis I studied the influence of various port choice factors on container port competitiveness and modelled the impact of oil price changes using the port competition model which I developed as part of this thesis.

Port choice modelling has been a great topic for me as it combines transportation, modelling and economics. I have experienced the period of my thesis as interesting and very instructive, but sometime also as a struggle.

This thesis could not have been concluded without the help of a number of people. First of all, I would like to thank my thesis committee. Bart Wiegmans, who has been my daily supervisor, has helped me shape my research, give feedback on my report and supported me during the whole thesis process. Ewout Bückmann, for his help in the modelling process and being a great sparring partner. Simme Veldman, for his extensive knowledge of maritime economics and his effort to help me understand the research topic. Ron van Duin for his methodological notes and Rob Zuidwijk for his eye for detail.

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SUMMARY

Introduction
Over the last two decades, global container transport has grown rapidly, and transport between Asia and Europe in particular. This increase in container transport has led to larger container terminals and ports, the largest of which are currently situated along the North Sea coastline, in the Hamburg-Le Havre range. The ease of handling containers, both at ports and hinterland transport has made container transport much more flexible and price elastic. This has caused the captive hinterland for container ports to diminish. This has, in turn, lead to fierce competition between container ports.

The competition between container ports is affected by various factors in the container transport sector. Changes in these factors can have significant influence on ports and their competitiveness. Major changes include, but are not limited to: increasing ship size (which reduces maritime transport costs), global warming (which makes the use of the Northern Sea Route possible in the future) and the uncertainty concerning the volatility of oil prices. Other factors can include policy changes, such as: internalising CO2 cost via the emission reduction and trade scheme, and modal split targets for hinterland freight transport.

The impact of such changes on the competitiveness of container ports is difficult to assess and predict. It is, however, possible to make quantitative prognoses of container flows in order to analyse possible impacts of different changes on port competitiveness. If container flows can be predicted, i.e. modelled, then the impact of different policies, investments and scenarios can be quantified and analysed.

This study focusses on the design and development of a port competition model that is able to simulate impacts of major changes on container port imports, in order to make analysis of container port development. Hence, the following research question for this study is formulated:

‘How can container port competition for the European mainland ports be modelled and how will the port competition develop in the future?’

Competitiveness in this study is measured using the volume of container imports per port, for flows from Asia to Europe, for 31 ports situated on the mainland of Europe. Given that Europe imports considerably more from Asia than it exports, the imports are considered normative. It is reasoned that the port choice for fully loaded ships
from Asia is more important than the port choice of the half full ships returning to Asia.

Port Competition Model

A competitive port is chosen more frequently than a less competitive port, therefore port competition is often modelled as a port choice problem. When looking at port choice, the complete transport chain should be considered, the port that is embedded in the most (favourable) transport chains is chosen most frequently. A review of port choice literature has provided an elaborate overview of important port choice factors. From this overview, twelve port choice factors are selected: maritime costs, hinterland costs, port costs, maritime transport time, hinterland transport time, port dwell time, number of deep sea port calls, number of short sea services, water depth (part of port infrastructure), number of inland waterway services, number of rail services, and demand for containers. These factors are primarily chosen due to the fact that they are most frequently mentioned as key factors by the port choice decision makers, shippers, forwarders and shipping lines. Secondly, for modelling purposes it is important to use quantitative factors that are applicable for port choice and not specific for terminal choice. Thirdly, publicly available and comparable data for these factors could be found for all 31 ports considered in this study.

With these factors, port choice can be modelled. This is done by using a widely applied multinomial logit discrete choice model, used for route choice modelling. This method is further developed and used to determine the probability of route choice based on the utility of the route compared to the utility of alternative routes. The probability of a route is interpreted as the market share of that route. Utility is defined as a linear function of the port choice factors with corresponding weights and is based on the micro-economic utility theory. This theory states that an individual will always choose the option with the highest utility. A route covers the complete transport chain and consists of: maritime transport from Asia to Europe (including feeder transport), transhipment at a port and hinterland transport to the final destination. For hinterland transport, the modes of road, rail and inland waterway can be used.

The weights for the different port choice factors are, in turn, found by comparing the port choice factors with Origin Destination (OD) data, using multivariate regression analyses. However, actual OD data on container flows from Asia to Europe or between European ports and hinterland regions are not known. Therefore, an OD matrix is simulated in two steps, using a doubly constrained distribution model also known as a mode routing choice model. First, a rough OD matrix is constructed using a distribution function based on the input variables: total costs, total time, and ‘value of time’, which is also known as the Generalized Cost method. Second, the rough OD matrix is balanced using balancing factors based on the constraints of the matrix, this method is also known as bi-proportional fitting. The constraints of the matrix are: the container imports per port per hinterland mode, and the hinterland
demand for containers. After being sufficiently balanced, the matrix is named ‘base OD matrix’.

Using the quantified port choice factors and the base OD matrix as input, a weighted regression analysis is applied to determine the statistical significance and weights of the twelve port choice factors. It is important to take into account that the sign of the weight coefficient is conform literature, seeing as the sign determines whether a factor has a positive or negative influence on the utility. This, in turn, results in five significant factors: maritime transport costs, hinterland transport costs, hinterland transport time, number of deep sea port calls, and a negative dummy variable for rail transport. Maritime transport costs, hinterland transport costs, and hinterland transport time all have a negative weight coefficient, which means that when transport costs or time increase, the utility will decrease. The number of deep sea port calls has a positive sign, whereas the dummy variable for rail transport has a negative sign. Further analysis shows that an increasing number of inland waterway transport and rail services have significant positive affect on utility. However, both these port choice factors are not included in the port competition model as their weight coefficients cannot be computed at the same time as for the earlier found five port choice factors. Hence, their relative influences on port choice cannot be tested.

**Results**

From the results of the regression analysis, the utility function is made, which contains five port choice factors and their corresponding weights. This utility function is used within the multinomial logit function which then gives the number of TEU per route. When all flows that use the same port are summed, the total import per port is computed; this is called the port competition model. In order to test the performance of the port competition model, the model outcomes are compared with the actual port imports found from historical port statistics. The performance is measured by the R2 value, which indicates the level of variance that is explained by the model. The port competition model has an R2 value of 0.77, which means that the model explains 77% of the variance in the port imports. As this model is built using a simulated OD matrix, it is important to determine whether or not the model performs better than the Generalised Cost method that simulated the first step of the OD matrix. Hence, the performance of the Generalized Cost method is tested the same way as the port competition model. The R2 value of the Generalized Cost method is 0.64, which is lower than the R2 value found for the port competition model. This lower value of R2 indicates that the port competition model using five port choice factors performs better than the generalized cost method used for the OD simulation.

The application of the port competition model is tested using a case study of variable oil prices. A scenario with varying oil prices is used to analyse the development of container imports per coastline. The oil price scenario is chosen because oil price has a direct influence on transport costs but differs per transport mode. The results show that higher oil prices lead to an increase in import for the Mediterranean ports and
unchanged import for the North Sea and Black Sea ports. The ports along the Baltic Sea, Adriatic Sea and the Atlantic will see their container imports decrease with increasing oil prices. For Switzerland, located in the heart of Europe, the shift of imports per coastline is significant. Higher oil prices lead to an increased import from the Mediterranean ports and a decline in imports from the North Sea ports. Besides port imports, modal split changes and the use of feeder services are also calculated by the model. An increasing oil price results in a higher use of inland waterway and rail transport, at the expense of road transport.

Conclusions
The developed port competition model can analyse the effects of global trends and policy changes concerning the container transport sector on the imports per port, modal split changes and the use of feeder services, for the European mainland. The model can be applied to determine impacts on port competitiveness or support decision making for: policy changes, investments in infrastructure, or shipping trends.

This research shows that the prediction power of a logit model is improved by introducing five port and mode specific variables: maritime transport costs, hinterland transport costs, hinterland transport time, number of deep sea port calls, and a negative dummy variable for rail transport.

Recommendations for future model improvements include using more port choice factors, such as port reliability, port efficiency and port services. The model can also be expanded, to include for instance port imports and exports, and by including container transport from other parts of the world as well. From a scientific and business perspective, it is recommended that bill of lading data gathered by customs, which includes origin destination data, would be made publicly available on a European level. This would fit the ‘open data’ policy of the European Union to make public data available for its citizens.
# TABLE OF CONTENTS

PREFACE ..................................................................................................................... III

SUMMARY.................................................................................................................... IV

1 INTRODUCTION ..................................................................................................... 1
   1.1 Problem Introduction ....................................................................................... 1
   1.2 Research Objective ......................................................................................... 4
   1.3 Research Question ......................................................................................... 5
   1.4 Scope ............................................................................................................... 5
   1.5 Report Structure ............................................................................................ 6

2 ANALYSIS OF PORT CHOICE ........................................................................... 8
   2.1 Transport Chain .............................................................................................. 8
   2.2 Port Choice Factors per Actor ........................................................................ 9
      2.2.1 Shipping Lines ......................................................................................... 9
      2.2.2 Shippers and Forwarders ....................................................................... 10
      2.2.3 Ports and Terminals ............................................................................... 10
      2.2.4 Third Party Logistics Provider ................................................................. 11
      2.2.5 Overview of Factors ............................................................................... 11
   2.3 Selection of Port Choice Factors .................................................................... 12
      2.3.1 Excluded Factors .................................................................................... 12
      2.3.2 Included Factors ...................................................................................... 14
      2.3.3 Selected Port Choice Factors .................................................................. 15
   2.4 Conclusion Port Choice Factors ..................................................................... 16

3 PORT CHOICE MODELLING METHODS ....................................................... 17
   3.1 Conceptual Choice Model ............................................................................. 17
   3.2 Transport Modelling Approach .................................................................... 18
      3.2.1 Four stage model .................................................................................... 18
      3.2.2 Modelling Approach ............................................................................. 19
   3.3 Transport Modelling Methods ...................................................................... 20
      3.3.1 Utility Theory ......................................................................................... 20
      3.3.2 Multinomial Logit Function .................................................................... 21
      3.3.3 Prediction Model ..................................................................................... 22
   3.4 Conclusion Transport Modelling ................................................................... 23

4 DATA COLLECTION AND ANALYSIS ......................................................... 24
   4.1 Port Choice Factors ....................................................................................... 24
      4.1.1 Maritime Transport Cost ...................................................................... 24
      4.1.2 Maritime Transport Time ...................................................................... 26
4.1.3 Number of Port Calls ................................................................. 27
4.1.4 Port Handling Cost ................................................................. 28
4.1.5 Port Dwell Time ................................................................. 28
4.1.6 Water Depth ................................................................. 29
4.1.7 Number of Feeder Services ................................................................. 29
4.1.8 Number of Intermodal Services ................................................................. 29
4.1.9 Hinterland Transport Cost ................................................................. 29
4.1.10 Hinterland Transport Time ................................................................. 30
4.2 Container Demand ................................................................. 31
4.2.1 Supply of Containers from Asia ................................................................. 31
4.2.2 Demand for Containers in Europe ................................................................. 32
4.3 Port Imports ................................................................. 33
4.3.1 Port Imports 2010 ................................................................. 33
4.3.2 Port Modal Split ................................................................. 33
4.4 Conclusions Data Collection and Analysis ................................................................. 34

5 CONSTRUCTION OF BASE OD MATRIX ................................. 35
5.1 Origin Destination Simulation Approach ................................................................. 35
5.1.1 Other studies ................................................................. 35
5.1.2 Doubly Constrained Distribution Model ................................................................. 36
5.2 Distribution Function ................................................................. 37
5.2.1 Generalized Cost ................................................................. 38
5.2.2 Value of Time ................................................................. 38
5.2.3 Beta ................................................................. 39
5.3 Calibration of the Distribution Function ................................................................. 40
5.3.1 Performance Indicators ................................................................. 40
5.3.2 Simulation Results ................................................................. 41
5.3.3 Interpretation of Results ................................................................. 42
5.3.4 Sensitivity Analysis ................................................................. 43
5.4 Balancing OD Matrix ................................................................. 44
5.4.1 Balancing the OD Matrix ................................................................. 44
5.4.2 Consolidation ................................................................. 45
5.5 Conclusions OD matrix ................................................................. 46

6 STATISTICAL ANALYSIS ................................................................. 47
6.1 Statistical Method ................................................................. 47
6.1.1 Research Problem ................................................................. 47
6.1.2 Analysis Plan ................................................................. 48
6.1.3 Assumption Evaluation ................................................................. 49
6.2 Statistical Results ................................................................. 51
6.2.1 Regression Estimates ................................................................. 51
6.2.2 Interpretation of the Results ................................................................. 53
6.2.3 Validation ................................................................. 56
F. Number of Short Sea Services ................................................................. 117
G. Hinterland Intermodal Services and Frequencies .............................. 119
H. Hinterland Transport Costs ............................................................... 120
I. Hinterland Transport Time, Distance and Speed ................................. 123
J. Supply of Containers ........................................................................ 129
K. Port Import 2010 ............................................................................. 133
L. Port Modal Split ............................................................................... 135
M. Oil Prices ......................................................................................... 137
N. Modelling OD Matrix ...................................................................... 140
O. Statistical Analyses ........................................................................ 142
P. Oil Price Scenario ........................................................................... 144
1 INTRODUCTION

In this chapter the problem introduction is given, it includes background information, ongoing changes that face the container transport sector and the problem definition. Next, the research objective and research question are formulated. Finally, the scope of the study and the report structure are presented.

1.1 Problem Introduction

Background

International trade has increased rapidly due to globalization. Global trade volume has grown with 8% annually since 2000 (UNCTAD, 2012). Currently 80% of all trade volume is done using shipping (UNESCAP, 2012). Drivers of globalization include trade liberalization, technological development and production factors such as labour costs. Making use of these comparative advantages of countries demands standardization and low transport costs (Kumar and Hoffmann, 2002).

Containerization has been a great facilitator in this process as it provides standardized boxes which are measured in TEU (Twenty foot Equivalent Unit) that can be transported by different modes of transport. This improves logistics and lowers transport costs. The ongoing increase of container ship size has lowered the transportation costs even further (Cullinane and Khanna, 2000). This continues as ships become even larger.

The popularity of container use has grown rapidly over the last few decades. The container volumes have grown between 6.6% and 8.5% per year for the last decade (UNESCAP). Due to the economic crisis of 2008 the average annual container growth has been lower. However this growth has recovered with an annual growth of 6.9% from 2009 till 2012 (Notteboom, 2013). It is suggested that for every 1% increase in global economic growth, the container volume growth is 1.5% (UNESCAP). This is due to the increase in trade but also due to the fact that more goods are transported by container, the so called container penetration. This growth has led to more and larger container terminals at seaports. Especially ports near consumer markets like North West Europe and production markets like China are large (World-Shipping-Council, 2012) and still growing. This has led to large flows of containers from Asia to Europe.
Problem Introduction
Currently the largest ports in Europe are situated in the Hamburg-Le Havre range and serve the Northwest European market (Notteboom, 2008). They do not only serve as a gateway port but also have positioned themselves as a hub-port. There is competition between the ports along the North Sea as they serve the same hinterland. According to Haralambides (2002) the captive hinterlands for container ports has diminished due to a highly competitive market.

This is due to the ease of handling at ports and the ability of containers for intermodal use for the hinterland (Notteboom and Rodrigue, 2008). Because of the high flexibility and the large market, the container market is attractive and easy to access for different ports and parties. There is not only competition between sea carriers and hinterland transport companies, but also between terminals and ports.

In order to reach Switzerland from Asia for example, two general routes can be chosen, see Figure 1-1. These are maritime transport to a North Sea port and then transport by truck, train or barge to the destination (dashed line), or maritime transport to a Mediterranean port and then transport by truck or train to the destination (solid line).

It may seem that the latter route would be cheaper as the travelled distance is smaller but other factors like ship size and transport consolidation also influence the transport costs. Besides transport costs also other factors influence route and port choice, these include transport time or service and quality factors such as frequency of services (Aronietis et al., 2011).
Trends and policy changes

The competition between ports is influenced by different factors in the container transport sector. Major changes in this sector and for these factors could therefore influence port competition. Changes include trends, policy changes and future uncertainties.

Container ships are continuing to become larger, Maersk has deployed its triple E class ship with a capacity of 18,000 TEU in the summer of 2013 (Maersk, 2013a). This will further increase the supply of transport capacity and will lower the maritime transport cost per container. Secondly, sailing speeds of deep sea ships have decreased significantly over the last decade, from an average speed of 25 knots down to 15 knots, so called slow steaming (Rodrigue et al., 2009). Lowering sailing speeds saves fuel costs, however lower sailing speeds also mean longer transport times.

The environmental aspect becomes increasingly important and policy changes emphasize this. Maritime transport will have to use low Sulphur fuels in the Baltic and North Sea from 2015 (Kalli et al., 2009), these fuel types are more expensive than regular bunker fuels which makes maritime transport more expensive for these regions. Globally, maritime transport will possibly have to join the CO₂ emission reduction and trading scheme (IMO, 2009). This will also make maritime transport more expensive and could be an incentive to use larger and more fuel efficient ships.
Increasing fuel costs will possibly result in even lower sailing speeds. Hinterland transport is faces with modal split policies of ports (PoR, 2013) and from the European Union (European-Commission, 2011). These policies intend to increase the usage of intermodal transport such as transport using inland waterways and rail to lower CO₂ emissions and congestion.

Besides trends and policy changes also the development of the oil price could affect port competition factors. The development of the oil price is volatile and uncertain but its influence on transport costs is evident.

Other major changes that could affect port competition are: the breakthrough of 3D printing (Harvard-Business-Review, 2013), which could result in products being manufactured close to the market instead of in the Far East; the return of production from the Far-East to Europe (FD, 2012); the use of the Arctic route instead of the Suez Channel (The-Arctic-Institute, 2011) due to global warming; or the further expansion and integration of the European market (European-Commission, 2012) which makes trade easier and more competitive.

**Problem Definition**

The impact of these changes on the route- and port choice of container transport is difficult to predict. It is, however, desirable to make quantitative prognoses of container flows to analyse possible impacts of different trends and policy changes. If container flows can be predicted (modelled), then the impact of different policies and investments can be analysed and scenarios can be quantified.

In order to quantify the impacts of different trends and policies on the container ports in Europe a quantitative (simulation or prediction) model will need to be developed. This model should contain port and route choice factors that affect port competitiveness. Port choice factors and the changes should therefore be determined and quantified, and their influence weight.

**1.2 Research Objective**

From the problem definition a research objective can be formulated.

“The objective of this research is to develop a port choice model that is able to shows the impact of different trends and policy changes on the competitiveness of container ports for the European mainland”.
1.3 Research Question

From the research goal the research questions can be formulated. The research question should be formulated such, that answering it is fulfilling the research goal.

From the research objective the main research question can be formulated:

‘How can container port competition for the European mainland ports be modelled and how will the port competition develop in the future?’

1.4 Scope

Geographical Scope
The geographical scope indicates the boundaries of the study. The study focusses on the European mainland, it therefore excludes Great Britain and Scandinavia. The countries included are either member of the European Union (EU) or European Free Trade Association (EFTA) or are candidate countries to join the EU, see Figure 1-2.

The hinterland regions of these countries are modelled on a NUTS-2 level. NUTS is an abbreviation for Nomenclature of Territorial Units for Statistics used by Eurostat (2012). The NUTS system is a hierarchical system for dividing up the economic territory of the EU in administrative regions. A NUTS lever 2 region has between 0.8-3 million inhabitants; in the Netherland all provinces are considered NUTS-2. This study includes 231 NUTS-2 hinterland regions.

Ports and Coastlines
The scope includes the coastlines of the Baltic Sea, North Sea, Mediterranean Sea, Adriatic Sea, Aegean Sea and Black Sea. For modelling purposes the Aegean Sea and Black Sea are modelled together under the name Black Sea.

For this study 31 ports are analysed, these are mainly the larger container ports when considering their container throughput. Some smaller ports are also included in order to get a good geographic coverage of the European mainland, see Figure 1-2.

Container Imports
For this study container imports from Asia to the European mainland are studied. The flow of containers from Asia is the largest flow and has increased the quickest (UNCTAD, 2009). Secondly, Europe imports more products from Asia than it exports, so the size of the container imports is normative. This means that factors concerning export flows or empty container that influence port competition are not included in this study.
1.5 Report Structure

The structure of the report is as follows;

In chapter 2 an analysis of port choice and the selection of port choice factors, based on a literature review and interviews, is presented.

In chapter 3 the conceptual port choice model and the modelling methodology are presented, which will serve as the basis of the port competition model.

Chapter 4 describes the data collection and analysis for the port choice factors included in the model.

Chapter 5 includes the construction of the base origin destination matrix which is used as input for the statistical analysis.

In chapter 6 the statistical analysis is presented which includes the regression analysis and determination of the port choice factor coefficients.

In chapter 7 the port competition model is built and its performance is discussed.

A showcase is presented in chapter 8. This showcase includes a changing oil price scenario to show the application of the model.

Finally, in chapter 9, the conclusions, applications and recommendations are given.
The link between the different chapters, the general modelling approach and report structure of this study is given in Figure 1-3.
2 ANALYSIS OF PORT CHOICE

A port that is chosen frequently for a hinterland region will obtain a larger market share and is therefore considered to be more competitive than a port that is chosen less frequent. Studying port competition therefore means determining factors that influence port choice. This chapter is an analysis of the different factors that influence port choice. Port choice is influenced by the characteristics of the transport chain and the actors involved in this transport chain. At the end of this chapter a selection of port choice factors is made and an overview of port choice factors used in this study is given.

2.1 Transport Chain

According to Robinson (2002) ports should not be viewed as a single entity but as part of, and embedded in a value chain. When looking at port choice, we should therefore look at the complete supply chain, and choose the best chain. The port that is embedded in the most supply chains is chosen the most. This definition has since been adopted by many (Magala and Sammons, 2008). However, as supply chains are different per company, analysing supply chains is impossible, therefore the transport chains which the supply chain makes use of are analysed.

The transport chains consist out of different links which represent different activities and different actors, see Figure 2-1. The transport chain shows all the major activities to transport cargo from its origin to its destination. These activities include foreland transport, container handling at a port of departure, sea transport, container handling at port of destination and hinterland transport. These activities can be split into two types, transportation and transhipment. Transportation is the activity of moving a good, in this case a container, from one place to another place. Transhipment is the activity moving the container between modes of transport or in/out of storage or buffer. For all these activities different actors are involved.
In this study the transport chain origin is assumed to be the Asia and the destination is a region in the European mainland. The maritime (sea) transport is done by deep sea ships and the hinterland transport is done by the modes truck, train and barge. Transhipment is done at the container terminals that are situated in the ports, hinterland transhipment can be done in smaller inland terminals.

In this study the foreland part of the chain (origin to port of container loading) will not be taken into account, the starting point will be the maritime transport link. Therefore only one deep sea port is taken into account, in this case a port on the mainland of Europe. The scope boundaries are visualized in Figure 2-1.

2.2 Port Choice Factors per Actor

Various actors play a role in different parts of the transport chain. These include; shippers, stevedores, terminal operators, port authorities, shipping companies, forwarders, third party logistics providers, trucking companies and others (Robinson, 2002). However the number of actors that make the port choice is much smaller. In literature especially the role of shippers, forwarders and shipping lines has been studied. They have been identified as the key decision makers concerning port choice. The roles of terminal operators, logistics providers, port authorities and governments on port choice have been researched in a limited number of studies (Aronietis et al., 2011).

2.2.1 Shipping Lines

The major shipping lines have gained decision power since their market share has increased and the number of players has decreased. Many carriers have extended their business model by merging with terminal operators, creating dedicated terminals. This has been possible because of consolidation, vertical- and horizontal integration between the carriers and terminal operators has taken place. This has resulted in a very high market share for only a few major groups, their strength has increased through mergers and alliances (Wiegmans et al., 2008) (Notteboom and
Winkelmans, 2001). Currently the three largest carriers Maersk, MSC and CMA CGM are planning to form a new alliance called P3 (Dagblad-Transport, 2013). This would further strengthen their position towards their competitors. This alliance could become such a dominant player that it could potentially abuse its market power and negotiate lower port dues for example. Shipping lines are now seen as the major decision maker when it comes to port choice (Aronietis et al., 2011).

For the shipping lines the following choice factors have been found: port costs, port infrastructure, port services & turn-around-time, location to hinterland market, cargo base, feeder connectivity and availability of hinterland connections (Lrn et al., 2004) (Ha, 2003) (Song and Yeo, 2004) (Tongzon and Sawant, 2007) (Shintani et al., 2007) (Wiegmans et al., 2008) (Chang et al., 2008) (Karlaftis et al., 2009, Aronietis et al., 2011).

These factors are very much port oriented and less dependent on the transport chain.

### 2.2.2 Shippers and Forwarders

The shippers or consignees are the owners of the cargo and pay for the transport. They are interested in the rates of the carriers and the handling costs of the terminal but also at transport times of the shipment. The forwarders or agents organize the transport and hire transport companies to transport the cargo; they make the practical transport decisions. Their interests are in finding the best (affordable) solution for their clients and they can bundle cargo to obtain consolidation effects.


These factors are also very port oriented and less on the supply chain. Total transport time has not been mentioned specifically and total costs only a few times. This is unexpected as costs are found to be the most important factor (Aronietis et al., 2011) and time a dominant factor in selecting an ocean carrier (Notteboom, 2006). It could however also mean that some cost and time factors are more important than others.

### 2.2.3 Ports and Terminals

Ports are in most cases state owned and are managed by a port authority. Ports obviously do not make port choice decisions for container transport but they do evaluate the port choice factors of their clients. Their clients include container terminals that are often privately owned and responsible for the container handling. Terminals usually have long lasting contracts and do not switch ports often, however when other ports are more attractive they will consider investing in a different port. The port choice factors of terminals are therefore important for the port authorities.
An interview has been taken with an employee of the European Container Terminal (ECT) (Mueller, 2013b) and the Port Authority of Rotterdam (Mueller, 2013c). Both state that terminals and ports across Europe are becoming more alike and that handling efficiency of the North Sea port are comparable.

There are basically three factors that influence the competitiveness of a port: nautical access, feeder transport connectivity and hinterland services. Nautical access includes the water depth of a port and its ability to receive large ships. Feeder transport connectivity describes the number of connections a port has with other ports, this is important for the hub function or transhipment function of a port. The number of hinterland services includes the number of intermodal services and frequencies and the available infrastructure. These are important for the container imports that need to be transported to their destination in the hinterland.

2.2.4 Third Party Logistics Provider

Third party logistics providers manage a complete supply chain for their customers, whereas forwarders only organize the cargo transport. A supply chain includes the transport of goods but also the storage and warehousing of cargo. Container terminals located in a port are part of a supply chain therefore supply chain factors and transport logistics factors play a role in the port choice. This ‘terminalisation’ of the supply chain (Rodrigue and Notteboom, 2009), effectively means that terminals are integrated in the entire supply chain and can also function as buffers in the supply chain. This shows the potential of terminals as transport logistics centres (Bichou and Gray, 2004).

Different logistics and supply chain factors are found: total costs, total transport time, total distance, pipeline costs, time reliability, value density of cargo, size of cargo supply, size of cargo demand and availability/number of hinterland connections (Panayides, 2006) (Iannone and Thore, 2010) (de Jong and Ben-Akiva, 2007) (Nordas et al., 2006) (Schumacher et al., 2007) (Hausman et al., 2005) (Tavasszy et al., 2009).

2.2.5 Overview of Factors

The port choice factors mentioned by the actors are organized in Table 2-1 according to their position in the transport chain. In the left column the locations in the transport chain are given and in the right column the factors are given. The supply and demand factors indicate the total volume of container trade and the destination of the container flow. The maritime and hinterland transport indicate the transport between origins, destinations and ports. The port characteristics give information on the comparative competitiveness of individual ports. Pipeline costs and value density are related to the cargo characteristics.
### Table 2-1 Port Choice Factors from Literature

<table>
<thead>
<tr>
<th>Location in the Transport Chain</th>
<th>Port Choice Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Foreland</td>
<td>Cargo Supply</td>
</tr>
<tr>
<td>Maritime Transport</td>
<td>Frequency Ship Service</td>
</tr>
<tr>
<td>Port</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Port Costs</td>
</tr>
<tr>
<td></td>
<td>Feeder Connectivity</td>
</tr>
<tr>
<td></td>
<td>Port Efficiency (turn-around-time)</td>
</tr>
<tr>
<td></td>
<td>Port Reliability (customs)</td>
</tr>
<tr>
<td></td>
<td>Geographic Location</td>
</tr>
<tr>
<td></td>
<td>Port Services</td>
</tr>
<tr>
<td></td>
<td>Port Infrastructure (water depth)</td>
</tr>
<tr>
<td>Hinterland Transport</td>
<td>Availability of Hinterland Connections (number of connections, frequency, capacity infrastructure)</td>
</tr>
<tr>
<td>Hinterland</td>
<td>Cargo Demand</td>
</tr>
<tr>
<td>General</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Distance</td>
</tr>
<tr>
<td></td>
<td>Total Costs</td>
</tr>
<tr>
<td></td>
<td>Total Transport Time</td>
</tr>
<tr>
<td></td>
<td>Pipeline Costs</td>
</tr>
<tr>
<td></td>
<td>Time Reliability</td>
</tr>
<tr>
<td></td>
<td>Value Density Cargo</td>
</tr>
</tbody>
</table>

#### 2.3 Selection of Port Choice Factors

In this section a selection of port choice factors is made that is used for this study. For modelling purposes, port choice factors will need to be quantified therefore only port choice factors are included that can be quantified. In some cases that means a factor will not be included in this study in other cases the factor is split into smaller sub-factors. Another consideration is the availability of reliable and comparable data for the factors. An analysis is given per factor; the selected factors for the model are presented in Figure 2-2.

#### 2.3.1 Excluded Factors

The factor ‘Cargo supply’ can mean two things: the supply of container from an Asian port destined for Europe or the return flow of containers from a European port destined for Asia. The first case suggests that ports with a large supply of containers influences route choice as shipping companies will call ports where they can load/unload as many containers as possible. This factor is incorporated in the shipping line schedules which will be used to determine an average roundtrip of a container ship. The second case is not applicable for this study, as only European container imports are taken into account. This means that this factor is not used explicitly as a port choice factor.
The factor ‘port reliability’ constitutes of all reliability aspects concerning the port. According to Zhang (Mueller, 2013d) these can be roughly divided into two categories: time related (punctuality) and the (intact) arrival of the container to its destination. The last category is not a major problem since the introduction of ICT. The punctuality of the arrival of a container is dependent on the shipping lines, terminals, customs, port labour unions and availability of capacity of the infrastructure. For this study no distinction is made between shipping lines and terminals. As terminals and shipping lines operate on a global scale it is assumed that their reliability will be the same for every port, it is however difficult to measure reliability. Finally, most time deviations that occur during sailing or unloading at the ports are absorbed by the container stacks, which act as a buffer. The role of customs is discussed in the factor ‘port services’. The role of labour unions is discussed in ‘port efficiency’. The availability of the infrastructure can be split into two categories; these are port infrastructure and hinterland infrastructure. Hinterland infrastructure will be discussed in the factor ‘availability of hinterland connections’. The port infrastructure is discussed in the factor ‘water depth’.

The factor ‘port efficiency’ is used to identify how efficient a port is in handling containers. This relates to the factors ‘port reliability’ and ‘port services’ but it is more quantitative as it can be measured using input-output models. Studies have been done to calculate maximum efficiencies of ports using frontier and envelopment methods (Liu, 2010). The quality of container handling in a port is mostly dependent on the quality of the terminal. This includes crane capacity and labour productivity. Crane capacity can be lacking at older terminals and labour productivity is heavily influenced by strikes of labour unions. According to Koeman (Mueller, 2013c) port efficiencies for the North Sea ports is comparable, whereas the port efficiency for the other European ports is lower. No public data was found for all the ports included in this study, especially data for the Southern and Eastern European ports was not found. Commercial parties benchmark the different ports, including their efficiencies, however purchasing this data was too expensive for this study. It is therefore assumed that higher or lower port efficiencies are translated into lower and higher port costs.

The factor ‘port services’ includes the services like pilotage, customs, fuel bunkering and others. This factor is difficult to quantify as it includes different types of sub-factors. Pilotage and customs services are mandatory in all ports but reliable data on the service quality per port is not found. It has been suggested that Southern European ports have inefficient custom services compared to Northern European ports but no data is found that compares the customs services per port. As for bunker fuels, low bunker fuel prices could attract more ships. For this study it is assumed that ships will bunker fuel at any of the few ports they call, independent of fuel prices, which offers the lowest price.
The factor ‘geographic location’ is not a distinct quantitative factor. This factor is used to describe different geographic aspects of a port's location. For a gateway port this means the nearness of a port to the end consumers to describe its captive hinterland. For a transhipment port it means its location in respect to the large transport flows. For hub ports it includes both the stated above. The captive hinterland can be described as the area around the port where competition with other ports is minimal due to the relative large distance and thereby costs to the other ports. Besides the size of this captive area also the size of the demand for goods in this area is of importance, the demand density. For example, in highly populated areas the demand for goods per km² will be higher than for low populated areas. In this study, the container demand is computed per region and the costs between the ports and these regions are calculated separately. Therefore, the port choice factor ‘geographic location’ is included in a more direct way and will not be used separately.

The factor ‘time reliability’ is a general factor that can be applied to the total transport chain. According to Davydenko (Mueller, 2013a) it describes the deviation of the actual arrival time and the promised arrival time of a container at a certain location. In order to optimize a supply chain this time deviation should be very small. When this is the case the reliability of a container being on time is very high. However, this time reliability is dependent on many different factors in the complete transport chain and not only the port. Secondly, the time reliability is very specific per transport, per company and information on it is difficult to capture as it is competition sensitive. The factor is therefore not used in this study.

In logistics, ‘pipeline costs’ are an important factor when choosing or designing the supply chain. Pipeline costs include all costs incurred between a supplier or producer and the final consumer. These costs include transport costs, warehousing costs, depreciation costs, time costs and capital costs. The complete supply chain can be seen as moving stock, the capital costs are the interest costs of owning that stock. These capital costs are dependent on the ‘value density of the cargo’, another port choice factor. Value dense cargo, has higher capital costs per container than cargo that has a lower value density. In transport modelling this phenomenon is called ‘value of time’. According to the author, all cargo transported by deep sea container ship is not worth to be transported by air. Its value density is therefore not extremely high. The differences in cargo value can be of influence for hinterland transport but the transport time for hinterland transport is relatively short compared to the maritime transport time. Therefore no distinction is made for cargo type instead an average value for ‘value of time’ is used in this study. Transport costs are part of the pipeline costs but will be quantified separately.

### 2.3.2 Included Factors

For container handling in the ports, the factor ‘port infrastructure’ is of importance. This factor includes quays, cranes, stacking area, water depth, nautical
manoeuvrability and others. The capacity of a port is not taken into account in this study. It is assumed that new terminals are built when the capacity is not sufficient. It should be noted that larger ships also need larger cranes and longer quays; this element is not taken into account as it concerns the capacity of the terminals and not the port. The most important element is the water depth as it is very expensive to deepen a port and the sailing channel to it. The water depth is important as larger ships are deeper.

The factor ‘availability of hinterland connections’ is a combination of different factors and cannot be quantified by itself. It includes the availability of infrastructure for the use of different hinterland modes and the service level of the transport on the infrastructure. For infrastructure this means the availability to use the different modes of road, rail and inland waterway and the capacity of that infrastructure. The existence of infrastructure is easy to measure but the capacity is difficult to determine. This is solved by using different transport times on different hinterland routes, high quality infrastructure and connections will lead to higher service speeds. Speeds and time are easy to quantify so they are applicable in the model. For intermodal services, also the frequency and the number of different services that are offered can easily be quantified.

The general factors ‘total costs’ and ‘total time’ will be used in this study. They are however built up of a maritime, port and hinterland part. It is therefore possible to use them as separate sub-factors. This creates six sub-factors: maritime transport costs, maritime transport time, port costs, port dwell time, hinterland transport costs, and hinterland transport time.

The general factor ‘distance’ is used as a proxy for transport costs and transport time in most studies. It is therefore better to determine the actual transport cost and transport time, especially considering the use of three different hinterland modes which have different cost per kilometre. The factor distance is therefore used as a variable for costs and time but not as an explicit factor.

The maritime factors ‘frequency of ship services’ and ‘number of feeder services’ are included in this study. The ‘demand’ for containers per hinterland region can be expressed in a single value and is therefore suitable for this study.

2.3.3 Selected Port Choice Factors

The port choice factor analysis has led to twelve port choice factors: maritime transport time, maritime transport costs, port handling costs, port dwell time, number of port calls, number feeder services, water depth of port, number of rail services, number of IWT services, hinterland transport cost, hinterland transport time, and demand. In Figure 2-2 a visualization of the chosen port choice factors and their position in the transport chain is presented.

It should be noted that some factors are not included in the model but they could still be an explanation for residual model errors.
2.4 Conclusion Port Choice Factors

A review on port choice literature has provided an elaborate overview of important port choice factors. From this overview, twelve port choice factors are selected: maritime costs, hinterland costs, port costs, maritime transport time, hinterland transport time, port dwell time, number of deep sea port calls, number of short sea services, water depth (part of port infrastructure), number of inland waterway services, number of rail services, and demand for containers.

These factors are primarily chosen due to the fact that they are mentioned by the key port choice decision makers, shippers, forwarders and shipping lines. Secondly, for modelling purposes it is important to use quantitative factors that are applicable for port choice and not specific for terminal choice. Thirdly, publically available and comparable data for these factors is found for all 31 ports.
3 PORT CHOICE MODELLING METHODS

This chapter describes the port choice model which is used as the base for the final port competition model. The conceptual model is discussed and the modelling methods are described.

3.1 Conceptual Choice Model

From the port choice analysis important port choice factors and their place in the transport chain are found, see Figure 2-2. From the transport chain a translation is made to the conceptual model, shown in Figure 3-1. The model shows the paths that can be taken to arrive at hinterland destination $j$ from the origin Asia. In this case ships from Asia sail to a port $i$ from which hinterland transport is taken to hinterland region $j$. The path choices that are taken in every step are in essence the modelling problem, which is a transport modelling problem. The paths connecting the origin with a destination is called a route, this includes a maritime leg, a port and a hinterland leg. For every hinterland mode a different path is given.

The choices made are based on the factors found in the port choice analysis. A route is chosen based on the characteristics of each transport leg and each port. The size of the flow on that route is based on the demand of the final destination. As some ports will not have a direct maritime connection with Asia, feeder ships can sail between ports in Europe. This is visualized with the blue vertical arrow between the ports in Figure 3-1.
3.2 Transport Modelling Approach

From the conceptual model a quantitative model needs to be built. The choice model is typical transport modelling problem, therefore the classic four stage transport model is first discussed. From this method a custom method for this study is derived which is then described.

3.2.1 Four stage model

A widely used transport model is the classic transport model, also known as the four-stage model (Ben-Akiva and Lerman, 1985). The four consecutive stages are trip generation, trip distribution, modal split and trip assignment; see the model in blue in Figure 3-2. First the number of trips is computed, then they are distributed over the area and an Origin Destination matrix is created, then the mode choice is determined and finally the trips are assigned to the infrastructural network.

In this study of freight modelling, TEU-trips are modelled instead of person trips. The number of TEU trips is the number of TEU that are transported between a port and a hinterland destination. The port is taken as the new origin instead of Asia; this is because otherwise there would only be one origin.

Trip generation states how many trips are made. In this case the container demand per hinterland region is the driver of trip generation. The stages trip distribution and modal split are done sequentially. In this study it is assumed that there are no specific factors that influence modal split other than those that influence the trip distribution. It is assumed that route choice is made by the decision makers maximizing their utility, maximization of utility is elaborated upon in section 3.3. The trip distribution and modal split is performed using a multinomial logit function, see section 3.3.2.
The final stage of trip assignment is not applied in this study. It is assumed that there is only one route per mode between a port and a hinterland region. Capacity of the infrastructure network is not taken into account explicitly. The new model setup is shown in green in Figure 3-2.

**Figure 3-2 Classic Transport Model (blue) & Port Choice Transport Model (green)**

### 3.2.2 Modelling Approach

From the altered transport model a more detailed approach is given, Figure 3-3. The step TEU trip generation is formulated as the ‘demand for container per region’; the demand is calculated in section 4.2.

The step TEU distribution and modal split is explained in the remaining steps of the port choice model method, see Figure 3-3. The main part of the distribution and modal split is the multinomial logit distribution function. A utility function is used as input for the MNL function which includes the port choice factors and their weights. The output of the MNL function is the probability of a chosen route, when this is multiplied with the demand of the region connected to that route, the number of containers per route can be found. The last step of the model includes the summation of these route flows in order to calculate the imports per port.

The models steps visualized in white are explained in this chapter, the steps visualized in blue are described in the next chapters. The last step, red, is the considered to be the final output of the model.

**Figure 3-3 Port Choice Model Method**
3.3 Transport Modelling Methods

The conceptual model and modelling approach have been discussed. In this section the modelling methods are discussed.

3.3.1 Utility Theory

Transportation of containers is done when this is useful or profitable for the owner of the container (or the cargo inside the container). When the transport costs are higher than the profitability of the transport, then the transport will not be undertaken. In transport modelling the profitability or usefulness of transport is defined as utility.

According to utility travel choice theory it is assumed that a trip is only made when the utility of reaching the destination is higher than the combined utility of staying at the origin and the disutility (costs) of the transport (Bovy et al., 2006). The theory assumes that decision makers behave rational and maximize their utility. For this study that means that the decision maker will always choose the transport route that gives the most utility. Furthermore it is assumed that the actors have perfect information about the market and that switching between alternatives is costless.

For this study the demand for containers is considered a given fact, so it must have been profitable for the importing actor. It is unknown what the utility of the imported container is therefore the utility of reaching the destination of all the container trips are treated equal and as they are not important they are set to zero (0). The disutility of the container transport is however different per route and should therefore be taken into account. As the actor wants to maximize utility it will want to minimize disutility. The disutility can be written as the negative utility and is assumed to be a linear function of different attributes and is specific for every route. The route includes a combination of port i, hinterland mode m, and hinterland region j. The maritime transport costs and transport time are added to the chosen port i. The utility is written in Equation 1.

\[ U_{ijm} = \alpha_1 X_{1(ijm)} + \cdots + \alpha_n X_{n(ijm)} + \varepsilon_{ijm} \]

Equation 1

\( U_{ijm} \) = utility of the route from port i to hinterland region j using mode m
\( X_{n(ijm)} \) = attribute n for route ijm
\( \alpha_n \) = coefficient n
\( \varepsilon \) = error term

The attributes \( (X_{n(ijm)}) \) included in the utility function are the port choice factors found significant in the statistical analysis of the port choice factors. The attributes used in the utility function are quantified in section 4.1.

For the utility function each attribute has its own corresponding coefficient \((\alpha_n)\), representing the relative importance as perceived by the decision maker. These
coefficients can be found from empirical studies like surveys which are broadly used in the transport modelling of trips made by people. For freight transport models these coefficients are rare to find or are model specific. The coefficients are therefore determined for this study specifically; this is done using statistical analysis in chapter 6.

An error term \((\varepsilon_{ijm})\) is included in the utility function that represents the unobserved utility factors and measurement errors. It is assumed that the disturbances or errors \((\varepsilon_{ijm})\) are independent, identically distributed (IID) and Gumbel distributed. When this is the case the error term can be replaced by a scaling parameter \(\mu\) (Ben-Akiva and Lerman, 1985).

More detailed information on the utility function can be found in Appendix A.

### 3.3.2 Multinominal Logit Function

The Multinominal Logit function (MNL) is used for the trip distribution for this study. The multinomial logit function gives the probability that a certain route is chosen given its utility. The S-shaped curve of the MNL, see Figure 3-4, seems to represent choice behaviour better than for instance an all-or-nothing assignment. Moreover, MNL is the most popular, widely applied and practical discrete choice model (Ortuzar and Willumsen, 2011). More information can be found in Appendix A.

The MNL function can be written as:

\[
P_{ijm} = \frac{e^{u_{ijm}}}{\sum_i \sum_m e^{u_{ijm}}} \quad \text{Equation 2}
\]

\(P_{ijm}\) = probability that port i is used for transport to hinterland region j using mode m
\(U_{ijm}\) = utility for the route from port i to hinterland region j using mode m

When the MNL function is applied for two routes, Route 1 and Route 2 with their corresponding utilities, \(U_1\) and \(U_2\), the following graph can be made, see Figure 3-4. The probability \((P_2)\) of choosing route 2 with utility \(U_2\) depends on the utilities of both route 1 and route 2, see Equation 2. If both utilities are equal \((\Delta U = U_2 - U_1 = 0)\) the probability \((P_2)\) of route 2 is 50%.

If the utility of route 2 is larger than the utility of route 1 \((U_2 > U_1)\) than \((\Delta U = U_2 - U_1 > 0)\) and then the probability of choosing that route is larger than 50%. If the utility of route 2 is smaller than the utility of route 1 \((U_2 < U_1)\) than \((\Delta U = U_2 - U_1 < 0)\) then the probability of choosing that route is smaller than 50%.

In this case route 1 can be seen as the basic route, as the probability of route 2 is dependent on the utility of route 2 and the utility of route 1. The utility of route 1 \((U_1)\) can therefore also be formulated as \(U_{\text{basic}}\).
The absolute value of the utility of route 2 ($U_2$) is not of importance for determining the probability of choosing that route, but the difference between the utility of route 2 and the basic route ($\Delta U=U_2-U_{\text{basic}}$) is.

This principal is used in the statistical analysis in chapter 6, further elaboration can be found there.

![Figure 3-4 Multinomial Logit Function](image)

### 3.3.3 Prediction Model

The final step of the model is to determine the total imports per port. This is done using the prediction model. Its goal is to find the total number of TEU imported from Asia per port, given the container demand and distribution of flows based on the utility of the different routes.

The total container import per port ($T_{I_i}$) is found by multiplying the market share of a port ($P_{ijm}$) on a specific route with the demand of a hinterland region ($D_j$), see Equation 3. The demand of the hinterland regions is elaborated in section 4.2.2. $P_{ijm}$ is found using the multinomial logit function, see Equation 2. In this study three hinterland modes and 231 hinterland regions are studied.

$$T_{I_i} = \sum_{m=1}^{3} \sum_{j=1}^{231} (P_{ijm} \times D_j) \quad \text{Equation 3}$$

*TI<sub>i</sub>* = total import for port *i*

*P<sub>ijm</sub>* = probability of choosing route *ijm*

*D<sub>j</sub>* = demand for containers of region *j*

*m* = mode road, rail and IWT
3.4 Conclusion Transport Modelling

In this study port competitiveness is determined by modelling port choice. Port choice is part of route choice. For route choice, the widely applied multinomial logit discrete choice model is used. This method determines the probability of route choice based on the utility of the route compared to the utility of alternative routes. The probability of a route is interpreted as the market share of that route.

In transport modelling the profitability or usefulness of transport is defined as utility. Utility is defined as a linear function of the port choice factors with corresponding weights and is based on the micro-economic utility theory. This theory states that an individual will always choose the option with the highest utility.
4 DATA COLLECTION AND ANALYSIS

The selected port choice factors have been presented in chapter 0, and the modelling methods have been described in chapter 0. In this chapter the port choice factors are quantified, so they can be used as input for the utility function. Moreover, data on container flows and current port imports is gathered and analysed. Data collection methods and computations used in this chapter are described in more detail in the corresponding appendices.

4.1 Port Choice Factors

In this section data for the selected port choice factors is gathered and analysed. For most factors no direct useable data can be found, therefore the quantification of those factors is done by calculations made by the author.

4.1.1 Maritime Transport Cost

The maritime transport cost consists of the sailing costs from Asia to Europe incurred by the carriers. These costs are covered by the freight rates of the carriers; however these freight rates are very volatile, ranging between €300 and €1,500 in the year 2012 only, see Appendix B. This is mainly due to the changes in supply and demand and has little to do with transport costs incurred by the carriers. Average freight rates from Asia to Europe are benchmarked; these are however not specified per port. For the model a more stable value for maritime costs is needed, which is also specific per port or at least per coastline. Therefore a maritime costs structure has been made which is much more stable and useful for the intended use.

The maritime transport costs are the sailing costs from Asia to a European port and can be split into fixed cost and variable cost. The fixed costs include: capital costs, maintenance cost, manning cost, administration and insurance costs, and overhead.

The variable costs are predominantly the fuel costs but also include the Suez toll costs and usage of the container box. The fuel costs depend on fuel consumption and fuel price. Fuel consumption depends on ship size, sailing speed and logically sailing distance (Rodrigue et al., 2009). The effect of speed on fuel consumption is increasing exponential (Veldman, 2011), whereas increasing ship size has an exponential
decreasing effect on fuel consumption (Veldman, 2011). The effects of speed and ship size on fuel consumption have been derived in this study, detailed information on this derivation and on the fixed and variable costs can be found in Appendix B.

When the costs are split into fixed and variable cost for a vessel of 8,000 TEU sailing at 17 knots with an oil price of $100 and an utilisation degree of 100%, than these would be: variable cost of €0.01 per TEU per nautical mile and fixed cost of €3.52 per TEU per day, see Appendix B.

The maritime cost per TEU from Asia to the North Sea is, depending on service speed and ship size, shown in Figure 4-1. The costs are around €300 per TEU per trip, this is consistent with literature (Francesetti, 2005). Larger ships have smaller fixed and variable costs per TEU than smaller ships have, these economies of scale are the drivers for the ever growing ships size.

Besides deep sea maritime transport also short sea and feeder transport falls in the category of maritime transport. Feeder transport is used between the larger ports with a hub function and the smaller ports. Container transport to Tallinn for example comprises of deep sea transport to Hamburg and then feeder transport to Tallinn. For feeder transport a fixed cost of €14.72 per TEU per day and a variable cost of €0.08 per TEU per nautical mile are found (TML, 2010). Detailed information can be found in Appendix B.

An overview of the maritime cost influencing variables is presented in Table 4-1.
### Table 4-1 Overview of Maritime Cost factors

<table>
<thead>
<tr>
<th></th>
<th>North Sea</th>
<th>Mediterranean</th>
<th>Short Sea</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maritime Distance (nm)</td>
<td>11.700</td>
<td>9.800</td>
<td>500</td>
</tr>
<tr>
<td>Sailing speed (knots)</td>
<td>17</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Number of port calls</td>
<td>7</td>
<td>7</td>
<td>-</td>
</tr>
<tr>
<td>Maritime sailing time (days)</td>
<td>28</td>
<td>24</td>
<td>2.2</td>
</tr>
<tr>
<td>Maritime transport time (days)</td>
<td>35</td>
<td>31</td>
<td>2.2</td>
</tr>
<tr>
<td>Average ship size (TEU)</td>
<td>8.500</td>
<td>6.600</td>
<td>500</td>
</tr>
<tr>
<td>Cost (€/TEU/nm)</td>
<td>0.009</td>
<td>0.011</td>
<td>0.08</td>
</tr>
<tr>
<td>Cost (€/TEU/day)</td>
<td>6.30</td>
<td>6.80</td>
<td>14.64</td>
</tr>
<tr>
<td>Total Maritime Costs (€/TEU)</td>
<td>331</td>
<td>318</td>
<td>72</td>
</tr>
</tbody>
</table>

#### 4.1.2 Maritime Transport Time

The maritime transport time is defined as half of a roundtrip time of a scheduled containership service. Current roundtrip schedule times are known. Factors that influence these times are mainly sailing speed, sailing distance and the number of port calls.

As schedules are known, some general statements can be given. There are roughly two direct service routes from Asia, to the North Sea ports and from Asia to the Mediterranean Sea ports. These schedules have some differences and some similarities. Differences are sailing distance and sailing time, similarities are frequency, speed and number of port calls.

Six different design service loops have been made to model maritime transport time, see Figure 4-2. These six loops correspond to the six coastlines that have been identified: the Baltic Sea, North Sea, Atlantic, Mediterranean Sea, Adriatic Sea and the Black Sea combined with the Aegean Sea.

Per loop, schedule characteristics are given, this means that all ports on the same coastline will have the same transport time. Determining port specific maritime transport times has proved to be impossible as different carrier schedules have a different port call order. Detailed information on the schedules and maritime transport time per coastline can be found in Appendix C.
4.1.3 Number of Port Calls

The frequency of ships departing and arriving at ports is determined in the sailing schedules. In the researched schedules (Drewry, 2011), a frequency is found of one departure per week per port per schedule. This results in an inter-arrival time of 7 days. There is however a difference in the number of services that call a certain port. From the researched schedules the number of port calls has been filtered and are visualized in Figure 4-3.

It can be seen that certain ports have much more weekly calls than others. Considering that many ship schedules look alike (have port calls in Singapore, Hong Kong and Shanghai) than the number of port calls per week could be seen as the relative frequency.
4.1.4 Port Handling Cost

For the port handling cost the terminal handling charges (THC), International Shipping and Port Facility Security Code (ISPS) and documentation fee are considered (B/L). The port dues are not taken into account as they differ per ship size, number of TEU loaded and unloaded.

The terminal handling charges differ per port, ranging from €88 per container for Klaipeda to €204 for Hamburg (OOCL, 2009) (DAL, 2012, Maersk, 2009) (CMACGM, 2012) (APL, 2013) (Hapag-Lloyd, 2010). The values are an average of the THC charged by different carriers and terminals between 2009 and 2013. The average THC for all ports considered is €148. The terminal handling charges are presented in Appendix D.


From this the average port handling cost is assumed to be around €198 per container, which is €124 per TEU with a standard deviation of €19. In this study the individual port costs are used, these can be found in Appendix D.

4.1.5 Port Dwell Time

The port handling time is found to be around 1 day per ship. This has been found by looking at ship schedules (Maersk, 2013b) and literature (Notteboom and Vernimmen, 2009). However the port time for a container is longer and is referred to as dwell time. Dwell time is the time a container sits in the stack on the terminal. Dwell times are found between 2 and 7 days for a container terminal (OECD, 2010) (Texan, 2009) (Merckx, 2005) (UNCTAD, 2012) (Auckland, 2013). With an average of 6.5 days for ports in the Hamburg-le Havre range, for transhipment dwell times are
Container Port Development

found to be around 3 days (Kemme, 2013). APMT has a target of 6 days dwell time for import and no more than 7 days of storage for export (APMT, 2013). MSC charges storage charges when a container is not picked up within 7 days (MSC, 2013).

Considering the used literature an average dwell time of 6 days is used for all imports per port and a dwell time of 3 days is used for transhipment.

4.1.6 Water Depth

Water depth is found to be one of the most important infrastructural elements because it is very expensive to deepen the port and the entry to the port. Secondly it has an impact on the size of ship that can enter a port. Larger ships have a larger water draft and can only enter deeper sea ports.

The maximum water depth for all ports is found (Containerisation-International, 2011) and presented in Appendix E. Secondly a function for the water draft of ships dependent on their capacity is made. This makes it possible to see what ships sizes are able to berth in a port. Currently the largest container vessels have a maximum draft of 16 meters. About half of the ports in this study have that water depth.

4.1.7 Number of Feeder Services

The number of short sea services per port is an indicator of feeder connectivity. These calls are for maritime transport and should not be confused with barge transport which is considered hinterland transport. The feeder transport is maritime transport and facilitates the deep sea transport in gaining enough volumes for a stop at a hub port. From intermodal links (Ecorys, 2013) feeder services and frequencies are known for the different ports. Detailed information is found in Annex F.

4.1.8 Number of Intermodal Services

The number of intermodal services is split into rail and inland waterway services. Per port the number of services and frequencies has been derived from Intermodal links (Ecorys, 2013). This (online) database has up to 70% of all rail, barge and feeder services within Europe. Services directly departing from the ports and, using no more than one transhipment, are taken into account. The number of services and frequencies per port can be found in Appendix G.

4.1.9 Hinterland Transport Cost

Hinterland transport cost is defined as the cost of transporting a TEU from a port to a hinterland region. It is comprised of fixed costs and variable costs and differentiated for different modes. The modes that are included are truck, train and barge. They use the road, rail and inland waterway as infrastructure. For the fixed costs, transport time is of importance, for variable cost distance is of importance. When modes other than truck are used, also container handling costs at an inland terminal and trucking cost to the final destination are added.
The distances and transport times between all ports and all hinterland regions have been extracted from the ETISplus database (ETISplus-Consortium, 2013). This has been done for all modes, however not all regions have access to an inland waterway, for those regions the option of a barge is omitted. Detailed information on distances and travel times can be found in Appendix H.

The unit costs are given in Table 4-2. The costs per mode where derived from literature (NEA, 2009) (De Jong et al., 2004). The variable costs assume an oil price of $100 per barrel. Besides vehicle costs, also toll charges are hinterland cost. Toll costs have been calculated using a software tool (PTV, 2013) per OD pair. The toll costs vary a lot and are found to be between €0 and €0.40 per kilometre. Toll costs are especially high in the Alps and in France. Belgium and the Netherlands do not have these toll charges. For the train rail usage costs are included (ProRail, 2013). The container handling costs at an inland terminal are set to €31.25 per container transhipment (measured in TEU) (Wiegmans and Konings, 2011) (Mueller, 2013b). More detailed information on the cost built up can be found in Appendix H.

<table>
<thead>
<tr>
<th>Hinterland Modes Available</th>
</tr>
</thead>
</table>
| The mode of transport that is used to transport containers from a port to a hinterland region is limited to the available infrastructure and services. A port or region that is not located near an inland waterway will not be able to transport goods using a barge. This limits the mode choice down to road and rail. It is found that all regions have access to a rail and road connection. In practice rail will not always be used for freight transport or cannot be used in the future as capacity is lacking. Reliable information on capacity problems or infrastructural problems for rail was not found for the complete scope area of this study. For this study it is therefore assumed that all rail connections can be used and that there is no capacity problem. Infrastructural quality is measured by transport speed. The infrastructure availability is known from ETISplus (ETISplus-Consortium, 2013).

4.1.10 Hinterland Transport Time

Hinterland transport time is used as a separate port choice factor but is also used as input for the fixed cost for hinterland transport time. The transport time depends on the distance but also on the quality of the infrastructure; the travelling speed on a highway is larger than on a provincial road. The ETISplus database (ETISplus-Consortium, 2013) gives transport times, next to transport distance.
The transport times are based on the maximum allowable speed per link but also include waiting times for locks for instance. From the transport times and distances, average speeds are computed. From the average speeds it is observed that for truck also the downtime (sleeping) is included. The speeds therefore vary per travel distance and per origin destination pair which is very interesting.

The transport times, and therefore the average speeds, found from the Etisplus database cannot be applied directly as they do not seem to be accurate in all cases, especially for rail transport. The average transport speeds found for rail transport are much higher than indicated by literature (NEA, 2009) (RailwayPro, 2014).

Therefore the average speeds per mode are changed based on literature, see Appendix I. The average speed for truck is set to 55 km/h, for rail to 35 km/h and for IWT to 8 km/h. The structure of the ETIS database is however kept, as the database includes difference in infrastructure quality per route. This is possible as the all transport times have been altered such that the average travel speeds is different, it does not mean that all the travel speeds are the same.

The handling time at an inland terminal is assumed to be the same everywhere and is set to 24 hours.

4.2 Container Demand

An important port choice factor is container demand. If the hinterland demand near a port is high, the port is more likely to be called by a deep sea ship. The demand is also used as a model input variable; it is therefore an important factor.

The container demand per hinterland region is unknown so it is computed using the total supply of container from Asia and multiplying it by the portion of Gross Regional Product (GRP) and GRP/capita, see Figure 4-4. First, container supply from Asia is calculated and secondly the regional portion of that supply is determined.

\[
\text{Demand for Containers per region} = \text{Total Supply of Containers from Asia} \times \left(\frac{\text{GRP per region}}{\text{Total GRP}}\right) \times \left(\frac{\text{GRP/capita per region}}{\text{Total GRP/capita}}\right)
\]

\[\text{Figure 4-4 Modelling Container Demand}\]

4.2.1 Supply of Containers from Asia

Detailed information on OD patterns of containers on a global scale is not available. Trade patterns and size are known but these are registered either in monetary value...
or tonnage. This includes all trade, so also liquid and dry bulk. Therefore the supply side for container transport needs to be constructed.

For this study the specific origin is not needed, as long as the cargo passes the Suez channel it is sufficient. It is considered that all containerships with a destination in Europe sailing Asia will sail through the Suez channel. Aggregated global container flows have been published by different organizations (Drewry, 2011) (UNCTAD, 2011) (Containerisation-International, 2011) (ESPO, 2013) (EUROSTAT, 2013) (World-Shipping-Council, 2013).

The data found is represented using different definitions, meaning the data cannot be directly compared. Therefore a pragmatic data adaption is used filtering the data towards the information intended. All data used is from the base year 2010. The data is filtered such that the number of full containers imported by the scope area and transported through the Suez channel is known. The process of filtering is elaborated upon in Appendix J.

For the year 2010 an average number of 12.5 million full TEU have passed the Suez channel on their way to the scope area, with a standard deviation of 1.35 million TEU. In this study the value of 12.5 million TEU will be used as the number of TEU reaching the scope area from Asia.

4.2.2 Demand for Containers in Europe

The hinterland is divided into 231 NUTS-2 regions which will function as the destination regions. The import per region is unknown so reconstruction of the demand is necessary. This is done by approximating the relative demand per region compared to other regions. The total supply is known, so only the relative demand per region needs to be known.

Explanatory factors for trade have been identified and quantified, the most import being GDP of the trading countries, the GDP per capita of the trading countries and distance between them as a proxy for cost and time (Hausman et al., 2005) (Groot et al., 2004). These factors combined gave an R² of 0.65 and 0.69.

For this study the trade partner is Asia, considering no particular country but the whole region. The trade created by the GDP and GDP per capita of the exporting country will not be needed, as the supply is already calculated in section 4.2.1. The importance of the variable distance as a proxy for cost and time is the main subject of this study and will therefore be researched separately. This leaves the variables GDP and GDP per capita of the importing country as the most important variables for demand of import. GDP and GDP per capita data is found from EUROSTAT (2013), ETISplus-Consortium (2013) and the CIA fact book (CIA, 2013).

The elasticity’s for GDP and GDP per capita on trade have been found in literature and are presented in Table 4-3. These factors show the elasticity per factor, meaning that if the GDP for an importing region grows with 1% the average import for this
region will grow with 0.89%. The elasticity’s explain the change in trade but not the actual trade. They do tell us that GDP and GDP per capita influence trade positively. From the average elasticity’s an average weight factor is derived. In this study the weighted GDP and GDP per capita data are used to determine the relative demand for containers per region.

<table>
<thead>
<tr>
<th>Table 4-3 Trade Demand Coefficients</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Groot et al., 2004)</td>
</tr>
<tr>
<td>Log of Importers GDP</td>
</tr>
<tr>
<td>Log of Importers GDP per Capita</td>
</tr>
</tbody>
</table>

4.3 Port Imports

The port imports are used in the simulation of the Origin Destination matrix in chapter 5. In this section the port imports and modal splits are determined.

4.3.1 Port Imports 2010

The total import of the number of TEU is known per port from literature (Containerisation-International, 2011) (ESPO, 2013) (Drewry, 2011). The total number of TEU that comes from Asia and that goes through these ports is calculated in section 4.2.2. These values do not correspond as the port imports also include imports from other parts of the world. Therefore some computations are made.

For the ports different transhipment percentages are taken into account. There are three types of ports acknowledged here, transhipment ports, hub ports and gateway ports. Transhipment ports have a lot of transhipment (80%) like the port of Algeciras. Hub ports are the larger ports in a region with an average transhipment percentage (31%) like Rotterdam. Gateway ports are the smaller ports that are feedered from transhipment- and hub ports. They have a very low transhipment percentage (10%) like Riga. For empty containers, an average value of 21% is used.

Considering the percentage of transhipment, empty containers and containers coming only from Asia, the actual import per port is calculated. These values are found in Appendix K. When the imports are multiplied with the modal split the number of containers per mode can be found.

4.3.2 Port Modal Split

The modal splits are important for the determination of the attractiveness of the modes, infrastructural availability, and are used in the model when assigning containers to modes. The modal split data was found from different port reports (Barcelona, 2011) (Bremerports, 2011) (Hamburg, 2012) (MDS-Transmodal-Limited, 2011) (PoR, 2013) (Wolters, 2011) (Bay, 2011) (Gussmagg, 2007) (Wachter and Antwerp, 2011, Notteboom, 2010). The data includes the modal split for all the
containers from and to the hinterland. The data makes no difference for imports or for the origins of the containers.

Where data was missing an educated guess was made by considering train and barge services from intermodal links (Ecorys, 2013) and by looking at the presence cranes for the handling of containers on train per port. When information was still lacking a comparison with other ports in the region was made and experts were asked for their guess on the modal split per port. This has resulted in the modal split for all considered ports. The information is found in Appendix L.

4.4 Conclusions Data Collection and Analysis

This chapter has presented the data collection and analysis for the selected port choice factors. For all the selected factors, data was found from literature or the data was built by the author using data from literature. Especially for the cost related factors, which are a function of various variables, a cost structure is built by the author. For maritime costs, a cost function is built with sailing speed, ship size and sailing distance as variables. Therefore the maritime costs can be calculated for any combination of the aforementioned variables. The costs for inland waterway transport also take into account that on some waterways, only small vessel can sail, and that therefore the costs per container are higher than for routes where larger vessel can sail.

The data used for the number of short sea services, rail services and inland waterway services, is unique for this study. The data is retrieved from the intermodal links database, which was introduced in 2013. Therefore comparable data for transport services for all ports and hinterland regions is used in this study.

The demand for containers is based on the total supply of containers from Asia. This supply of containers was not known for the scope area. In this study, various sources are used to compute this supply. The pragmatic data adaption for filtering all the different data is found to be a useful method when only aggregated data is available.
5 CONSTRUCTION OF BASE OD MATRIX

Before the utility function can be used as input for the trip distribution and modal split, the coefficients for the different attributes need to be calculated. This is done using a regression analysis with the actual data on Origin Destination (OD) flows. However, for this study no data was found available for all Origin (port) Destination (hinterland region) pairs for the scope area. Therefore the OD patterns and flows are simulated. This chapter discusses the construction of the base OD matrix used for the regression analysis.

5.1 Origin Destination Simulation Approach

In order to determine the coefficients of the utility function, the model needs to be compared to actual Origin Destination data. Publicly available Origin Destination data for containers and mode of transport is non-existent for the whole of Europe.

5.1.1 Other studies

In the US, OD data is gathered using Bill of Lading information which can then be used for analytical research (Anderson et al., 2009). For Spain customs data on containerized OD flows has been used (Veldman et al., 2011), and for the direct hinterland of Rotterdam and Antwerp container flows have been found for the 1997 and 2001 (Veldman and Buckmann, 2003).

However, for the whole of Europe this is not the case, so larger European studies therefore use trade data from EU Comext and UN Comtrade databases to determine OD patterns (Tavasszy et al., 2011) (Zondag et al., 2010) (Burgess et al., 2008). This data is given in tons and values per pair of countries. From this data, the number of containers is computed and is then distributed over different hinterland regions using simulation algorithms.

This study has a different approach, instead of looking at trade data the actual number of containers shipped from Asia to Europe is taken as base. The number of containers transported from Asia to Europe has been calculated in section 4.2.1 and the container imports and port modal splits have been studied in section 4.3. The demand for the different hinterland regions has been computed in section 4.2.2. This
gives a firm basis for the actual Origin Destination flows. However, the distribution of the container flows from the European ports of entrance towards their hinterland destination is not known, these flows should therefore be simulated. This is done using the doubly constrained distribution model which could also be explained as a mode routing choice model. In transport modelling this method is used for passenger transport and is derived from the gravity model (Bovy et al., 2006).

5.1.2 Doubly Constrained Distribution Model

The Origin Destination (OD) matrix is built using a doubly constrained simultaneous distribution/modal split model. The construction of the OD matrix is done in two steps. A basic OD matrix is simulated using a distribution function. The basic matrix is then balanced using port import and modal split data (production) and demand data (attraction) to form the final simulated OD matrix, in this study called the base OD matrix.

The model is double constrained as production and attraction of container is known. This data is used as the constraints of the matrix. The distribution of the container flows is simulated using a distribution also known as a deterrence function which uses the input variables: total costs, total time, value of time and scaling parameter β. The variables ‘total cost’ and ‘total time’ have been found per route from data collected in chapter 4. The variables ‘value of time’ and ‘β’ are found by calibration. After the calibration, the simulated OD matrix is balanced. Using balancing factors, the OD flows in the matrix are equalized to the constraints of the matrix. This is done in an iterative process. The OD matrix construction method is visualized in Figure 5-1.

Mathematical Explanation
The doubly constrained distribution method can also be explained mathematical, see Equation 4 (Bovy et al., 2006)
The number of TEU transported between port i and region j \((T_{ijm})\) is dependent on the total attraction of region j \((A_j)\), production of port i \((P_{im})\) and the accessibility between the two \((F_{ijm})\).

\[
T_{ijm} = a_{im} \times b_j \times A_j \times P_{im} \times F_{ijm}
\]

Equation 4

For which holds

\[
\sum_j T_{ijm} = P_{im} \\
\sum_{im} T_{ijm} = A_j
\]

\(T_{ijm}\) = the number of TEU transported between port i and region j using mode m  
\(A_j\) = number of TEU arriving at region j  
\(P_{im}\) = number of TEU departing port i using mode m  
\(F_{ijm}\) = the accessibility of j from i with mode m  
\(\alpha_{im}\) and \(b_j\) = balancing parameters

Balancing parameters \((\alpha_{im}\) and \(b_j)\) are the balancing factors for the trip constraints, see Equation 5. The balancing parameters are formulated in an implicit manner, determining them is done using an iterative procedure. For the first iteration the starting value is given in Equation 6. The balancing parameters are discussed further in section 0.

\[
a_{im} = \frac{1}{\sum_j (A_j \times b_j \times F_{ijm})} \\
b_j = \frac{1}{\sum_{im} (P_{im} \times \alpha_{im} \times F_{ijm})}
\]

Equation 5

Equation 6

Starting first iteration with:

\[
a_{im} = \frac{1}{P_{im} \times F_{ijm}}
\]

The number of departing TEU per port and mode \((P_{im})\), and the number of arriving TEU per region \((A_j)\) are known. The accessibility of a route \((F_{ijm})\) is found using a deterrence function also known as a distribution function.

5.2 Distribution Function

The accessibility of a route \((F_{ijm})\) is found using a deterrence function also known as a distribution function. The distribution function represents the relative willingness to make a trip as a function of the generalized travel costs (Bovy et al., 2006).

For this study an exponential distribution/deterrence function is used, see Equation 7. The input for the exponential function is the generalized costs. A scaling parameter \(\beta\)
is added to the function which indicates how sensitive the accessibility is to a change in generalized cost.

\[ F_{ijm} = e^{\beta \cdot GC_{ijm}} \]  \hspace{1cm} \textit{Equation 7}

\( GC \) = Generalized Cost  
\( \beta \) = scaling parameter

### 5.2.1 Generalized Cost

The distribution function uses generalized cost as its input variable. The method of generalised cost is chosen as it is commonly used in transport modelling (Bovy et al., 2006). Generalized cost incorporates monetary costs as well as time costs. The unit of time used is hours whereas the monetary cost used is euro. In order to add these costs the time spent on a route is multiplied by a coefficient called value of time (\( \text{vot} \)), see Equation 8.

\[ GC_{ijm} = TC_{ijm} + \text{vot} \times TT_{ijm} \]  \hspace{1cm} \textit{Equation 8}

\( GC \) = Generalized Cost  
\( \text{Vot} \) = value of time  
\( TC_{ijm} \) = Total transport Cost from Asia via port i to region j using mode m  
\( TT_{ijm} \) = Total transport Time from Asia via port i to region j using mode m

### 5.2.2 Value of Time

The value of time is a factor that links the time attribute to the monetary attribute. It gives the relation between time and money and how they can be interchanged. The value of time shows how much a client or transporter is willing to pay to shorten the travel time, or is willing to wait to get the transported good cheaper.

Popular methods to find the value of ‘value of time’ are stated preference methods and modal split models. In literature, many value of time values for freight transport are found. Roughly there are two types of value of time; one considering all logistics and all transport related cost per time unit and one only considering the logistics costs of the cargo per time unit.

For this study the latter ‘\( \text{vot} \)’ is used as the transport costs are known and used in the model already. The ‘\( \text{vot} \)’ should therefore reflect the additional value that is incurred when transport time is decreased; these values are sometimes called ‘value of reliability’. The value of time factor consists for the largest part of stock costs, capital costs and the depreciation costs of the cargo (Davydenko et al., 2012). Most of these ‘\( \text{vot} \)’s’ are differentiated by product type or cargo type. This is due to the different values of these different cargo types and their related depreciation costs.

Other factors include risk, flexibility and production loss (De Jong et al., 2004). This means that high value, market trend sensitive or perishable products generally have a higher value of time compared to bulk cargo. Products transported by containers
from Asia are mostly consumer goods, values of time from different studies have been found, see Table 5-1.

The values found lie between €0.32 and €10.50 per TEU per hour, depending on the cargo type and mode used. As the values of the different studies differ quite a lot, this study will look at a range of values that lie between €0 and €5 per TEU/hour. The lower values have been chosen as the value of time of maritime transport is considered lower than that of land transport.

<table>
<thead>
<tr>
<th>Author</th>
<th>Value of Time (€/TEU/hour (2010))</th>
</tr>
</thead>
<tbody>
<tr>
<td>(De Jong et al., 2004)</td>
<td>2.85</td>
</tr>
<tr>
<td>(Significance et al., 2012)</td>
<td>4.00</td>
</tr>
<tr>
<td>(Tavasszy et al., 2011)</td>
<td>4.00</td>
</tr>
<tr>
<td>(Davydenko et al., 2012)</td>
<td>1.80 - 10.50</td>
</tr>
<tr>
<td>(RETRACK, 2012)</td>
<td>0.50 - 4.00</td>
</tr>
<tr>
<td>(Janic, 2007)</td>
<td>0.41</td>
</tr>
<tr>
<td>(Dekker, 2005)</td>
<td>0.32</td>
</tr>
<tr>
<td>(TML, 2010)</td>
<td>0.86</td>
</tr>
</tbody>
</table>

5.2.3 Beta

The scaling factor \( \beta \) (beta) that is used in the generalised cost function describes the slope of the curve of the logit function. When a very large value (\( \beta = \infty \)) is used then an all-or-nothing assignment is simulated, when a very low value (\( \beta = 0 \)) is used then all alternatives are weighted the same and costs are not of importance anymore. A value for \( \beta \) (\( 0 < \beta < \infty \)) should be found and used that characterizes and calibrates the model best.

The scaling parameter is model specific and is used for calibration of the model. The parameter can be estimated using Hyman’s method (Ortuzar and Willumsen, 2011). For this method the weighted average trip distance must be known. For passenger- or urban transport this is usually known but for container transport no general value was found. Secondly, transport distances vary enormously as some regions are located relatively close to a port, whereas others are located far away from any port. Thirdly, the average distances will differ per mode. Hyman’s method was tested using an estimated average transport distance but this was unsuccessful as \( \beta \) rushed to 0 in only 2 iteration steps.

An indication of \( \beta \) is made based on available freight modelling literature. For the world container model of TNO (Tavasszy et al., 2011) a \( \beta \) of 0.0045 is used. In the study of Ecorys (Macharis et al., 2004) values between 0.0005 and 0.025 are used. According to (Veldman and Buckmann, 2003) values between 0.0016 and 0.0045 were applicable. Values mentioned in (Jin, 2010) are 0.0032 and 0.0045 with a maximum of 0.015.
Although these values cannot be ‘borrowed’, they do give an idea of the order of the value. From the literature it is assumed that $\beta$ will be between 0.0005 and 0.015. The parameter value used in this study is estimated using a calibration method.

5.3 Calibration of the Distribution Function

The distribution function has two unknown variables: value of time and scaling parameter $\beta$. The ranges of beta ($\beta$) and value of time ($\text{vot}$) are known, but to find the best fit the minimal difference between the modelled port throughput and the actual throughput must be found. The optimization process tries to find the best fit between the simulated OD matrix and the known sides (constraints) of the matrix. The constraints are the actual port import per mode (production) and the modelled attraction per hinterland region (attraction).

Simulations are done for different combinations of $\text{vot}$ and $\beta$. These simulations are tested using five different performance indicators.

5.3.1 Performance Indicators

The five performance indicators are: $R^2$ value, least square error, weighted least square error, absolute error and absolute mode error. These indicators are calculated by comparing the port imports per mode calculated found in section 4.3 with the imports calculated using the distribution function.

The most common optimization method is least square error or ordinary least square for linear regressions. In this method the differences between the actual and the modelled throughput is squared and added. By minimizing the total summation the smallest error between the modelled and the actual value is found.

Because not all ports are of similar size, the difference between the modelled and the actual throughput can vary a lot. Therefore the same analysis is done with a weighted least square method. Weights are given to the different observation in order to make it easier to compare the larger ports with the smaller ports. The weights given are the inverse of the observed port imports.

A third indicator is the $R^2$ value which lies between 0 and 1, 0 meaning no model fit and 1 meaning perfect model fit. The $R^2$ value tells us how much of the variance in model can be explained by the function, it is found in a similar way as the least square error.

The fourth indicator is absolute difference which measures the total number of TEU that are misallocated; it is the sum of differences. This indicator is similar with the least square indicator but the differences are not squared so the influence of the larger ports is smaller.

Besides, the best fit per port, also the mode choice is analysed. An optimization has therefore been done per mode, minimizing the difference between the modelled
number of TEU per mode and the actual number of TEU using a specific mode. It should not be a leading indicator but can be used when comparing models and their performance on modal split.

The performance indicators least square error, weighted least square and $R^2$, are considered to be the most important as they are most commonly used.

5.3.2 Simulation Results

The simulation results for the different performance indicators are presented in this section.

Least Square Error

For different value of time values and different beta’s the least square error is found, Figure 5-2. The error increases drastically for a value of time higher than 3€. Secondly the error increases much quicker for higher values of beta. This means a low value for beta is more stable but also creates less distinction in route choice. This corresponds with the theory for beta mentioned in section 5.2.3 which states that a low beta value will decrease the impact of generalized cost and therefore the differences between routes. The smallest error found was for a value of time of €1.30 and a beta of -0.0074.

![Least Square Error](image)

$R^2$

The performance of the $R^2$ value is given in Figure 5-3. It shows that the maximum $R^2$ value is found for a value of time of €1.10 and decreases steadily for higher values. The difference between the different beta values is small. This means that the value of the beta is not of high importance for the explanation of the variance.
Results overview

The results of the five different analyses are presented in Table 5-2. The graphs of the other three indicators can be found in Appendix N.

<table>
<thead>
<tr>
<th>Type of Analysis</th>
<th>Value of Time (€/TEU/hour)</th>
<th>β</th>
<th>Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum R²</td>
<td>1.10</td>
<td>0.0064</td>
<td>0.64</td>
</tr>
<tr>
<td>Least Square Error</td>
<td>1.30</td>
<td>0.0074</td>
<td>2.2E+12</td>
</tr>
<tr>
<td>Weighted Least Square Error</td>
<td>3.00</td>
<td>0.014</td>
<td>18.149.587</td>
</tr>
<tr>
<td>Minimal Absolute Error</td>
<td>1.25</td>
<td>0.009</td>
<td>7.605.533</td>
</tr>
<tr>
<td>Minimal Absolute Modes Error</td>
<td>2.60</td>
<td>0.0099</td>
<td>65.408</td>
</tr>
</tbody>
</table>

5.3.3 Interpretation of Results

From the results table (Table 5-2) it can be seen that β lies between 0.0064 and 0.014, the value of time lies between 1.10 and 3.0 €/TEU/hour. These values are within the range as mentioned in section 5.2.2 and 5.2.3. The errors found seem quite large; this is probably due to assumptions in the data.

The maximization of R² and the least square error have similar values for vot and beta. This has to do with the fact that they are computed in a similar way. The absolute error has similar values for R² and beta.

The weighted least square error and the absolute mode error have the largest values. For higher value of time values, road transport becomes more interesting as it generally has a shorter transport time. The performance of the modal split indicator is found to be very sensitive to changes in value of time and beta. As it is not very stable, the interpretation of the indicator values is more difficult.
The weighted least square error has similar values as the absolute mode error. The fact that some ports do not use transport by train, means that the weight calculated for that observation is zero. This reduces the number of observation as the modelled number of TEU transported by train is not taken into account. Secondly, when the simulated modal split is more accurate (a low absolute mode error) than less containers are transported by train and the impact of those left out observations is smaller. Therefore, the weighted least square errors values for value of time are similar to those of the absolute mode error which indicates the overall modal split level.

It is considered that the $R^2$ value and the least square are the most stable indicators, their values are therefore leading. For the next modelling step, the chosen values are $\beta = -0.007$ and $vot = €1.25$ TEU/hour, these are the averages of the $R^2$ and least square error results.

5.3.4 Sensitivity Analysis

A sensitivity analysis is done for the values of beta and value of time. This analysis is done to see what the impact would be if the chosen values were to be incorrect.

Four cases are analysed and compared to the base case for the five performance indicators. The values for the base case are $\beta = 0.007$ and $vot = €1.25$ TEU/hour. For the high case these values are increased with 20% and for the low case these values are decreased with 20%. For the positive case the beta is decreased with 20% and the value of time is increased with 20%. For the negative case this is the other way around.

From the results table, Table 5-3, it can be seen that for all cases the values are very stable and deviate less than 20%. Only for the mode difference the deviation is much larger, especially for the high and low case. On a whole it can be concluded that the generalized cost function is stable and that minor errors will not amplitude.

<table>
<thead>
<tr>
<th>Type of Analysis</th>
<th>Deviation from Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum $R^2$</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>-2%</td>
</tr>
<tr>
<td>Least Square Error</td>
<td>2.2E+12</td>
</tr>
<tr>
<td></td>
<td>1%</td>
</tr>
<tr>
<td>Weighted Least Square Error</td>
<td>30.532.261</td>
</tr>
<tr>
<td></td>
<td>-13%</td>
</tr>
<tr>
<td>Minimal Absolute Error</td>
<td>7.752.663</td>
</tr>
<tr>
<td></td>
<td>-1%</td>
</tr>
<tr>
<td>Minimal Absolute Modes Error</td>
<td>3.092.678</td>
</tr>
<tr>
<td></td>
<td>-29%</td>
</tr>
</tbody>
</table>
Used Distribution Function
The values $\beta = 0.007$ and $\nu_t = €1.25$ TEU/hour are used in the distribution function, see Equation 9.

$$F_{ijm} = e^{-0.007 \times (TC_{ijm} + 1.25 \times TT_{ijm})}$$  \hspace{1cm} \text{Equation 9}

$\text{TC}_{ijm} = \text{Total transport Cost from Asia via port } i \text{ to region } j \text{ using mode } m$

$\text{TT}_{ijm} = \text{Total transport Time from Asia via port } i \text{ to region } j \text{ using mode } m$

5.4 Balancing OD Matrix
The second step of the OD matrix simulation is the balancing of the matrix using the balancing factors and the constraints.

5.4.1 Balancing the OD Matrix
The difference between the modelled port imports and the actual imports is still very large, with 7,752,663 misallocated TEU on a total of 12,543,000. In order to reduce this difference, the OD matrix is balanced using the balancing factors.

This is a very rough method to reduce the differences between modelled and actual port imports. It is used in transport planning for the estimation of new OD matrices based on an old OD matrix by applying correction coefficients. These are also known as balancing factors, introduced in transportation modelling by Furness in 1965 (Ortuzar and Willumsen, 2011). The balancing factors are calculated in such a way that the constraints of the matrix are satisfied. This is an iterative process, as the balancing factors are alternately calculated and applied to the rows and the columns of the matrix. This process is done until the constraints are satisfied. This method, or a variant of it, is used in different fields of science and has different names such as: RAS method, matrix balancing algorithm, iterative proportional fitting, and bi-proportional techniques (Lahr and Mesnard, 2004).

The advantage of this method is that it relatively easy to execute and the consistency of the matrix is guaranteed. The disadvantage is that minor errors can be amplified by the application of successive correction factors (Ortuzar and Willumsen, 2011).

The rows and columns are separately and alternately multiplied by a balancing factor, as mentioned in section 5.1. In practice the balancing factors are calculated by dividing the actual imports with the modelled imports. If the modelled import is under-estimated then all the flows will be amplified. If the modelled import is over-estimated than the flows will be reduced. This process reduces the difference between the modelled values and the actual values.

This process continues until the difference between the modelled import and the actual import changes with less than 1% per iteration step. It is considered that OD matrix will not become much better after that. For this study 64 iterations were needed for this to happen, see the blue line in Figure 5-4. The absolute difference
Container Port Development

decreased from 7,752,663 misallocated TEU down to 193,479 misallocated TEU, a drop of 98%.

5.4.2 Consolidation

For the modes train and barge, the number of TEU transported per OD link is of the essence. Trains and barges will only provide a service if enough containers make use of that service. Secondly, transport costs of these modes increase if the utilization degree decreases, the costs of intermodal transport is therefore only lower than for transport by road if the utilization degree is high enough. This critical number of containers must be met before this potential OD link will be used, so a consolidation step is performed.

The number of current train and barge services is found from intermodal links (Ecorys, 2013) and the number of TEU transported by train and barge has been calculated from the port modal splits. From this data it is found that an average train carries 31 TEU and an average barge carries 85 TEU. This is around 45% of their maximum capacity but only takes containers from Asia into account. Considering intra-European transport and containers from other parts of the world making use of the same train and barge, these averages seem plausible and will therefore be used as a threshold value for the use of train and barge.

Besides a minimum number of TEU per mode, also a minimum number of TEU per inland terminal is used. It is assumed that an inland rail and an inland barge terminal should have a throughput of 20,000 containers per year. Considering a TEU factor of 1.6, only imports and 45% of that import to be from Asia, a minimum of 7,200 TEU per year should be realized for an inland terminal to be feasible.

During the balancing operations these consolidation steps are undertaken. This is not done at the start of the balancing as it could have major influence on the outcome of the base OD matrix. The consolidation step for the number of TEU per train and
barge link is undertaken after iteration step 8. The consolidation step for the number of TEU for an inland terminal is taken after iteration step 10.

Due to the balancing of the OD matrix, the number of routes has decreased from 7.593 to 2.962. This is caused as very small flows disappear during the balancing and consolidation steps. The final balanced OD matrix is now the base OD matrix which will be used as input for the statistical analyses.

5.5 Conclusions OD matrix

In this chapter an Origin Destination matrix is constructed, which is used as input for the statistical analysis. The construction of the OD matrix is necessary as there is no publically available data on container flows. The construction of the OD matrix is done using the doubly constrained distribution method.

The approach for the construction of the OD matrix used in this study is different from most other studies, which use trade data as basis for their OD matrix. From trade data, the number of containers is derived and is then allocated to hinterland regions using different algorithms. This study has looked directly at the container flows, using port import statistics and the supply of container from Asia established in chapter 0.

The distribution of the containers is done using a distribution function. The calibration of this function, with β and ‘value of time’ as input variables, is found using a least square error method. During the balancing of the OD matrix, consolidation steps are taken for the transport mode rail and inland waterway. This means that rail and IWT services are only considered when a threshold value has been passed to make consolidated transport interesting.
6 STATISTICAL ANALYSIS

This chapter describes the statistics method and results of the statistical analysis. As input the base OD matrix and the port data are used. The results of the analysis will yield the statistical significant port choice factors and their corresponding coefficients. The results are used as input for the utility function.

6.1 Statistical Method

The base OD matrix of chapter 0 and the port choice factor data of chapter 0 are used as input for the statistical analysis. Using multivariate regression analysis significant port choice factors and their coefficients are found, see Figure 6-1. The six step model framework for multivariate analysis (Hair et al.) is used for the statistical analysis. The six steps are: definition of the research problem, the analysis plan, assumption evaluation, regression estimates, interpretation of the estimates and validation. After the six steps, an additional in depth analysis is done on certain aspects of the statistical analysis. The statistical analysis is performed using the software package SPSS.

![Figure 6-1 Statistical Method](image)

6.1.1 Research Problem

For linear regression analysis, the logit function must be written as a linear function. The logit function has the property of Independence from Irrelevant Alternatives (IIA). This is usually explained as a negative property with its infamous blue/red bus example, but can also be used in its advantage. The IIA property states that the ratio or probability of any two alternatives is entirely unaffected by the systematic utilities of any other alternative (Ben-Akiva and Lerman, 1985). This property is also known as the first axiom or choice axiom of McFadden. If all routes to a hinterland region j
are compared with a basic route, than using the property stated above Equation 10 can be made. The complete derivation is found in Appendix A. It is called the Berkson-Theil method (Ben-Akiva and Lerman, 1985) and is used to estimate parameters of a multinomial logit model. The coefficients can then be found using least square estimation.

\[
\ln \left( \frac{P_{ijm}}{P_{\text{basic}}} \right) = \Delta U = U_{ijm} - U_{\text{basic}} = a_n (X_{n(ijm)} - X_{n(basic)}) \quad \text{Equation 10}
\]

The dependent used in the regression analysis is \( \Delta U \). The route from the port of Antwerp to the different hinterland regions by truck is considered the basic route. More information on \( \Delta U \) and the basic route can be found in section 3.3.2. The port of Antwerp is chosen as reliable data is found for this port which is important as it affects all the routes. Furthermore, Antwerp is a very competitive port that has a large hinterland, so it is accurate as a basic route for the hinterland regions. The mode truck is used as this is the most frequently used mode and it is possible to reach any destination. This is important as for all routes a basic route must be used. The independents \( X_n \) are the different port choice attributes, which have a linear and functional relationship in the utility function \( U_{ijm} \). The goal is to find which independents significantly influence the dependent and with how much.

The data is considered metric with the goal of finding a single dependent with multiple independents, multiple regression analysis is considered to be the applicable statistical analysis.

### 6.1.2 Analysis Plan

A sample size of 2,724 routes, also called observations, is used; this is lower than the 2,962 routes found in the base OD matrix. By applying Equation 10, with basic route Antwerp by road, all the routes from Antwerp by road are set to zero. Therefore, the sample size has decreased.

Dummy variables have been added for the modes rail and inland waterway. The data used as input for the statistical analyses consists of functional or modelled data (e.g. Maritime Costs) and of actual data (e.g. Water depth). The character of the relationships between the independents and the dependent as well as the relationship between the independents are schematized in the relations scheme, Appendix O.

Outliers are dismissed; these are found when the standardized value of a variable is \( \pm 3 \). These are found for total cost, hinterland cost and total time. In total 26 values have been deleted most of which are from Greece.

The observations are weighted with the number of TEU for that observation. This is done as the study looks at the level of TEU. By weighting the sample, the number of zones, which is arbitrary, is dismissed. Secondly, the limited number of IWT and Rail flows, which are quite large due the consolidation, is taken into account.
In Table 6-1 an overview is presented of the number of observations and the number of TEU used in the regression analyses compared to the base OD matrix. Not only the number of routes has changed, also the number of TEU has decreased due to the fact that observations from Antwerp by road are zero.

<table>
<thead>
<tr>
<th></th>
<th>Baltic</th>
<th>North</th>
<th>Atlantic</th>
<th>Med</th>
<th>Adriatic</th>
<th>Aegean/Black</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEU Base Import</td>
<td>411.318</td>
<td>7.944.864</td>
<td>532.996</td>
<td>2.973.884</td>
<td>341.948</td>
<td>337.991</td>
<td>12.543.000</td>
</tr>
<tr>
<td>%</td>
<td>3%</td>
<td>63%</td>
<td>4%</td>
<td>24%</td>
<td>3%</td>
<td>3%</td>
<td>100%</td>
</tr>
<tr>
<td>Routes</td>
<td>266</td>
<td>1335</td>
<td>151</td>
<td>711</td>
<td>375</td>
<td>124</td>
<td>2.962</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Baltic</th>
<th>North</th>
<th>Atlantic</th>
<th>Med</th>
<th>Adriatic</th>
<th>Aegean/Black</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>TEU SPSS Import</td>
<td>388.958</td>
<td>6.902.615</td>
<td>512.255</td>
<td>2.854.775</td>
<td>319.943</td>
<td>100.878</td>
<td>11.079.424</td>
</tr>
<tr>
<td>%</td>
<td>4%</td>
<td>62%</td>
<td>5%</td>
<td>26%</td>
<td>3%</td>
<td>1%</td>
<td>100%</td>
</tr>
<tr>
<td>Routes</td>
<td>266</td>
<td>1123</td>
<td>151</td>
<td>709</td>
<td>375</td>
<td>100</td>
<td>2.724</td>
</tr>
</tbody>
</table>

There are different types of variables included in the regression analysis. These include port variables, coast variables, mode variables and flow variables. Port variables include the variables such as number of port calls which are specific for every port. Coast variables are specific for every coastline such as the maritime costs. The mode variables are specific per mode such as the number of rail services. The flow variables include the hinterland costs and hinterland time variables.

In order to find the significance of every variable different statistical analysis are done to find the influence of every variable on the overall utility. First a general regression is made including all the variables. Thereafter regressions for the different variable types are done in order to better understand the relative influence of each variable.

6.1.3 Assumption Evaluation

From the data a correlation table is rendered, see Appendix O. All of the factors have a significant correlation to the dependent, but not all signs are as expected. Some independents are a function of other independents. For example, total cost is built of maritime, port and hinterland costs. It is not desirable to include both the total and the hinterland costs in the regression as these factors are highly correlated.

The main assumption is that higher costs lead to a lower utility. A scatterplot is made for the utility and the total costs, see Figure 6-2. The graph shows the utility of a route on the y-axis and the total cost of that route on the x-axis. The different colours represent the 31 different ports.

It can be clearly seen that when the costs for a route are higher than for a competing route, the utility of that route becomes lower. The relation is linear and is for all ports the same. Between the ports there is however a difference, the utility found when the...
cost is zero differs per port. This can be viewed as the attractiveness or popularity of a port.

A regression line is plotted over the weighted dataset which gives the best fit. The line is however less steep then expected based on the visual interpretation of the observations per port. This is due to the fact that SPSS finds the least square error based on the vertical distance between the line and the observations and not on the orthogonal distances.

This effect can be countered by looking at each port separately, but this would only yield port specific coefficients which are not of interest. Another option is a nested regression in which different stages of the port choice are analysed in different steps. Nests would then be made viewing the different choice steps, for instance, by first looking at the maritime cost, followed by the hinterland costs. In this study it is however assumed that all routes are independent of each other.

Taking into account that the utilities have been simulated and the fact that different types of variables are used, a typical multivariate regression technique seems to be the safest method of statistical analysis. Whereas this type of regression is suitable for this study, separate regressions are also made for the different coastlines and modes, to better understand the impact of each variable.
6.2 **Statistical Results**

In this section, the regression analysis results, the interpretation of the results and the validation are presented.

6.2.1 **Regression Estimates**

During the regression analyses a stepwise method is used that consecutively introduces the factor with the highest correlation with the dependent. Multiple combinations are tested; the most interesting ones are presented. Collinearity is viewed using the VIF factor, the inverse of the tolerance, which will not be higher than 5. Collinearity describes the overlap of the explanatory variables, if the overlap is too large, then the model fit will not increase with the introduction of that variable. The regression is performed in nine consecutive steps in order to see which factors contribute to the model fit. The model fit is measured in $R^2$ which represent the portion of variance in the model explained by the different factors. The $R^2$ has values between 0 and 1, 0 meaning no variance is explained and 1 meaning all variance is explained and therefore a total model fit. The $R^2$ is adjusted for the number of factors used which gives the adjusted $R^2$. The values shown in Table 6-2 are the unstandardized betas; the t-values are presented between brackets. T-values larger than 2 or smaller than -2 are significant.

The first regression step uses the variables ‘total cost’ and ‘total time’. These variables are chosen as the simulated OD matrix is based on these variables. These variables are found to be significant and have a negative sign as expected. This means that when the cost or the time for a route is increased the utility of that route decreases. The adjusted $R^2$ value found is 0.796 which means that 79.6% of the model variance can be explained by just these two variables.

In the second step the variables ‘total cost’ and ‘total time’ are split in the variables ‘maritime cost’, ‘port cost’, ‘hinterland cost’, ‘maritime time’, ‘dwell time’ and ‘hinterland time’. This gives a higher adjusted $R^2$ value of 0.839. However for the variables ‘port cost’, ‘maritime time’ and ‘dwell time’ the sign seems to be wrong as they are positive instead of negative.

The third step includes the variables of step 2 which have a negative sign. When only these variables are used an adjusted $R^2$ value of 0.821 is found this is higher than 0.796 found in step 1. This means that the model fit has increased by using the variables ‘maritime cost’, ‘hinterland cost’ and ‘hinterland time’.

The variable ‘maritime cost’ includes the deep sea cost as well as the feeder cost which is incurred for certain ports. This means that ports that have a direct connection automatically have lower maritime costs than ports that are not directly connected and have additional feeder costs. To check whether the variable ‘maritime cost’ is stable and not a hidden proxy for feeder ports, a dummy for feeder ports
‘dummy feeder port’ is introduced in step 4. It can be seen that this dummy has a positive sign and the variable ‘maritime cost’ stays negative, with a higher t-value. As gateway ports are considered to be less attractive instead of more attractive than hubports, the variable ‘dummy feeder port’ is dismissed in further regression steps.

In steps 5 to 7, port variables are introduced. First the ‘number of port calls’ is analysed. This variable only includes the number of direct port calls from deep sea ships. This variable has a positive influence on the utility and on the model fit as the adjusted R$^2$ value is 0.823.

In step 6, the variables ‘number of IWT services’ and ‘number of Rail services’ are added to the regression. The variable ‘number of rail services’ has a negative sign, which indicates that if the number of rail services in a port increases, the port’s utility decreases. This is assumed to be incorrect, so therefore this variable is dismissed from further regression steps.

In step 7, the variable ‘number of short sea services’ is introduced. This variable indicates the number of short sea connections of a port. This variable is found insignificant, due to its low t-value, it also has a negative sign. Furthermore, the variable ‘number of IWT services’ has also been given a negative sign. The t-value is low which indicates that the correlation is weak. These variables are therefore dismissed from further regression steps.

The variable ‘water depth’ is added to the regression in step 8. This variable indicates the water depth of a port for the container terminals, measured in meters. It is assumed deeper ports can attract larger ships which increases the utility of a port. It can be seen that ‘water depth’ has a great positive influence on the utility and on the model fit, with an adjusted R$^2$ value of 0.843. However, the variable ‘number of port calls’ has switched from a positive to negative sign. For this study it is assumed that the causality between number of port calls and the utility is higher than between water depth and the utility, which has clearly a higher correlation. For the next regression steps, the variable ‘water depth’ is therefore dismissed.

In the 9th and final step, mode specific dummies are tested. In order to see if the modes of rail and IWT are different from road, a dummy variable is used for these two modes. From regression 9, it can be seen that the variable ‘dummy rail’ has a significant negative coefficient which indicates that the modus rail is not popular. The model fit is 0.826 which is an improvement. The variable ‘dummy IWT’ was found to be insignificant and has no positive contribution to the model fit, it has therefore been discarded.
### Table 6-2 Results General Regression Analyses

<table>
<thead>
<tr>
<th>Step:</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Costs</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.0054</td>
</tr>
<tr>
<td>Cost Hinterland</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.005</td>
<td>-0.0054</td>
</tr>
<tr>
<td>Cost Maritime</td>
<td>-0.091</td>
<td>-0.029</td>
<td>-0.069</td>
<td>-0.027</td>
<td>-0.027</td>
<td>-0.026</td>
<td>-0.024</td>
<td>-0.027</td>
<td></td>
</tr>
<tr>
<td>Cost Port</td>
<td>0.011</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Time</td>
<td>-0.043</td>
<td>-0.190</td>
<td>-0.152</td>
<td>-0.130</td>
<td>-0.206</td>
<td>-0.211</td>
<td>-0.206</td>
<td>-0.255</td>
<td>-0.151</td>
</tr>
<tr>
<td>Time Hinterland</td>
<td>-0.190</td>
<td>-0.152</td>
<td>-0.130</td>
<td>-0.206</td>
<td>-0.211</td>
<td>-0.206</td>
<td>-0.255</td>
<td>-0.151</td>
<td></td>
</tr>
<tr>
<td>Time Maritime</td>
<td>0.189</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Dwell</td>
<td>1.134</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Port calls</td>
<td>0.024</td>
<td>0.032</td>
<td>0.025</td>
<td>-0.026</td>
<td>0.025</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of IWT services</td>
<td>0.006</td>
<td>-0.003</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Rail services</td>
<td>-0.022</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Short Sea Services</td>
<td>-0.001</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Depth</td>
<td>0.364</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dummy Rail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.612</td>
<td>(-7.4)</td>
</tr>
<tr>
<td>Dummy Feeder Port</td>
<td></td>
<td>3.082</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.796</td>
<td>0.838</td>
<td>0.820</td>
<td>0.827</td>
<td>0.823</td>
<td>0.825</td>
<td>0.823</td>
<td>0.843</td>
<td>0.826</td>
</tr>
</tbody>
</table>

Unstandardized beta’s (t-value)

### 6.2.2 Interpretation of the Results

When interpreting the result of the regression analysis not only the model fit is important but also what the results tell us about the data and modelling techniques used, as well as the real world and the port decision making process. Some variables might do well in the model fit but do not directly reflect the choices made by the shippers and forwarders or the shipping companies.

From Table 6-2 it is clear that the variables ‘total cost’ and ‘total time’ are significant explanatory variables for the model, explaining almost 80% of the variance of the
utility. This seems realistic as costs and time are referred to as important variables for decision making. Secondly, the simulated base OD matrix uses these two key variables as input, it is therefore not surprising that they do well in the regression analysis. For every €1 that the total costs go up, the utility will decrease with 0.005. For every day that the transport takes longer, the utility will decrease with 0.043. The coefficient of -0.005 for total cost is similar to the beta for the generalised cost function of -0.007. When the coefficient -0.043 for total time is divided by the coefficient of the total cost, the value of time is found. For regression step 1, this would be €0.36 per hour. This is lower than the €1.25 used in the generalised cost function.

When the total costs and total transport time are split into more specific variables, the picture changes slightly. Port costs, dwell time and maritime time have a positive sign. The positive sign indicates that when these costs or times go up, the utility would increase, which is counter economic law of demand. This states that when prices increase, demand will decrease; in this case a lower demand due to higher costs means a decrease in utility. The same holds for the time factors.

The dwell times for the various ports are the same as specific information per port is not found; this means that the variable ‘dwell time’ acts as a constant in the regression, the meaning of the coefficient can therefore be ignored. The positive correlation of the variable ‘port cost’ could indicate that a more popular port (higher utility) is faced with a higher demand as more ships will want to call that port. This will then increase the terminal handling charges within that port. Another explanation could be that the higher terminal handling charges are found in the North Sea area were labour prices are higher yet the ports in this region are popular as well. A third explanation could be that more expensive ports are also more reliable and efficient, which would lead to a higher utility. However, as it is unknown why higher port costs are associated with a higher port utility, the port costs are not useful as an independent variable.

Hinterland transport time is found to be a better predictor for the model than total transport time. This is probably because the largest ports, located around the North Sea, have a higher maritime transport time then the smaller ports located around the Mediterranean Sea. The hinterland transport cost are highly significant in all the regression with a stable coefficient of -0.005 and high t-values. When the value of time for the hinterland transport is computed according to the coefficients, a value of €1.27 is found. This is very close to the value used in the generalised cost function of €1.25. This means that the regression analyses has found the relation between cost, time and utility as put in the constructed OD matrix using the generalised cost function.

In step 4, the influence of gateway ports compared to hub-ports on port utility is analysed, a dummy for feeder ports is added to the regression. Just as for maritime transport time, also the maritime costs could be influenced by the fact that a gateway
port has much higher maritime costs, this is however not the case as the feeder dummy has a positive sign.

For regressions 5 to 8, port specific variables are tested. The number of direct port calls from deep sea services has a positive effect on the utility. This means that if a port attracts more deep sea services, its utility will increase. As not all ships call the same ports in Asia, this variable could also be a proxy for the number of direct links to different ports in Asia. It could also be a proxy for reliability, for instance when a container from Singapore to Rotterdam is not on the scheduled ship, it can be put on the next ship departing to Rotterdam within the same day, whereas for Constanta it would have to wait at least a day. A third argument for this relation is that a deep sea ship will call 4 ports in Europe on average, this means that ports are only called when they have a container demand that exceeds a certain critical mass. When this critical mass is reached a deep sea ship will call this port over another port. This means it will also unload containers in this port that have a destination outside the captive hinterland. It should be noted that this effect has nothing to do with costs or time. As this variable is the only significant port variable, the risk is that other (unmeasured) port characteristics could be loaded on this variable. However, considering the stable value of the coefficient in the general regression analysis it is assumed that this is not the case.

The number of hinterland services for rail and IWT is expected to have a positive influence on the utility as ports that offer different modes for the hinterland transport would be expected to have a higher utility. According to regression steps 6 and 7 this is not the case. The relative low t-value is also distinctive for these two variables. Detailed analysis on the mode variables is done in section 6.3.

The number of short sea services variable indicates to what extend a port is a transshipment port. It therefore indicates how much a port transships but not necessary how much volume a port imports for its hinterland. Secondly, most short sea shipping is used for intra-European transport. For this study only imports from Asia by deep sea ships are taken into account so short sea transport from the North Sea ports to the Mediterranean ports does not seem to be very relevant. It is assumed that more or larger deep sea ships call a port with many short sea connections or that a gateway port with many short sea connections will have a higher utility then gateway ports that only have a few connections. The variable ‘number of short sea services’ has a very small coefficient and a low t-value. It is therefore considered to have no direct influence on the ports utility.

The variable ‘water depth’ has a strong positive correlation with the utility considering the high t-value. When this variable is entered, the variable ‘number of port calls’ switches from sign. This means that both variables cannot be used at the same time. For this study it is assumed that the causality between number of port calls and the utility is higher than between water depth and the utility. This is because the number of port calls captures many different choice factors from the
shipping lines whereas water depth is only one factor. Furthermore, deeper water makes a port more attractive and leads indirectly also to a higher number of port calls.

In the last regression step, mode specific dummies are tested. It is found that rail transport has a significant negative utility. This means that on basis of the cost and time much more containers would be transported by rail, but they are not. The number of TEU transported by rail has been overestimated during the construction of the OD matrix. This means that during the balancing of the matrix, rail transport is minimized. This effect is seen in the statistical regression. The transport by rail is overestimated because all the ports in this study have a rail connection which can theoretically be used but in practice these are not used. The transport via inland waterways has nog significant dummy variable.

Taking the model fit and the interpretation of the variables into account the regression analyses of step 9 seems to be the most appropriate. It has a reasonable model fit of 0.826 and includes the variables that seem to represent the decision making process of the shippers best.

6.2.3 Validation

The validation is done in two parts; first the dataset used is validated, secondly the selected port choice factors are validated with literature.

Dataset

For the validation within the dataset, the dataset has been randomly split into two subsamples. These subsamples are than used for a regression using the variables found to contribute best to the model fit. Using this technique the significance of each variable, its coefficient and the overall model fit can be validated. Especially the variables with a relative low t-value are of interest as they are based on a smaller number of observations or on a smaller correlation. The idea behind this technique is that only when a variable is significant in both sub-samples, it is fine to use. Secondly, the full sample should be the average of both sub-samples; otherwise the data is not used properly.

In Table 6-3 the results of the dataset validation are shown. It can be seen that all the signs between the samples are similar. Secondly they are all significant and thirdly the coefficients of the full sample are the average of the two sub samples. The variable ‘dummy rail’ shows the largest variance between the two samples, this is due to the relative low number of containers that are transported by rail compared to the number of containers transported via road.

For the full sample also the standardized beta values are presented, they show the relative influence of the independent variables on the dependant variable.
Table 6-3 Results Regression Analyses Validation

<table>
<thead>
<tr>
<th></th>
<th>Full Sample</th>
<th>Sub-Sample 1</th>
<th>Sub-Sample 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Hinterland</td>
<td>-0.005 (-96.8) [-0.979]</td>
<td>-0.005 (-65.1)</td>
<td>-0.005 (-71.6)</td>
</tr>
<tr>
<td>Cost Maritime</td>
<td>-0.027 (-16.3) [-0.158]</td>
<td>-0.026 (-11)</td>
<td>-0.027 (-11.9)</td>
</tr>
<tr>
<td>Time Hinterland</td>
<td>-0.151 (-6.0) [-0.059]</td>
<td>-0.140 (-3.8)</td>
<td>-0.162 (-4.7)</td>
</tr>
<tr>
<td>Number of port calls</td>
<td>0.025 (6.4) [0.061]</td>
<td>0.023 (4.3)</td>
<td>0.027 (4.7)</td>
</tr>
<tr>
<td>Dummy Rail</td>
<td>-0.612 (-7.4) [-0.064]</td>
<td>-0.424 (-3.6)</td>
<td>-0.797 (-7.0)</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.826</td>
<td>0.820</td>
<td>0.832</td>
</tr>
<tr>
<td>N</td>
<td>2724</td>
<td>1354</td>
<td>1370</td>
</tr>
</tbody>
</table>

Unstandardized beta, (t-values), [standardized beta]

**Literature**

The second part of the validation compares the results found in step 9 of the regression analyses with literature.

From Table 6-3 it can be seen that hinterland costs has the highest t-value and the highest standardized beta. This means it is the strongest and most accurate explanatory variable of the studied variables. In the literature studied, the hinterland costs are rarely mentioned specifically; total costs and the ports geographic location are mentioned often. The hinterland costs play a major role in both factors. The hinterland costs are a major part of the total costs and depend largely on the distance between the port and the hinterland destination. When a port has a good geographic location, it will be located close to a large hinterland, where the distances are small and the demand is high.

The second most influential variable is maritime costs. The maritime costs include deep sea cost as well as feeder costs when applicable. No studies were found where a distinction between direct and indirect (deep sea + feeder) shipping is made. A maritime cost is not mentioned separately as an important choice factor, although it is part of the total costs. The unstandardized beta (-0.027) is higher than for the hinterland costs, this is different than expected. This deviation can be explained by the fact that the number of different maritime costs observations is much lower than for the hinterland costs as the maritime costs are calculated per coastline, therefore the reliability of this coefficient is lower. Secondly, the difference in maritime costs between gateway ports and hub-ports is present; this could influence the coefficient size.

The variable hinterland time was not mentioned specifically in literature as an important port choice factor, whereas total transport time is mentioned. The factor transport time is difficult to capture separately as it is also used as input for the transport costs, this could be the reason of the lower t-value. For this study it is logical that the hinterland transport time is significant instead of the total transport time, as the dwell times are considered to be the same for all ports and the maritime
transport time to be similar per coastline. The hinterland transport time is especially of importance for mode choice, where transport by barge takes much longer than by truck. This is further analysed in section 6.3.

The hinterland transport costs are highly significant in all the regressions with a stable coefficient of -0.005. For every € 1 that the hinterland costs go up, the utility will decrease with 0.005. For every day that the hinterland transport takes longer, the utility will decrease with 0.151. When the coefficient for hinterland time is divided by the coefficient of hinterland cost, then the value of time for hinterland transport can be computed, a value of €30 per TEU per day is found. When the value of time for the total transport is computed, a value of €9 per TEU per day is found. These values are considered to be quite low but plausible, as value of time values are found between €12 and €96 per TEU per day (RETRACK, 2012). The fact that the hinterland value of time is larger than the total value of time is (including maritime transport time) is in line with literature (Veldman et al., 2005) in which the value of time of maritime transport is valued lower than hinterland transport value of time.

The variable ‘number of port calls’ is the only port variable found significant. This variable has been identified in literature as a port choice factor for shippers. This factor purely states the number of port calls by deep sea ships and does not take into account any direct cost or time components. The positive effect of increasing number of port calls is mentioned in literature as the Mohring effect, which states that an increase in frequency of service leads to positive effects (Veldman et al., 2011).

The last variable is a dummy variable for the mode rail. This dummy is included because rail transport is found to be less attractive then cost and time variables can explain. In practice transport by rail suffers from different problems that undermine its reliability. Either the capacity of the track is too low, border changes take time, different gauges and different voltages are used per country, slots are planned far in advance etc… Considering that other modes do not have these problems, it is not surprising that the mode rail has a negative utility. These and other rail specific problems have also been identified by the European Commission, which they call ‘administrative, technical and regulatory obstacles found present in the rail sector in the EU’ (EC, 2013).

Based on the validation of the port choice factors, the variables found in the regression analysis can be used for the utility function. However, some further in depth analysis is needed to better understand the influence of various variables.
6.3 In Depth Analysis

In this section additional analysis is done on the data for specific variable types. First a comparison is done for the weight and the unweight regression. Secondly, regressions are taken within the different coastlines. The third regression shows the results per mode.

6.3.1 Weighted vs Unweight Regression

In section 6.1.2 the assumption is made that a weighted regression is the best option. In this section the regression results for the weight and the unweight observations are compared to see if this assumption is supported, the results can be found in Table 6-4.

The table shows the different variables that are found to be significant. It can be seen that the unweight regression has 2.724 observations as mentioned in 6.1.2. It has an adjusted R\(^2\) value of 0.657 which is lower than the 0.826 found for the weight regression.

The variables that have been found significant are quite different; only the variables ‘cost hinterland’ and ‘number of port calls’ are similar. The coefficients found for these variables are also quite similar; this makes them look quite stable. The unweight regression has no variable ‘cost maritime’ but instead has a ‘dummy feeder port’ variable. This dummy variable indicates that when a feeder port is used, the utility will go down with 1.619. This means no distinction is made for the deep sea costs but only if feeder transport is used or not.

The interesting variables that are found significant are the variables ‘number of IWT services’ and ‘number of rail services’. Apparently, routes that have a small flow size have advantage of higher number of services. The routes with small flow size are the routes by truck as they are not consolidated. This means that truck transport benefits from higher number of intermodal services. This seems strange, although it is theorised that ports with a high number of hinterland services have a higher utility, as syncho-modal transport can be offered.

Because of the higher R\(^2\) value for the weighted regression, the assumption of using the weighted regression analysis is supported. However, the unweight regression does indicate that the variables ‘number of IWT services’ and ‘number of rail services’ are of influence on the ports utility.
6.3.2 Regression per Coastlines

This analyses shows which factors are of influence for the competition between ports that share the same coastline. This can be viewed as a type of nested regression, as sub samples are used for a regression. The results per coastline are found in Table 6-5.

The table shows the number of (weighted) observations (N) which differs a lot between coastlines. The adjusted R² values are all higher than then 0.826. There are many differences between the coastlines but for every coastline, except for the Black and Aegean coastline, the hinterland cost variable is significant. The coefficients for this variable are a little larger than for the overall regression, which can be explained as the hinterland scatterplot looks similar to that of the total cost, see Figure 6-2. When a subset is used, the regression line becomes steeper hence the higher coefficient.

The maritime cost variable is not significant for most coasts, as the maritime costs are the same within a coastline. Only the Mediterranean coastline has both gateway and hub-ports which explains why this variable is significant for this coastline only.

The most interesting regression is found for the North Sea coast as it has the most significant variables. The North Sea ports are the only ports that offer IWT; this is why only for this coast the number of IWT services and a dummy for IWT is found. As this regression is limited to the routes that use these ports, the IWT variable becomes significant. This could mean that if a port offers IWT, the number of services is important and increasing the number of services increases a ports utility. IWT is however less attractive than transport by road, given the negative dummy variable for IWT.

The results also show that the influence of the North Sea ports, due to their large number of observations, on the general outcomes is quite large.

Table 6-4 Weight vs Unweight regression

<table>
<thead>
<tr>
<th></th>
<th>Weight</th>
<th>Unweight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Hinterland</td>
<td>-0.005 (-96.8)</td>
<td>-0.005 (-68.1)</td>
</tr>
<tr>
<td>Cost Maritime</td>
<td>-0.027 (-16.3)</td>
<td></td>
</tr>
<tr>
<td>Time Hinterland</td>
<td>-0.151 (-6.0)</td>
<td></td>
</tr>
<tr>
<td>Number of port calls</td>
<td>0.025 (6.4)</td>
<td>0.030 (4.1)</td>
</tr>
<tr>
<td>Number of IWT services</td>
<td>0.021 (5.7)</td>
<td></td>
</tr>
<tr>
<td>Number of Rail services</td>
<td>0.034 (6.5)</td>
<td></td>
</tr>
<tr>
<td>Dummy Rail</td>
<td>-0.612 (-7.4)</td>
<td>-1.619 (-12.0)</td>
</tr>
<tr>
<td>Dummy Feeder Port</td>
<td></td>
<td>-1.619 (-12.0)</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.826</td>
<td>0.657</td>
</tr>
<tr>
<td>N</td>
<td>11,079.424</td>
<td>2,724</td>
</tr>
</tbody>
</table>

Unstandardized beta, (t-values)
### Table 6-5 Results Regression Analyses within Coastlines

<table>
<thead>
<tr>
<th></th>
<th>Baltic</th>
<th>North</th>
<th>Atlantic</th>
<th>Med.</th>
<th>Adriatic</th>
<th>Aegean/Black</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost</td>
<td>-0.005</td>
<td>-0.007</td>
<td>-0.006</td>
<td>-0.006</td>
<td>-0.006</td>
<td></td>
</tr>
<tr>
<td>Hinterland</td>
<td>(-59.7)</td>
<td>(-138.5)</td>
<td>(-89.1)</td>
<td>(-70.2)</td>
<td>(-55.8)</td>
<td></td>
</tr>
<tr>
<td>Cost Maritime</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-0.074</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(-20.7)</td>
<td></td>
</tr>
<tr>
<td>Time</td>
<td></td>
<td>-0.203</td>
<td></td>
<td></td>
<td></td>
<td>-1.518</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(-16.8)</td>
<td></td>
<td></td>
<td></td>
<td>(-47.9)</td>
</tr>
<tr>
<td>Hinterland</td>
<td></td>
<td>0.016</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of port calls</td>
<td>0.016</td>
<td>(17.0)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of IWT services</td>
<td>0.015</td>
<td>(20.4)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Rail services</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of Short Sea Services</td>
<td>0.386</td>
<td>(43.7)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dummy IWT</td>
<td>-0.260</td>
<td></td>
<td>-0.006</td>
<td>2.406</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-5.8)</td>
<td></td>
<td>(-11.7)</td>
<td>(40.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dummy Rail</td>
<td>-0.295</td>
<td></td>
<td>-3.006</td>
<td>2.406</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-11.7)</td>
<td></td>
<td>(-10.0)</td>
<td>(40.2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.930</td>
<td>0.969</td>
<td>0.981</td>
<td>0.876</td>
<td>0.957</td>
<td>0.949</td>
</tr>
<tr>
<td>N</td>
<td>388.958</td>
<td>6902.615</td>
<td>512.255</td>
<td>2854.775</td>
<td>319.943</td>
<td>100.878</td>
</tr>
</tbody>
</table>

Unstandardized beta, (t-values)

#### 6.3.3 Regression per Mode

A regression analysis is done for the specific hinterland modes, the results are presented in Table 6-6. The results are compared with the full sample from the general regression.

For the road sample no major differences are seen compared to the general regression, only the hinterland time variable is not significant anymore. This means that there are no large differences in travel times which have not been captured by the hinterland costs, for road transport.

The rail sample shows that hinterland travel times are of importance; this would mean that there is a greater deviation in travel times for rail transport, compared to road transport. For rail transport, the coefficient for hinterland transport time is negative and quite large; this could explain why there is a negative dummy for rail in the full sample. Secondly, the number of rail services is significant and has positive influence on the use of ports that offer many rail services.

In the IWT sample the variables cost maritime and numbers of port calls are not significant. The maritime costs are not significant as they are the same for all IWT, which are only offered for North Sea ports. The hinterland cost coefficient (-0.008) is
larger than for the full sample. This could explain why IWT has a negative dummy in Table 6-5. The table also shows that the number of IWT services has a positive influence on the port utility.

This analysis shows that also the variables ‘number of IWT services’ and ‘number of rail services’ are found significant. The analysis indicates that when rail or inland waterway transport is used, a higher number of services lead to a higher port utility. However, these variables cannot be used in the utility function. The coefficients found in the detailed regression cannot be used directly with the coefficients found for the five port choice factors. The coefficients of both variables cannot be computed at the same time as for the earlier found five port choice factors. Hence, their relative influence on port choice cannot be tested.

Table 6-6 Regression Results per Mode

<table>
<thead>
<tr>
<th></th>
<th>Full Sample</th>
<th>Road-Sample</th>
<th>Rail-Sample</th>
<th>IWT-Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Hinterland</td>
<td>-0.005 (-96.8)</td>
<td>-0.006 (-93.8)</td>
<td>-0.005 (-33.4)</td>
<td>-0.008 (-28.3)</td>
</tr>
<tr>
<td>Cost Maritime</td>
<td>-0.027 (-16.3)</td>
<td>-0.029 (-15.9)</td>
<td>-0.008 (-3.0)</td>
<td>-</td>
</tr>
<tr>
<td>Time Hinterland</td>
<td>-0.151 (-6.0)</td>
<td>-0.305 (-6.3)</td>
<td>-0.280 (-10.8)</td>
<td>-</td>
</tr>
<tr>
<td>Number of port calls</td>
<td>0.025 (6.4)</td>
<td>0.021 (4.3)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Number of IWT Services</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.022 (7.0)</td>
</tr>
<tr>
<td>Number of Rail services</td>
<td>-</td>
<td>-</td>
<td>0.033 (7.8)</td>
<td>-</td>
</tr>
<tr>
<td>Dummy Rail</td>
<td>-0.612 (-7.4)</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Adjusted R²</td>
<td>0.826</td>
<td>0.824</td>
<td>0.846</td>
<td>0.977</td>
</tr>
<tr>
<td>N</td>
<td>2724</td>
<td>2309</td>
<td>342</td>
<td>73</td>
</tr>
</tbody>
</table>

Unstandardized beta, (t-values)

6.4 Conclusions Statistical Analysis

From the statistical analysis five port choice factors are found significant that also have the right sign: hinterland transport costs, maritime transport costs, hinterland transport time, number of deep sea port calls, and a dummy for rail transport. The combination of these significant variables gives an adjusted R² value of 0.826. These factors and their corresponding coefficients will be used in the utility function.

Detailed analysis shows that also the variables ‘number of IWT services’ and ‘number of rail services’ are found significant. The analysis indicates that when rail or inland waterway transport is used, a higher number of services lead to a higher port utility. These variables can however not be used in the utility function. The coefficients found in the detailed regression cannot be used directly with the coefficients found for the five port choice factors. The coefficients of both variables cannot be computed
at the same time as for the earlier found five port choice factors. Hence, their relative influence on port choice cannot be tested.

From the cost and time coefficients, ‘value of time’ is calculated. Hinterland value of time is considered €30 per TEU per day and total value of time €9 per TEU per day. The fact that the hinterland value of time is larger than the total value of time (including maritime transport time) is in line with literature in which the value of time of maritime transport is valued lower than hinterland transport value of time.
In this chapter the prediction model also known as the port competition model is constructed and tested. First, the utility function that is used in the model is constructed. Then the model performance is tested and compared to the generalized cost function that is used for the construction of the OD matrix.

### 7.1 Utility Function

From the results of the regression analyses (Table 6-3), the utility function is produced. This is shown in Equation 11. This function is used within the logit model as presented in section 3.3.

\[
U_{ijm} = -0.0054 \times HC_{ijm} - 0.027 \times MC_i - 0.151 \times HT_{ijm} + 0.025 \times PC_i - 0.612 \times DR_m
\]

*Equation 11*

- \( U_{ijm} \) = utility from port i to hinterland region j using mode m
- \( HC_{ijm} \) = hinterland cost from port i to hinterland region je using mode m (€)
- \( MC_i \) = maritime cost for port i (€)
- \( HT_{ijm} \) = hinterland transport time from port i to hinterland region j using mode m (days)
- \( PC_i \) = number of port calls for port i (per week)
- \( DR_m \) = Dummy for transport by rail

### 7.2 Performance of the Port Competition Model

In this section the performance of the port competition model is tested. This is done using performance indicators and by visualisations of the performance.

#### 7.2.1 Performance Results

In section 5.3 five performance indicators are used to find \( \beta \) and ‘value of time’ for the generalised costs function. These indicators are now used to measure the results of the port choice model with the input of the utility function formulated in Equation 11.

As this model is built using a simulated OD matrix, it is important to determine whether or not the model performs better than the Generalised Cost method that simulated the first step of the OD matrix. The results are compared to the results of
the generalised cost function in order to see if the performance using the utility function has increased compared to the generalized cost function.

For the generalised cost function a value of time of €1.25 and a $\beta$ of -0.007 are used. It should be noted that the values for the performance indicators are found using the prediction model. These values can therefore not directly be compared with values found in the statistical analyses.

The results of this comparison are shown in Table 7-1. The column marked GC is the generalised cost function as found in section 5.3. The column marked utility gives the result for the model using the utility function as stated in section 7.1. The last column gives the percentile difference between the two approaches.

From this comparison it can be seen that the utility function scores better on all five indicators. The $R^2$ value has increased with 20% whereas the indicators for errors have decreased between 16% and 34%.

<table>
<thead>
<tr>
<th>Type of Analysis</th>
<th>GC</th>
<th>Utility</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum $R^2$</td>
<td>0.64</td>
<td>0.77</td>
<td>+20%</td>
</tr>
<tr>
<td>Least Square Error</td>
<td>2.2E+12</td>
<td>1.5E+12</td>
<td>-32%</td>
</tr>
<tr>
<td>Weighted Least Square Error</td>
<td>30.532.261</td>
<td>20.087.806</td>
<td>-34%</td>
</tr>
<tr>
<td>Minimal Absolute Error</td>
<td>7.752.663</td>
<td>6.535.727</td>
<td>-16%</td>
</tr>
<tr>
<td>Minimal Absolute Modes Error</td>
<td>3.092.678</td>
<td>2.180.042</td>
<td>-30%</td>
</tr>
</tbody>
</table>

7.2.2 Interpretation of Results

The port choice model using the utility function scores better than when using the generalised cost function, see Table 7-1. This means that the port choice model using the utility function predicts the port imports per mode better than the generalised cost function. Therefore, the port choice factors ‘number of port calls’ and ‘dummy for rail transport’ have increased the prediction power over the generalized cost function.

As input for the statistical analysis the constructed ‘base OD matrix’ is used. This OD matrix is simulated using the generalized cost function. The performance of the generalized cost function is therefore similar to what is put into the model. This performance does therefore not indicate very much.

The utility function includes the variables ‘number of port calls’ and ‘dummy for rail transport’ which have not been used for the simulation of the OD matrix. The improved performance using these ‘extra’ variables therefore indicates the improvement of the model compared to the generalized cost function. Because the outcomes of the model are compared with the actual port imports, the values of the performance indicators can be used to determine the performance of the model.
7.2.3 Sensitivity Analyses

A sensitivity analysis for the generalised cost function is made in section 5.3.4. For the utility function a similar sensitivity analysis is done. The coefficients used in the utility function have been increased and decreased with 20% for the high and low case respectively. For the negative case the coefficients with a minus are increased with 20% and the positive values are decreased with 20%. For the positive case this is vice versa.

The results of this analysis can be found in Table 7-2, which show the deviations from the base case. The sensitivity is similar to that of the generalised cost function, see Table 5-3. Only the mode difference has a larger sensitivity than the generalised cost function for the negative and positive case. This is due to the fact that the utility function has a dummy variable for the mode rail. This dummy has a large impact on the modal split and therefore on the mode difference.

<table>
<thead>
<tr>
<th>Type of Analysis</th>
<th>Deviation from Base Case</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Base</td>
</tr>
<tr>
<td>Maximum R^2</td>
<td>0.77</td>
</tr>
<tr>
<td>Least Square Error</td>
<td>1.5E+12</td>
</tr>
<tr>
<td>Weighted Least Square Error</td>
<td>20.087.806</td>
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<tr>
<td>Minimal Absolute Error</td>
<td>6.535.727</td>
</tr>
<tr>
<td>Minimal Absolute Modes Error</td>
<td>2.180.042</td>
</tr>
</tbody>
</table>

7.2.4 Imports per Coastline

Both the utility function and the generalised cost function are compared using the performance indicators. In order to visualize the difference between the two functions the port imports per coastline are shown in Figure 7-1. The graph shows the number of TEU that are imported from Asia per coastline. The blue bars represent the import for 2010 from the port statistics. The red bars represent the utility function and the green bars represent the generalized cost function, both for an oil price of $100.

The utility function performs better for the North Sea, Mediterranean Sea, Adriatic Sea, and Black Sea coastlines. Whereas the generalized cost function performs better for the Baltic Sea and Atlantic coastlines.

It should be noted that in general the utility function performs better per coastline, but on a port level there are some deviations.
7.2.5 Modal Split

From Table 7-1 it is seen that the difference in mode use has improved, this can be clearly seen Figure 7-2. The figure shows the modal split for 2010 which was found from port statistics, measured in TEU*trips for all the ports. It also shows the modal split for the utility function and the generalised cost function. Both are based on an oil price of $100. From the figure it can be seen that the modal split found with the utility function represents the base year of 2010 slightly better than the generalised cost function. However from the sensitivity analyses it is found that the modal split is quite sensitive to deviations of the coefficients for cost and time.
7.3 Conclusion Port Competition Model

From the results for the performance of the utility function compared to the generalised cost function it can be concluded that utility function performs better than the generalized cost function. The utility function scores better on all performance indicators. The $R^2$ value has increased with 20% to a value of 0.77. This means that 77% of the variance of the port imports is explained by the port choice factors included in the utility function. This is better than for the generalised cost function that is used in the simulation of the ‘base OD matrix’.

The final port competition model is built. It consists out of the utility function, the multinomial logit function, and the summation of all the container transport flows per port. The port competition model represents best the base year 2010 on both imports per coastline as for modal split.
8 OIL PRICE SCENARIO

In this chapter a single scenario is worked out to act as showcase for possible applications of the port competition model. The scenario presented is the oil price scenario, in which the effect of different oil prices on container import flows is presented.

8.1 Oil Price Changes

Fuel costs are a major component of the total transportation costs, for both maritime and hinterland transportation. Fuel costs are largely dependent on the oil price, when the oil price increases, the fuel costs will increase as well. The structure of transport costs is different for each transport mode which means that a change in fuel costs will influence the total transport costs per mode differently. A change in transport costs will affect the modal split of hinterland transport and the use of feeder transport. This makes the oil price a variable that can have a high impact on the transportation sector and makes it interesting to analyse the influence of a changing oil price on modal split, port choice, coastline choice and therefore on port competitiveness.

As long as oil prices are stable and predictable the influence of oil price on transport costs and port choice is relatively small, but the oil price is affected by global demand and supply and can therefore be somewhat volatile. Determining future oil prices is therefore impossible, so possible oil prices scenarios are made. The US Energy Information Administration has made projections for development of future Brent crude oil prices, see Figure 8-1 (EIA, 2011). The figure shows the oil prices of the past and three scenarios of oil price developments. Based on these scenario projections, this study will look at five different oil prices per barrel: $50, $100, $150, $200 and $250.

Besides the oil price uncertainty, also other factors can influence fuel costs, such as changes in environmental or tax regulations.

In order to determine the development of port competitiveness for changing oil prices, the impact of container imports is analysed using the port competition model. The hinterland transport costs and the maritime transport costs are the variables in the utility function that are influenced by a change in oil price.
8.2 Effects of Changing Oil Price

When the oil price changes, the fuel cost will change which influences the transport costs per mode of transport. When the hinterland transport costs change, the modal split will change as a result. Secondly, due to a change in oil price the maritime transport costs will change, which influences feeder and deep sea transport.

8.2.1 Modal Split Changes

The three different hinterland modes have different cost structures; a change in the oil price will therefore have a different impact on the total transport costs of the different modes. The total cost changes resulted from an oil price change are presented in Appendix P. The result is a change in modal split for hinterland transport, shown in Figure 8-2. The figure shows the market share of the different modes as a percentage of the total number of TEU-trips per oil price. TEU-trips is the number of TEU that are transported for all ports, the TEU are allocated to the main mode of transport. The distance of the trip is not taken into account.

From Figure 8-2 it can be seen that when oil prices increase, the share of TEU-trips for road transport will decrease. The modes rail and IWT will increase their market share. Due to the lower use of fuel per container for these two modes, the total transport costs have increased less than for road transport. Hence, their relative utility is increased and therefore the use of these modes has increased.

In the port competition model it is considered that all ports have access to the road and rail infrastructure. For transport by barge, inland waterways are necessary; these lie predominantly in North West of Europe. This could give the North Sea ports an advantage over the Mediterranean ports as they can offer a cheaper mode of
transport. This effect has however not been found in this study, as the ports with inland waterways have not increased their total market share.

![Figure 8-2 Influence of Oil Price on Modal Split](image)

### 8.2.2 Gateway ports vs Hub-ports

Besides the change in modal split, also a change in maritime transport is found. When land transportation costs increase, it might be more cost efficient to transship a container to a feeder vessel and sail it to a smaller port, closer to its final destination. This way the inland distance is reduced and the costs are lowered. This will only happen when the cost benefits of a smaller hinterland distance are larger than the incurred extra feeder costs.

The use of feeder transport is dependent on the maritime cost coefficient and on the influence of a changing oil price on feeder transport costs. When the oil price increases also the feeder costs will increase, making it less attractive to use a feeder service to reach a gateway port. The maritime cost coefficient in the utility function is larger than the hinterland cost coefficient; increasing feeder costs will therefore decrease the utility quicker than hinterland transport costs.

Figure 8-3 shows the share of imports for a gateway port and a hub-port. Feeder vessels transship containers from a large hub-port to a smaller gateway port, which does not attract any deep sea vessels. The share of imports of a gateway port therefore shows the use of feeder transport. From Figure 8-3 it can be seen that the share of feeder transport decreases when the oil prices increase.
8.2.3 Coastline Choice Deep Sea Transport

When the oil price increases, the deep sea maritime costs per nautical mile will increase as well. As the maritime costs are also dependent on sailing distance it is hypothesized that ports along the further located North Sea coast will lose containers to the nearer located Mediterranean ports.

Figure 8-4 shows the share of TEU that are transhipped and imported for the hub-ports per coastline. For the North Sea hub-ports this includes imports from the North Sea ports and imports from the Baltic ports that are feedered from the North Sea hub-ports. The Atlantic and Adriatic ports are feedered from Mediterranean hub-ports. It can be seen that changing oil prices have no influence on the choice of coastline for the deep sea vessel. The cost differences are little, so no transport change in deep sea transport per coastline is observed.

For deep sea ships the maritime costs are also dependent on ship size. For this study the average deep sea vessel size and average sailing distance per coastline is used. Deep sea vessels that call ports along the North Sea are on average larger, and therefore more fuel efficient per container, than ships that call ports along the Mediterranean Sea. This means that although ships that sail to a North Sea port have a longer sailing distance, the total maritime costs will only be a little higher than for Mediterranean ports, as the costs per nautical mile are lower for larger ships.
8.2.4 Effects on Coastline Imports

Finally, the effects of a changing oil price on transport costs affect the container imports per coastline. The imports per coastline are presented in Figure 8-5 they are measured in the number of imported TEU, so excluding transhipment.

For the North Sea coastline it can be seen that the import will remain almost the same. The coastlines with feeder ports, the Baltic, Atlantic, and Adriatic, will have lower imports when the oil price increases. The Mediterranean ports will have higher container imports, largely at the expense of ports in the Adriatic Sea and along the Atlantic. The imports for the ports around the Black and Aegean Sea stay stable. This is mainly because there is not much competition between the few ports in this area.

The change in import for the Mediterranean and the Adriatic Sea ports based on oil price changes is the largest and most interesting. From the utility function, described in section 7.1, it can be seen that number of port calls has a positive influence on ports attractiveness. When the number of containers to the Mediterranean ports increase the number of port calls will increase as well, which will than make the port even more attractive. If the number of port calls does not increase, than the ships will have to become larger which means the maritime costs will lower, making the Mediterranean ports more attractive as well.
The imports per coastline for the complete European Mainland are analysed. The change in imports per coastline is relatively small, however for highly competitive hinterland regions, such as Switzerland, located in the centre of Europe the shift in coastline imports is much larger.

The imports for Switzerland for the coastlines of the North Sea, Mediterranean Sea, and Adriatic Sea are presented in Figure 8-6. The import from ports located along the Baltic Sea, Atlantic and Black Sea are negligible.

When the oil price increases, ceteris paribus, the market share for the Mediterranean ports increases, whereas the North Sea coast loses market share, see Figure 8-6. This is partly due to the fact that the deep sea maritime transport costs increase less for the Mediterranean ports than for the North Sea ports and largely due to the increased hinterland costs from the further located North Sea ports. The Adriatic Sea ports lose market share as feeder transport has become more expensive and cannot compete with hinterland transport from the Mediterranean ports.

This means that an increase in oil price affects coastline port choice of hinterland regions located in the centre of Europe.
8.4 Conclusions Oil Price Scenario

The application of the port competition model is tested using a showcase. A scenario with varying oil prices is used to analyse the development of container imports per coastline. The oil price scenario is chosen because oil price has a direct influence on transport costs which differs per transport mode. The results show that higher oil prices lead to an increase in import for the Mediterranean ports and unchanged import for the North Sea and Black Sea ports. The ports along the Baltic Sea, Adriatic Sea and the Atlantic will see their container imports decrease. For Switzerland, located in the heart of Europe, the shift of imports per coastline is significant. Higher oil prices lead to an increased import from the Mediterranean ports and a decline in imports from the North Sea ports. Besides port imports, modal split changes and the use of feeder services are also analysed by the model. An increasing oil price results in a higher use of inland waterway and rail transport, at the expense of road transport.

Overall, it can be concluded that cost increases (caused by oil price increases or other factors) lead to increasing pressure to realize scale economies both in deep-sea transport and hinterland transport.
9 CONCLUSIONS & RECOMMENDATIONS

In this chapter the conclusions and recommendations of this study are presented. These are followed by a discussion about possible applications and review of the model.

9.1 Conclusions

In this study, a port choice model is designed and developed in order to model container imports from Asia for 31 European container ports. This model can analyze the effect of global trends and policy changes concerning the container transport sector on the volume of imports per port, in order to analyze the development of container port competitiveness. Furthermore, modal split changes and the use of feeder services can be analyzed. The developed port choice model is unique as it covers the complete European mainland, containing 231 hinterland regions.

A review of port choice literature has provided an elaborate overview of important port choice factors. From this overview, twelve port choice factors are selected and used for statistical analysis. This has resulted in five significant port choice factors: hinterland transport costs, maritime transport costs, hinterland transport time, number of port calls and a negative dummy variable for rail transport.

Increasing hinterland transport costs, maritime transport costs and hinterland transport time all negatively influence a port’s utility. An increasing number of deep sea port calls has a positive effect on the port’s utility, whereas the use of rail transport has negative effect on the utility of the mode rail. From the factor coefficients found in the statistical analysis, the ‘value of time’ is calculated; for the hinterland transport a value of €30/TEU/day is found. This is higher than the €9/TEU/day found, when considering the complete transport chain. This is in line with literature.

Further analysis has shown that an increasing number of rail and IWT services increases the utility of a port and therefore increases the competitiveness of a port. These service variables are included in this study thanks to the recent introduction of the intermodal link database that offers scheduled service timetables for intermodal
transport in Europe. The rail and IWT service variables are however not used as input for the port choice model, as their relative weight cannot be calculated at the same time as the aforementioned five port choice factors.

The developed port choice model, using the five significant port choice factors, has a $R^2$ value of 0.77, whereas the model based on only cost and time factors has a $R^2$ value of 0.64. This means that the developed port choice model, using the five significant port choice factors, performs 20% better. The modelling approach has therefore shown that the prediction power of logit model can be increased using port and mode specific variables.

Using this model, port competitiveness development is tested using a changing oil price scenario. The oil price scenario is chosen because oil price has a direct influence on transport costs but differs per transport mode. Higher oil prices lead to an increase in import for the Mediterranean ports and unchanged import for the North Sea and Black Sea ports. The ports along the Baltic Sea, Adriatic Sea and the Atlantic face lower container imports as a response to higher oil prices, as short sea transport becomes unattractive. The change in total imports per coastline is small but for example for Switzerland, located in the heart of Europe, the shift of imports per coastline is significant. Higher oil prices lead to an increased import from the Mediterranean ports and a decline in imports from the North Sea ports.

An increasing oil price also results in a higher use of inland waterway and rail transport, at the expense of road transport. This is due to the smaller increase in transport costs for the intermodal transport modes. However, the increase of market share for these modes has no positive influence on the total container import of ports that offer intermodal transport.

It can be concluded that oil price changes will not lead to major changes in competitiveness of ports in general, but do influence port competitiveness for highly competitive hinterland regions, which are served by different coastlines.
9.2 Recommendations

Due to the models generic nature it can be applied for different uses, which also means that it will have its shortcomings for these different goals. This would mean that different recommendation can be given for different model application. In this section however, only a limited number of general recommendations for further research and model improvements are given.

Improve Input Data

The outcomes of the model are influence most by the utility function that includes the statistically significant port choice factors and their weight coefficients, both are found from the statistical analysis. Improving the port choice data and Origin Destination data, used as input for the statistical analysis, therefore improves the model.

- In this study twelve port choice factors are used. If reliable and comparable data were available for some of the excluded port choice factors, then the modelling could become better. Especially port choice factors such as port reliability, port efficiency, and port service would be of great interest and possibly of influence on port choice.

- For the currently used port choice factors, more accurate data would improve the model. For example, the labour cost component used in this study is considered to be similar around the whole of Europe, in reality this will differ per region. Secondly, the deep sea maritime costs are calculated per coastline. If maritime costs would be available per port this would increase the accuracy of the model as well.

- The container Origin Destination data used in the regression analysis is retrieved form the simulated OD matrix. The OD matrix has been simulated as there is no publically available data on container transport to the hinterland. Other studies use container flow data for a specific region or trade data as basis for a simulated OD matrix. It would be of great help from both scientific and business perspective if the European Union would gather Bill of Lading data from customs, and make it publically available via for instance Eurostat. This would fit in the ‘open data’ policy of the EU, to make public data open for everyone to use.

Expand Scope of Model

The current model looks at container imports for the European mainland from Asia. The container port competitiveness is however also based on other aspects that have outside the scope of this research.

- The model could include container imports and exports, from not only Asia but also other parts of the world. This way also port choice factors that are related to export flows can be incorporated in the model.
Another improvement could be implementing capacity related factors and constraints. These constraints can be on hinterland infrastructure such as the railway capacity or on the ports, such as maximum ship length. These capacity constraints can become of importance with the current introduction of the 16,000 TEU containerships.

**Modelling Method**

In this study a multinomial logit model is used as basis for the distribution of container trips. In the multinomial logit function each alternative is assumed to be independent, in practice this is not always the case. Ports situated along the same coastline have similar maritime costs for example. It would then be logical that choosing a coastline and then choosing a port, is modelled separately. This can be done using a nested logit method (Ortuzar and Willumsen, 2011).
9.3 Model Applications

The port choice model is a generic model for container port imports and container flows to the European hinterland. The power of the model is to identify how and to what extent container flow characteristics will change when changes in the port choice factors occur. The model is generic which means it can be applied for different study purposes concerning container transport. Basically the model can be used as a quick scan tool on three different levels: the micro, meso and macro level.

Micro
On the micro level, the effect of local changes on port imports and market share of hinterland modes can be analysed. A client could for example be a port authority that would like to know what the effect is of toll charges in the port area on its competitiveness. A loss in competitiveness could lead to a decrease in container imports which could cost the port money.

Although it is very difficult to compute specific ports competitiveness, with all of the local factors that influence it, a general analysis of the effect of increasing hinterland transport costs on port competitiveness can be made.

Meso
The meso level looks at the effect of continental trends and policy changes. For example the introduction of European environmental, transport or tax policies influence transport flows on a large scale that affects more than just a single port.

A client could for example be the European Commission, which would like to see what affect a better railway infrastructure, with higher average speeds, has on the modal split of container transport flows from Asia. These changes are not local as they affect all the flows and ports.

Macro
The macro level includes global trends that affect the complete container transport system and are difficult to steer or influence. These changes can include technological, environmental, social or economic changes. For instance the influence of changing oil prices on ports competitiveness.

The model is theoretically best suited for this type of analysis as both the trends and the model have no local components. The model includes cost structures of different modes and different routes with demand based on GDP. Changing general variables such as oil price or GDP growth can be used easily in this model.
REFERENCES


APL. 2013. Surcharge Flyers for Europe Trades.


AUCKLAND, P. O. 2013. Truck Service Statistics.

B-MOBILITY 2010. INFRASTRUCTUURPRIJSZETTING BIJ HET SPOOR.


BIMCO. 2013. Container Forecast [Online].

BOVAG 2013. Opbouw Dieselprijs.


DAL. 2012. Terminal Handling Charges Europe.


DAVYDENKO, I., ZHANG, M. & TAVASSZY, L. 2012. Assessment of SMART-CM platform benefits as the result of shorter transport time. TNO.


ECORYS 2013. Intermodal links.


INDEX, W. C. 2013. World Container Index.


MAERSK. 2013a. *Maersk Fleet* [Online].
MDS-TRANSOMODAL-LIMITED 2011. Market study on the potential cargo capacity of the North Adriatic ports system in the container sector. NAPA.
MOVE, D. 2010. ETISplus.
MUELLER, M. A. 2013b. RE: Interview Jan Nater ECT.
MUELLER, M. A. 2013c. RE: Interview Jan Willem Koeman Port of Rotterdam.
MUELLER, M. A. 2013d. RE: Interview Mo Zhang TU Delft.
NOTTEBOOM, T. 2013. Recent traffic dynamics in the European container port system. Port Technology International.
OECD 2010. TRANSCONTINENTAL INFRASTRUCTURE NEEDS TO 2030 / 2050.
OOCL. 2009. EUROPEAN TERMINAL HANDLING CHARGES/PORT SECURITY CHARGES ALL TRADE LANES.
POR 2013. Modal Split Containers.
PTV 2013. PTV Map&Guide.
PURVIN & GERTZ 2009. Impacts of the EU refining industry IMO specification fuel.

84

RETRACK 2012. Potential for Eurasia land bridge corridors & logistics developments along the corridors.


UNESCAP Container Growth.

UNESCAP 2012. TRADE AND DEVELOPMENT REPORT.


LIST OF FIGURES

Figure 1-1 North and South route to Switzerland.............................................3
Figure 1-2 Scope Area and Ports........................................................................6
Figure 1-3 Report Structure .............................................................................7
Figure 2-1 Transport Chain ..............................................................................9
Figure 2-2 Selected Port Choice Factors and their position in the Transport Chain ...16
Figure 3-1 Conceptual Port Choice Model ........................................................18
Figure 3-2 Classic Transport Model (blue) & Port Choice Transport Model (green)...19
Figure 3-3 Port Choice Model Method .............................................................19
Figure 3-4 Multinomial Logit Function .............................................................22
Figure 4-1 Maritime Cost per TEU for the route Asia - North Sea ....................25
Figure 4-2 Designed Maritime Sea Loops ..........................................................27
Figure 4-3 Number of Direct Service from Asia per week ...............................28
Figure 4-4 Modelling Container Demand .......................................................31
Figure 5-1 Visualisation of the OD matrix construction method .......................36
Figure 5-2 Least Square Error .........................................................................41
Figure 5-3 R² value .........................................................................................42
Figure 5-4 Iteration Steps ...............................................................................45
Figure 6-1 Statistical Method ..........................................................................47
Figure 6-2 Scatterplot Utility vs Total Cost.....................................................50
Figure 7-1 Imports per Coastline (number of TEU) .........................................67
Figure 7-2 Modal Split ....................................................................................67
Figure 8-1 Average annual Brent spot crude oil Prices (EIA, 2011) ....................70
Figure 8-2 Influence of Oil Price on Modal Split ..........................................71
Figure 8-3 Imports for Gateway- and Hub-ports for different oil prices ..........72
Figure 8-4 Deep Sea transport to hub-ports per Coastline ..............................73
Figure 8-5 Influence of Oil Price on Import per Coastline in number of TEU ....74
Figure 8-6 Imports for Switzerland per Coastline .........................................75
Figure 0-1 Freight Rates Asia-Europe .............................................................98
Figure 0-2 Fuel Consumption for Ship Size and Service Speeds ....................99
Figure 0-3 Fuel Consumption as function of Sailing Speed .............................100
Figure 0-4 Fuel Consumption as a function of Ship Size ................................101
Figure 0-5 Modelled Fuel Consumption .........................................................102
Figure 0-6 Ship Price vs Capacity ..................................................................104
Figure 0-7 Maritime Costs per TEU per year ..................................................105
Figure 0-8 Maritime Costs per TEU for different Fuel Prices .........................106
Figure 0-9 Maritime Cost per nautical mile ................................................................. 106
Figure 0-10 Maritime Cost per TEU from Asia to Europe ........................................... 107
Figure 0-11 Water Depth per Port ............................................................................... 115
Figure 0-12 Water Draft Ships .................................................................................... 116
Figure 0-13 NUTS regions aggregation operation ....................................................... 125
Figure 0-14 Speed IWT ................................................................................................. 127
Figure 0-15 Speed Train ............................................................................................... 128
Figure 0-16 Speed Truck .............................................................................................. 128
Figure 0-17 Average annual Brent spot crude Oil Prices .............................................. 137
Figure 0-18 Diesel Prices per Litre .............................................................................. 138
Figure 0-19 Bunker Fuel Price Development ............................................................... 139
Figure 0-20 Absolute Error .......................................................................................... 140
Figure 0-21 Weighted Least Square Error ................................................................... 141
Figure 0-22 Absolute Mode Error ............................................................................... 141
Figure 0-23 Relation Scheme ....................................................................................... 142
Figure 0-24 Hinterland Cost for different Oil Prices for a distance of 500 km .......... 144
Figure 0-25 Total Maritime Cost per Coastline for different Oil Prices ....................... 144
LIST OF TABLES

Table 2-1 Port Choice Factors from Literature .......................................................... 12
Table 4-1 Overview of Maritime Cost factors ............................................................. 26
Table 4-2 Hinterland Costs ....................................................................................... 30
Table 4-3 Trade Demand Coefficients ........................................................................ 33
Table 5-1 Literature on Value of Time ....................................................................... 39
Table 5-2 Results Performance Indicators with Optimised Values ......................... 42
Table 5-3 Sensitivity Analyses Generalised Cost Function ...................................... 43
Table 6-1 Number of Observations and TEU used per Coastline ......................... 49
Table 6-2 Results General Regression Analyses ....................................................... 53
Table 6-3 Results Regression Analyses Validation .................................................. 57
Table 6-4 Weight vs Unweight regression ................................................................. 60
Table 6-5 Results Regression Analyses within Coastlines ....................................... 61
Table 6-6 Regression Results per Mode .................................................................... 62
Table 7-1 Comparison Generalized Cost function with Utility Function ................ 65
Table 7-2 Sensitivity Analysis Utility Function ......................................................... 66
Table 0-1 Bunker Fuel Types ................................................................................... 102
Table 0-2 Maritime Ship Services ............................................................................ 108
Table 0-3 Transport Times per Coastline .................................................................. 109
Table 0-4 Maritime Transport Time per Port ............................................................. 110
Table 0-5 Port Costs ................................................................................................ 112
Table 0-6 Number of Short Sea Services and Frequencies per Port ...................... 117
Table 0-7 Intermodal Frequencies and Services ...................................................... 119
Table 0-8 ETIS code structure ................................................................................ 124
Table 0-9 NUTS aggregation operation ................................................................. 125
Table 0-10 Average Distances ................................................................................. 125
Table 0-11 Container Transport Data ..................................................................... 130
Table 0-12 Multiplication Factors ........................................................................... 131
Table 0-13 Harmonized Container Transport Data ................................................. 132
Table 0-14 Port Throughput 2010 ............................................................................ 133
Table 0-15 Hinterland Mode availability and Modal Split ...................................... 135
Table 0-16 Bunker Fuel Prices ................................................................................. 138
Table 0-17 Correlations Table ................................................................................ 143
**GLOSSARY**

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
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<tr>
<td>Captive Hinterland</td>
<td>a region for which a port has a dominant position</td>
</tr>
<tr>
<td>Container</td>
<td>a steel box used for the transportation of cargo (measured in TEU)</td>
</tr>
<tr>
<td>Contestable Hinterland</td>
<td>a region for which no port has a dominant position</td>
</tr>
<tr>
<td>Deep sea transport</td>
<td>intercontinental, cross ocean shipping</td>
</tr>
<tr>
<td>Destination</td>
<td>the place a container is transported to</td>
</tr>
<tr>
<td>European mainland</td>
<td>continental Europe, excluding European islands (and in this study Scandinavia)</td>
</tr>
<tr>
<td>Feeder transport</td>
<td>transport by sea going vessel, distributing/collecting cargo from/to hub ports to/from smaller gateway ports</td>
</tr>
<tr>
<td>Gateway port</td>
<td>a port where the vast majority of the cargo is transhipped between maritime transport and land base transport</td>
</tr>
<tr>
<td>Hinterland</td>
<td>a region lying inland from a port (achterland)</td>
</tr>
<tr>
<td>Hub port</td>
<td>a port that is neither a gateway- nor a transhipment port</td>
</tr>
<tr>
<td>Import</td>
<td>a commodity, article or service brought in from abroad</td>
</tr>
<tr>
<td>Intermodal</td>
<td>involving two or more modes of transport conveying a good, without handling the good itself</td>
</tr>
<tr>
<td>IWT Services</td>
<td>scheduled inland waterway transport, with a fixed origin and destination</td>
</tr>
<tr>
<td>Matrix</td>
<td>a rectangular array of quantities or expressions in rows and columns that is treated as a single entity</td>
</tr>
<tr>
<td>Maritime transport</td>
<td>transport by ship</td>
</tr>
<tr>
<td>Modal split</td>
<td>the share of transport using a specific mode</td>
</tr>
<tr>
<td>Mode</td>
<td>means of transport (e.g. by road, by rail etc…)</td>
</tr>
<tr>
<td>Origin</td>
<td>starting point</td>
</tr>
<tr>
<td>Port</td>
<td>a place or area where ships are (un)loaded, harbour</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
</tr>
<tr>
<td>-------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------</td>
</tr>
<tr>
<td>Rail Services</td>
<td>scheduled rail transport, with a fixed origin and destination</td>
</tr>
<tr>
<td>Route</td>
<td>a course or combination of paths taken in getting from a starting point to a destination</td>
</tr>
<tr>
<td>Short Sea Shipping</td>
<td>coastal shipping, transport by sea, includes feeder transport</td>
</tr>
<tr>
<td>Supply chain</td>
<td>the sequence of processes involved in production and distribution of a commodity</td>
</tr>
<tr>
<td>Terminal</td>
<td>a facility where ships are (un)loaded, located in a port</td>
</tr>
<tr>
<td>Transhipment</td>
<td>the shipment of a container to an intermediate destination, used to change from means of transport</td>
</tr>
<tr>
<td>Transhipment port</td>
<td>a port where the vast majority of the cargo is transhipped from one ship to another ship</td>
</tr>
<tr>
<td>Transport(ation)</td>
<td>the movement of goods from one place to another by means of a vehicle</td>
</tr>
<tr>
<td>Utility</td>
<td>the state of being useful, profitable, or beneficial (nut)</td>
</tr>
</tbody>
</table>
## ABREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EFTA</td>
<td>European Free Trade Association</td>
</tr>
<tr>
<td>GC</td>
<td>Generalized Costs</td>
</tr>
<tr>
<td>IWT</td>
<td>Inland Waterway Transport</td>
</tr>
<tr>
<td>MNL</td>
<td>Multinomial Logit</td>
</tr>
<tr>
<td>TEU</td>
<td>Twenty foot Equivalent Unit</td>
</tr>
<tr>
<td>THC</td>
<td>terminal handling charges</td>
</tr>
<tr>
<td>Vot</td>
<td>value of time</td>
</tr>
</tbody>
</table>
APPENDICES
A. Multinomial Logit

The multinomial logit model (MNL) is a discrete choice model which has specific properties which makes it so useful for (route) choice modelling. The MNL function is written in the form seen in Equation 12. With \( P_{ijm} \) being the probability of alternative ijm and \( U_{ijm} \) being the utility of that alternative. The multinomial logit function is derived from the utility theory.

\[
P_{ijm} = \frac{e^{U_{ijm}}}{\sum_i \sum_m e^{U_{ijm}}} \tag{Equation 12}
\]

Utility Theory

According to utility travel choice theory it is assumed that a trip is only made when the utility of the destination is higher than the utility of the origin and the disutility (costs) of the trip combined (Bovy et al., 2006), see Equation 13. In the utility theory it is assumed that actors behave rational and maximize their utility. Furthermore it is assumed that the actors have perfect information about the market and that switching between alternatives is costless.

For this study the demand for containers is given and all purposes for trips are treated equal. The utility (choice) for the import of a container is already established, which means that for all trips in this study Equation 13 has been met. The utility of the origin and destination are not of importance they are set to zero (0). As the actor wants to maximize utility it will want to minimize disutility \( Z_{ijm} \), see Equation 14. The disutility can be written as a negative utility and from now on will be called the utility.

\[
U_j - U_i - Z_{ijm} > 0 \tag{Equation 13}
\]

\[
\max(-U_{ijm}) = \min(Z_{ijm}) \tag{Equation 14}
\]

\( U_i \) = utility origin

\( U_j \) = utility destination

\( Z_{ijm} \) = disutility trip

The utility function is subject to the origin i, destination j and mode m (\( U_{ijm} \)). It has a deterministic (\( V_{ijm} \)) and a random component (\( \varepsilon_{ijm} \)), see Equation 15. The deterministic component (\( V_{ijm} \)) is the sum of observed utility, in our case, a linear function of different (observed) attributes (\( X_{ijm} \)) and their coefficients (\( \alpha_n \)), see Equation 16. The attributes (\( X_{ijm} \)) and their values are known but their coefficients (\( \alpha_n \)) are not. The coefficients will be found using a regression analysis on the linearized MNL function, which can be performed due to the IIA property. The random component (\( \varepsilon_{ijm} \)) is used for the unobserved factors that influence choice.

\[
U_{ijm} = V_{ijm} + \varepsilon_{ijm} \tag{Equation 15}
\]
The routes with the highest utility are chosen, for a destination \( j \) routes from different ports \( i \) using different modes \( m \) are considered. When multiple alternatives are available route \( x \) (a combination of port \( i \) and mode \( m \)) is chosen above route \( y \) when the utility of alternative \( x \) is higher than that of \( y \), see Equation 17. Which becomes Equation 18.

\[
U_x > U_y
\]

Equation 17

\[
V_x + \varepsilon_x > V_y + \varepsilon_y
\]

Equation 18

**Derivation Logit model**

The probability of selecting alternative \( x \) is given in Equation 19. The disturbances \( (\varepsilon_{ijm}) \) are assumed independent, identically distributed (IID) according to a Gumbel distribution with scale parameter \( \mu \). When this is the case, the logit function can be written as found in Equation 20, with variance parameter \( \mu \) (Ben-Akiva and Lerman, 1985).

\[
\text{Prob}[\text{select } x] = \text{Prob}[V_x + \varepsilon_x > \max (V_y + \varepsilon_y)]
\]

Equation 19

\[
\text{Prob}[\text{select } x] = \frac{e^{\mu V_x}}{\sum_y e^{\mu V_y}}
\]

Equation 20

For this study, Equation 20 is rewritten in order to be useful. Alternative \( x \) can be split into an origin part (port \( i \)), a destination (hinterland region \( j \)) and a mode (mode \( m \)), see Equation 21. A new utility function can be found when the coefficients \( (\alpha_n) \) are standardized for the variance parameter \( \mu \), see Equation 22 (Bovy et al., 2006). When these are combined Equation 23 is found.

\[
P_{ijm} = \frac{e^{\mu V_{ijm}}}{\sum_i \sum_m e^{\mu V_{ijm}}}
\]

Equation 21

\[
U_{ijm} = \mu V_{ijm} = \mu x_1 X_{1(ijm)} + \cdots + \mu x_n X_{n(ijm)}
\]

Equation 22

\[
P_{ijm} = \frac{e^{U_{ijm}}}{\sum_i \sum_m e^{U_{ijm}}}
\]

Equation 23

**Linearizing MNL**

For the linear regression, the logit function must be written as a linear function. The logit function has the property of Independence from Irrelevant Alternatives (IIA). This is usually explained as a negative property with its famous blue/red bus example, but can also be used in its advantage. The IIA property states that the ratio or probability of any two alternatives is entirely unaffected by the systematic utilities of any other alternative (Ben-Akiva and Lerman, 1985). This property is also known
as the first axiom or choice axiom of McFadden. The property of the IIA is mathematically shown in Equation 24.

\[
P_{ijm} = \frac{\sum_{m=1}^{M} \sum_{l=1}^{L} e^{U_{ijm}}}{\sum_{m=1}^{M} \sum_{l=1}^{L} e^{U_{ijm}} - U_{basic}} = e^{U_{ijm} - U_{basic}} \quad \text{Equation 24}
\]

If all routes to a hinterland region \(j\) are compared with a basic route, than using the property stated above, the Berkson-Theil method (Ben-Akiva and Lerman, 1985) can be used. This method is used to estimate parameters of a multinomial logit model.

The probability of a route \((P_{ijm})\) can be found by dividing the number of containers on that route \((Q_{ijm})\) by the total number of containers to that region \((Q_j)\). In the final prediction model, \(Q_{ijm}\) is found using the utility function. However in this case the coefficients of the utility function will need to be found. Therefore the \(Q_{ijm}\) is estimated using a Generalised Cost function (GC). This is done in chapter 0.

When \(Q_{ijm}\) is found, \(P_{ijm}\) can be calculated, see Equation 25. From the regular MNL function Equation 26 is found.

Using the IIA property of unaffected ratio of utility of two alternatives Equation 27 can be formulated. It says that the ratio between \(P_{ijm}\) and \(P_{basic}\) will not change even if the utility will change. The basic route is a route from every hinterland region \(j\) to the port of Antwerp using transport by road.

In Equation 28 the normal logarithm of Equation 27 is taken in order to get rid of the \(e\) to the power of \(U\). This leaves a linear function for the utility \(U\).

When Equation 27 is entered in Equation 28 then Equation 29 is found. Combing Equation 28 and Equation 29 gives the final equation that is used for the regression analysis, Equation 30.

\[
P_{ijm} = \frac{Q_{ijm}}{Q_j} \quad \text{Equation 25}
\]

\[
P_{ijm} = e^{U_{ijm}} \quad \text{Equation 26}
\]

\[
P_{ijm} = \frac{\sum_{m=1}^{M} \sum_{l=1}^{L} e^{U_{ijm}}}{\sum_{m=1}^{M} \sum_{l=1}^{L} e^{U_{ijm}} - U_{basic}} = e^{U_{ijm} - U_{basic}} \quad \text{Equation 27}
\]

\[
\ln \left( \frac{P_{ijm}}{P_{basic}} \right) = \ln(P_{ijm}) - \ln(P_{basic}) = U_{ijm} - U_{basic} \quad \text{Equation 28}
\]
\[ \Delta U = U_{ijm} - U_{\text{basic}} \]
\[ = \alpha_1 (X_{1(ijm)} - X_{1(\text{basic})}) + \cdots + \alpha_n (X_{n(ijm)} - X_{n(\text{basic})}) \quad \text{Equation 29} \]

\[ \ln \left( \frac{P_{ijm}}{P_{\text{basic}}} \right) = \Delta U = U_{ijm} - U_{\text{basic}} = \alpha_n (X_{n(ijm)} - X_{n(\text{basic})}) \quad \text{Equation 30} \]
B. **Maritime Transport Costs**

Maritime cost consists of fixed costs and variable costs. When costs per unit are found they can be applied to different alternative routes. The maritime costs are calculated as the freight rates are very volatile and difficult to model with.

**Freight Rates**

The maritime costs have been calculated and used as they are much more stable than the freight rates. The freight rates can however be used to validate the maritime costs and to recognize that there is a difference between cost and price.

The freight rates per TEU for the leg Asia to Europe are presented in Figure 0-1. The data uses price in US dollars, for simplicity the Euro price is given as well. The graph is based on data from different sources (UNCTAD, 2009) (BIMCO, 2013) (Index, 2013). It is clear that the rate is very volatile with prices ranging between $500 and $2,000. The calculated average price is $1,269 with a standard deviation of $468.

The main drivers for the price are demand and supply for transport. After 2008 the demand decreased very fast due to the financial crisis. In 2010 the economic crisis hit Europe which shows another decrease in demand for products. Currently the supply for transport is increasing quite rapidly with the introduction of the ultra large containerships. This will drop prices again is expected.

![Figure 0-1 Freight Rates Asia-Europe](image-url)
Variable Costs
The variable costs mainly consist of fuel costs. Other variable costs are toll costs, surcharges and container costs. The fuel costs consist of fuel consumption and fuel prices. The fuel consumption depends on sailing speed and ship size.

Fuel Consumption
As described in literature (Rodrigue et al., 2009) fuel consumption is directly related to vessel size and sailing speed. A larger vessel will consume more fuel per nautical mile then a smaller vessel and a higher sailing speed will burn more fuel then low sailing speeds. As fuel consumption is directly related to operating cost and emissions, carriers have a major incentive to lower fuel consumption. This has led to two major trends in container shipping, slow steaming and larger ships.

Slow steaming means that ships operate on sailing speeds between 15-18 knots, while the original design sailing speed was between 20-25 knots. Larger ships have higher fuel consumption then smaller ships, but the consumption per TEU is much lower in large ship compared to a small ship. The fuel consumption per operation speed and per ship size is presented in Figure 0-2, (Notteboom and Vernimmen, 2009).

![Figure 0-2 Fuel Consumption for Ship Size and Service Speeds](image)

For the model it is helpful if the vessel speed and vessel capacity could be changed independently. It would also be helpful if it is possible to use ship sizes that have different capacities as those mentioned in Figure 0-2, or even extrapolate fuel usage for future ships. It is therefore necessary to compute the fuel usage as a function of vessel speed and vessel capacity separately.
This is done by separately approaching the function of fuel usage for speed and capacity. For the function of speed the capacity of the vessel is not taken into account and for the function for vessel size, speed is not taken into account. This is done using the visual data from Figure 0-2, which is based on data from AXS Alphaliner and Germanisher Loyd.

**Speed**

In order to find the effect of speed on the fuel consumption a best fit curve was made for the different ship sizes with speed as variable. As the fuel consumption is known for each ship size and speed the weight of the variable speed can be found. When the weights of the variable speed for the different ships sizes is averaged a general function for fuel consumption purely based on speed is found, see Equation 31.

\[
FC = 0.0146 \times v^{2.983}
\]

*Equation 31*

FC= fuel consumption per ship in tons/day

v= vessel speed in knots

It can be seen that fuel consumption is heavily influenced by the speed, almost to the power of 3. The factor found is 2.983 which is similar to factors found in literature 2.963 by (Veldman, 2011) and 3.13 by (Cullinane and Khanna). The function is shown in Figure 0-3.

![Figure 0-3 Fuel Consumption as function of Sailing Speed](image)

**Ship size**

The same is done for ship size, for ship size Equation 32 has been derived. The elasticity factor is 0.533 which is positive and smaller than 1. It is comparable with factors found in literature, 0.417 by (Veldman, 2011) for post panama ships and 0.48 by Ryder and Chapel (Veldman, 2011). If fuel consumption is measured per TEU instead of per ship, then Equation 33 is found. The elasticity factor has now become

\[
FC = 0.0146 \times v^{2.983}
\]

*Equation 32*

FC= fuel consumption per ship in tons/day

v= vessel speed in knots

It can be seen that fuel consumption is heavily influenced by the speed, almost to the power of 3. The factor found is 2.983 which is similar to factors found in literature 2.963 by (Veldman, 2011) and 3.13 by (Cullinane and Khanna). The function is shown in Figure 0-3.

![Figure 0-3 Fuel Consumption as function of Sailing Speed](image)

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negative, which means economies of scale are applicable. The fuel consumption for ship size is visualized in Figure 0-4.

\[
FC_{\text{ship}} = 1.158 \times sc^{0.533} \quad \text{Equation 32}
\]

\[
FC_{\text{teu}} = 1.158 \times sc^{-0.467} \quad \text{Equation 33}
\]

FC= fuel consumption in tons/day
sc= ship capacity in number of TEU

\[FC = 0.00014 \times v^{2.98} \times sc^{0.53} \quad \text{Equation 34}\]

For combinations of ship size and sailing speed, Figure 0-5 gives an impression of the outcomes of the function. Based on the available data a fuel consumption indication for a ship with 18,000 TEU is made. However, newly designed ships will probably be more energy efficient so the line will probably drop.
Fuel costs currently comprise about 50% of the operation costs of a container ship (Kalli et al., 2009, Rodrigue et al., 2009). Besides the fuel consumption, also the fuel price is of great importance on the fuel costs. There are roughly two kinds of bunker fuels, heavy fuel oils and light fuel oils. The heavy fuel oils contain relatively much sulphur and are the cheapest. The light fuel oils contain only a little sulphur but are more expensive. The different fuel types and descriptions are given in Table 0-1. From Appendix M it is found that heavy bunker fuel oils cost around 85% of the oil price whereas light bunker fuel oils cost around 132% of the oil price.

Conform the IMO regulations on SECA’s (Sulphur Emission Control Area) (Kalli et al., 2009) the Baltic Sea, North Sea and Channel are declared SECA’s from 2010. This means that the fuel used in these areas can not contain more than 1% sulphur from January 2010 and not more the 0.1% from January 2015. That means that in these seas

![Figure 0-5 Modelled Fuel Consumption](image)

**Table 0-1 Bunker Fuel Types**

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Description</th>
<th>Sulphur Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Fuel Oils</td>
<td>IFO380</td>
<td>Sulphur (&lt;4.5%)</td>
</tr>
<tr>
<td></td>
<td>IFO180</td>
<td>Sulphur (&lt;4.5%)</td>
</tr>
<tr>
<td></td>
<td>LS380</td>
<td>Sulphur (&lt;1.5%)</td>
</tr>
<tr>
<td></td>
<td>LS180</td>
<td>Sulphur (&lt;1.5%)</td>
</tr>
<tr>
<td>Light Fuel Oils</td>
<td>MDO</td>
<td>Sulphur (&lt;0.1%)</td>
</tr>
<tr>
<td></td>
<td>MGO</td>
<td>Sulphur (&lt;0.1%)</td>
</tr>
<tr>
<td></td>
<td>LSMGO</td>
<td>Sulphur (&lt;0.1%)</td>
</tr>
</tbody>
</table>
only light fuel oils can be used. However, as these seas are only a small part of the total sailing distance for the ships this study will assume that all fuel used is heavy fuel.

**Toll, Surcharges & Container costs**

Another category of variable costs are toll and surcharges. The toll comprises of the toll paid for using the Suez channel. The costs differ per ship type and loading degree. For this study a fixed cost of $68 (€50) per TEU is used (Johns and Associates, 2005).

Surcharges found in the maritime sector are the BAF and CAF. The BAF is the Bunker Adjustment Factor which takes fluctuations of bunker fuel prices into account. The CAF is the Currency Adjustment Factor, which takes currency exchange rates into account. Another used surcharge is the Aden Gulf Surcharge, also called Emergency Risk Charge. This charge is used for the risk of piracy, especially in the Gulf of Aden.

For this study these charges will not be used.

The usage of a container also costs money. The container costs include capital costs, maintenance costs and storage costs. These costs are set to €1 per TEU per day.

**Fixed Costs**

The fixed costs comprise of capital, maintenance, manning, overhead, insurance and administration costs.

**Capital Costs**

The capital cost of a vessel is determined by the price of a ship, interest paid and lifetime of the vessel. With a lifetime of a vessel of 20 years and an interest rate of 8%, the annuity will be 10%. This means that the yearly capital cost is 10% of the ship price for a period of 20 years. In order to compute the capital cost, the ship price must be known.

From Drewry (Drewry, 2011) a dataset of 50 ships with their capacity and price in US dollars is retrieved for the years 2010 and 2011. In order to determine the ships price as a function of its capacity a regression analyses has been done. The elasticity factor is found to be 0.78, with an $R^2 = 0.99$. In literature Veldman found 0.733 for post panamax ships and Cullinane and Khanna found 0.759 (Veldman, 2011). This has led to Equation 35.

If the price of a ship is divided by the ships capacity, then the elasticity becomes -0.22, see Equation 36. The negative value indicates the decreasing prices per TEU, hence the economies of scale. Both functions are visualized in Figure 0-6.

\[ P_{ship} = 0.0818 \times sc^{0.78} \]  

*Equation 35*
\[ P_{\text{teu}} = 0.0818 \times SC^{-0.22} \]
\[ CC = 10\% \times P \]

\( P \) = price in US dollars
\( SC \) = ships capacity in TEU
\( CC \) = capital costs

Maintenance, Manning and Overhead

Other maritime cost factors are maintenance, insurance, administration and manning costs. Maintenance, insurance and administration cost is assumed at 4\% of the ship’s price per year. This is similar to the 3-5\% of Cullinane and Khanna ( ) but a bit lower than values mentioned by Rodrigue et al. (2009).

Manning cost is assumed as $1.000.000 per year.

Overhead costs are assumed at 10\% of the fixed costs.

Total Maritime Cost

Based on the observations and calculations done by the author, Equation 38 for maritime cost per TEU is made. This function includes capital cost, fuel cost, maintenance cost, manning cost, toll costs and container costs, with variables ship size/capacity, fuel price, sailing speed, exchange rate, sailing distance, interest rates and utilization degree.

\[ MC = \frac{\left( (c_1 + m_1) + (0.0001 + sc^{0.53}) + 0.00001 \times sc \right) \times \text{EXP} \times (0.00001 + sc^{0.53}) + 1000.000 \times (sc + sc^2)}{sc^{0.53}} \]  

\[ \text{Equation 38} \]
MC = maritime cost (in euro per teu per year)
Ci = capital interest (10%)
Mi = maintenance percentage of ship price (includes insurance, administration) (4%)
Sc = ship capacity (in TEU)
Fp = fuel price (per ton in dollars)
Di = distance sailed in a year (in nautical miles) (112500)
V = sailing speed (in knots)
Tsc = toll, surcharge & container cost per year per teu
Exri = exchange rate (dollar to euro) (1:1.35)
Ud = utilization degree (in percentage)

If the costs are split into fixed and variable cost for a vessel of 8,000 TEU sailing at 17 knots with an oil price of $100 and a 100% utilization degree, than these would be:

Variable cost of € 0.01 per TEU per nautical mile

Fixed cost of € 0.14 per TEU per hour

Figure 0-7 shows the yearly cost per TEU for an average schedule per ship size as a function of sailing speed. It clearly shows the economies of scale that are obtained when sailing with a (fully utilized) larger ship.

The influence of different fuel prices on the cost per TEU can be seen in Figure 0-8. For low speeds the differences are relatively low, but especially for higher speeds the difference in fuel price is clearly seen and increases.
The total maritime cost can also be seen as a function of ship size. The cost per TEU per nautical mile has elasticity ranges between -0.35 and -0.4 depending on the sailing speed, see Figure 0-9. This is similar to the elasticity of -0.35 from literature (Veldman, 2011).
This will lead to a TEU cost for a trip from Asia to Europe with a 100% utilization, see Figure 0-10. These costs are used in the model.

![Maritime Cost per TEU from Asia to Europe](image)

**Figure 0-10 Maritime Cost per TEU from Asia to Europe**

**Feeder and Short Sea Shipping**

For feeder transport an average ship size of 600 TEU is assumed. The average feeder distance for the scope area is set to 500 nautical miles with a sailing speed of 17 knots which is similar to the deep sea sailing speed. It is assumed that feeder transport is direct from hub-port to gateway port. This means that for a feeder service only 1 port is called. From an EU study (TML, 2010) the following cost figures have been derived: variable cost of €0.08 per TEU per nautical mile and fixed cost of €14.72 per TEU per day.

Distance and sailing speed are considered fixed, which leads to a travel time of 2.2 days. The fixed costs are therefore considered to be €32.37 per TEU per trip.

The variable costs depend fully on the fuel price. The fuel used is assumed to be IFO fuel and the same cost structure is used as for deep sea shipping. For an oil price of $100 the variable cost are €0.08/TEU/nm. When the oil price doubles the variable cost will double as well.
C. Maritime Transport Time

Ships services are designed by the carriers and are usually similar for each week. However, different services call different ports. Therefore all services are different but some general statements can be made.

Maritime Ship Services Characteristics

In order to calculate maritime transport cost and time, characteristics of the container shipping services will need to be known. Factors that are of influence are: sailing distance, sailing time, number of services, frequency of service, ports called and capacity of ship. The services, capacity, port of call and service time are found in Drewry (2011). The distances of the service roundtrips are calculated using Dataloy (2013). In total 50 ship services between Europe and Asia are analysed. Two distinct services or loops are identified, a North Sea-Asia service and a Mediterranean Sea-Asia service. This has to do with the fact that these are two different coastlines. Characteristics of the services are shown in Table 0-2. The data is presented with an average and a standard deviation per characteristic.

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>North Sea - Asia</th>
<th>Mediterranean Sea - Asia</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>Standard Deviation</td>
</tr>
<tr>
<td>Number of Direct Services</td>
<td>33</td>
<td>-</td>
</tr>
<tr>
<td>Capacity of Vessel (TEU)</td>
<td>8.462</td>
<td>2.818</td>
</tr>
<tr>
<td>Frequency service (times per week)</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Roundtrip Time (days)</td>
<td>71.5</td>
<td>7.9</td>
</tr>
<tr>
<td>Ships per Service Loop</td>
<td>9.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Port Calls per Roundtrip</td>
<td>13.3</td>
<td>2.6</td>
</tr>
<tr>
<td>- Port Calls Europe</td>
<td>4.5</td>
<td>1.6</td>
</tr>
<tr>
<td>- Port Calls Asia</td>
<td>8.6</td>
<td>2.2</td>
</tr>
<tr>
<td>Distance Roundtrip (nm)</td>
<td>22.969</td>
<td>2.301</td>
</tr>
<tr>
<td>- Distance within Europe (nm)</td>
<td>7.481</td>
<td>378</td>
</tr>
<tr>
<td>- Distance within Asia (nm)</td>
<td>15.488</td>
<td>2.276</td>
</tr>
</tbody>
</table>

From Table 0-2 the following can be concluded. There are more direct services to the North Sea then to the Mediterranean and operating larger ships. This results in a much larger flow to the North Sea compared to the Mediterranean Sea. Another major difference is the sailing distance in Europe. The roundtrip distance Suez-North Sea-Suez is twice as long as the roundtrip Suez-Mediterranean Sea-Suez. This difference in distance can also be seen in the average roundtrip time, which is a week longer for the North Sea route. Due to the longer roundtrip time but the equal
frequency of service, an extra ship is deployed. This suggests that sailing speeds are the same in both routes. When the number of calls is considered an average sailing speed of 17 knots is found.

The North Sea routes schedules call on average one more port then the Mediterranean routes in Europe, this can be explained by the fact that many ships with destination North Sea, make a transhipment stop in the Mediterranean sea, for example in Marsaxlokk or Algeciras. From these transhipment ports short sea services within the Mediterranean are deployed.

**Coastlines**

Shipping services are designed in such a way that a ship makes roundtrips and calling multiple ports in a single loop. The transport time is considered to be half of the roundtrip time. The roundtrip times differ per service loop as each service loop calls different coastlines. For this study five coastlines have been selected as possible competing coastlines. These are The Baltic Sea, North Sea, Mediterranean Sea, Adriatic Sea and Black Sea. For these coastlines design service loops are made in order to make a sound estimation of the maritime transport time per coastline.

Currently there are three direct routes deployed from Asia to Europe (Drewry, 2011). These are to the North Sea, Mediterranean Sea and to the Black Sea. Containers that have a destination to a port in the Baltic and Adriatic Sea are feedered from a transhipment hub. This will increase their transport time. The transport times per coastline are presented in Table 0-3.

<table>
<thead>
<tr>
<th>Table 0-3 Transport Times per Coastline</th>
</tr>
</thead>
<tbody>
<tr>
<td>Loop 1</td>
</tr>
<tr>
<td>Baltic Sea</td>
</tr>
<tr>
<td>Distance Europe (nm)</td>
</tr>
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<td>Distance Asia (nm)</td>
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<tr>
<td>Distance Feeder (nm)</td>
</tr>
<tr>
<td>Total Distance (nm)</td>
</tr>
<tr>
<td>Number of Ports Europe</td>
</tr>
<tr>
<td>Number of Ports Asia</td>
</tr>
<tr>
<td>Total number of Ports</td>
</tr>
<tr>
<td>Average Speed (knots)</td>
</tr>
<tr>
<td>Transport Time Sailing (days)</td>
</tr>
<tr>
<td>Transport Time Ports (days)</td>
</tr>
<tr>
<td>Transport Time Sailing Feeder</td>
</tr>
<tr>
<td>Port</td>
</tr>
<tr>
<td>------------------</td>
</tr>
<tr>
<td>Antwerp</td>
</tr>
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</tr>
<tr>
<td>Varna</td>
</tr>
<tr>
<td>Bremen</td>
</tr>
<tr>
<td>Hamburg</td>
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<td>Tallinn</td>
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<td>Bilbao</td>
</tr>
<tr>
<td>Barcelona</td>
</tr>
<tr>
<td>Valencia</td>
</tr>
<tr>
<td>Algeciras</td>
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<td>Le Havre</td>
</tr>
<tr>
<td>Marseille</td>
</tr>
<tr>
<td>Thessaloniki</td>
</tr>
<tr>
<td>Piraeus</td>
</tr>
<tr>
<td>Rijeka</td>
</tr>
<tr>
<td>Genova / Le Spezia</td>
</tr>
<tr>
<td>Venetia</td>
</tr>
<tr>
<td>Trieste</td>
</tr>
<tr>
<td>Livorno</td>
</tr>
<tr>
<td>Napoli</td>
</tr>
<tr>
<td>Taranto</td>
</tr>
<tr>
<td>GiaoTauro</td>
</tr>
<tr>
<td>Klaipeda</td>
</tr>
<tr>
<td>Riga</td>
</tr>
<tr>
<td>Rotterdam</td>
</tr>
<tr>
<td>Gdansk / Gdynia</td>
</tr>
<tr>
<td>Leixoes</td>
</tr>
<tr>
<td>Lisbon</td>
</tr>
</tbody>
</table>

Maritime Transport Time per Port
When the transport times per service loop are considered an average maritime transport time per port can be calculated, see Table 0-4.
<table>
<thead>
<tr>
<th>City</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sines</td>
<td>38,2</td>
</tr>
<tr>
<td>Constanta</td>
<td>31,3</td>
</tr>
<tr>
<td>Koper</td>
<td>38,2</td>
</tr>
</tbody>
</table>
For the port handling cost the terminal handling charges (THC), International Shipping and Port Facility Security Code (ISPS) and documentation fee are considered (B/L). The port dues are not taken into account. When the mentioned charges are added, the total port handling cost as used in this study, is found, see Table 0-5.

<table>
<thead>
<tr>
<th>Port</th>
<th>Terminal Handling Charge in €</th>
<th>ISPS and B/L</th>
<th>Total € per Container</th>
<th>Total € per TEU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
<td>160</td>
<td>50</td>
<td>210</td>
<td>131</td>
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<tr>
<td>Zeebrugge</td>
<td>160</td>
<td>50</td>
<td>210</td>
<td>131</td>
</tr>
<tr>
<td>Varna</td>
<td>150</td>
<td>50</td>
<td>200</td>
<td>125</td>
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<td>Bremen</td>
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<td>256</td>
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<td>160</td>
</tr>
<tr>
<td>Tallinn</td>
<td>113</td>
<td>50</td>
<td>163</td>
<td>102</td>
</tr>
<tr>
<td>Bilbao</td>
<td>157</td>
<td>50</td>
<td>207</td>
<td>129</td>
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<tr>
<td>Barcelona</td>
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<td>213</td>
<td>133</td>
</tr>
<tr>
<td>Valencia</td>
<td>163</td>
<td>50</td>
<td>213</td>
<td>133</td>
</tr>
<tr>
<td>Algeciras</td>
<td>163</td>
<td>50</td>
<td>213</td>
<td>133</td>
</tr>
<tr>
<td>Le Havre</td>
<td>177</td>
<td>50</td>
<td>227</td>
<td>142</td>
</tr>
<tr>
<td>Marseille</td>
<td>182</td>
<td>50</td>
<td>232</td>
<td>145</td>
</tr>
<tr>
<td>Thessaloniki</td>
<td>111</td>
<td>50</td>
<td>161</td>
<td>101</td>
</tr>
<tr>
<td>Piraeus</td>
<td>117</td>
<td>50</td>
<td>167</td>
<td>104</td>
</tr>
<tr>
<td>Rijeka</td>
<td>149</td>
<td>50</td>
<td>199</td>
<td>124</td>
</tr>
<tr>
<td>Genova / Le Spezia</td>
<td>154</td>
<td>50</td>
<td>204</td>
<td>128</td>
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<td>Venetia</td>
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<td>Trieste</td>
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</tr>
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<td>Livorno</td>
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</tr>
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<td>Napoli</td>
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<td>207</td>
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</tr>
<tr>
<td>Taranto</td>
<td>157</td>
<td>50</td>
<td>207</td>
<td>129</td>
</tr>
<tr>
<td>Giaoi Tauro</td>
<td>157</td>
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<td>207</td>
<td>129</td>
</tr>
<tr>
<td>Klaipeda</td>
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<td>50</td>
<td>138</td>
<td>86</td>
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<td>Riga</td>
<td>105</td>
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<tr>
<td>Rotterdam</td>
<td>188</td>
<td>50</td>
<td>238</td>
<td>148</td>
</tr>
<tr>
<td>Gdansk / Gdynia</td>
<td>76</td>
<td>50</td>
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<td>79</td>
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<td>Leixoes</td>
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<td>50</td>
<td>193</td>
<td>121</td>
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<tr>
<td>Lisbon</td>
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<td>50</td>
<td>193</td>
<td>121</td>
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<td>-------</td>
<td>------</td>
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<td>-----</td>
<td>------</td>
</tr>
<tr>
<td>Sines</td>
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<td>50</td>
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<td>Koper</td>
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<tr>
<td>Average</td>
<td>148</td>
<td>50</td>
<td>198</td>
<td>124</td>
</tr>
<tr>
<td>SD</td>
<td>30</td>
<td>0</td>
<td>30</td>
<td>19</td>
</tr>
</tbody>
</table>
E. Water Depth

The availability of infrastructure is found to be an important factor for port choice. The infrastructure in a port comprises of different elements such as quays, cranes, roads, railways, IT systems etc... In this study one element is chosen from the infrastructure pallet, which is water depth.

Water depth is found to be one of the most important elements because it is very expensive to deepen the port and the entry to the port. Secondly it has a major impact on the size of ship that can enter a port. Larger ships have a larger water draft and can only enter deep sea ports.

Design Limitations

The limitations of draft can be categorized in two basic categories. The category channels & straits and the category ports & terminals. For the first category examples are the Panama Channel, the Suez Channel, the Malacca Strait and the Sunda Strait. Most global traffic passes these sites. Deepening these sites is very expensive or even impossible. Many ships are designed to fall within the limitations of these places; these design dimensions have been called the Panamax, Suezmax and Malaccamax. These sites will only be adapted when a leap in ship size has been made, as for instance the New Panama Channel is being constructed after the Post-Panamax ships have been vastly deployed.

The second category depth limitations for container ships are caused by local infrastructure like bridges, slushes and shallow terminals. These limitations usually do not impact the design of general and global oriented ships. Therefore a limitation in this category will lead to a lower number of port calls, the ships simply cannot berth at these places.

Port Limitations

The maximum depths of the ports are presented in Figure 0-11 (Containerisation-International, 2011). Currently the largest container ships have a maximum water draft of 16 meters. About half of the ports in this study have a water depth of at least 16 meters and can therefore receive the largest container vessels. However, most liner vessels are smaller (4.000 - 8.000 TEU) which can enter most ports. It is for deep ships still possible to enter more shallow ports, this usually when they are not maximally loaded and when they sail during high tide.
Ship Design

Besides infrastructural limitations also ship design is important when looking at water depth. What capacity do ships have for a certain water depth?

The maximum (water) draft of 46 vessels is analysed and presented in Figure 0-12. The ships data was retrieved from the fleet of container ships of Maersk (Maersk, 2013a). A regression analyses is made which shows an elasticity of 0.19. This fits with the literature which gives elasticity’s between 0.168 and 0.272 (Veldman, 2011). It shows that although ships become larger they do not become much deeper. Instead they will become longer, wider and higher. This will off course affect the port and terminal infrastructure as larger cranes and longer quays will be necessary, the implications of this is however out of the scope of this study.

When the depth elasticity would be extrapolated for the Suez-max and Malacca-max, then ultra large container ships can be made. Currently, the largest ships are 16.000 – 18.000 TEU which is the Triple E class of Maersk (Maersk, 2013a). The depth limitations of the Malacca strait will not be of a problem in the coming future. This means that ships could continue to grow even larger without having depth restrictions of these straits.

Figure 0-11 Water Depth per Port
Conclusion Depth

It should be recognized that the depths presented in Figure 0-11, are maximum water depths of ports, and that the drafts in Figure 0-12 are maximum water drafts of a ship. In practice the tide will also be of importance for the depth of a port. Secondly, ships are rarely on their maximum draft as they are not always fully loaded or loaded with maximum weight.

The fact that the depth of most ports is close to the draft of current ships, could indicate that ports will deepen their ports when necessary. This would mean that water depth is of importance.
F. **Number of Short Sea Services**

The feeder connectivity of the ports is a measure of the quality of the ports, as the more services and frequency a port has with other ports, the more interesting it is to serve as a hub port. From Intermodel Links (Ecorys, 2013) the number of short sea services and frequencies are known, they are presented in Table 0-6.

<table>
<thead>
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<th>Port</th>
<th>Scope Services</th>
<th>Scope Frequency</th>
<th>Out of Scope Services</th>
<th>Out of Scope Frequency</th>
<th>Total Services</th>
<th>Total Frequency</th>
</tr>
</thead>
<tbody>
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<td>8</td>
<td>2</td>
<td>2</td>
<td>5</td>
<td>10</td>
</tr>
<tr>
<td>Antwerp</td>
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<td>10</td>
<td>37</td>
<td>19</td>
<td>51</td>
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<td>Barcelona</td>
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<td>5</td>
<td>4</td>
<td>7</td>
<td>7</td>
<td>12</td>
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<td>4</td>
<td>23</td>
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<td>42</td>
</tr>
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<td>11</td>
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<td>4</td>
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<td>9</td>
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<td>10</td>
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<td>489</td>
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</tr>
</tbody>
</table>
G. Hinterland Intermodal Services and Frequencies

The frequency of intermodal services is of importance for the usage of such services. Not only the frequency but also the mere fact that there is an intermodal service between a port and a hinterland region is of importance. The services and frequencies have been found using intermodal links (Ecorys, 2013) and are checked with modal splits of these ports.

Intermodal links is an online database for intermodal transport in Europe built by Ecorys. It contains train, barge and short sea shipping schedules. The services which depart from a port have been identified and used in the model. Only intermodal chains that have one transfer or transhipment have been considered for this study.

The number of services and frequencies per port are given in Table 0-7.

<table>
<thead>
<tr>
<th>Port</th>
<th>Train Frequencies</th>
<th>Train Services</th>
<th>Barge Frequencies</th>
<th>Barge Services</th>
<th>Total Frequencies</th>
<th>Total Services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
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<td>115</td>
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<td>332</td>
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<td></td>
<td>16</td>
<td>3</td>
</tr>
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<td>366</td>
<td>86</td>
<td>1828</td>
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</table>
H. **Hinterland Transport Costs**

Hinterland transport cost is defined as the cost of transporting a TEU from a port to a hinterland region. It is comprised of fixed costs and variable costs for different modes. The modes that are included are truck, train and barge. They use the road, rail and inland waterway as infrastructure. For the fixed costs, transport time is of importance, for variable cost distance is of importance. Distance and time are calculated in Appendix I When modes other than truck are used, also container handling costs at an inland terminal and trucking from the inland terminal to the final destination are added.

The cost structures have been derived from the modaliteiten vergelijker from NEA (NEA, 2009) and (De Jong et al., 2004). They have mapped the cost structures since 1980 for Rijkswaterstaat. The costs for the year 2009 are used and adapted with the EU inflation rate of 2.1% for 2010. As all data in this study is used for the year 2010, the cost structure will also be based on the year 2010.

All costs calculated consider a utilization degree, for truck this is set on 100%, for train, IWT and the inland terminal on 80%. The idea behind the difference is that a truck will only be used when it is loaded while a train or barge will also depart when they are not fully utilized. The costs will go up or down linear with the utilization degree.

**Road**

Cost can be split in fixed costs and variable cost. The fixed cost includes capital-, personnel-, administration-, insurance- and overhead costs. Variable cost includes fuel cost and maintenance cost. Costs are given for a large container truck (2 TEU) and a smaller container truck (1 TEU). The share of both trucks in kilometres driven and time spent is similar, but slightly higher for the large trucks. For this study a container factor of 1.6 is used, this means that an average container is 1.6 TEU. The TEU factor has been derived from port data (ESPO, 2013) and corresponds with the ratio large and small container truck. The costs for both types of trucks are averaged.

For fuel consumption, 2 km/l is assumed for a large truck and 3 km/l for a small truck.

The fuel price is based on the oil price and is calculated by multiplying the oil price per litre with 2.6. This results in a diesel price of €1.21 per litre. More information on the fuel prices can be found in Appendix M.

**Toll**

In many European countries toll is paid on motorways or for tunnels. These tolls can be paid per road section or per kilometre, which differs per country. Currently the European Commission is trying to harmonize the collection of toll using a new system called the European Electric Toll System (EETS).
The toll charges have been calculated using a software tool (PTV, 2013) per OD pair. The toll costs vary a lot and are found to be between €0 and €0.40 per kilometre. Toll costs are especially high in the Alps and in France. Belgium and the Netherlands do not have these toll charges.

This gives:

Variable cost of € 0.38 per TEU per kilometre

Fixed cost of € 28.17 per TEU per hour

The fuel cost contribute for about 90% to the variable cost but only for about 25% of the total road costs, this is a little more then found in literature (15%-20%) (Rodrigue et al., 2009). This can be explained by the relative high fuel prices in the Netherland and North-West Europe.

**Rail**

Cost can be split in fixed costs and variable cost. The fixed cost includes capital-, personnel-, administration-, insurance- and overhead costs. Variable cost includes fuel cost and maintenance cost.

It is assumed that a train carries an average of 82 TEU with 80% utilization and drives on EN590 diesel. Diesel under the EN590 regulation has lower duties which makes it around 15% cheaper than regular diesel (Esselink, 2012). It is considered 90% of the variable cost consists of fuel costs and the average train will have a fuel consumption of 0.125 km/l.

On top of the fuel cost a rail usage fee is to be paid. In the case of container trains this is around €2 per train kilometre (ProRail, 2013), which is around €0.03 per TEU kilometre. This is similar in the rest of Europe (B-Mobility, 2010).

This gives:

Variable cost of € 0.17 per TEU per kilometre

Fixed cost of € 21.70 per TEU per hour

**IWT**

The cost structure for a barge is similar to that of a train. A barge can however carry more containers which drops the transport price considerably. It is assumed an average barge has a capacity of 200 TEU and a fuel consumption of 0.08 km/l (BvO, 2011).

The inland waterways have different size classes also known as Conference Europeenne de Ministres de Transport (CEMT) classes. These classes define the size of the waterway and the size of ship that can sail through it. These class characteristics have been added to the inland waterway infrastructure using waterway maps of Europe (Donau, 2005). The classes and will also influence the cost structure, using CEMT ship classes an differentiation per ship class is made on the
number of TEU they can carry (Rijkswaterstaat, 2011). Based on the cost structure of NEA (NEA, 2009) different costs are allocated to the different ship classes.

For a 200 TEU ship with 80% utilization this gives:

Variable cost of € 0.08 per TEU per kilometre.

Fixed cost of € 1.36 per TEU per hour.

**Inland Terminals**

When other modes than the truck are used, some egress transport by truck must be done from the inland terminal to the hinterland destination. Besides the trucking cost, also inland terminal handling costs are made. Calculations on handling cost have been made by Wiegmans and Konings (2011) which range between 24 €/handling for a large fully utilized terminal to 103 €/handling for a small 60% utilized terminal. In this study all cost calculations have been made using an 80% utilization degree, which can be adapted in the model. In this case the handling cost will then range between 24 €/handling and 62 €/handling. In an interview with Jan Nater from ECT (Mueller, 2013b) a rough estimation was made of 25 €/handling at a European gateway inland terminal. As these terminals are relatively large, the costs seem to match. Therefore 25 €/handling is used.

With transhipment two handlings are necessary per container, from train/barge into the stack and from the stack onto the truck. Secondly, the handling is per container, with a TEU factor of 1.6 and a utilization degree of 80% is assumed. The cost will then be 39.06 €/TEU.
I. **Hinterland Transport Time, Distance and Speed**

The hinterland transport time and distance are to different factors, but they have been calculated in the same way. The factor time is seen as a separate choice factor but is also used as input for the cost factor. The distance factor is used as input for the variable cost and distance is obviously of great importance for the transport time. In this study distance is not used to calculate transport time because data for transport time was found separately.

Data for travel distance and transport times per hinterland mode are found in the ETISplus database (MOVE, 2010). “ETISplus is a European Transport policy Information System, combining data, analytical modelling with maps (GIS)”, constructed for DG MOVE under the seventh framework programme (ETISplus- Consortium, 2013).

**NUTS regions**

Impedance is a term used in transport for resistance which is usually quantified in cost and time. In this case impedance is distance and time. The Origin Destination matrix in the model is made up of 31 ports, 231 hinterland regions (NUTS-2) and 3 modes (truck, train, and barge). This adds up to a potential 21,483 relations, for which transport distance and time are needed. The ETISplus database is used (MOVE, 2010) which provides this impedance.

ETISplus gives the impedance (travel distance and travel time) between NUTS-3 regions. NUTS stands for Nomenclature of Territorial Units for Statistics which is a hierarchical system for dividing up the economic territory of the EU (Eurostat, 2012). It consists of 3 levels, NUTS-1 which is a major socio-economic region, NUTS-2 is a basic region and NUTS-3 is small region. A NUTS-1 region typically has 3-7 million inhabitants, a NUTS-2 region has 0.8-3 million inhabitants and a NUTS-3 region has usually 150,000-800,000 inhabitants. All provinces in the Netherland are considered to be NUTS-2 regions, the COROP regions that lie within a province are considered to be NUTS-3 regions. The European Union has in total 1294 of NUTS-3regions. This is a too high level of detail, so a NUTS-2 level of detail is chosen.

**NUTS regions in ETIS**

The ETIS data is aggregate to NUTS-2 regions, for both travel time and travel distance. The calculations are done the same way and are executed using Microsoft Access. The NUTS regions have an EU code but this is different from the ETIS code system for regions. A translation key is made to substitute codes. The structure of the code is given in Table 0-8.

In ETIS, a NUTS-3 region has an ID code of 9 digits. The first digit determines the continent; the next two digits determine the country. The NUTS-1 region is then determined by the fourth and fifth digit, the NUTS-2 region within this NUTS-1
region is determined by the sixth and seventh digit. The last two digits determine the NUTS-3 region.

### Table 0-8 ETIS code structure

<table>
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<th>NUTS-3 Code (EU)</th>
<th>Translation</th>
<th>ETIS_3_code</th>
<th>ETIS_2_code</th>
</tr>
</thead>
<tbody>
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<td>Continent: Europe = 1</td>
<td>124030206</td>
<td>1240302</td>
</tr>
<tr>
<td></td>
<td>Country: Netherlands = 24</td>
<td></td>
<td></td>
</tr>
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<td></td>
<td>NUTS-1 region: WEST = 3 = 03</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NUTS-2 region: North = 2 = 02</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>NUTS-3 region: 6 =06</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

A NUTS-2 region has an ID code of 7 digits. When simply dropping the last two digits of a NUTS-3 ID code, a NUTS-2 ID code is found. This principle has been used to aggregate data, both for the distances as the travel times.

The aggregation of data gives average distances and times between NUTS-2 regions and within NUTS-2 regions. The average distance within a region is used to determine the egress costs. An example of the aggregation operation is shown in the next section.

**Example**

An example for the aggregation operation is given. Figure 0-13 shows two NUTS-2 regions which both consist of four NUTS-3 regions. The distances between these regions are given in Table 0-9.

The lines and numbers in green represent the distances between NUTS-3 regions of different mother NUTS-2 regions. The yellow lines and numbers represent the distances between NUTS-3 regions within the same mother NUTS-2 region.

When these sixteen green distances are averaged, the distances between two different NUTS-2 regions is given, see Table 0-10. As each NUTS-3 region is an origin (O) and a destination (D) zone, the average distance is calculated twice. Due to rounding errors, the distances could vary a little.

The average distance of a NUTS-3 region to the gravity point of its own NUTS-2 region is half of the average mutual distance of the NUTS-3 regions. These distances are represented in yellow, averaging those gives the average mutual distance. The distance to the gravity point is however half of this distance. In the case of region 1120702, the average distance to the gravity point is 146 km / 2 = 73 km. This means that in this case, the egress distance used for intermodal transport is 73 km. This will also be done for the access distance of ports.
Egress Transport

When modes such as train and barge are used for the transport of containers, their destination will be an inland terminal. The inland terminal is located along the railway or waterway network. From the inland terminal the containers is then trucked to its final destination. In the example it is shown that distances within a NUTS-2 region can be calculated. These distances are used as the base for the egress transport.

From ETIS it is known that inland waterway terminals are located on the edge of a region. Their average distance to a destination within the region is therefore the
measured average intern distance. This distance is used for the egress distance travelled by truck.

For an inland rail terminal it is assumed that it is located in a region and that the average egress distance is half of the intern impedance of that region as described in the example.

The distances and travel times are given between regions, but should be known between the ports and the regions. An access distance should therefore be introduced to cover the distance between the deep sea port and the gravity point of the region it is in. ETIS has recognized this problem and has defined the ports as the gravity points of their region. This is done for rail and IWT transport but not for road transport. This means that, where road has no egress distance it does have an access distance. The access distance is found in the same way as the egress distance.

**Speed**

From the given hinterland distances and travel times the speeds can be calculated. The speeds are used to verify if the travel distances and times used are logical. For the three different modes a scatterplot is made, with on the y-axis and trip distance on the x-axis. This way the relation between speed and travelled distance can be seen.

**IWT**

The speed of 16,363 links between NUTS-3 regions is calculated and presented in Figure 0-14. The speeds are calculated from the travel times found in ETISplus. The travel times are defined as the time between leaving the origin and arriving at the destination. This means it includes docking and waiting times for slushes. The average speed is 6km/h. From literature (Movares, 2010) (NEA, 2009), speeds of 8 – 14 km/h are found. The higher speeds are usually reached sailing downstream while sailing up stream is more difficult. From the literature it is difficult to find which time components are included.

In this study only imports are looked at, which means that the containers are shipped from a sea port to an inland destination. The ships will therefore always sail stream upwards, resulting in a lower speed. An average speed of 8 km/h has therefore been assumed.
Train

The speed of 76.087 links between NUTS-3 regions is calculated and presented Figure 0-15. The speeds are calculated from the travel times found in ETISplus. The travel times are derived from the free flow speeds of different rail sections. This means that the assumption in this travel times is that the trains will drive continue on the maximum possible speed. The average speed is found to be 54km/h. From literature (NEA, 2009) (Rodrique et al., 2009) (Movares, 2010) (Macharis et al., 2004) (Deiss’, 2013), speeds of 17 – 57 km/h are found. The most cited average speed for international freight trains is 35 km/h.

It is not realistic that the trains drive at the free flow speed, an average speed of 35 km/h seems more reasonable. The train travel times are therefore increased such that the average speed becomes 35 km/h.
The speed of 93.524 links between NUTS-3 regions is calculated and presented Figure 0-16. The speeds are calculated from the travel times found in ETISplus. The travel times are derived. The average speed is found to be 35km/h. However, this takes into account that longer trips have much lower speeds due to resting periods. When only shorter trips are made, within 48 hours, than the average speed for truck will go up to around 55 km/h. This is similar as found in literature (NEA, 2009).

The average speed for truck that is used is 55km/h.
J. Supply of Containers

Detailed information on OD patterns of containers on a global scale is not available. Trade patterns and size are known but these are registered either in monetary value or tonnage. This includes all trade, so also liquid and dry bulk. Therefore OD patterns will be reconstructed; in this appendix the supply side is reconstructed.

For this study the specific origin is not needed, as long as the cargo passes the Suez channel it is sufficient. It is considered that all containerships with a destination in Europe sailing from Asia will sail through the Suez channel. Aggregated global container flows have been published by different organisations (Drewry, 2011, EUROSTAT, 2013) (ESPO, 2013, Containerisation-International, 2011) (World-Shipping-Council, 2013) (UNCTAD, 2011). Two sorts of data are of interest; the number of full TEU transported through the Suez channel to the scope area and the total number of TEU transported and handled to/in the scope area. The data found is represented using different definitions meaning the data cannot be directly compared. Therefore a pragmatic data adaption is used filtering the data towards the information intended.

The method comprises of data from different sources with different definitions but all from 2010. The data is shown in Table 0-11, in such a way that is visible which different elements the total TEU number comprises of. The goal is to filter the data such that the number of full containers imported by the scope area and transported through the Suez channel is known. The process of filtering step by step is done by multiplication of each row in order to get to the same definition as the goal. The multiplication factors have been calculated using the same references and are shown in Table 0-12.

For the model the total number of TEU travelling through the Suez channel and imported by the scope area must be known, this is called the GOAL. Statistics on imported TEU per country, handled containers per port and shipped containers are known, however these can also include: transhipment, export, empty containers, interregional traffic and out of scope flows. It is therefore necessary to adapt the available data such that it can be used for the model.
The flows through the Suez channel can be obtained from Drewry (Drewry, 2011) and the United Nations Conference on Trade and Development (UNCTAD, 2011). These are the ‘net’ flows, so excluding empties and transhipment, for the year 2010. The ‘bruto’ totals include empties and transhipment. From this table it can be seen that in the year 2010 almost 16 million TEU was imported by Europe through the Suez channel. This accounts for around 80% of all inter-continental container import of Europe.

As the scope area is smaller than the whole of Europe an additional calculation must be made. From Eurostat (EUROSTAT, 2013) the annual total number of TEU handled per country in a main port can be extracted, this includes loaded and empty containers. The term main port suggests large ports but it also includes relative small ports with less than 100.000 TEU of annual port throughput. From the data it is calculated that the scope area counts for 85% of the EU container handling.
From databases of the European Sea Ports Organisation (ESPO, 2013), the maritime company Containerisation International (Containerisation-International, 2011) and the World Shipping Council (World-Shipping-Council, 2013), a distinction within port flows was made for import, export, loaded and empty containers. Data was used for ports in the scope area for the years 2009 and 2010. From this data the percentage for import and empty containers can be derived. This is then compared to the percentage calculated from Drewry (Drewry, 2011). As expected the number of TEU imported is 50% of the total TEU handled. From the number of TEU handled 21% is empty, meaning 79% is loaded. These figures are very stable and haven’t changed much in thirty years. From the total handled TEU, 31% is transhipment. This figure has been steadily growing the last decades.

The calculated percentages are presented in Table 0-12. The last column shows the percentages used in this study. The percentages act as multiplication factors for the data found from different sources. This is done in order to harmonize all the data such that the number of full TEU that is shipped through the Suez channel with a hinterland destination in the scope area is found.

<table>
<thead>
<tr>
<th></th>
<th>Eurostat</th>
<th>Drewry</th>
<th>World Ship.</th>
<th>CI</th>
<th>ESPO</th>
<th>UNCTAD</th>
<th>Used</th>
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<td>50%</td>
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<tr>
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</tbody>
</table>

After six calculation steps Table 0-13 is derived. The table shows that all the definitions are now the same as the goal, so the number of TEU can be compared. For the year 2010 an average number of 12.5 million full TEU have passed the Suez channel on their way to the scope area. The standard deviation is 1.35 million TEU or 11% of the mean. In this study the value of 12.5 million TEU will be used as the number of TEU reaching the scope area from Asia.
<table>
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</tr>
<tr>
<td>Average</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>12.542.847</td>
</tr>
<tr>
<td>S.D.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.350.220</td>
</tr>
</tbody>
</table>
### K. Port Import 2010

The actual import of full containers from Asia per port is presented in Table 0-14. The transhipment percentages differ per port type, whereas the percentages of empties (21%) and Suez (80%) are constant for all ports. The percentages are found in Table 0-12.

<table>
<thead>
<tr>
<th>Port</th>
<th>Total Import</th>
<th>Transhipment percentage</th>
<th>Import Asia (excl. transhipment and empties)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antwerp</td>
<td>4.147.835</td>
<td>31%</td>
<td>1.805.057</td>
</tr>
<tr>
<td>Zeebrugge</td>
<td>1.224.218</td>
<td>31%</td>
<td>497.468</td>
</tr>
<tr>
<td>Varna</td>
<td>59.351</td>
<td>10%</td>
<td>33.715</td>
</tr>
<tr>
<td>Bremen</td>
<td>2.417.371</td>
<td>31%</td>
<td>1.076.466</td>
</tr>
<tr>
<td>Hamburg</td>
<td>3.982.933</td>
<td>31%</td>
<td>1.833.445</td>
</tr>
<tr>
<td>Tallinn</td>
<td>75.985</td>
<td>10%</td>
<td>43.164</td>
</tr>
<tr>
<td>Bilbao</td>
<td>264.228</td>
<td>10%</td>
<td>127.675</td>
</tr>
<tr>
<td>Barcelona</td>
<td>968.559</td>
<td>31%</td>
<td>406.852</td>
</tr>
<tr>
<td>Valencia</td>
<td>2.102.820</td>
<td>31%</td>
<td>910.115</td>
</tr>
<tr>
<td>Algeciras</td>
<td>1.401.215</td>
<td>80%</td>
<td>182.046</td>
</tr>
<tr>
<td>Le Havre</td>
<td>1.179.870</td>
<td>31%</td>
<td>536.715</td>
</tr>
<tr>
<td>Marseille</td>
<td>489.650</td>
<td>31%</td>
<td>212.149</td>
</tr>
<tr>
<td>Thessaloniki</td>
<td>135.854</td>
<td>10%</td>
<td>76.548</td>
</tr>
<tr>
<td>Piraeus</td>
<td>257.795</td>
<td>31%</td>
<td>123.698</td>
</tr>
<tr>
<td>Rijeka</td>
<td>68.524</td>
<td>31%</td>
<td>29.843</td>
</tr>
<tr>
<td>Genova / Le Spezia</td>
<td>1.525.362</td>
<td>31%</td>
<td>629.479</td>
</tr>
<tr>
<td>Venetia</td>
<td>200.437</td>
<td>31%</td>
<td>73.796</td>
</tr>
<tr>
<td>Trieste</td>
<td>138.326</td>
<td>31%</td>
<td>61.340</td>
</tr>
<tr>
<td>Livorno</td>
<td>302.653</td>
<td>10%</td>
<td>120.570</td>
</tr>
<tr>
<td>Napoli</td>
<td>266.091</td>
<td>10%</td>
<td>118.994</td>
</tr>
<tr>
<td>Taranto</td>
<td>290.923</td>
<td>80%</td>
<td>36.731</td>
</tr>
<tr>
<td>Giacinto Tauro</td>
<td>1.425.631</td>
<td>80%</td>
<td>179.966</td>
</tr>
<tr>
<td>Klaipeda</td>
<td>148.012</td>
<td>10%</td>
<td>83.776</td>
</tr>
<tr>
<td>Riga</td>
<td>132.716</td>
<td>10%</td>
<td>82.649</td>
</tr>
<tr>
<td>Rotterdam</td>
<td>5.584.364</td>
<td>31%</td>
<td>2.511.095</td>
</tr>
<tr>
<td>Gdansk / Gdynia</td>
<td>494.390</td>
<td>31%</td>
<td>163.011</td>
</tr>
<tr>
<td>Leixoes</td>
<td>242.645</td>
<td>10%</td>
<td>127.614</td>
</tr>
<tr>
<td>Lisbon</td>
<td>255.338</td>
<td>10%</td>
<td>119.190</td>
</tr>
<tr>
<td>Sines</td>
<td>191.186</td>
<td>10%</td>
<td>83.203</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>----------</td>
<td>-------</td>
<td>-----</td>
<td>-------</td>
</tr>
<tr>
<td></td>
<td>276.174</td>
<td>31%</td>
<td>121.224</td>
</tr>
<tr>
<td>Koper</td>
<td>220.362</td>
<td>10%</td>
<td>135.407</td>
</tr>
<tr>
<td>Total</td>
<td>30.470.814</td>
<td></td>
<td>12.543.000</td>
</tr>
</tbody>
</table>
L. Port Modal Split

Table 0-15 shows which infrastructure is available at the different ports. It can be seen that all ports are connected by road and rail. Some ports are connected by inland waterways. The table also shows the modal split for the different ports, this gives a good indication of the utilization of the different infrastructure networks, especially rail.

<table>
<thead>
<tr>
<th>Port</th>
<th>Modal Split</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Road</td>
<td>Rail</td>
<td>IWT</td>
</tr>
<tr>
<td>Antwerp</td>
<td>56%</td>
<td>11%</td>
<td>33%</td>
</tr>
<tr>
<td>Zeebrugge</td>
<td>55%</td>
<td>44%</td>
<td>1%</td>
</tr>
<tr>
<td>Varna</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Bremen</td>
<td>51%</td>
<td>45%</td>
<td>4%</td>
</tr>
<tr>
<td>Hamburg</td>
<td>62%</td>
<td>36%</td>
<td>2%</td>
</tr>
<tr>
<td>Tallinn</td>
<td>99%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Bilbao</td>
<td>99%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Barcelona</td>
<td>92%</td>
<td>8%</td>
<td>0%</td>
</tr>
<tr>
<td>Valencia</td>
<td>95%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Algeciras</td>
<td>99%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Le Havre</td>
<td>87%</td>
<td>6%</td>
<td>7%</td>
</tr>
<tr>
<td>Marseille</td>
<td>82%</td>
<td>12%</td>
<td>6%</td>
</tr>
<tr>
<td>Thessaloniki</td>
<td>99%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Piraeus</td>
<td>99%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Rijeka</td>
<td>90%</td>
<td>10%</td>
<td>0%</td>
</tr>
<tr>
<td>Genova / Le Spezia</td>
<td>75%</td>
<td>25%</td>
<td>0%</td>
</tr>
<tr>
<td>Venetia</td>
<td>83%</td>
<td>3%</td>
<td>14%</td>
</tr>
<tr>
<td>Trieste</td>
<td>60%</td>
<td>40%</td>
<td>0%</td>
</tr>
<tr>
<td>Livorno</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Napoli</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Taranto</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Giau Tauro</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Klaipeda</td>
<td>100%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Riga</td>
<td>99%</td>
<td>1%</td>
<td>0%</td>
</tr>
<tr>
<td>Riga</td>
<td>57%</td>
<td>10%</td>
<td>33%</td>
</tr>
<tr>
<td>Gdansk / Gdynia</td>
<td>70%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Lisboa</td>
<td>95%</td>
<td>5%</td>
<td>0%</td>
</tr>
</tbody>
</table>

Table 0-15 Hinterland Mode availability and Modal Split
<table>
<thead>
<tr>
<th>City</th>
<th>95%</th>
<th>5%</th>
<th>0%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sines</td>
<td>95%</td>
<td>5%</td>
<td>0%</td>
</tr>
<tr>
<td>Constanta</td>
<td>48%</td>
<td>47%</td>
<td>5%</td>
</tr>
<tr>
<td>Koper</td>
<td>40%</td>
<td>60%</td>
<td>0%</td>
</tr>
</tbody>
</table>
M. Oil Prices

The oil prices determine the fuel prices for maritime and hinterland transport. The oil price has an impact on bunker fuel prices and diesel prices.

Oil Price

The US Energy Information Administration has analysed the Brent crude oil prices of the past and has made projections for the future on the development of the prices (EIA, 2011). The prices (2011 dollars) and projections are shown in Figure 0-17. The figure shows the past oil prices for 2011 dollar prices and shows three projections. These are a low, medium and high oil price projection.

![Average annual Brent spot crude Oil Prices](image)

**Figure 0-17 Average annual Brent spot crude Oil Prices**

Diesel Price

The diesel prices are used as input for the variable cost of the hinterland transport costs. The average diesel prices (including tax) for the Netherland, Germany, Belgium, Italy and France have been found (EIA, 2013). The diesel prices and are visualised in Figure 0-18. The figure shows the diesel prices for the Netherland (green) and the average for the European countries listed above (blue). The red line is the diesel price in the Netherlands without VAT (TLN, 2013). It can be seen that the price without VAT is lower. The fact that they are equal in 2003 has to do with the changing exchange rate.

When the diesel prices in Europe are compared with the Brent crude oil prices for the last 10 years it is found that the price of a litre of diesel is around 3.3 times the price of litre of crude oil, in dollars. This is similar with the factor found by the Bovag of 3.1 (Bovag, 2013). When the VAT of 20% is taken into account the factor will be 2.6. This price built up is used to determine the fuel costs for hinterland transport.
Bunker Fuels

There are roughly two kinds of bunker fuels, heavy fuel oils and light fuel oils. The heavy fuel oils contain relatively much sulphur and are the cheapest. The light fuel oils contain only a little sulphur but are more expensive. The different fuel types and their prices are given in Table 0-16. The prices mentioned are a snapshot and derived from (Bunkerworld, 2013).

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>Price ($/MT) (June 4, 2013) (Rotterdam)</th>
<th>Price ($/MT) (June 4, 2013) (Singapore)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy Fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IFO380</td>
<td>574</td>
<td>596</td>
</tr>
<tr>
<td>IFO180</td>
<td>596</td>
<td>607</td>
</tr>
<tr>
<td>LS380</td>
<td>602</td>
<td>670</td>
</tr>
<tr>
<td>LS180</td>
<td>624</td>
<td>686</td>
</tr>
<tr>
<td>Light Fuel</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MDO</td>
<td>-</td>
<td>837</td>
</tr>
<tr>
<td>MGO</td>
<td>833</td>
<td>847</td>
</tr>
<tr>
<td>LSMGO</td>
<td>833</td>
<td>868</td>
</tr>
</tbody>
</table>

It can be seen that the prices within the fuel types heavy and light are similar. The prices between the groups however are quite large. When taking the development of the bunker fuel prices over the last seven years into account, this difference can be clearly seen, see Figure 0-19 (Zeeland, 2013) (Bunkerworld, 2013) The average of the heavy fuel IFO380 and IFO180 is shown in red and the MDO is shown in green. While these lines do not show the prices of the individual fuel types, they do give a clear indication of the price and the difference in price between the heavy and the light fuel.
Light fuel is more expensive as the fuel needs to be processed more before it can be used. Secondly heavy fuel is more difficult to use for other applications than shipping, thereby the demand for this fuel type is lower than for lighter fuels which lowers the price.

The average price difference between the fuel types is 56%, which means that light fuel types are on average 56% more expensive than the heavy fuel types, based on average prices between 2005 and 2013. According to Purvin and Gertz (2009) the price difference could be even higher, ranging between 60% and 75%.

The Brent crude oil prices are compared with the bunker fuel prices. It is found that the average heavy bunker fuel price is 85% of the oil price and the average light bunker fuel price is 132% of the oil price.
N. Modelling OD Matrix

OD flows are unknown so they are modelled. This is done using a simple generalized costs function which is based on cost and time. By using this method, only two unknown variables will be used. These are the ‘value of time’ (vot) and the scale factor $\beta$ (beta).

Five performance indicators are used to measure the performance of the parameters $\beta$ and vot. The performance of the least square error and the $R^2$ value are presented in chapter 0. In this appendix, the three other performance indicators are presented. These are: Absolute error (Figure 0-20), weighted least square (Figure 0-21) and mode error (Figure 0-22).

![Figure 0-20 Absolute Error](image-url)
Figure 0-21 Weighted Least Square Error

Figure 0-22 Absolute Mode Error
O. Statistical Analyses

Relations scheme

Figure 0-23 Relation Scheme
**Correlation Table**

<table>
<thead>
<tr>
<th>Independent Variables</th>
<th>Dependent: Utility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flow_{ijm}</td>
<td>.406**</td>
</tr>
<tr>
<td>dmodeflow_road</td>
<td>-.128**</td>
</tr>
<tr>
<td>dmodeflow_rail</td>
<td>.106**</td>
</tr>
<tr>
<td>dmodeflow_iwt</td>
<td>.066**</td>
</tr>
<tr>
<td>Dummy Feeder Port</td>
<td>-.083**</td>
</tr>
<tr>
<td>CostMarDeepSea</td>
<td>.090**</td>
</tr>
<tr>
<td>Total Maritime Cost</td>
<td>-.062**</td>
</tr>
<tr>
<td>CostPort</td>
<td>.060**</td>
</tr>
<tr>
<td>CostHintTot</td>
<td>-.721**</td>
</tr>
<tr>
<td>CostTotal</td>
<td>-.728**</td>
</tr>
<tr>
<td>TimeMar</td>
<td>.054**</td>
</tr>
<tr>
<td>TimeMarFeed</td>
<td>.066**</td>
</tr>
<tr>
<td>TimeDwell</td>
<td>-.083**</td>
</tr>
<tr>
<td>TimeHintTot</td>
<td>-.481**</td>
</tr>
<tr>
<td>TimeTotal</td>
<td>-.148**</td>
</tr>
<tr>
<td>DistMar</td>
<td>.103**</td>
</tr>
<tr>
<td>DistHint</td>
<td>-.694**</td>
</tr>
<tr>
<td>DistAgg</td>
<td>-.069**</td>
</tr>
<tr>
<td>DistTotal</td>
<td>-.103**</td>
</tr>
<tr>
<td>PortDepth</td>
<td>.155**</td>
</tr>
<tr>
<td>PortMarFreq</td>
<td>.116**</td>
</tr>
<tr>
<td>dIWT</td>
<td>-.030</td>
</tr>
<tr>
<td>SSSerTotal</td>
<td>.110**</td>
</tr>
<tr>
<td>SSFreqTotal</td>
<td>.148**</td>
</tr>
<tr>
<td>RailSerPort</td>
<td>.059**</td>
</tr>
<tr>
<td>RailFreqPort</td>
<td>.104**</td>
</tr>
<tr>
<td>IWTSerPort</td>
<td>.104**</td>
</tr>
<tr>
<td>IWTFreqPort</td>
<td>.101**</td>
</tr>
</tbody>
</table>

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

c. Cannot be computed because at least one of the variables is constant.

N = 2750

*Table 0-17 Correlations Table*
P. Oil Price Scenario

In this appendix the absolute maritime and hinterland transport costs are shown for different oil prices. This is of importance as the logit function looks at absolute utility differences.

For hinterland transport, costs are calculated for a distance of 500 km. The development of the total transport costs is shown in Figure 0-24.

For maritime transport, costs are calculated per coastline for transport from Asia. The costs include deep sea costs and feeder transport costs. The costs development is visualized in Figure 0-25.