Predicting the effects of CO2 emission to analyze container flows using an extended World Container Model

Rongwei Zou || Stud nr 4179722

MSc. Thesis, October 2014

Delft University of Technology

Transport Infrastructure and Logistics (TIL)

Academic Committee:

Prof.dr.ir. Lóránt Tavasszy (TUDelft TPM/TNO)

Dr. Ron van Duin (TUDelft TPM)

Dr. Bart Wiegmans (TUDelft CEG)

MSc. Ronald Apriliyanto Halim (TUDelft TPM)

Summary

At present, the problem of the greenhouse effect pushes people to pay more attention to the effects of emission. Carbon dioxide is one of the main greenhouse gases. And freight transportation represents the primary contributor of CO_2 emission compared to other sectors. Thus, the emission of container transport, which is the main method of transportation all over the world, is the main research object in this thesis. The impact of CO_2 emission is a hot topic in transportation that will be highlighted in the near future. One question will challenge our conventional modeling and traffic operations:

How can the World Container Model be extended to model the effects of CO_2-emission cost and what effects on international container flows are expected?

First, in order to gain insight into these developments and to create a base for constructing scenarios, wide research has been performed on trends and developments and their impact on the global transportation system. Megatrends include three parts: technological, environment and resource, and political.

Technological: With the development of global trade, larger ships will be needed to respond to future increased demand. The trend towards lager ships has accelerated in recent years and can be observed with the increasing capacity of container vessel as improvements in science occur. Larger ships have the advantage of scale economies, but whether they successfully enter into service remains open to question if considering the diseconomies that depend on cargo flow, shipping distance, port efficiency and constraints, etc.

Environment and resources: In the last few years, worldwide resource scarcity has been mentioned as a threat, including energy resources and those needed for manufacturing. Deep-sea shipping requires globally available fuels and thus will tend towards LNG (Liquefied Natural Gas) and biodiesel, if it becomes available. Nuclear energy suffers from public perception problems but may come to the fore sometime in the future if it is eventually perceived as a safe alternative.

Political: In order to reduce greenhouse gas emission by transport, transport policy on national and international levels has been developed. Examples include the European White Paper Transport Policy for the European Union and the Nationaal Verkeer en Vervoersplan (NVVP) for the Netherlands. Emission credit trading programs also contribute considerably as an improvement over command-and-control pollution abatement programs.

Next, the World Container Model (WCM) is used as a fundamental model in this thesis. Due to the threat of climate change, changes in energy policy and so on, the future circumstances of container flows are less certain. The World Container Model (WCM) has been developed as an efficient tool to analyze possible shifts in future container transport demand and the impacts of relevant transport policies. It is a strategic model for the movement of containers on a global scale and predicts yearly container flows over the world's shipping routes.

However, the WCM does not take into account the effects of CO_2 emission, which is not the expected model that operators want. The effects of CO_2 emission in the transport process, especially the costs, play a more and more important role in the consideration of international container transport. During the process of choosing transport routes, there are some relationships with the effects of emission. That is to say, before transport routes are chosen, not only the cost of the transport but also the environmental effects will be taken into account in this thesis research. (Liao, Lu, & Tseng, Carbon dioxide emissions and inland container transport in Taiwan, 2011)

In other words, an extended WCM is designed and developed that takes into account the costs of CO_2 emission. The new model offers a desirable contribution that provides insight into a range of new possible structures of global trade patterns as well as consequences for the transportation system.

The first part of the main research question is answered first. The World Container Model has been extended with a new scenario executed in the model. This new scenario is designed to add the cost of CO_2 emission into the cost of travel time and transfer. There are three important factors in the function: maritime (0.025 euro per TUE), hinterland (0.57 euro per TEU) and transfer. During the process of calculation, these factors are changed by adding the respective unit cost of the corresponding CO_2 emission (during maritime and hinterland transport, at terminal). In this way, the unit cost per container move increase. Then the effects of CO_2 emission should be visible from the outcomes of the model.

With this extended World Container Model, the second part of the main research question can be answered. From the outcomes, the effects of CO_2 emission cost on international container flows can be analyzed.

The outcomes reveal that the competitiveness of ports on a global scale changes. It is noteworthy that some ports, like Amsterdam, previously with small throughputs and transhipment, experience a new opportunity for development and prosperity. However, some important ports, like the port of Rotterdam, retain their competitiveness thanks to their advantages of geographic location and insistence on policies for controlling emission. In short, due to the impact on the cost of extra CO_2 emitted, the routes of maritime container transport have been reselected and throughput has been redistributed.

Afterwards, these effects are further analyzed in consideration of two scenarios. Based on the analysis and the scenarios that have been modeled using the extended World Container Model, the applicability of this model and the analysis for the effects of different policies and measures can be tested and verified.

- Scenario A: slow steaming (the speed of vessels slows down)
- Scenario B: CO_2 price (the price of CO_2 emission changes as time passes)

For scenario A: most of the European ports retain their attractiveness, which is enhanced by the growth of their throughput. Meanwhile, with the decreasing speed, the throughputs of these ports will increase further. For instance, the port of Antwerp is one of the ports that will probably lose their competitiveness in container transportation in Europe, if the measure of slow steaming shall be taken to reduce the CO_2 emission. The similar situation could also occur in the ports of Amsterdam, Le Havre and Bremen.

For scenario B: with an increased CO_2 tax, most of the European ports like Rotterdam and Hamburg will experience greater chances for development because of the large number of containers being imported and exported. In contrast, the ports of Antwerp, Amsterdam, Le Havre and Bremen show negative outcomes of throughputs from the extended World Container Model. This finding may imply that these ports will face challenges in response to an increase in the CO_2 price in the future.

In both scenarios, the ports of Antwerp, Amsterdam, Le Havre and Bremen show negative outcomes of throughputs from the extended World Container Model. On the contrary, other ports in Europe, like Rotterdam and Hamburg, retain their competitiveness in future international container traffic. The different situations may occur due to the effects of handling cost. For example, the handling cost at the port of Rotterdam is less expensive than that at the port of Antwerp, mainly because the port of Rotterdam has more efficient handling equipment and better hinterland connection.

Finally, the method used to calculate the total volume of CO_2 emission is introduced. It is achieved by data modeling on the basics of the extended WCM. The port of Rotterdam, as a case, is studied with analysis of all scenarios and the calculation of CO_2 emission.

For scenario A: with the speed of vessels slowing down, the throughputs of the port of Rotterdam increase. Beyond doubt, this results in the growth of CO_2 emission at the area of the terminal. But for maritime container transport, the total volume of CO_2 emission is decreased along with the speed cut, mainly because of the reduction in the number of routes towards and away from the port of Rotterdam (the number of routes to or from Rotterdam decreases from 2,290 to 2,140).

For scenario B: with the growth of the CO_2 tax, the port of Rotterdam still retains its attractiveness as one of the largest ports in the world. Its throughput and transhipment continue to increase. On the other side, for maritime transport, the CO_2 emitted by containers moving towards and away from Rotterdam will be reduced as the CO_2 tax increases.

To conclude, this report has proposed a method of predicting global container transport that incorporates travel time and traffic CO_2 emission in the composite route choice cost function, which provides reasonable suggestions on the effects of a given scenario to reduce the emission.

According to the results of the scenarios, the port of Rotterdam will experience positive effects with the growth of throughput and transhipment. When considering increasing CO_2 emission in the future, Rotterdam still needs to focus on improving the efficiency of handling at terminal. Such consideration depends on operation performances and terminal configurations. This measure works only over the long term and the costs are high but it is very effective. The impacts and probabilities should be adjusted over time. In response to increasing CO_2 emission, the strategy should also focus on energy conservation and renewable energy. These considerations also correspond with the actual situation, which confirms the outcomes of our extended WCM reasonably.

The other ports in Europe, like Antwerp, which exhibit negative effects as a result of scenarios, need to be more careful. The extended WCM in this research has shown that it can be used to assess the effects of a wide range of developments. As a strategic tool for policy development, it is able to assist the port to support decisions and take appropriate measures.

Preface

This Master's thesis project represents the completion of my study at the Faculty of Transport, Infrastructure and Logistics at the Delft University of Technology. It is the product of joint study in the faculty in TPM and CITG.

I am very lucky to have Prof.dr.ir. L.A. Tavasszy, Dr. Ron van Duin, Dr. Bart Wiegmans and MSc. Ronald Apriliyanto Halim as my supervisors for the Master's thesis. I would like to express my deepest appreciation for their persistent support, guidance and patience throughout the duration of my research. Frankly speaking, I chose the thesis project mainly because of my great interest in the topic. Moreover, it is related to the field of my following job. Before making this decision, I clearly knew there would be many difficulties since the project utilizes the complex World Container Model. But Prof. Tavasszy always gave me motivation to keep going with his warm smile. Dr. Ron van Duin also provided his comments to me about the problem of emission at terminal. Without his help, I could not have finished my thesis so smoothly. Dr. Bart Wiegmans is one of my favorite teachers in the Faculty of Civil Engineering. He has helped me considerably with the logic of my Master's thesis. I especially want to thank my daily supervisor, Ronald Halim, for his enthusiasm during meetings, his quick and valuable response to my problems and his encouragement in allowing me to make my own decisions. Most importantly, he always gave me useful help and spirited encouragement when I encountered difficulties during the thesis.

I really enjoyed my time at TU Delft. The courses from the faculty of TPM, CITG and 3ME support my future work in fundamental knowledge. The experience of resolving the challenges in this thesis has made me improve greatly in dealing with such kinds of research problems.

Finally, I would like to thank my family and my friends for their material and spiritual support. My research would not have been possible without their help. Thanks to all the people who smiled at me. Good luck to all of you!

Rongwei Zou
Delft, University of Technology
The Netherlands
October 2014

Contents

List of tables

List of figures

1. Introduction and problem description

1.1 Introduction

At present, climate change, global warming, the greenhouse effect, urban air pollution problems and urban traffic congestion force people to pay more attention to the effects of emission in transportation. The climate change caused by greenhouse gas (GHG) emission is considered one of the biggest challenges of our time. To avoid severe consequences for society, CO_2 needs to be stabilized to limit average global warming.

From the IEA CO_2 emission statistics report (shown in Figure 1), modern industry is the main source of greenhouse gas emission, which produces carbon dioxide (CO_2), sulfur dioxide (SO_2), nitrogen oxides (NO_X), hydrocarbons (HCs), and particulate matter (PM). In particular, carbon dioxide (CO_2) has been primarily produced. Among the various sectors, transport is the second largest sector that produces about 22 percent of CO_2 emission. With globalization and the growth of economies, there will be more and more transportation activities, which will produce higher levels of CO_2 in the future. (Barth & Boriboonsomsin, 2008)

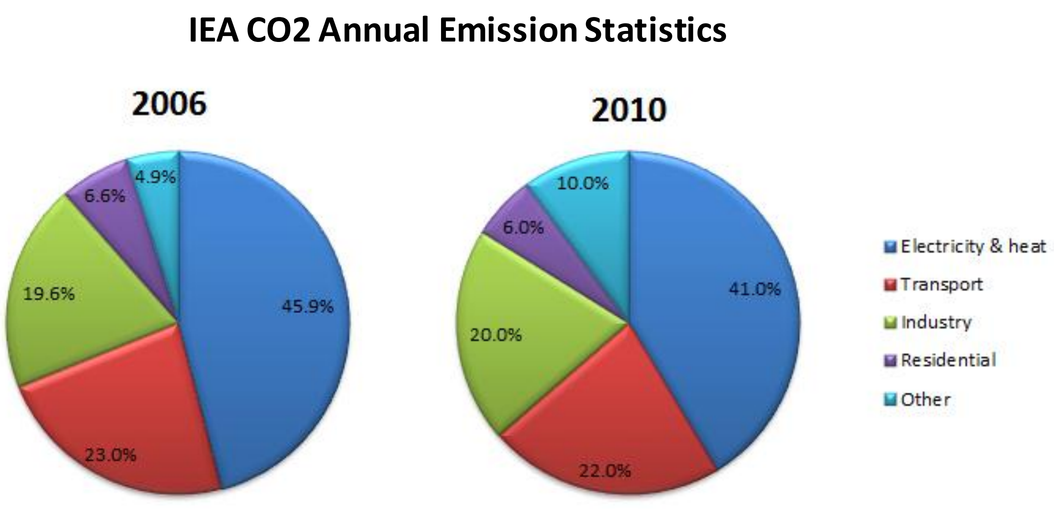

Figure 1 IEA CO_2 emission statistics for 2006 and 2010 (Hoeven, 2012)

Further, in the field of international transportation, freight transportation, which occurs mostly by sea in containers, comprises the primary proportion. Along with the continuing containerization of world trade, which has already been reported as a tendency as early as 1970, world container transport has become one of the main sources of CO_2 emission. Although not all products can be containerized, the containerization of world trade continues to develop because of its own advantages. Containerization as a technological change arises from shipping goods via containers rather than through the traditional break-bulk method that has characterized international shipping since antiquity. Besides, this trend has not only stimulated trade in containerizable products but has also had complementary effects on non-containerizables like automobiles. (Notteboom & Rodrigue, 2009) The container itself exhibits many advantages compared with other modes of transport: it makes transportation more convenient, handling and transferring easily in the port, thus improving efficiency. Traveling time and cost, to some extent, are reduced by using the container in world trade. But until now, the relationship between CO_2 emission and containers has not been fully understood. (Bernhofen, El-Sahli, & Kneller, 2011)

In association with the development of the international transport system, there have been significant impacts on climate change, accounting for between 20 and 25 percent of world energy consumption and CO_2-emission (in Europe 35 percent). There is increasing pressure on governments and industries to come forward with climate-friendly strategies. (European Commission, 2012)

The increasing amount of transportation directly results in increased transport emission; the environmental effects of shipping include not only greenhouse gas emission but also oil pollution. Carbon dioxide emission from shipping is estimated to be 4 to 5 percent of the global total, and nowadays 90 percent of the world's goods are carried by sea. Moreover, according to research by industry and European academics, world trade is constantly increasing. (John, 2007) CO_2 emission from shipping is double those from aviation and growing at an alarming rate, which will have serious effects on global warming. Thus, how to reduce CO_2 emission in container transport has become a worldwide challenge.

1.2 Problem definition

Due to the threat of climate change, changes in energy policy and so on, the future of container flows is less certain. The World Container Model (WCM) has been developed as an efficient tool to analyze possible shifts in future container transport demand and the impacts of relevant transport policies. It is a strategic model for the movement of containers on a global scale and predicts yearly container flows over the world's shipping routes. However, this existing model can't directly and efficiently measure the effects of CO_2 emission.

The effects of CO_2 emission in the transport process, especially the costs, play a more and more important role in the consideration of international container transport. During the process of choosing transport routes, there are some relationships with the effects of emission. That is to say, before the transport routes are chosen, not only the cost of the transport but also the environmental effects will be taken into account in this thesis research. (Liao, Lu, & Tseng, Carbon dioxide emissions and inland container transport in Taiwan, 2011)

Therefore, the World Container Model studied in this report will be extended to take the effects of CO_2 emission into consideration. The objective function or cost function contain more components, such as travel time (speed), travel distance, emission, etc. By doing this, the extended WCM will be able to analyze the effects of CO_2 emission and provide solutions to managerial and policy problems. (Tavasszy, Minderhoud, Perrin, & Notteboom, 2011)

1.3 Research questions

The above-described problems point to the need for research on long-term developments in and effects of the accompanying emission on worldwide container flows. Governments and environmental organizations are especially interested in these effects, as they must make critical decisions for long-term investments. In this research, the effects on CO_2 emission wwill be assessed using the World Container Model. Therefore, the **main research question** is:

How can the World Container Model be extended to model the effects of CO_2-emission cost and what effects on international container flows are expected?

Related to this main research question, a set of sub-questions has also been defined to help structure the research process. These sub-questions are listed below.

1. Are current policies lacking in controlling CO_2 emission?
2. Which traffic-emission calculation model is more accurate for this study?
3. How can the cost of CO_2 emission from traffic be incorporated along with travel time cost into the WCM?
4. What are the effects of varying CO2 prices?
5. What scenarios are relevant and what are their effects on future transportation patterns?
6. What will be the volume of future trade flows that can be predicted?

1.4 Project objective

This graduation project will focus on analyzing the effects of adding the cost of CO_2 emission into the World Container Model and providing a solution to policy and managerial problems. The objective is to provide insight into the impact of CO_2 emission on the pattern of world container transport over the long term (2040). Further, by analyzing possible scenarios, the extended WCM provides port managers and carriers with reasonable guidance to make good decisions for controlling the growth of CO_2 emission in the future.

1.5 Research methodology

1.5.1 Methodology flow chart

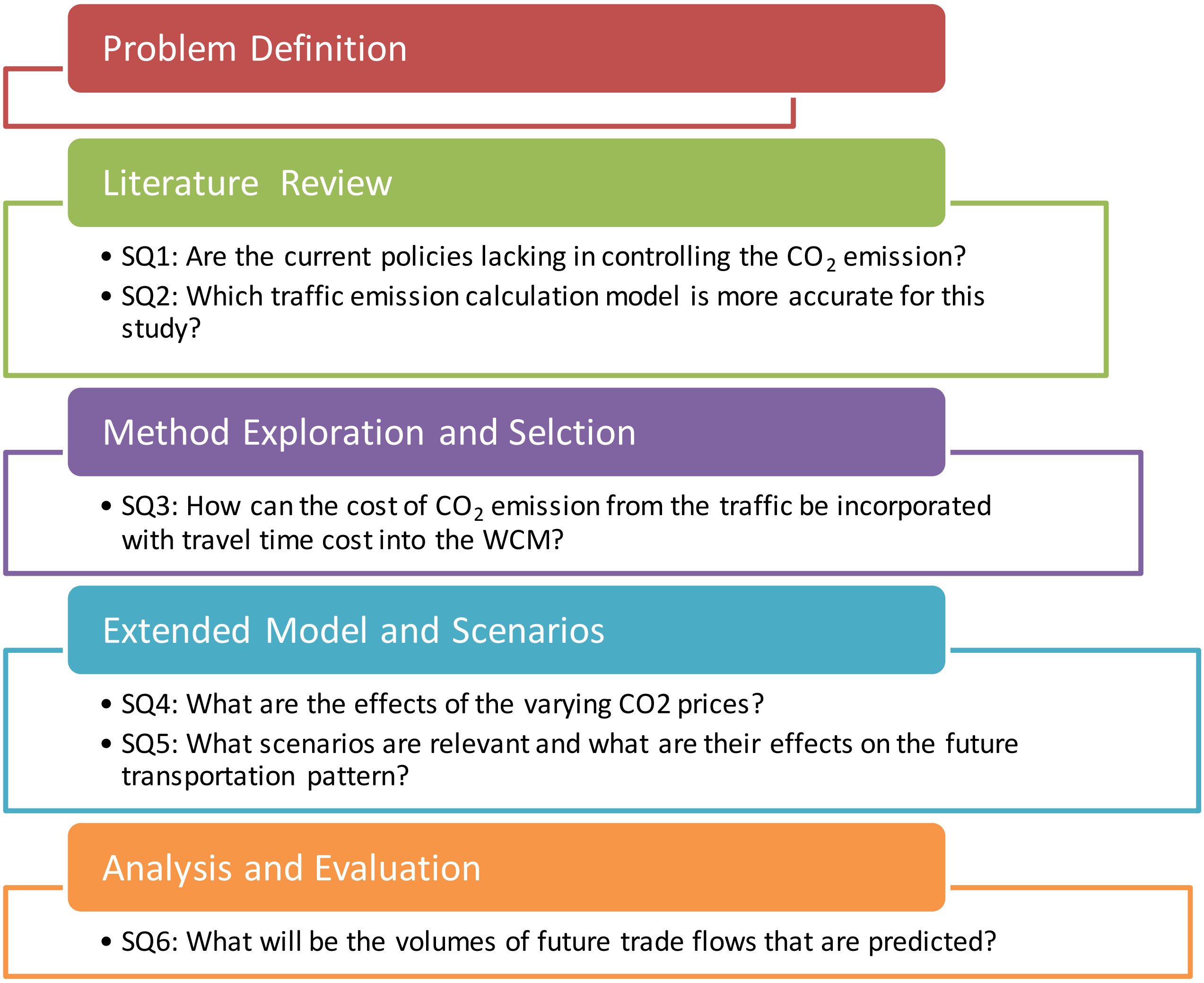

Figure 2 Thesis methodology

1.5.2 Methodology description

The methodology used in this thesis consists of five steps. In Step 1, the background and problems related to current policies in controlling CO_2 emission are reviewed with some general findings. The existing traffic-emission models that result in these problems, as well as the identification of megatrends, are further studied through a detailed literature review in Step 2.

In Step 3, the conceptual method, "incorporating traffic CO_2 emission cost along with travel time cost in route choice cost function," is proposed to achieve the extended World Container Model.

In Step 4, the World Container Model is extended by considering the effects of CO_2 emission in JAVA. Some scenarios will be applied to the model. The port of Rotterdam, as a case study, is analyzed by this adapted WCM. The results are analyzed in Step 5 and related policies are considered to make some recommendations for future research. The evaluation based on the modeling outcomes that answered the research questions will also be elaborated.

1.6 Thesis outline

The outline of this report is provided in Figure 3. Overall, the report is divided into three parts: problem description, method and results.

The problem description blocks include Chapters 1 and 2. Chapter 1 provides a general introduction, such as the current traffic situation. The literature review and theoretical framework related to the main topic of this thesis are presented in Chapter 2. Chapter 3 introduces the World Container Model and analyzes the consequences of adding the effects of CO_2 emission to it. Scenarios are developed to demonstrate the possible direction of global container flow based on the output in Chapter 4. An example of the port of Rotterdam is provided in Chapter 5 as a case study. Chapter 6 draws a conclusion by answering the research question through the results and offers some final thoughts and recommendations.

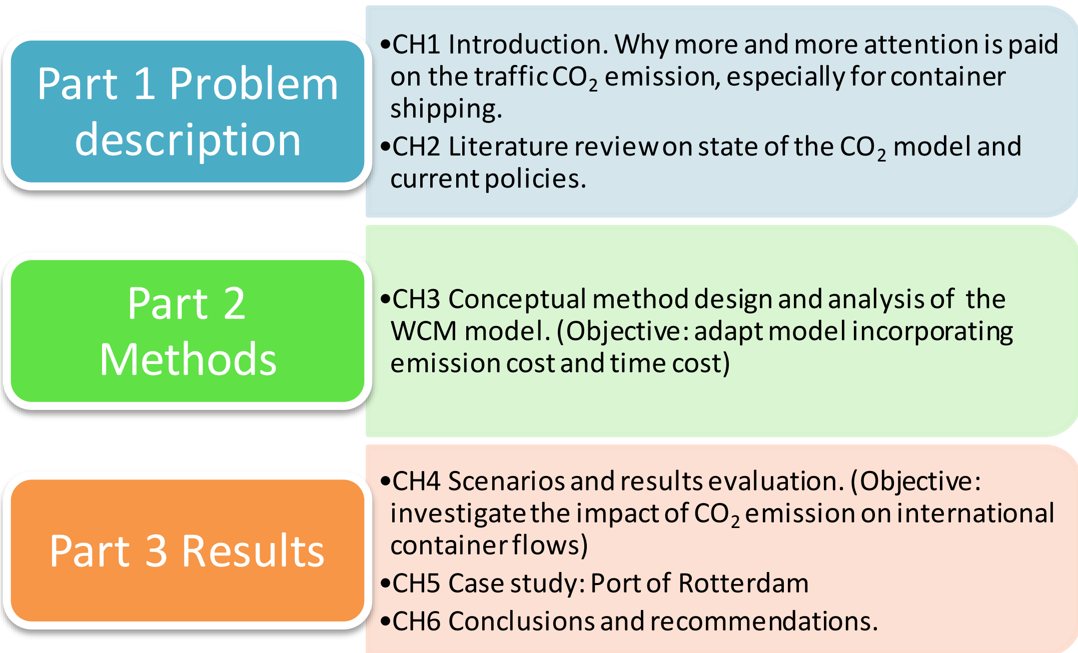

Figure 3 Thesis structure and reading guideline

2. Impact of CO_2 emission on transport from literature review

To gain insight into the existing policy options and a model to evaluate the effects of CO_2 emission from the global transportation system, a literature research has been performed. Using scientific literature as well as newspapers and business reviews, current achievements and fundamental knowledge have been introduced to provide the basis for constructing scenarios and build a sound background for the research.

In this chapter, a method for calculating CO_2 emission is elaborated. The relative formula and model implemented with the formula to calculate the cost of CO_2 emission are given. Meanwhile, the megatrends about reducing emission are provided in various fields for different stakeholders: technological, environment and resources, and political. This thesis is motivated by these current measures to reduce CO_2 emission.

2.1 Current formula and model of CO_2 emission

An operational activity-based method is used to estimate CO_2 emission from container shipping. Song Dongping and Xu Jingjing have noted that most shippers have no direct access to energy or fuel consumption data since the vast majority of freight transport operations of the European chemical industry are outsourced. In the absence of such data, shippers can estimate the CO_2 emission of their transport operations by using an activity-based calculation method. (Song & Xu, 2012)

The activity-based method uses the following formula:

$$
\begin{aligned}
CO2\ emissions &= Transport\ volume\ by\ transport\ mode \\
&\times average\ transport\ distance \\
by\ transport\ mode & \\
&\times average\ CO2\ emission\ factor\ per\ tonne \\
&- km\ bytransport\ mode
\end{aligned}
$$

Another method is the Energy-based approach, which obtains energy or fuel use, and applies the standard emission conversion factor to convert the values of energy or fuel into CO_2 emission. This method has encouraged carriers that have direct access to fuel consumption data to collect all these data. As is well known, every liter of fuel consumed will result in a certain amount of CO_2 emission. Thus, the activity-based method uses the following formula:

$$CO2\ emissions = fuel\ consumption \times fuel\ emission\ conversion\ factor$$

In this thesis, CO_2 emission problems in relation to container shipping are taken into consideration. By taking into account the characteristics of container shipping, an operational activity-based method is used to estimate the CO_2 emission index of ships. It is demonstrated that there are two important measures to reduce CO_2-emission KPI: improving port-handling rates and adopting more efficient repositioning policies. The former implies a requirement to have additional investment on the port side; nevertheless the latter is more preferable as it can lead to both economic and environmental benefits. These findings also suggest that the detailed operational activity-based method should be used in order to make a more accurate estimation of CO_2 emission. But if the aggregated method is used, appropriate ship speed and load factor must be selected. (Benedek & Rilett, 1998)

These two methods, as important references in this thesis, are used to calculate the total volume of CO_2 emission in both the process of maritime transport (activity-based calculation method) and the process of handling at terminal (the Energy-based approach). However, they are not suitable for calculating the cost of CO_2 emission because the value of CO_2 emission is much smaller compared to the number of transport throughputs and transhipment.

The estimation model for the CO_2 footprint of container terminal port operations provides a method to assess the CO_2 emission in the terminal operation. Based on the quantitative analysis of energy consumption in the terminal operation process, the emission factors at the terminal consist of equipment used by each sub-process, the energy-consumption pattern of various types of equipment, the average distance within a sub-process and the deployment of the equipment. (Geerlings & Van Duin, 2011)

One of the research objectives in this thesis is to calculate the total volume of CO_2 emission, which includes the emission during maritime transport as well as at terminal. Then, different scenarios can be implemented and the changes in CO_2 emission can be obtained. It is motivated by this estimation model to calculate the volume of CO_2 emission at terminal.

The global transport model (GloTraM) is considered the latest version that can represent possible technology and operational decisions by owners and operators of vessels in the future. Further, the Low Carbon Shipping project is undertaking a detailed and holistic analysis of the global shipping system, its energy use and its potential to abate future CO_2 emission. (Smith, Mark, Sophia, & Eoin, 2011)

However, the GloTraM is deterministic; thus, the results provide no illustration of the uncertainty inherent in the calculation of future emission. The purpose of this model is to illustrate the potential capabilities of a future model, not authoritative and rigorous estimations of future emission. At the same time, the improvement of the quality of the input data and assumptions is an ongoing task, which means this version of the model's outputs are currently only suitable for qualitative rather than quantitative analysis. The model should not be used for policy development or any commercial decision making.

2.2 Future development: Identification of megatrends

A key development, as reported in the 2012 edition of the Review of Maritime Transport (UNCTAD Handbook of Statistics 2012, 2012), is the adoption of a set of technical and operational measures to increase energy efficiency and reduce emission of GHGs from international shipping . The new measures have introduced the Energy Efficiency Design Index (EEDI) for new ships and the Ship Energy Efficiency Management Plan (SEEMP) for all ships. (The International Council on Clean Transportation, 2011)

According to the Second IMO GHG Study 2009 (IMO, 2009), technical and operational measures have significant potential for the reduction of GHG emission from international shipping. Three main megatrends from the literature study are elaborated in the following sections, which have various types of effects for container transportation.

2.2.1. Technological

With the development of global trade, larger ships are needed to respond to future increasing demand. Also, economy of scale has driven the development of container shipping right from the beginning. (Payer, 2002) The trend towards lager ships has accelerated in recent years and can be observed with the increasing capacity of container vessels as improvements in science occur. From the newest report, nowadays, the largest container ship is named “Triple-E” with about 18,000 TEU owned by Maersk. (Wikipedia, 2013) The Triple-E will carry 16 percent more containers than Emma Mærsk. It takes economy of scale to a new level because the additional capacity is not matched by additional engine power. Meanwhile, with the rapid development of technology, more efficient and environment-friendly ships can be built with less fuel consumption or even other bunkers like LNG, which is so-called sustainable transport. (Jolley, 2004)

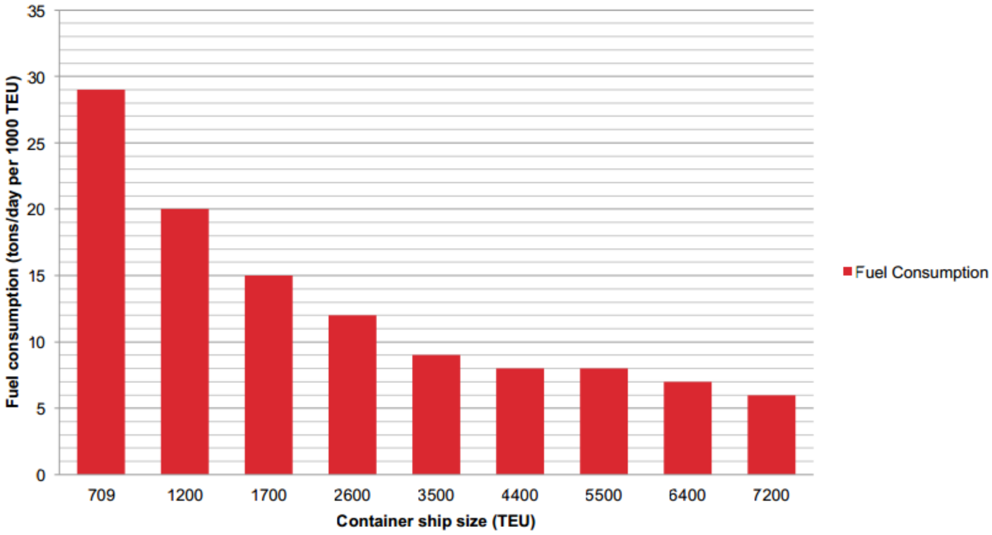

Figure 4 Relationships between capacity and CO_2 emission (Jolley, 2004)

As Figure 4 shows, the use of high-capacity vessels could enjoy the advantages of economy of scale, which in the future will achieve a reduction in CO_2 emission. Assuming the Triple Es consume 164 tons of fuel a day (excluding diesel), the estimated IFO bunker cost of the Maersk Mc-Kinney Moller (18,270 TEU) would already be 35 percent lower than a typical 13,100 TEU vessel on a per TEU carried basis – $218/TEU versus $333/TEU. (Why Size Matters: Container Ship Economies of Scale, 2013) Container shipping benefits from economies of scale in maritime shipping, transhipment and inland transportation. The rationale of maritime container shipping companies to have larger ships becomes obvious when the benefits, in terms of lower costs per TEU, increase with the capacity of ships. This tendency becomes more obvious when more Triple-E vessels are built and come into service. There is thus a powerful trend to increase the size of ships, but this may lead to diseconomies into other components of container shipping.

For port terminals, the growth in ship capacity comes with increasing problems to cope with large amounts of containers to be transshipped over short periods of time, as shipping companies want to reduce their port time as much as possible (improved ship asset utilization and keeping up with schedule integrity). Larger cranes and larger quantities of land needed for container operations, namely temporary warehousing on container yards, may become prohibitive, triggering diseconomies of scale to be assumed by port authorities and terminal operators.

For inland transportation, congestion growing capacity, such as more trucks converging towards terminal gates, leads to diseconomies. Because of technical innovations and functional changes in inland transportation (such as using rail instead of trucking to move containers away from or towards terminals), it is unclear what is the effective capacity beyond which diseconomies of scale are achieved. (Jean-Paul Rodrigue , 2013)

In short, larger ships have the advantage of scale economies, but whether they will successfully enter into service remains open to question if considering the diseconomies that arise from cargo flow, shipping distance, port efficiency and constraints, etc.

In the WCM, it is assumed that the capacity of the vessel is large. In other words, no matter how many containers there are, only one vessel is needed to carry all them. The more flows, the more CO_2 emission which results in much higher cost. But in reality, this scenario could not occur.

The truth is, when calculating the cost of CO_2 during the process of transportation, the output with less flow (like 10 TEU) is much smaller than the one in fact considering the emission from the vessel itself (excluded from the model). Similarly, the vessel carrying a large number of containers actually produces less CO_2 emission than the model calculates, mainly because of reasonable planning. Besides, the formula (an operational activity-based method) for calculating the cost of CO_2 emission is linear, which is not convincing.

2.2.2. Environment and resources

Considering factors related to the environment and resources that will play a role, two major trends can be observed: worldwide resource scarcity and alternative energy.

In the last few years, worldwide resource scarcity has been frequently mentioned as a threat, including energy resources and those needed for manufacturing. Looking at energy resources, oil is currently the world's most important energy source, supplying 34 percent of primary energy. The International Energy Agency (IEA) predicts that global oil demand will grow by an average of one percent annually until 2030. But the price of oil has increased very quickly, mainly because of scarcity (from $50 in January 2009 to $100 in February 2011). The price of oil has a large influence on transportation that relies on it for fuel. For the world's container transport, worldwide resource scarcity determines its growth and future development by affecting transport cost. (International Energy Agency, 2013)

Meanwhile, there is the trend of climate change highly associated with carbon emission. Government and society are under pressure to take measures to control or solve the problems of emission. The transportation sector will be extra sensitive to such measures as it accounts for both a large share in total emission. The main drivers for the use of alternative fuels are the desire to reduce greenhouse gas emission and the need to meet upcoming air pollution requirements. In the long term, short-sea shipping is expected to take advantage of locally produced fuels such as biogas, biodiesel, methanol, shoreside electricity and hydrogen. Deep-sea shipping requires globally available fuels and so it will tend towards LNG (Liquefied Natural

Gas) and biodiesel, if it becomes available. Nuclear energy suffers from public perception problems but may come to the fore sometime in the future if it is eventually perceived as a safe alternative. (Wikipedia, 2013)

Because LNG has a higher hydrogen-to-carbon ratio in comparison to conventional fuels, the specific CO_2 emission is lower. In addition, LNG does not contain sulphur, which results in (almost) no Sox emissions and almost no PM-emissions. A disadvantage of LNG is the potential for increasing methane emission (CH4). (Veritas, 2010)

NO_x	SO_x	GHG	PM
60% reduction	90-100% reduction	0-25%	72% reduction
Note: the upper limit CO_2 percentage is taken from the 2010 DNV. The age of LNG is here; other percentages come from 2009 IMO Second IMO GHG study.			

Table 1 Environmental effects of LNG (Clean Shipping Technology, 2014)

There are some technical issues concerning the use of biofuels that increase the risk of an engine shut down, like storage stability, bio fouling (accumulation of for example microorganisms and algae) in the fuel tank and increased engine deposits. Those technical issues can be avoided by using biofuels that are first hydrogenated in a refinery. However, the additional energy needed for this ‘pre-treatment’ limits the reduction potential of those biofuels. The emission saving potential depends on the type of biofuel, how it is produced and the amount of biofuels used. In recent years, the sustainability of biofuels has been heavily debated. Questions are raised not only in relation to emission savings, but also with regard to indirect land use effects and the effects on food prices. (S. Kalligeros, 2003)

Last but not least, human activities with modern machines and energies produce carbon dioxide and other greenhouse gases, which increase the threat of global warming. Thus, CO_2 emission is a worldwide issue that concerns governments and people. The Kyoto protocol in the United Nations Framework Convention on Climate Change (UNFCCC, 2013) is an international treaty that sets binding obligations on industrialized countries to reduce emission of greenhouse gases for each member country.

2.2.3. Political

At the EU level, international maritime transport remains the only transport mode not included in the EU's GHG emission reduction commitment. Greenhouse gas emission from shipping accounts for 4 percent of EU GHG emission today. At the same time, GHG emission from shipping is expected to increase significantly in the future. Along with the growth prediction of world trade, EU-related emission from shipping is expected to increase further by 51 percent by 2050 compared with 2010-levels, despite the adoption of minimum ship efficiency standards for new ships by the International Maritime Organization (IMO) in 2011. (European Commission, 2014)

At the global level, emission from maritime transport continues to increase due to the expected growth of the world economy and the related demand for transport. This increase is expected to occur despite the availability of operational measures and developing technologies to reduce the specific energy consumption and CO_2 emission of the vessels.

The EU performs very well with a global approach led by the IMO, which is one of the most appropriate international forums to regulate emission from shipping. Despite the slow pace of IMO discussions to prevent negative consequences for the climate, the EU will continue to engage in international developments to reduce GHG emission from ships. It will continuously monitor the progress and consider future actions.

In order to reduce greenhouse gas emission from transportation, transport policy on national and international levels has been developed. Examples include the European White Paper Transport Policy for the European Union and the Nationaal Verkeer en Vervoersplan (NVVP) for the Netherlands.

In the European White paper transport policy for the European Union has indicated that if nothing is done to reverse the traffic growth trend, CO_2 emission from transport can be expected to increase by around 50 percent to reach 1,113 billion tons in 2010, compared to the 739 million tons recorded in 1990. (European White Paper Transport, 2010) What's more, road transport is regarded as the main culprit since it alone accounts for 84 percent of the CO_2 emission attributable to transport. However, less attention is paid to the global transport especially the current policies on ocean shipping.

In the National Traffic and Transport Plan (NVVP), traffic and transport policy is a much-discussed issue in the Netherlands due to the large number of traffic accidents, increased mobility and congestion, as well as the increase in polluting exhaust emission, and the amount of scarce space taken up by the traffic infrastructure. (National Traffic and Transport Plan 2001-2020, 2001) However, the fact is that the NVVP merely refers to existing policy where reducing carbon dioxide emission is concerned. (Department of Climate Change an Energy Efficiency, 2012)

Emission trading is a market-based approach used to control pollution by providing economic incentives for achieving reductions in the emission of pollutants. An emission trading system is a powerful policy instrument for managing industrial greenhouse gas (GHG) emission. The presence of a trading system encourages operational excellence and provides an incentive and path for the deployment of new and existing technologies.

Emission credit trading programs have been advanced as an improvement over command-and-control pollution abatement programs. One advantage claimed for trading is that it increases firms' incentives to develop and adopt more effective pollution control technologies. (David , 1989) Owing to the contribution of emission trading, as well as other approaches, the value of CO_2 emission (euro/kg) could be reduced.

2.3. Stakeholder analysis

Policy making always involves various actors (i.e. stakeholders). These actors usually have different objectives, goals and problems. They have different views on certain issues and diverse powers and instruments to influence the development of issues as well as the ultimate outcomes. Moreover, the dynamic interrelationship among these actors makes the situation more complex. Although it is hard to analyze such a complicated and unstructured mechanism of actors, a basic understanding is beneficial and indispensable for policy making and implementation. In this section, some suggestions based on the analysis of the scenarios are provided for stakeholders to illustrate their power and interest.

For CO_2 emission within the world's container transportation, which is related to container handling and the transport process, some main stakeholders are involved in the system. These main stakeholders include shippers, carriers, port authorities, terminal operators, local residents and environment organizations. The following power versus interest grid compares the level and difference of each stakeholder. (Eden, 1998)

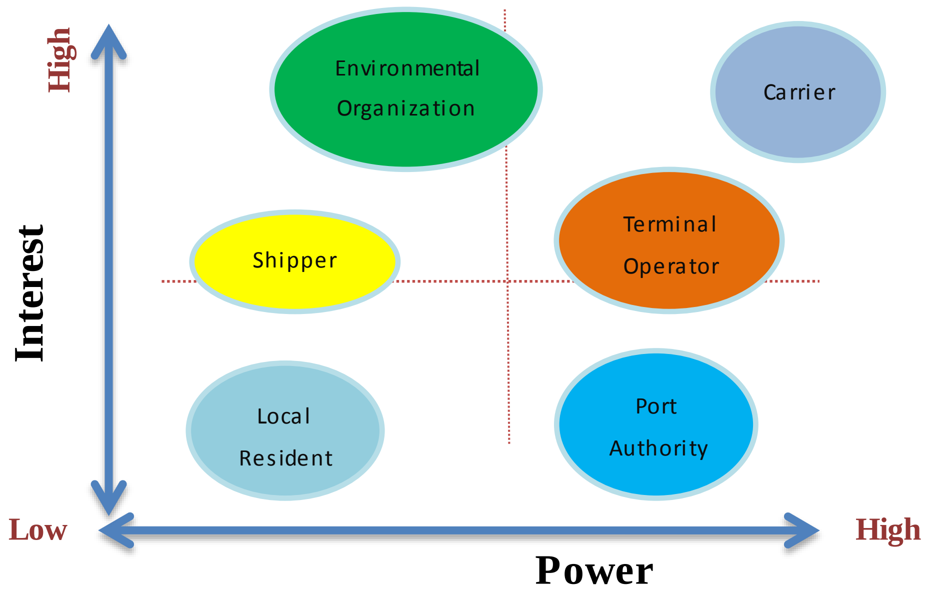

Figure 5 Power vs. interest grid

Because the effects of CO_2 emission are receiving more consideration throughout the whole world, the carrier responsible for transporting the container has the primary interest and power in this model, preferring the cheapest route via the choice of vessel. The policy maker develops legislation and new directives to control total CO_2 emission in both the transport sector and the area of the terminal against the increasing amount of containers transport in the future. The shipper has a high interest in travel time but low power to decide the route. The local residents who live around the port area and inland transport lines expect a high quality of life and keep a watchful eye on the effects on their living conditions. The lower the environmental pollution from the transport system, the happier they are. The environmental organizations pay attention to the issues, but they have little power to influence container operation. For the terminal manager, the port authority has greater power than the terminal operator, but the terminal operator focuses on the details of container handling and energy consumption at the terminal. (Stakeholder Analysis, 2013) So the terminal operator relatively has more interest than the port authority in this specific model. (See Table 20)

Based on the overview of stakeholders' interest and power, this project analyzes the effects of CO_2 emission mainly from the carriers' perspective. They pay more attention to the question, "How to choose the 'least' costly transport routes, including both the cost of transport and CO_2 emission, at a global level?" As carriers, there is enough power to control the operation process and gain insight into the amount of CO_2 emission. (Slack, 2001)

2.4. Chapter conclusion

In this chapter, the sub question 1 is answered. Three main megatrends from the literature study are elaborated, which include various policies for container transportation. However, the effectiveness of these current policies remains to be proven. That's why, in this report, an extended model is developed to provide insight into the impact of these policies on the pattern of world container transport over the long term. The interest and power of the stakeholders relate to these policies are also introduced.

Next, different traffic-emission calculation formula and model are provided to answer the sub question 2. An operational activity-based method and the Energy-based approach are introduced first. These two methods, as important references in this thesis, are used to calculate the total volume of CO_2 emission in both the process of maritime transport and the process of handling at terminal. However, they are not suitable for calculating the cost of CO_2 emission. The estimation model for the CO_2 footprint by Ron van Duin and Harry Geerlings is only applied in the terminal operations. The global transport model (GloTraM) is deterministic and provide no illustration of the uncertainty inherent in the calculation of future emission. Thus, a new model is needed to calculate the cost of CO_2 emission during the whole process of world container transport. And the outcomes could be shown in the map. But why the World Container Model is selected and how could the calculation methods be applied in it? In the next chapter, they will be elaborated in detail.

3. Model description and extension

In this chapter, the original World Container Model is introduced and its outcomes are given in two scenarios: 2006 and 2040. After that, the model is extended to consider CO_2 cost, which includes the cost of maritime, transfer and hinterland transport. With the data of unit cost, the calculating method is discussed and the outcomes of the extended WCM are also provided to analyze the difference compared to the original model.

3.1 World Container Model description

For the ports and their operators, the influence of long-term global developments in trade, logistics and transportation is unclear when considering the effect of the cost of CO_2 emission on container throughput. Uncertainty increases and growth might not be as sustainable as it has been in the past. Because of the continuous increase in CO_2 emission, current container flows may shift to other ports or even reverse direction. Insight into the effects is critical for controlling CO_2 emission and a model-based approach can assist in improving this. Existing tools, however, need to be improved before they can be used to analyze all costs.

There are already some effective models for analysis of the CO_2 emission, which have been mentioned in chapter 2. In this thesis project, the World Container Model is used as a fundamental model, which excels at combining a consistent description of worldwide trade flows, container flows and transportation services on a global scale, in addition to a port and multimodal route choice model. The model predicts yearly flows across the world's shipping routes and passing through more than 400 ports. It is based on trade among 200 countries, taking into account more than 800 maritime liner services. (Tavasszy & Halim, 2012)

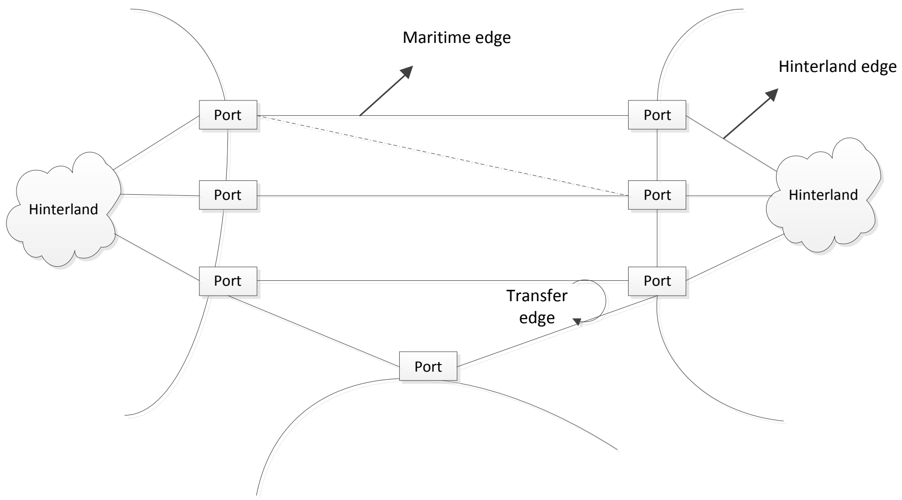

Figure 6 Representation of the network

The multimodal route and port choice procedure is achieved using an improved logic-choice model, which considers overlaps between alternative routes in the network (See Figure 6). The model considers transport times, tariffs and time sensitivity of goods. Moreover, it describes yearly container flows across the world's shipping routes and distinguishes between import, export and transhipment flows of containers at ports, as well as hinterland flows. (Adler, Blue, & Wu, 1999)

The model is calibrated against all available port throughput statistics. Scenario analyses performed with the model include the effect of low-speed shipping, the increase in land-based shipping costs, major infrastructures such as the Trans-Siberian rail line and the opening of Polar shipping routes. The model is being applied to the European Commission's Trans-European Networks program and the Rotterdam Port Authority, to develop long-term forecasts.

The generalized cost function in this model is provided by the following equation:

$$Cr = \sum_{p \in r} Ap + \sum_{l \in r} Cl + \alpha \cdot \left(\sum_{p \in r} Tp + \sum_{l \in r} tl\right) \quad (1)$$

Where Cr, costs of route r; p, ports used by the route; l, links used by the route; A_p, total cost of transhipment at port p; C_l, total cost of transportation over link l; T_p, time spent during transhipment at port p; t_l, time spent during transportation over link l; α, value of transport time.

By this formula, the cost of every route between ports is calculated combined with the algorithm of dijkstra shortest path. In the output of this model, throughputs, transhipment and fraction of thirteen ports in Europe have been printed out as examples to show the changes in 2006 and 2040. Detailed information is provided in Appendix A.1. Two scenarios have been applied to this World Container Model (2006 and 2040 with high growth). The results of route choice are shown in the following figures.

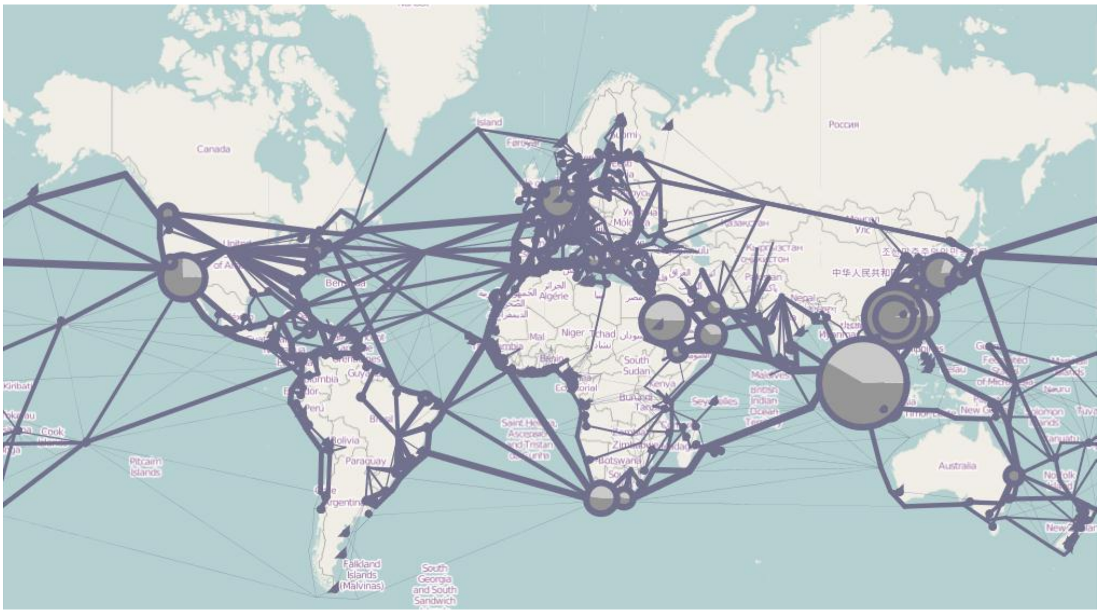

Figure 7 The outcome of Scenario 2006 in original WCM

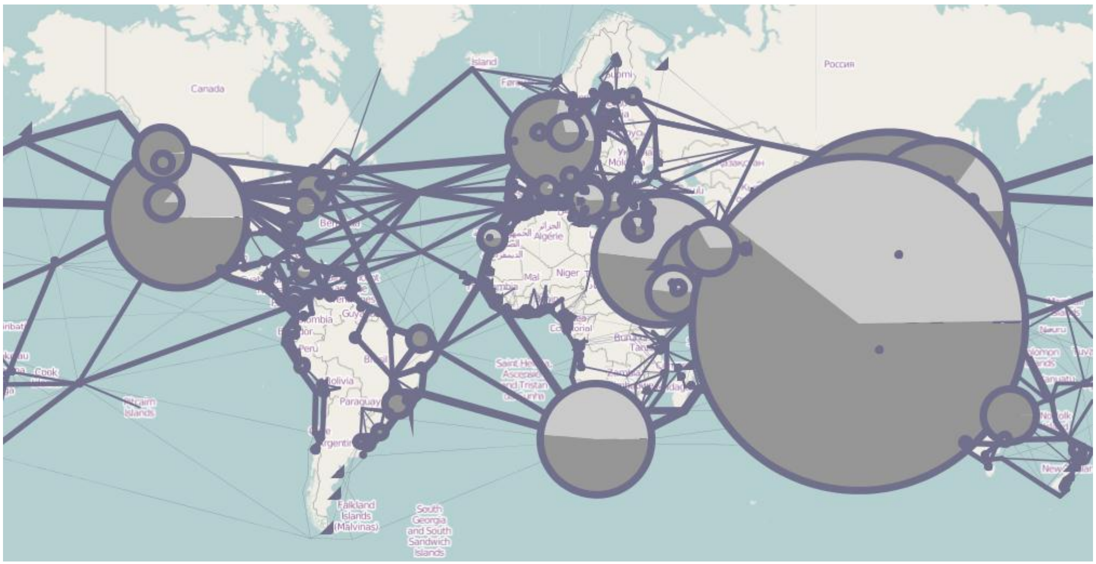

Figure 8 The outcome of Scenario 2040 with high growth in original WCM

From these two pictures, we can see that the routes of container transport don't change much but the throughputs and transhipments of ports all over the world increase considerably, mainly because of the rapid growth and development of global container transport that was mentioned in the previous chapter as the main tendency. The changes of the ports of Hamburg, Rotterdam and Antwerp have been singled out to illustrate the difference more clearly.

Throughput and Transhipment (TEU)	Scenario 2006	Scenario 2040	Difference	The percentage of changes compared with scenario 2006(%)
		ROTTN		
Throughput	4846671	11036613	6189942	127.72%
Transhipment	1610032	3722087	2112055	131.18%
		ANTWB		
Throughput	12217120	30961634	18744514	153.43%
Transhipment	4841677	12190794	7349117	151.79%
		HAMBD		
Throughput	12371385	31296252	18924868	152.97%
Transhipment	3577655	8987506	5409852	151.21%

Table 2 Difference of throughput and transhipment between Scenarios 2006 and 2040

However, the WCM itself doesn't contain the calculation of CO_2 emission when it forecasts long-term changes in the choice of ports and routes. As mentioned above in the introduction, more and more attention has been given to the cost of emission. Without a doubt, more CO_2 emission implies a much higher cost in energy consumption and tax. Then, a different transport route compared with the one that the WCM calculated may be chosen in practical operation, which makes the results of the WCM inaccurate, as well as the options of policies. Now that the throughputs and transhipments of ports have increased in such a rapid manner, what effects of the CO_2-emission cost on the international container flows are expected?

Thus, in order to research the effects of CO_2 emission on global container transportation and find reasonable solutions to reduce or control emission, it is advisable to extend the World Container Model by taking the cost of CO_2 emission into account when calculating.

3.2 WCM Extension on a global scale

In order to be able to quantify the effects of CO_2 emission, a modeling approach is applied using an extended World Container Model. The original model combined with a port and multimodal route choice model aims at choosing the optimal transport routes. (Wang, Wang, & Sun, 2012) The World Container Model isn't designed to study the effect of CO_2 emission to take into account. Accordingly, in this thesis, by considering the cost of the CO_2 emission, the WCM is extended and used to analyze these effects.

The cost of CO_2 emission within international container flows consists of three parts. The first is the cost during the process of transport by vessel. The important parameters include transport distance and speed. The second is the cost during the process of container operation at the terminal area, which can be evaluated by the estimation model of CO_2 footprint of container terminal port operation (Geerlings & Van Duin, 2011). The last part is the cost of CO_2 emission by truck, railway or barge in the hinterland. By integrating these three types of costs, together with the cost of transport itself, the effects of CO_2 emission for world container transport can be obtained.

3.2.1. Maritime transport

First, the cost of CO_2 emission during the process of maritime transport by vessel is calculated based on the value of CO_2 emission and the emission factor of the container vessel.

The Department of Energy and Climate Change in the United Kingdom, forecasts a carbon price that begins in 2013 at about €0.019 per kilogram and increases to approximately €0.0675 per kilogram in 2040. This forecast is consistent with the occurrence of one or more factors that have the effect of raising carbon prices. These factors include somewhat more aggressive emission reduction targets; greater restrictions on the use of offsets; restricted availability or high cost of technology alternatives such as nuclear, biomass and carbon capture and sequestration; and more aggressive international actions. (Luckow, Stanton, & Biewald, 2013) The unit of all these figures has been changed to euro per kilogram for better understanding and convenient calculating. The detailed data are shown in Table 3. (Department of Energy & Climate Change, 2013)

Year	Total carbon price (euro/kg)	Year	Total carbon price (euro/kg)
2013	0.019	**2027**	0.038
2014	0.02	**2028**	0.039
2015	0.022	**2029**	0.04
2016	0.023	**2030**	0.041
2017	0.025	**2031**	0.046
2018	0.027	**2032**	0.048
2019	0.029	**2033**	0.05
2020	0.032	**2034**	0.053
2021	0.033	**2035**	0.055
2022	0.034	**2036**	0.058
2023	0.034	**2037**	0.062
2024	0.035	**2038**	0.063
2025	0.036	**2039**	0.065
2026	0.037	**2040**	0.0675

Table 3 Forecast of the price of carbon from 2013 to 2040

From a study by the European Chemical Transport Association, the emission factor of container vessel can be obtained. The figure for the average deep-sea container vessel is used in this report after transferring to the standard unit. The factor values 9.24 X 10^{-2} kg/TEU.km from 8.4 g/ton.km (1TEU = 11ton), which is shown in the following table. (ECTA, cefic , & Responsible Care, 2011)

Container vessels	Emission factor (g/ton-km)	Transfer to (kg/TEU-km)
Small container vessel (2,500 tons)	13.5	14.85 X 10^{-2}
Larger container vessel (20000 tons)	11.5	12.65 X 10^{-2}
Average deep-sea container vessel	8.4	9.24 X 10^{-2}
(assuming mean 11-ton load per TEU)		

Table 4 Published emission factors for maritime transport

To sum up, the maritime factor for CO_2 emission (euro/TEU-km) can be calculated by the following formula:

$$CO2\ Maritime\ factor = CO2\ price \times emission\ factor$$

For 2040, as an example to illustrate, the maritime cost of CO_2 emission can be calculated as follows: 0.0675 euro/kg X 9.24 X 10^{-2} kg/TEU-km = 0.006237 euro/TEU-km (the original maritime factor for transport without the cost of CO_2 emission is 0.025 euro/TEU-km from the World Conatiner Model). All the unit maritime costs of CO_2 emission from 2013 to 2040 are shown in the following table.

Year	Unit cost of CO_2 for maritime transport (euro/TEU-km)	Year	Unit cost of CO_2 for maritime transport (euro/TEU-km)
2013	0.0017	**2027**	0.0035
2014	0.0019	**2028**	0.0036
2015	0.002	**2029**	0.0037
2016	0.0022	**2030**	0.0038
2017	0.0023	**2031**	0.0042
2018	0.0025	**2032**	0.0044
2019	0.0027	**2033**	0.0047
2020	0.003	**2034**	0.0049
2021	0.003	**2035**	0.0051
2022	0.0031	**2036**	0.0053
2023	0.0032	**2037**	0.0056
2024	0.0033	**2038**	0.0058
2025	0.0033	**2039**	0.0060
2026	0.0034	**2040**	0.0062

Table 5 Unit cost of CO_2 emission for maritime transport from 2013 to 2040

3.2.2. Handling and transfer at terminal

The estimation model for CO_2 footprint of container terminal port operation has been introduced in the literature review. The cost during the process of container operation at the terminal area can be evaluated by the model based on Ron Van Duin and Harry Geerlings' research, as well as the Energy-based approach. The unit cost of CO_2 emission during transhipment at port includes two parts: consumption by electricity and diesel. The entire formula is:

$$
\begin{aligned}
CO2\,Transfer\ factor &= Electricity + Diesel \\
&= CO2\ emission\ per\ kWh \\
&\quad \times fixed\ consumption\ per\ containermove \\
&\quad + fuel\ consumption
\end{aligned}
$$

The average consumption per containermove at terminal dates from Harry Geerlings and Ron van Duin's paper. For the emission of electricity, an assumption is made of 0.52 kg of CO_2-emission per kWh. This value is based on an average provided by some Dutch energy-suppliers. (Geerlings & Van Duin, 2011) The fixed consumption per container-move at terminal varies based on different types of equipment. In this report, the average consumption value of 6 kWh is used in the calculation based on the figures in Table 6.

Energy	Type of equipment	Fixed consumption per containermove
Electric	QC: Quay Crane	6.00 kWh
	BC: Barge Crane	4.00 kWh
	RC: Rail Crane	5.00 kWh
	ASC: Automated Stacking Crane	5.00 kWh
	RSC: Rail-mounted Stacking Crane	7.25 kWh
	P: Platform	5.00 kWh

Table 6 Energy consumption per type of equipment at terminal (Geerlings & Van Duin, 2011)

The fuel consumption produced by transferring containers at the terminal area is shown in the following table, utilizing data from research by the European Chemical Transport Association. The arithmetic average is 2.37 kg per liter.

Fuel type	Consumption (kg CO_2/liter)
Motor Gasoline	2.8
Diesel oil	2.9
Gas oil	2.9
Liquefied Petroleum Gas (LPG)	1.9
Biodiesel	1.9
Biogasoline	1.8

Table 7 Fuel emission conversion factors at terminal (ECTA, cefic, & Responsible Care, 2011)

With these data, the unit cost of CO_2 emission for transferring at terminal can be calculated. For 2014, as an example, the unit cost is (0.52 kg/kWh X 6 kWh/TEU + 2.37 kg/liter X 1liter/TEU) X 0.02 euro/kg = 0.11 euro/TEU. In the World Container Model, the unit cost for handling at terminal for all 437 ports is stored and imported when the model has been executed. The cost of CO_2 emission at terminal can be taken into account by adding the unit cost of CO_2 emission to the original handling unit cost. All the unit costs of CO_2 emission for transferring at terminal from 2013 to 2040 are shown in the following table.

Year	Unit cost of CO_2 for transferring (euro/TEU)	Year	Unit cost of CO_2 for transferring (euro/TEU)
2013	0.103	**2027**	0.208
2014	0.11	**2028**	0.214
2015	0.119	**2029**	0.219
2016	0.128	**2030**	0.225
2017	0.138	**2031**	0.25
2018	0.148	**2032**	0.264
2019	0.159	**2033**	0.277
2020	0.178	**2034**	0.29
2021	0.18	**2035**	0.304
2022	0.184	**2036**	0.317
2023	0.188	**2037**	0.33
2024	0.193	**2038**	0.344
2025	0.198	**2039**	0.357
2026	0.203	**2040**	0.371

Table 8 Unit cost of CO_2 emission for transferring at terminal from 2013 to 2040

3.2.3. Hinterland transport

The method of calculating the unit cost of CO_2 emission in the hinterland is given in this section. But it is a little bit complex compared with the other two unit costs mainly because of the intermodal transport.

For most European countries, in the hinterland, container traffic road transport plays a dominant role. Its current share in the modal split is about 60 percent, while barge and rail have shares of 30 and 10 percent respectively. Although the share of road transport has been more or less stable during the last five years, the number of containers transported by road still increased in this relatively short period of time. (Fremont & Franc, 2010) Until now, rail transport has played a modest role in container hinterland traffic for several reasons, including a lack of rail capacity. Barge transport has dramatically gained importance as a hinterland transport mode. The ability to offer cheap and reliable services has attracted the interest of shippers and carriers in barge transport, explaining the significant growth of container barge transport since the mid-eighties. (Visser, Konings, Pielage, & Wiegmans, 2007)

However, the scope of this thesis is global which means the situation of all the 437 container ports in the WCM in different countries must be considered. Some countries, unlike Europe, don't have much hinterland transport by barge. In order to calculate the cost of CO_2 emission in hinterland container transport, an assumption is made by considering all the situations for different ports: the share of road transport is 60 percent, while barge and rail each have a 20-percent share.

The average CO_2-emission factor recommended by McKinnon for road transport operations is 62g CO_2/ton-km. This value is based on an average load factor of 80 percent of the maximum vehicle payload and 25 percent of empty running. The average CO_2 emission for the calculation of CO_2 emission from rail transport operations is 22 gCO_2/ ton-km. This value is based on an extrapolation of a range of emission factors reported by reliable sources across Europe, taking into account the following factors:

1. Average split between diesel and electric haulage;
2. Average carbon intensity of the electrical power source;
3. Average energy efficiency of the locomotive;
4. Assumptions about average train load factors.

Using published data on average emission factors for barge movements on inland waterways, McKinnon is recommending an average value of 31 gCO_2/ton-km. (ECTA, cefic, & Responsible Care, 2011)

Then, the average value of CO_2 emission in hinterland container traffic can be calculated by employing an algorithm of weighted average and transferring the unit to kilogram per TEU per kilometer. It values 0.53 kg per TEU per km. Subsequently the final unit cost of CO_2 emission for hinterland transport can be calculated by multiplying the value of CO_2 emission by the carbon price. For example, in 2014, the forecast for the price of carbon is 0.02 euro per kilogram. The unit cost of CO_2 emission for hinterland container transport is thus: 0.02 euro/kg X 0.53 kg/TEU-km = 0.01 euro/TEU-km (the original unit cost without CO_2 is 0.57 euro per TEU per kilometer). All these costs from 2013 to 2040 are calculated and shown in the following table. (Sugawara & Niemeier, 2002)

Year	Unit cost of CO_2 for transferring (euro/TEU-km)	Year	Unit cost of CO_2 for transferring (euro/TEU-km)
2013	0.001	**2027**	0.02
2014	0.011	**2028**	0.021
2015	0.011	**2029**	0.021
2016	0.012	**2030**	0.022
2017	0.013	**2031**	0.024
2018	0.014	**2032**	0.025
2019	0.015	**2033**	0.027
2020	0.017	**2034**	0.028
2021	0.017	**2035**	0.029
2022	0.017	**2036**	0.031
2023	0.018	**2037**	0.032
2024	0.019	**2038**	0.033
2025	0.019	**2039**	0.035
2026	0.02	**2040**	0.036

Table 9 Unit cost of CO_2 emission for hinterland transport from 2013 to 2040

3.3. Analysis of the applicability of calculating method

After discussion of the relative factors, the cost and choice functions are determined in this section. The first idea is to add the calculation of the cost of CO_2 emission into the generalized cost function as follows:

$$Cr = \sum_{p\in r} Ap + \sum_{l\in r} Cl + \alpha \cdot \left(\sum_{p\in r} Tp + \sum_{l\in r} tl\right) + \beta \cdot \left(\sum_{p\in r} Ep + \sum_{l\in r} el\right) \qquad (2)$$

Where E_p, CO_2 emission during transhipment at port p; e_l, CO_2 emission during transportation over link l; β, value of CO_2 emission.

The data for the CO_2 emission calculation are based on the throughput in the port area, the length of link and speed (vessel and truck), which can be calculated in the World Container Model. The size of the vessels doesn't need to be specified because the model assumes that the capacity of the vessel is big enough to load all containers. What's more, the exhaust from the vessel is in general, much higher than the exhaust at a terminal. So in the calculation, the CO_2 emission at terminal includes both the emission produced during the handling and the transferring processes. The programming by JAVA in eclipse is written as pseudo-code, as shown in Appendix B.1.

However, in the process of actual operation, the outcomes of the extended WCM are unreasonable. This is mainly because of the big difference between the value of CO_2 emission and throughputs (β is only 0.02 euro per kilogram in 2014 based on the data from Table 3 and the throughput could be hundreds of millions per year). In other words, when we change the value of CO_2 emission, the effects become much bigger. In this sense, the impact of these changes is not convincing. What's more, this method makes the calculation more complex since the World Container Model must be executed twice. The throughput can only be obtained from the outcomes after the original model is executed once. Then, it is used to calculate the total cost, including CO_2-emission cost, in the extended WCM.

In order to solve this problem, the final method is to change the value of transport and transfer directly, and keep the original function unchanged. There are three important factors in the function: maritime (0.025 euro per TUE per kilometer), hinterland (0.57 euro per TEU per kilometer) and transfer. During the process of calculation, these factors are changed by adding the respective unit cost of the corresponding CO_2 emission (during maritime and hinterland transport, at terminal) into the original ones. In this way, the effects of CO_2 emission are visible from the outcomes of the model. The specific method is written as a new scenario by JAVA in eclipse and provided in Appendix B.2.

3.4. Outcomes of the extended WCM

In this thesis, the method introduced in the previous section is used to calculate the total cost and produce the outcomes. Figure 9 represents a snapshot of this extended World Container Model's map output in Scenario 2040. Compared with the graph of the original WCM, due to the impact of the extra cost of CO_2 emitted, the output implies that the transport routes have been reselected and throughput has been redistributed. Even though the United States, Europe and China still have the largest absolute import and export flows, container shipping is much more preferred, rather than inland transport, which decreased mainly because of the high cost when including the cost of CO_2 emission. Coastal transport develops to a certain extent. In other words, containerization of world trade continues until 2040. Overall, the route choice doesn't demonstrate an apparent change. Thus, this thesis will pay more attention to the effects of CO_2 emission on the throughput and transhipment of the ports.

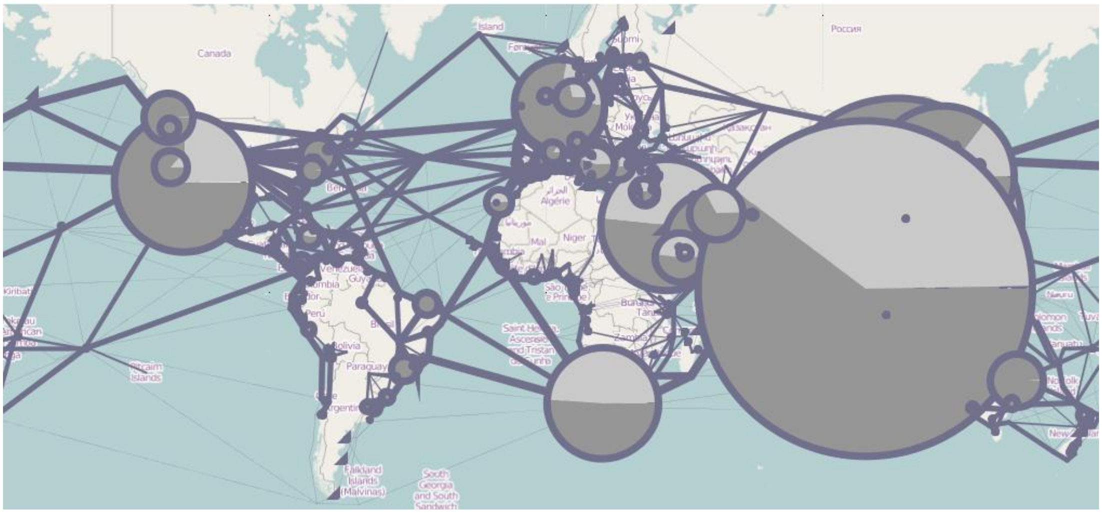

Figure 9 Map output of the extended World Container Model in 2040

One thing needs to be mentioned in advance. In reality, almost every port has already put in place different measures to control or reduce CO_2 emission. But in this thesis, it is assumed that all 437 ports have done nothing to control emission and they stand on the same scratch line without considering the effects of measures already implemented.

The throughput and transhipment of European ports produced in the extended WCM in 2040 are provided in Appendix A.2. Five important ports along the west coast of Europe (Rotterdam, Antwerp, Amsterdam, Hamburg and Le Havre) are singled out to demonstrate and analyze the changes of their throughput and transhipment in Table 10.

Throughput and Transhipment (TEU)	Scenario 2040		Difference (TEU)	Percentage of changes compared with original WCM (%)
	Original WCM	Extended WCM		
		HAMBD		
Throughput	11036613	10948421	-88192	-0.80%
Transhipment	3722087	3656302	-65785	-1.77%
		AMSTN		
Throughput	23999	25749	1750	+7.29%
Transhipment	0	0	0	
		ROTTN		
Throughput	31296252	31370101	73848	+0.24%
Transhipment	8987506	9070236	82730	+0.92%
		ANTWB		
Throughput	30961634	31171973	210339	+0.68%
Transhipment	12190794	12319338	128544	+1.05%
		LEHAF		
Throughput	4586592	4653256	66663	+1.45%
Transhipment	1186106	1196589	10483	+0.88%

Table 10 Changes of throughput and transhipment in 2040 compared with original WCM

The outcomes of the extended WCM forecast that the throughput and transhipment of the port of Rotterdam will increase slightly. Its throughput rises about 74,000 TEU (by 0.24 percent) in 2040. The transhipment experiences an even larger change by growing 0.92 percent about 83,000 TEU. Similar changes are forecasted in 2040 for the ports of Antwerp and Le Havre. Nevertheless, they experience larger growth for both throughput and transhipment. Something to note is that the throughput of Amsterdam increases 7.29 percent in 2040 compared with the original outcomes of the World Container Model. It is a large increase but its base number is small. All of these changes clearly demonstrate that these ports, with the increasing throughput and transhipment, remain competitive even though the effects of CO_2 emission can't be ignored in the future.

On the other hand, some European ports will encounter a crisis due to decreasing of throughput and transhipment in the future. The port of Hamburg is one of these. The throughput of Hamburg will decrease by 0.8 percent because of the effects of emission cost, while the transhipment will be reduced by about 1.77 percent (65,785 TEU) in 2040.

Obviously, the pattern of the world's container transport would be changed: some important ports that played a vital role in the world's container transport would be confronted with serious challenges and, other ports would spring up whose throughput increased rapidly.

In the extended WCM, the changes of throughputs for these five European ports from 2014 to 2040 are shown in Table 11. Their throughput increases or decreases because of the steady growth in CO_2 cost during maritime transport, at terminal and hinterland. Based on the figures analyzed and calculated above, the unit cost of CO_2 emission is 0.0019 euro per TEU in maritime transport. It is valued at 0.11 euro per TEU at terminal and 0.011 euro per TEU for hinterland traffic. These values are added to the original unit cost. To illustrate the variation clearly, bar graphs are provided in Figure 10.

Extended WCM	Year	2014	2040	Difference
Throughput (TEU)	HAMBD	11018585	10948421	-70164
	ANTWB	31006250	31171973	165723
	AMSTN	24523	25748	1225
	ROTTN	31324168	31370101	45933
	LEHAF	4606226	4653256	47029

Table 11 Changes of ports' throughput in the extended WCM from 2014 to 2040

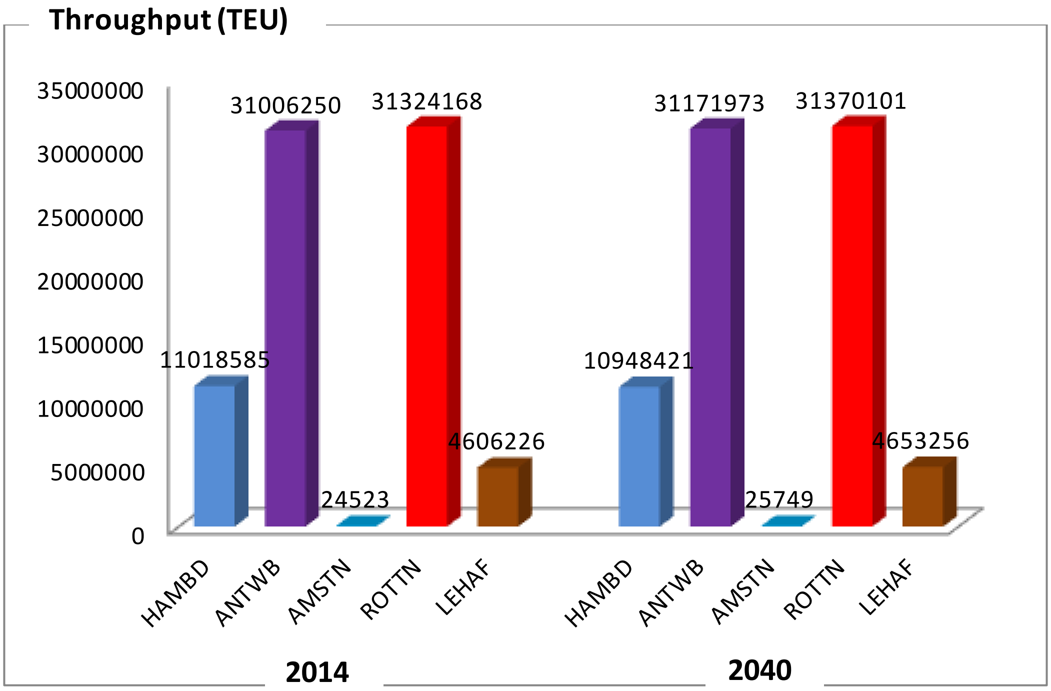

Figure 10 Variation of ports' throughput in the extended WCM from 2014 to 2040

In short, by adding the cost of CO_2 emission to the total cost of world container transport, containerization of world trade steps continues, with increasing throughputs and transhipment from 2014 to 2040. It is noteworthy that some ports with preciously small throughputs experience a new opportunity for development and prosperity if some efficient measures are taken to reduce the effects of CO_2 emission. However, European ports like the port of Rotterdam retain their competitiveness thanks to their advantages of geographic location and insistence on policies of controlling emission.

In addition, Eastern Asia, which has the largest ports at present, has widened the gap between it and its American and European counterparts. This has of course to do with anticipated growth in the next decades, which is much higher in Eastern Asia than in the Western world. China retains its position as the "factory of the world." Other ports in eastern Asia, especially Singapore, benefit from its strategic position as hubs at the center of intra-Asia trade. Singapore plays a key role in transhipment of trade between southern Asia since the cost of long-distance maritime transport has increased heavily by adding the cost of CO_2 emission.

From the outcomes of the extended WCM, the East-West route through the Suez Canal remains very important as the gateway between Europe and Asia. Note that the flow over the Pacific, for technical reasons, has not been displayed in the model. Other trade routes like those between South America and the rest of the world are mainly dominated by raw materials.

3.4 Chapter conclusion

In this chapter, the sub question 3 is answered. The World Container Model has been introduced as a fundamental model that describes worldwide container flows, in combination with a port and multimodal route choice model. On this basis, the extended WCM is developed by quantifying the effects of CO_2 emission towards current and future patterns of container transport. To achieve this, the operational activity-based method is applied to calculate the cost of CO_2 emission during the process of maritime transport. Meanwhile, cost at terminal is formulated based on Ron Van Duin and Harry Geerlings' research.

The output of the extended WCM illustrates the applicability of the model. The results have been briefly presented. A different choice of routes can be seen, mainly because of the extended cost including CO_2 emission. More obvious results are shown in the changes of ports' throughput and transhipment. The competitiveness of ports in the global scale change; there will be a brand-new pattern of world container transport.

4. Modeling scenarios

As described above, significant changes occur when the cost of world container transport includes the cost of CO_2 emission. Thus, it is useful to present scenarios that can be used to test the sensitivity of the container throughput and the rationality of the route choice. Policy makers could evaluate the impacts of these changes by quantifying CO_2 emission in the extended WCM and making their decisions accordingly. In order to study the possible changes and their effects, two scenarios has been created:

- Scenario A: Slow steaming (the speed of vessels slows down)
- Scenario B: CO_2 price (the price of CO_2 emission changes as time passes)

At present, increasing oil prices have resulted in the massive container ships that carry cargo to the four corners of the world having to sail at a slower speed in order to save fuel. The development of technology for ships is also an important direction: the existing fleet must be fitted with new technology that has a lower level of emission than is the case today. These trends have attracted more and more attention. People eager to know what the impact of increasing CO_2 price and slow steaming is on international container transport. That's why these two scenarios are selected to analyze in this report.

These two scenarios are systematic and full-range ones, which are elaborated in the following section. The analysis of the results is mainly focused on changes in 13 European ports.

4.1 Scenario A: Slow steaming

The speed of a vessel plays a vital role in fuel consumption by containership. The function mostly follows an exponential one above 14 knots, which shown in Figure 10. For instance, while a containership of around 8,000 TEU would consume about 225 tons of bunker fuel per day at 24 knots, at 21 knots this consumption drops to about 150 tons per day, a 33 percent decline. While shipping lines would prefer consuming the least amount of fuel by adopting lower speeds, this advantage is mitigated by longer shipping times as well as assigning more ships on a pendulum service to maintain the same port call frequency. (The geography of transport systems, 2009)

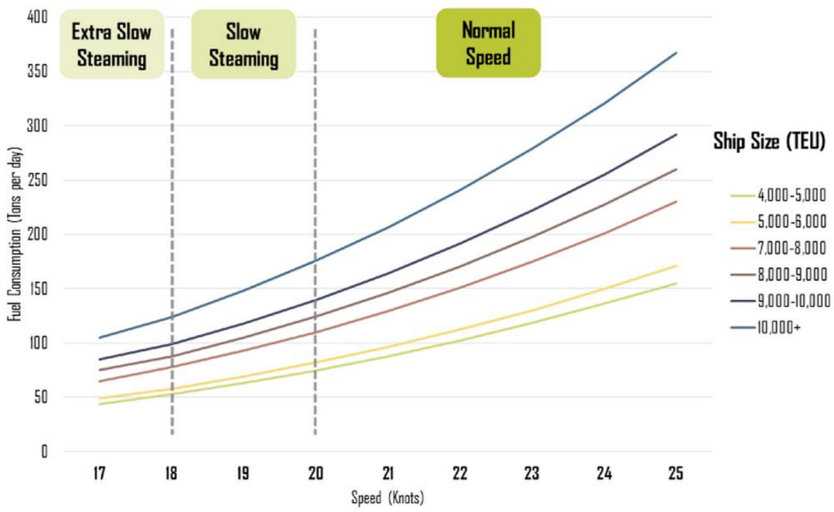

Figure 11 Fuel consumption: a function of ship size and cruising speed (The geography of transport systems, 2009)

However, with the tremendous growth of international trade over the past several decades, the high-speed vessel is preferred to satisfy increasing demand. According to a World Trade Organization (WTO) report, the volume of world trade has increased twenty-seven fold from $296 billion in 1950 to $8 trillion in 2005 (World Trade Organization, 2007). Although in recent years world trade has declined in volume, was down in 2012 and is expected to remain sluggish in the following few years, the WTO is still convinced that global trade could rebound. (World Trade Organization, 2013).

A speed arranging from 20 to 25 knots (37.0 - 46.3 km/hr) represents the optimal cruising speed a containership and its engine have been designed to travel at. It also reflects the hydrodynamic limits of the hull to perform within acceptable fuel consumption levels. Most container ships are designed to travel at speeds of around 24 knots. Transport with a substantial decline in speed (15-20 knots) aims at achieving a minimal level of fuel consumption, but at the expense of additional travel time, particularly over long distances (the compounding effect). This strategy can be applied to specific short distance routes. The lowest speed (12-15 knots) is technically possible, but lower speeds do not lead to any significant additional fuel economy. The level of service is however commercially unacceptable, so it is unlikely that maritime shipping companies would adopt such speeds.

In recent years, the shipping industry has registered a slowing down mainly due to the economic crisis that curtailed the fastest growth characterizing the early 2000s. This new landscape has had different impacts on the maritime sector because of the complexity of the relations between several areas of the world and of the varying impact of different production characteristics on the maritime sectors. Slow steaming in the shipping industry is seen as an answer to current shipping criticalities. Many firms react, slowing down the average speed of vessels, generating a cost reduction and a partial re-designing of the sector.

In fact, this new strategy influences several characteristics of the shipping industry, related to finance, environment, maritime services and inter-port competition, as shown in Figure 12.

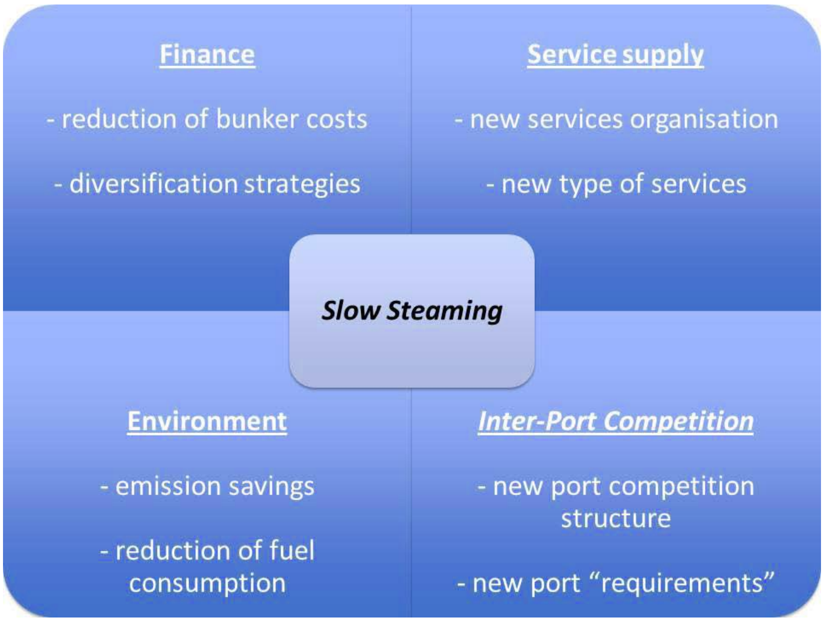

Figure 12 Impact of slow steaming (Ferrari, Tei, & Parola, 2012)

The reduction of speed means a decrease in fuel consumption with an immediate environmental benefit. This is basically true but the amount of fuel tonnage saved and the related polluting effects largely vary depending on the ship. On average, a ship used in an inter-continental route could save around 30 percent previous consumption in the case of a 4-knot speed reduction. (Drewry Maritime Research, 2011)

At the same time, slow steaming influences the emission of ports and ships because of the reduction in calling ports and the introduction of new ships that guarantee less emission than the old ones. It's interesting to note that some companies, like CMA-CGM, have introduced an emission calculator to use the reduction of speed, and thus of emission, as a competitive advantage as part of the new green economy solution.

In this scenario, the effects of slow steaming in world container transport will be analyzed according to the extended World Container Model in order to forecast the future developing pattern, specifically referring to the throughput and transhipment of ports on a global scale.

In the extended WCM, both the continental speed and maritime speed are defined as 1,000 km/day, which is around 23 knots (1 knot is equal to about 0.5 meters per second). To estimate the effects of vessel speed, several speeds of vessels are selected. The transformation of unit in the WCM from kilometers per day to knots is shown in Table 12.

Speed of vessel in knots		Speed of vessel (km/day)
25	>>>	1080
23	>>>	1000
20	>>>	864
17	>>>	735
14	>>>	605

Table 12 Unit transformation from knot to kilometer per day

The specific output of the throughput and transhipment is provided in Appendix A.3 and the percentages of the throughput changes are shown in Table 13.

	Speed (knots)	25	23	20	17	14
Throughput (TEU)	HAMBD	10938840 (0%)	10948420 (+0.09%)	11021897 (+0.76%)	11154072 (+1.97%)	11709670 (+7.05%)
	ANTWB	31440496 (0%)	31171973 (-0.85%)	30465151 (-3.10%)	29640765 (-5.72%)	28561916 (-9.16%)
	AMSTN	25976 (0%)	25749 (-0.88%)	25300 (-2.6%)	24998 (-3.76%)	24265 (-6.59%)
	ROTTN	31270622 (0%)	31370100 (+0.32%)	31652608 (+1.22%)	32032954 (+2.44%)	32492804 (+3.91%)
	LEHAF	4659645 (0%)	4653256 (-0.14%)	4645192 (-0.31%)	4567718 (-1.97%)	4383754 (-5.92%)

Table 13 Changes of throughput for different speed of vessels in 2040

From the output, which reveals the growth in their throughput, we can see that most of the European ports retain their attractiveness. For example, the port of Hamburg shows positive effects from decreasing the speed of vessels. Its throughputs increase from about 10.9 million TEU to almost 11.7 million TEU (reaching about 7.05 percent) when the speed slows down from 25 knots to 14 knots. This finding implies that its competitiveness continues along with the development of a slow-steaming strategy in the future. A similar situation occurs in the port of Rotterdam. By decreasing the speed, the throughputs of these ports increase.

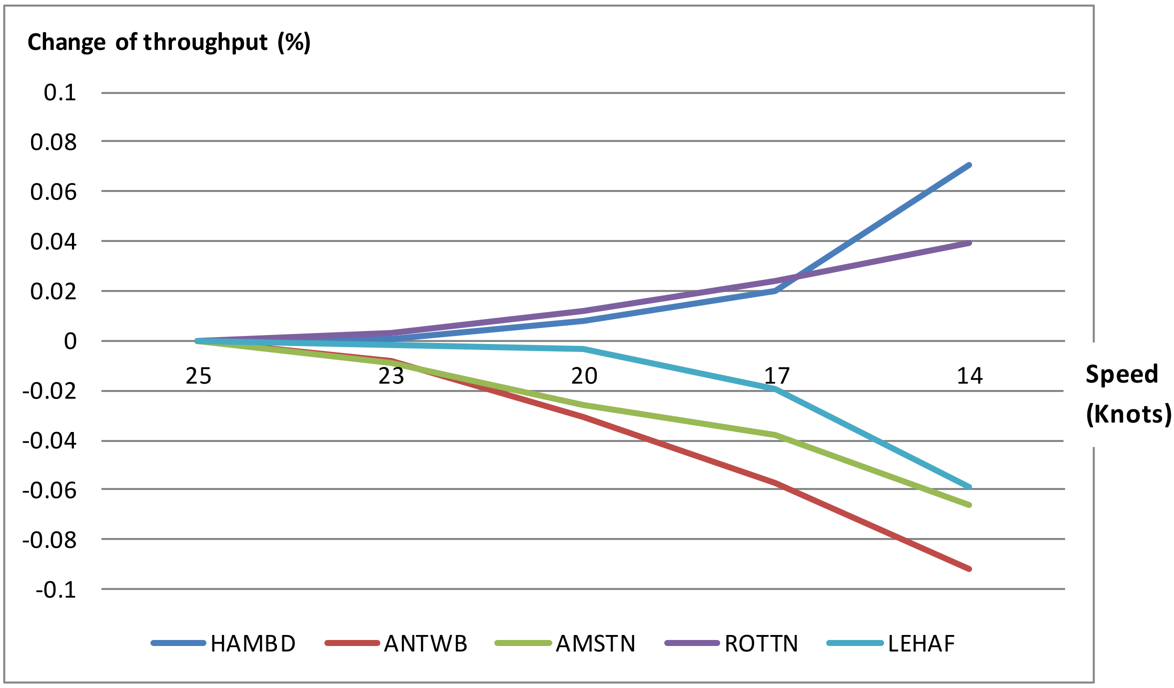

Figure 13 Changes of throughput at different speeds in 2040

However, not all ports can enjoy the advantages of low-speed vessels and benefit from the savings in fuel consumption. In the 13 European ports used as examples, the port of Antwerp, which plays a vital role in container transportation in Europe, probably will lose its competitiveness if the measure of slow steaming is taken to reduce CO_2 emission in the future. Its port manager and decision makers should be careful and make appropriately efficient policies to deal with this challenge. A similar situation also occurs in the ports of Amsterdam, Le Havre and Bremen.

4.2 Scenario B: CO_2 price

As mentioned in chapter 2, several policies have been introduced, by different organizations in order to control CO_2 emission. In other words, the CO_2 price itself can't continue growing indefinitely. Two important factors influence the cost of CO_2 emission: carbon allowances and carbon tax.

Allowances are certificates that give their holder the right to emit a unit of a particular pollutant. A fixed number of carbon allowances are issued by a government, some sold and, perhaps, some given away. Subsequent trade of allowances in a secondary market is common to this policy design. The price that firms must pay to obtain allowances increases their cost of doing business, thereby giving an advantage to firms with cleaner, greener operations, and creating an incentive to lower emission whenever it can be done for less than the price of allowances. The number of allowances—the "cap" in the cap-and-trade system—reflects the required society-wide emission reduction target. A greater reduction target results in a lower cap and a higher price for allowances.

A carbon tax also internalizes the externality of carbon pollution, but instead of selling or giving away rights to pollute (the allowance approach), a carbon tax creates an obligation for firms to pay a fee for each unit of carbon that they emit. In theory, if the value of damages were known with certainty, a tax could internalize the damages more accurately, by setting the tax rate equal to the damages; in practice, the valuation of damages is typically uncertain. In contrast to the government issuance of allowances, with a carbon tax, there is no fixed amount of possible emission (no "cap"). A cap-and-trade system specifies the amount of emission reduction, allowing variation in the price; a tax specifies the price on emission, allowing variation in the resulting reductions. In both cases, there is an incentive to reduce emission whenever it can be done for less than the prevailing price. In both cases, there is the option to continue emitting pollution, at the cost of either buying allowances or paying the tax. While some advocates have claimed that a tax is administratively simpler and reduces bureaucratic, regulatory and compliance costs, a general aversion to new taxes has meant that no carbon tax proposals have received substantial support in recent policy debate. (Luckow, Stanton, & Biewald, 2013)

Prudent planning requires electric utilities and other stakeholders in carbon-intensive industries to use a reasonable estimate of the future price of carbon dioxide (CO_2) emission when evaluating resource investment decisions with multi-decade lifetimes. However, forecasting a CO_2 price can be difficult. But the impact of CO_2 pricing could be analyzed based on the formula found in literature and the outcomes of the extended World Container model. It explains how this would impact the route choice of the ships and the throughput of the ports in Europe. (Carbon Disclosure Project, 2014)

In this scenario, the unit cost of CO_2 emission in maritime container transport varies based on the value from 2014 to 2040 and this value is applied in the model. By doing so, the total cost of maritime container transport (including the cost of CO_2 emission in the container flows) will change. The outcomes of the extended WCM illustrate the changes in throughputs and route choices. In the same way, 13 European ports are chosen as the main research objects to further explain these changes, which are provided in Appendix A.4. The changes of throughput in some important ports are shown in the following table.

	CO2 price (Euro/TEU-km)	0.002	0.003	0.004	0.005	0.006 (original unit cost in 2040)
Throughput (TEU)	HAMBD	10941508 (0%)	10942458 (+0.01%)	10944195 (+0.02%)	10946170 (+0.04%)	10948420 (+0.06%)
	ANTWB	31362943 (0%)	31342675 (-0.06%)	31284321 (-0.25%)	31228649 (-0.43%)	31171973 (-0.61%)
	AMSTN	25916 (0%)	25874 (-0.16%)	25832 (-0.33%)	25790 (-0.49%)	25749 (-0.65%)
	ROTTN	31294992 (0%)	31311941 (+0.05%)	31330567 (+0.11%)	31349902 (+0.18%)	31370100 (+0.24%)
	LEHAF	4653387 (+0%)	4651230 (-0.05%)	4649184 (-0.09%)	4647521 (-0.13%)	4653256 (-0.003%)

Table 14 Changes of throughput along with the change of CO_2 price in 2040

In the above table, the ports of Hamburg and Rotterdam reflect a similar variation tendency. Along with the growth in CO_2 price, their throughput increases at the same time. As the CO_2 tax increases in the future (in order to control the CO_2 emission and relative pollution), they will experience a greater chance for development because of the large number of containers they can import and export. On the other hand, the port of Antwerp (also Amsterdam, Le Havre and Bremen) is likely to lose its competitiveness in the future. The throughputs of ports with varying the CO_2 price change roughly linearly, which are shown in the following figure.

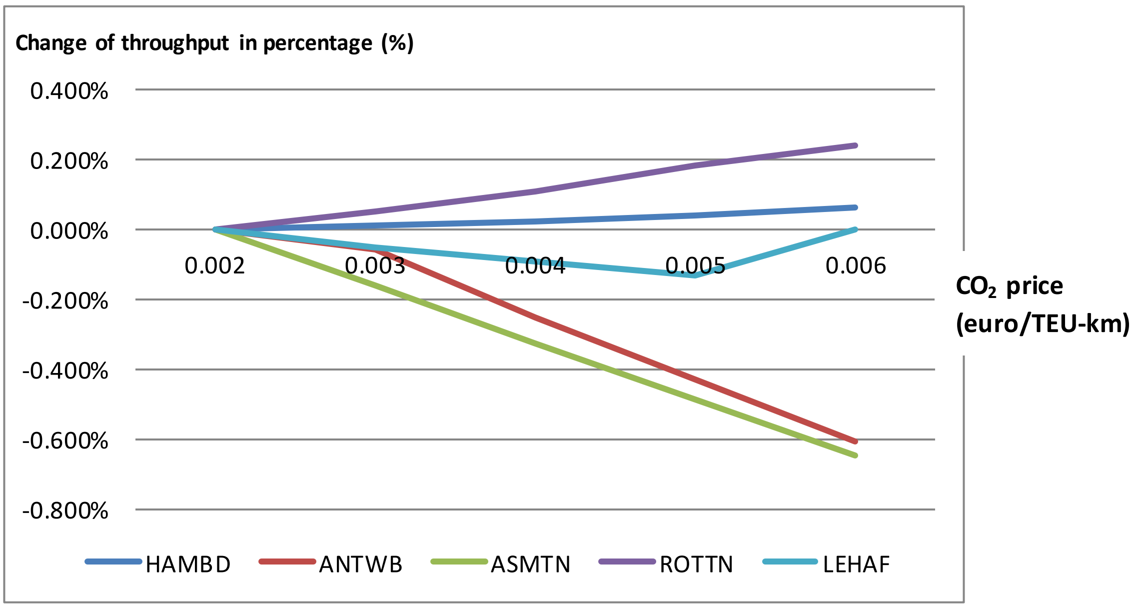

Figure 14 Changes of throughput at different CO_2 price in 2040

4.3 Overview of scenarios

In this chapter, the sub questions 4, 5 and 6 are answered. Two scenarios have been introduced and applied to the model. These scenarios have been developed precisely because they are representative and reflect a possible direction for development. In each scenario, the results show a different tendency. Thirteen European ports have been chosen as examples to reveal the positive or negative changes in competitiveness.

In both scenarios, the ports of Antwerp, Amsterdam, Le Havre and Bremen experience negative outcomes in throughputs from the extended World Container Model. This result may imply that these ports are faced with challenges from the implementation of a slow-steaming strategy and an increase in CO_2 price in the future. In contrast, other ports in Europe, like Rotterdam and Hamburg, retain their competitiveness in future international container traffic. The difference in situations occurs possibly due to the effects of handling cost. For example, the handling cost at the port of Rotterdam is cheaper than that at the port of Antwerp, mainly because that port of Rotterdam has more efficient handling equipment and a better hinterland connection.

5. Case study: port of Rotterdam

In this chapter, the port of Rotterdam is studied as a case by implementing the two scenarios introduced in the above chapter. Then, the calculation method for the total volume of CO_2 emission is discussed. The total volume of CO_2 emitted during maritime container transport is calculated and analyzed based on these two scenarios. Finally, the related stakeholders in world container transport and their interest are defined according to the outcomes of the extended WCM.

5.1. Analysis with the extended WCM

To further illustrate the advantages of extended World Container Model, this thesis has chosen Rotterdam as an example to gain insight into how these scenarios impact the total volume of CO_2 emission.

First, a general introduction and the current situation are provided. Rotterdam is the second-largest city in the Netherlands and one of the largest ports in the world. The port is the gateway to the European market of more than 350 million consumers and is one of the most important junctions of good flows in the world. The port of Rotterdam is managed by the Rotterdam Port Authority. However, this organization is not the owner of the port area. The owner of the port is the municipality of Rotterdam. The municipality leases its land on a leasehold basis to the PoRA. The PoRA in its turn leases the land also on a leasehold basis to individual organizations in the port area. Thus, the PoRA manages the port and financially exploits the area. (Port of Rotterdam, 2011)

Nowadays, the port of Rotterdam is responsible for sixteen percent of carbon dioxide (CO_2) emission in the Netherlands. But the Rotterdam Port Authority claims that they expect to become the most sustainable port city in the world by 2015 and it has also committed to cutting its carbon emission by half by 2025. This is a more ambitious target than the Netherland's national target of a 30 percent reduction by 2020. Energy efficiency measures and renewable energy (wind, biomass) will help to cut emission, but carbon capture and storage (CCS) will also be necessary to reach this ambitious goal. (Port of Rotterdam Authority, 2013)

5.1.1. Outcomes of the extended World Container Model

Second, the extended World Container model is modified to display the routes to and from the port of Rotterdam individually. Figures 15 and 16 are the map outputs for the route choice in 2040 for the WCM with and without the cost of CO_2 emission.

Figure 15 Routes to and from port of Rotterdam in original WCM in 2040

Figure 16 Routes to and from port of Rotterdam in extended WCM in 2040

From the figures, there is almost no difference in the routes all over the world. However, when the routes of containers transport are exported from the model, the number of routes towards and away from Rotterdam changes slightly, decreasing from 2,290 to 2,140. To cope with the increased cost when adding the cost of CO_2 emission in total, some current routes have been canceled. Carriers prefer to choose a transit port rather than transport to Rotterdam directly. In other words, to some extent, long-distance maritime transport loses its attraction to decision makers. (Korinek & Sourdin, 2009)

Throughput and Transhipment (TEU)	Scenario 2040		Difference (TEU)	Percentage of changes compared with original WCM (%)
	Original WCM	Extended WCM		
	ROTTN			
Throughput	31296252	31370101	73848	+0.24%
Transhipment	8987506	9070236	82730	+0.92%

Table 15 Comparison of throughput and transhipment for port of Rotterdam in 2040

In addition, Table 15 shows the changes in throughput and transhipment for the port of Rotterdam in 2040. The difference between the original and the extended WCM, implies that about a 0.24 percent increase in throughput can be forecasted for the port of Rotterdam in 2040 when considering the cost of CO_2 emission in the total transport cost. What's more, the number of transhipments grows more than 0.9 percent in 2040. These changes illustrate that the cost of CO_2 emission doesn't make a big difference for the development of the port of Rotterdam. Conversely, some positive effects can be expected since both the throughput and transhipment experience growth. This is mainly because of the "lower cost" of container transport. The total costs of all container routes all over the world increase due to the extra cost of CO_2 emission. It is same for all the ports. But the costs of routes to and from the port of Rotterdam are still lower than costs of some other ports, like port of Antwerp.

5.1.2. Outcomes of scenarios

Third, the outcomes for the analysis of the two scenarios analyzed in the last chapter are shown in Tables 16 and 17. The throughput of the port increases by about 4 percent in 2040 when the speed of vessels slows to 14 knots. In another scenario, the CO_2 price rises from 0.002 euro per TEU to 0.006 euro per TEU in 2040. From the results, we can see that the throughput of Rotterdam increases at the same time reaching about ten thousand TEU when the price is 0.002 euro per TEU. These findings illustrate that the port of Rotterdam will strengthen its competitive position in the future even with the effects of the slow steaming and increasing CO_2 price.

Thanks to the strong hinterland connections and secure position in region, the port of Rotterdam has great opportunity to function as the hub and gateway to Europe in a globalizing world. With a competitive advantage for receiving large container vessels and strong connections on Asian trade routes, Rotterdam can outperform their competitors in this case.

Speed (knots)		25	23	20	17	14
Throughput (TUE)	ROTTN	31270622 (0%)	31370100 (+0.32%)	31652608 (+1.22%)	32032954 (+2.44%)	32492804 (+3.91%)

Table 16 Change of throughput in scenario A in 2040

CO_2 price (Euro/TEU-km)		0.002	0.003	0.004	0.005	0.006
Throughput (TUE)	ROTTN	31294992 (0%)	31311941 (+0.05%)	31330567 (+0.11%)	31349902 (+0.18%)	31370100 (+0.24%)

Table 17 Change of throughput in scenario B in 2040

5.2. Analysis of CO_2 emission

In this section, the method of calculating the total volume of CO_2 emission during world container transport is explained. By comparing with the existing research from relative references, this method is verified for the port of Rotterdam. Following, the analysis of the outcomes is provided.

5.2.1. Calculation method for total volume of CO_2 emission

Since the outcomes of the different scenarios are analyzed clearly, a measure is needed to compare the effectiveness of different policies in reducing global CO_2 emission. Total CO_2 emission in maritime container transport is calculated based on the activity-based calculation method and the Energy-based approach, which have been introduced in chapter 2. Further, the method for assessing CO_2 emission at container terminals has been studied and explained in detail according to Ron Van Duin and Harry Geerlings' research. The calculation formulas are provided below and used to calculate the total volume of CO_2 emission in the extended World Container Model so that whenever these scenarios are changed, the total CO_2 emitted can be observed.

$$
\begin{aligned}
&Volume\ of\ CO2 \\
&\qquad = CO2\ emission\ in\ terminal \\
&\qquad + CO2\ emission\ during\ transport
\end{aligned}
$$

Where

$$
\begin{aligned}
&CO2\ emission\ at\ terminal \\
&= \sum CO2\ emission\ for\ handling + \sum \text{CO2 emission for transferring} \\
&= \sum Throughput \times (CO2\ per\ kWh \times\ consumption\ per\ container\ move \\
&+ \quad average\ distance\ container\ transfered\ at\ terminal \\
&\times \quad volume\ of\ CO2\ per\ km\ per\ TEU)
\end{aligned}
$$

$$
\begin{aligned}
&CO2\ during\ transportation \\
&= \sum Total\ flow\ per\ link \times\ distance\ \ of\ link \\
&\qquad \times volume\ of\ CO2\ per\ km\ per\ TEU
\end{aligned}
$$

5.2.2 Outcomes of CO_2 emission

Last but not least, the effectiveness of the two scenarios on the port of Rotterdam is analyzed based on the calculation of total volume of CO_2 emission. One important factor is that the port authority doesn't care much about the emission during maritime transport. But it is a good opportunity that this extended WCM can estimate the total volume of CO_2 emission in the shipping process with the throughput and length of link calculated. What's more, the emission at terminal has been studied by Ron Van Duin and Harry Geerlings in detail. Based on the formula introduced above, the CO_2 emitted in the process of handling operation at terminal is fixed per container with one kind of equipment. Thus, the changes in CO_2 emission at terminal are almost identical to the changes of the throughputs. Since these changes and the reason behind them have been analyzed in the previous chapter, the volume of CO_2 emission during maritime transport is regarded as the following research objective.

For scenario A (slow steaming), the obvious reason for introducing slow steaming is to save fuel. When fuel prices soared, the technical experts of one of the world's biggest shipping companies set about solving the problem. Slowing down is the solution they came up with. By 2009, significant fuel savings resulting from sailing at 12 knots instead of 24 have seen slow steaming become the standard operating procedure in their fleet. (MAN PrimeServ, 2011)

The newest built large vessel "Triple-E" is designed and optimized for lower speeds. Apart from the fact that the ships are bigger, their hulls are reportedly designed for around an average ship speed of only 23 knots, compared with over 24 knots for the first 13,000 TEU vessels. The unique hull design, energy-efficient engine and system that uses exhaust gas to produce extra energy to propel the ship, make the Triple-E unmatched in energy efficiency. This type of construction outlines the trend for future maritime transport by container ship. A small change in knots cuts fuel consumption and lowers CO_2 emission. The Triple-E is designed to be efficient across various vessel operations. Slow steaming has at once cut fuel consumption, improved reliability and lowered carbon emission.

The above-mentioned reductions include propulsion power only and assume a fixed relation between fuel consumption and carbon emission. Figure 17 relates to emission per nautical mile and is based on general data for larger container vessels. (Triple-E Efficiency, 2014)

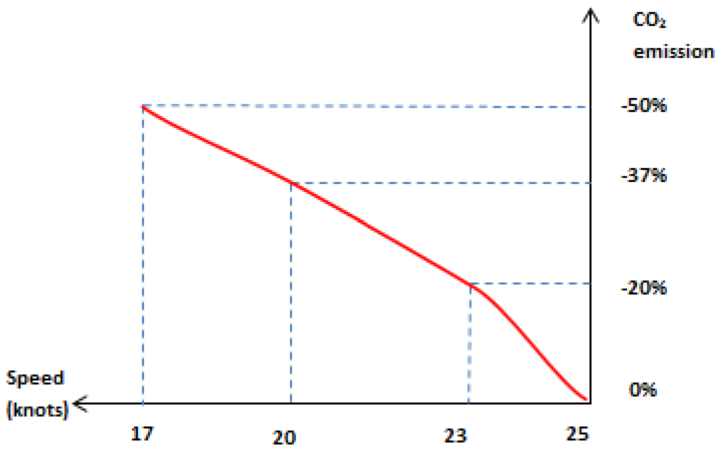

Figure 17 Relationships between speed and CO2 emission

From the figure, we can see that CO_2 emission decreased sharply along with the reduction in the ship speed from 25 to 23 knots. This decrease confirms that slow steaming saves bunkers, leading to a tradeoff between travel time and fuel consumption. According to research conducted by Rasmus Jorgensen, around two million tons of CO_2 was saved in 2010 by the Maersk Line thanks to slow steaming. (Rasmus Jorgensen, 2013)

However, these data from the Maersk are not entirely convincing. So what is the real situation? In this thesis, the calculation of CO_2 emission during maritime transport is implemented in the extended WCM. By varying the speed of the vessels, the outcomes show the changes in CO_2 emission in Table 18, which can be used to compare with the expected situation and validate the effectiveness of the scenario.

Port of Rotterdam in extended WCM

Speed (knots)	25	23	20	17	14
CO_2 emission (ton)	132353629	127456545	120971217	112632938	105618196
Index (percent)	100%	96.3%	91.4%	85.1%	79.8%

Table 18 Total volume of CO_2 emission and its changes by varying speed of vessels 2040

The trend of these changes is further demonstrated in the following figures by line charts. For scenario A, slow steaming, the throughput of the port of Rotterdam increases inversely (the red line in Figure 18). Beyond doubt, it results in the growth of CO_2 emission at the area of the terminal based on the calculation introduced in the previous section (5.1). But for maritime container transport, the total volume of CO_2 emission decreased along with the drop in speed. This result is mainly due to the reduction in the number of routes to and from port of Rotterdam (as mentioned above, the number of routes to or from Rotterdam decreases from 2,290 to 2,140). Due to the decrease in the speed, some shippers prefer short-distance shipping rather than long-distance transport in order to satisfy customers with shorter delivery times. The outcomes of the extended WCM concerning CO_2 emission show a similar tendency to that of Maersk's reference but the effects are not that exaggerated.

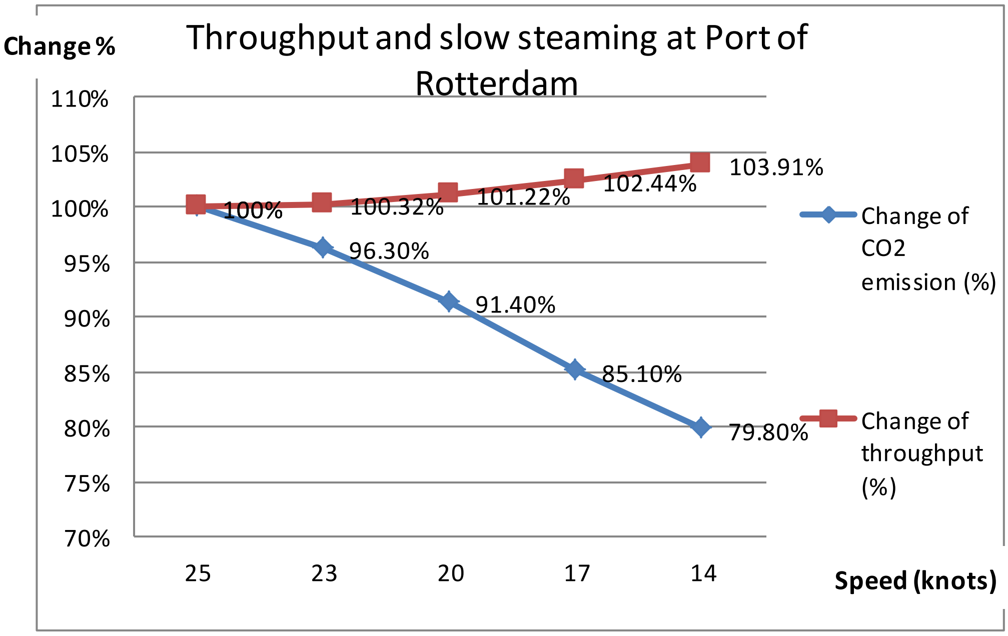

Figure 18 Changes in CO_2 emission by slow steaming for the port of Rotterdam in 2040

What's more, total volume of CO_2 emission and its changes with different CO_2 price in 2040 are also provided in Table 19.

Port of Rotterdam in extended WCM

CO_2 price (euro/TEU)	0.002	0.003	0.004	0.005	0.006
CO_2 emission (ton)	133322746	132256164	131189582	129456386	127456545
Index (percent)	100%	99.2%	98.4%	97.1%	95.6%

Table 19 Total volume of CO_2 emission and its changes with different CO_2 price in 2040

For scenario B, CO_2 price, with the growth of the tax, the port of Rotterdam still remains attractive as one of the largest ports in the world. Its throughput and transhipment continue to increase. On the other side, for maritime transport, the CO_2 emitted by containers to and from the port of Rotterdam decreases when the CO_2 tax increases.

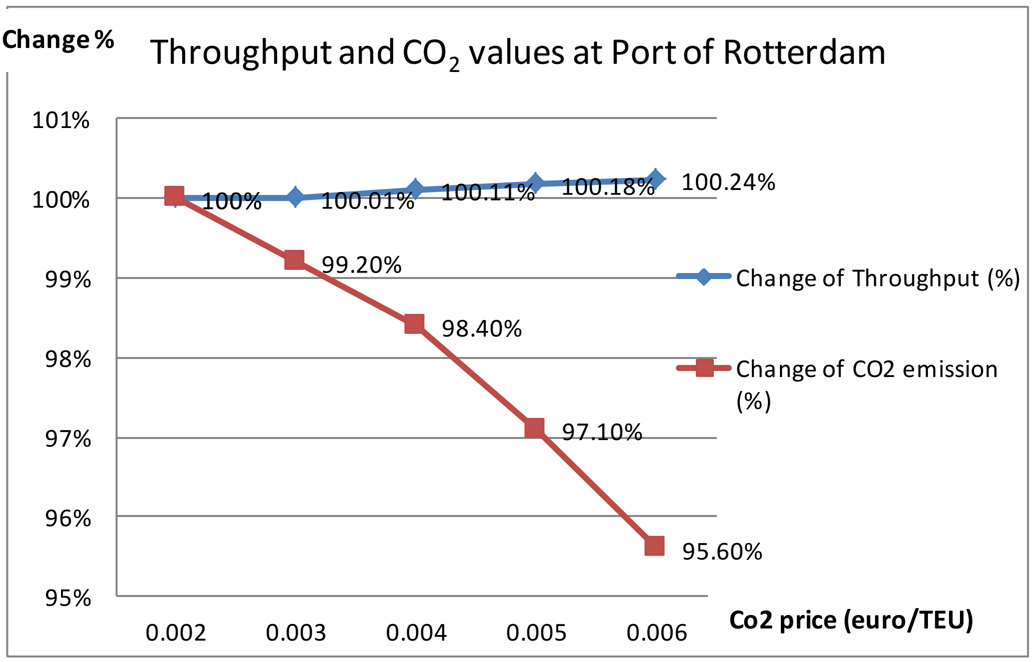

Figure 19 Changes of CO_2 emission by CO_2 price for port of Rotterdam in 2040

As mentioned before, this "positive" result profits from the economy of scale. Worldwide container transport with large capacity and low frequency will become main-stream in the future. Container shipping benefits from economies of scale in maritime shipping, transhipment and inland transportation. The rationale of maritime container shipping companies to have larger ships becomes obvious when the benefits, in terms of lower costs per TEU, increase with the capacity of ships. (Why Size Matters: Container Ship Economies of Scale, 2013)

According to the results of the extended WCM, the port of Rotterdam will benefit from these scenarios with the growth of throughput and transhipment. When considering increasing CO_2 emission at terminal in the future, the port of Rotterdam still needs to focus on improving efficiency of handling at terminal. Such efficiency depends on operation performances and terminal configurations. This measure has a larger impact, but it does not work in a short term and it is expensive. In response to increasing CO_2 emission, strategy should also focus on energy conservation and renewable energy. These considerations also reflect the actual situation, which have confirmed the outcomes of our extended WCM reasonably. (de Langen, 2005)

5.3. Outcomes of stakeholder analysis

The stakeholders' interest and power, which based on the outcomes of scenarios and CO_2 emission, are provided in Table 20.

Stakeholder	Interest	Power
Carrier	Least cost in the process of maritime transport and terminal handling; tariffs in different countries	Set route of transport; choose transhipment port; multi-model transport or not; choice of vessel to transport
Policy maker	Total volume of CO_2 emission; desire to know the tendency of future emission	Policy making; treaties
Shipper	Travel time; travel cost	Reasonable cost to pay regardless of emission; delivery time
Local residents & Environmental Organization	Pollution along transport route; quality of life; noise; land use	Protest
Port authority & Terminal operator	Handling time; efficiency of operation; throughput and transhipment capacity	Adaptation of the terminal layout; use of biofuel

Table 20 Interest and power of stakeholders

When considering the total volume of CO_2 emission in each scenario (decreased vessel speed and CO_2 price), the results show that both scenarios for port of Rotterdam perform well. The section on stakeholders and interest answered the sub research question. Compared with other stakeholders, carriers have the biggest interest in the cost of CO_2 emission. A few notes should be made on how to implement such a methodology. The policy maker of the port should not be focused on one (desired) scenario but must consider all possible scenarios and adjust over time. Port of Rotterdam should therefore continuously monitor trends and developments and ask themselves “in which scenario” they are.

5.4. Chapter conclusion

In this chapter, the port of Rotterdam is selected as a case to study the availability of the extended World Container Model. The results show positive effects on both scenarios. It’s mainly because that the port of Rotterdam has the strong hinterland connections, low handling cost, and good position in Europe. Its cost of world container transport is lower than other competitive ports except the port of Hamburg. The increasing throughput and transhipment can be seen from the outcomes of the extended model.

Besides, when considering the CO_2 emission, the container shipping benefits from economies of scale in maritime shipping, transhipment and inland transportation. After CO_2 price is increased or when speed of vessel is decreased, the total CO_2 emission reduces. But according to the stakeholder analysis, the port of Rotterdam still needs to focus on improving efficiency of handling at terminal. Strategy should also focus on energy conservation and renewable energy. The policy makers of the port of Rotterdam should not be focused on one (desired) scenario but must consider all possible scenarios and adjust over time. They should therefore continuously monitor trends and developments and ask themselves “in which scenario” they are.

6. Conclusion and recommendations

6.1 Introduction

The impact of CO_2 emission is a hot topic in transportation that will be highlighted in the near future. Many questions will challenge our conventional modeling and traffic operations.

In the current situation, many models are studied to calculate CO_2 emission in the course of transporting as well as in the area of the terminal. But the effects of CO_2 emission on the choice of routes cannot be displayed clearly on a world map. And the changes in throughput and transhipment for ports all over the world cannot be obtained at one time to compare the differences. These facts have rendered the related organizations unable to make convincing policies and measures. Further, since shipping emission can only be computed after a journey is finished, the introduction of emission into the cost function requires a model or simulation to take into account this delayed feedback.

In this thesis, the CO_2 emission produced by global container transport is the main research object. According to the research conducted, the World Container Model is a suitable tool, with imaging route choice and 437 container ports around the world, taking into account more than 800 maritime container liner services. The model includes import, export, throughputs and transhipment flows of containers at ports, as well as hinterland flows.

In order to achieve the objective of this Master's thesis, this model is redesigned to incorporate travel time cost and CO_2-emission cost in the route choice function and to investigate the performance impact of adding CO_2 emission concerns into route choice. The CO_2-emission cost includes two parts: the cost during transportation and at the terminal. An operational activity-based method is introduced to calculate the cost of CO_2 emission during transport. The formula at the terminal references the research of Ron van Duin and Harry Geerlings (the estimation model of CO_2 footprint of container terminal port operation). Afterwards, two scenarios and a case study are analyzed to provide guidance for carriers and policy makers. In addition, the calculation method of CO_2 emission during maritime transportation is introduced and used to illustrate the effects according to the case of the port of Rotterdam.

6.2 Conclusions on model outcomes

As more and more attention is paid to CO_2 emission, the original World Container Model, which does not take into account the effects of the CO_2 emission, is not a suitable model for operators. Thus, in this thesis, my extended WCM is designed and developed, which accounts for the cost of CO_2 emission. Such a model could provide good insight into a range of possible structures of global trade patterns and consequences for the transportation system.

Based on the analysis performed in the first chapters and the scenarios that have been modeled using an extended World Container Model, the main research question can be answered.

How can the World Container Model be extended to model the effects of CO_2-emission cost and what effects on international container flows are expected?

To answer the first part of the main research question, the World Container Model has been extended with a new scenario executed in the model. This new scenario is designed to add the cost of CO_2 emission into the cost of travel time and transfer. There are three important factors in the function: maritime (0.025 euro per TUE), hinterland (0.57 euro per TEU) and transfer. During the process of calculation, these factors are changed by adding the respective unit cost of the corresponding CO_2 emission (during maritime and hinterland transport, at terminal) into the original ones. In this way, the unit cost per container move increases by including the cost of CO_2 emission. Then the effects of CO_2 emission are visible from the outcomes of the model.

For the answer to the second part of the main research question, the containerization of world trade steps continues with increasing throughputs and transhipment from 2014 to 2040. But the competitiveness of ports on a global scale changes in a sense. Some ports, like Amsterdam, previously with small throughputs and transhipment, experience a new opportunity for development and prosperity. However, others, like the port of Rotterdam, retain their competitiveness thanks to their advantages of geographic location and insistence on policies for controlling emission.

Further analysis is mainly focused on 13 European ports. In scenario A (slow steaming), most of these European ports retain their attractiveness, which is enhanced by the growth of their throughput. Meanwhile, with the decrease in speed, the throughput of these ports will increase even more. It is likely that the competitiveness of European ports continues along with the development of the slow-steaming strategy in the future. However, not all ports can enjoy the advantages of low-speed vessels and benefit from the fuel saving consumption. The port of Antwerp is one of the ports that will probably lose its competitiveness in container transportation in Europe if a global measure of slow steaming is undertaken to reduce CO_2 emission. A similar situation also occurs in the ports of Amsterdam, Le Havre and Bremen. As for their port managers and decision makers, they should be careful and take appropriately efficient policy measures to deal with this challenge.

In scenario B, the price of CO_2 emission is changed to analyze the effects. As the CO_2 tax will be increasing in the future, most European ports like Rotterdam and Hamburg will experience great chances for development because of the large number of containers being imported and exported. On the other hand, the ports of Antwerp, Amsterdam, Le Havre and Bremen show negative outcomes of throughputs from the extended World Container Model. This result may imply that these ports are faced with challenges of the increasing CO_2 price in the future.

In conclusion, compared to the original model, the extended WCM has the capability of adding the cost of CO_2 emission into the total cost of container transport and analyzing its effects with more reasonable outcomes. With this model, other policies and strategies can also be applied to forecast their impacts on the ports. The relevant port manager is able to take effective measures based on their impacts before they are implemented.

6.3 Recommendation

This section will elaborate some recommendations that can be made for ports based on the research. It has been shown how the global scenarios affect the throughput in the European ports. But it must be realized that the scenarios presented do not reflect an exhaustive list of possible futures.

This report has proposed a method for predicting global container transport that incorporates travel time and traffic CO_2 emission in the composite route choice cost function, which provides reasonable suggestions on the potential effects that can be achieved from reducing the emission.

According to the results of the scenarios, the port of Rotterdam will experience positive effects from these scenarios with the growth of throughput and transhipment. When considering the increasing CO_2 emission at terminal in the future, Rotterdam still needs to focus on improving the efficiency of handling at terminal. Such considerations depend on the operation performances and terminal configurations. This measure would have more of an impact but it would work only over the long term and the cost would be high. The changing world should be considered during the implementation. Impacts and probabilities should be gradually examined. As a response to increasing CO_2 emission, the strategy should also focus on energy conservation and renewable energy. These considerations also correspond to the actual situation, which confirms the outcomes of the extended WCM reasonably.

Other ports in Europe, like Antwerp, which shows negative effects based on the scenarios need to be more careful. The extended WCM in this research has shown that it can be used to assess the effects of a wide range of developments. As a strategic tool for policy development, it is able to assist the port to make adequate decisions and take appropriate measures.

Based on the analysis of stakeholders, policy maker of the port should not be focused on one (desired) scenario but must consider all possible scenarios and adjust over time. Ports should therefore continuously monitor trends and developments and ask themselves "in which scenario" they are.

6.4 Model reflection and suggestions for further research

This section will discuss model limitations and offer suggestions for further improvements and extensions. Some major limitations and their implications will first be discussed.

1. A more feasible and systematic calculation method should be applied instead of the one used in this extended model. The formulas of the operational activity-based method and the method of calculating total CO_2 emission are linear, which could possibly be inaccurate.

2. The outcomes of throughput and transhipment in the extended WCM are not accurate without taking into account current efforts to reduce CO_2 emission. Every port takes different measures to reduce CO_2 emission. These measures, which have already been put into effect, are not considered in the extended WCM and it is assumed that all the ports do nothing in controlling emission.

3. Little consideration is given to the changes in hinterland connection. Since the emphasis of this report is to study maritime container transport, the CO_2 emission produced by truck, railway and barge in the process of transhipment is not the main research objective.

Considering this study is just a starting point of the extended WCM, a number of simplifications and assumptions were made in developing the method and the case study. Some improvements can be made in further research:

1. Other GHG like CH_4 and SO_2 also play a vital role in climate change. In this research, only the effects of CO_2 emission on world container transport are analyzed. Further research could focus on the emission from additional or even all the greenhouse gases.

2. In the original World Container Model, two container service lines were added to represent the Trans-Siberian land-bridge (a set of long-distance railway connections between China and Europe) and the Northern polar cap.

(Tavasszy, Michiel, Jean-francois, & Theo, 2011) In future work, the impact of opening new routes should be added into the analysis since transport routes sometimes change.

3. Further research could trace ships with all the relevant information. For example, which destinations, and which hinterland destinations, create high levels of pollution, etc. What's more, multimodal transport, as an important type of shipping, should also be regarded as a factor when deciding the routes.

4. The efficient and effective management of empty containers is an important problem in the shipping industry. Not only does it have an economic effect, but it also has an environmental and sustainability impact, since the reduction of empty container movement will reduce fuel consumption and reduce congestion and emission. (Managing Empty Containers, 2009)

Bibliography

Adler, J., Blue, V., & Wu, T. (1999). *Assessing driver and network performance under biobjective route guidance systems.* Washington, DC: Presented at the 78th Transportation Research Board.

Barth, M., & Boriboonsomsin, K. (2008). Real-World Carbon Dioxide Impacts of Traffci Congestion. In *Transportation Research Record* (pp. 163-171).

Benedek, C., & Rilett, L. (1998). *Equitable traffic assignment with environmental cost function.* Journal of Transprotation Engineering.

Bernhofen, D. M., El-Sahli, Z., & Kneller, R. (2011). *Estimating the effects of containerization on world trade.*

Carbon Disclosure Project. (2014). *Corporate use of carbon prices: Commentary from corporations, investors and thought leaders.*

Clean Shipping Technology. (2014, 7 30). Retrieved from Clean North Sea Shipping (CNSS): http://cleantech.cnss.no/air-pollutant-tech/nox/liquefied-natural-gas-lng/

David , M. A. (1989). Emission credit trading and the incentive to adopt new pollution abatement technology. *Journal of Environmental Economics and Management*, 52-57.

de Langen, P. W. (2005). Trends and Opportunities for the long term development of Rotterdam's port complex. *Coastal Management*, pp. 200-224.

Department of Climate Change an Energy Efficiency. (2012). *A Plan for Implementing Climate Change Science in Australia.* Australian Government.

Department of Energy & Climate Change. (2013). *Updated short-term traded carbon values used for modelling purposes.*

Diepen, A. v. (2011, 11 22). Predicting effects of global long term scenarios on container throughput of the port of rotterdam using an extended World Container Model.

Drewry Maritime Research. (2011). *Quarterly Drewry Report.* London: Container Forecast.

EC. (2001). *White Paper: European transport policy for 2010: time to decide.* Brussels: European Commission.

ECTA, cefic , & Responsible Care. (2011). *Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations.* European Chemical Transport Association.

Eden, C. a. (1998). *Making Strategy: The Journey of Strategic Management.* London: Sage Publications.

European Chemical Transport Association. (2011). *Guidelines for Measuring and Managing CO2 Emission from Freight Transport Operations.*

European Commission. (2012). *Trends in Global CO2 Emission.* PBL Netherlands Environmental Assessment Agency.

European Commission. (2014). Retrieved from The policies of climate action: http://ec.europa.eu/clima/policies/g-gas/index_en.htm

European White Paper Transport. (2010).

Ferrari, C., Tei, A., & Parola, F. (2012). *Facing the economic crisis by cutting costs: The impact of slow-steaming on container shipping networks.* Taiwan: International Association of Maritime Economists (IAME).

Fremont, A., & Franc, P. (2010). *Hinterland transportation in Europe: Combined transport versus* *road transport.* Journal of Transport geography.

Geerlings, H., & Van Duin, R. (2011). Estimating CO2 Footprints of Container Terminal Port-Operations. *WIT Press Journals*, pp. 459-473.

Global transport. (1970). Containerisation International.

Hans G. Payer. (2002). *Economic and technical aspects of mega-container carriers.* Hamburg: Germanische Lloyd .

Harry Geerlings, & Ron van Duin. (2011). *A new method for assessing CO2-emissions from container terminals: a promising approach applied in Rotterdam.*

Hoeven, M. V. (2012). *CO2 Emission from Fuel Combustion.* International Energy Agency.

IMO. (2009). *International Maritime Organization.*

Intergovernmental panel on climate change. (n.d.). Retrieved 1 13, 2014, from IPCC: http://www.ipcc-data.org/observ/ddc_co2.html

International Energy Agency. (2013). *World energy outlook.*

J., J., J. Scott Hawker, & James J. Winebrake. (2011). *Geospatial Intermodal Freight Transport (GIFT) Model with Cargo Flow Analysis.*

Jean-Paul Rodrigue . (2013). *The Geography of transport systems .* New York.

John, V. (2007). CO2 output from shipping twice as much as airlines. *The Guardian*.

Jolley, A. (2004). *New Technologies, Industry Developments and Emission Trends in Key Sectors: The Land Transportation Sector.* Victoria University of Technology.

K. HASSELMANN, S. H. (1997). *SENSITIVITY STUDY OF OPTIMAL CO2 EMISSION PATHS USING A SIMPLIFIED STRUCTURAL INTEGRATED ASSESSMENT MODEL.* Hamburg, Germany: Max-Planck-Institut f ¨ur Meteorologie.

Korinek, J., & Sourdin, P. (2009). *Maritime Transport Costs and Their Impact on Trade.* OECD.

Liao, C.-H., Lu, C.-S., & Tseng, P.-H. (2011, 7). Carbon dioxide emissions and inland container transport in Taiwan. *Journal of Transport Geography*, pp. pp 722-728.

Luckow, P., Stanton, E. A., & Biewald, B. (2013). *2013 Carbon Dioxide Price Forecast.* Cambridge: Synapse.

MAN PrimeServ. (2011). *Slow Steaming Practices in the Global Shipping Industry.*

Managing Empty Containers. (2009, 2). *Department of Toxic substances control .*

National Traffic and Transport Plan 2001-2020. (2001).

Notteboom, T., & Rodrigue, J.-P. (2009). The future of containerization: perspectives from maritime and inland freight distribution. *GeoJournal*, 7-22.

Payer, H. (2002). *Economic and technical aspects of mega-container carriers.* Hamburg: Germanische Lloyd.

Port of Rotterdam. (2011). *Port Vistion 2030.* Rotterdam: Port of Rotterdam.

Port of Rotterdam Authority. (2013). *Annual Report.* Port of Rotterdam Authority.

Rasmus Jorgensen. (2013). *The full story of slow steaming.* Denmark: Maersk Group.

S. Kalligeros, F. Z. (2003). *An investigation of using biodiesel/marine diesel blends on the performance of a stationary diesel engine.*

Slack, B. (2001). *Globalisation in Maritime Transportation: Competition, uncertainty and implications for port development strategy.* Milan: Fondazione Eni Enrico Mattei.

Smith, T., Mark, B., Sophia, P., & Eoin, O. (2011). *Description of GloTraM-2, a prototype model to calculate the future energy, emissions and costs of the global shipping industry.*

Song, D.-P., & Xu, J. (2012). *An operational activity-based method to estimate CO2 emissions from* *container shipping considering empty container repositioning.*

Stakeholder Analysis. (2013). Retrieved 10 20, 2013, from Stakeholdermap: http://www.stakeholdermap.com/stakeholder-analysis.html

Sugawara, S., & Niemeier, D. (2002). How much can vehicle emissions be reduced? Exploratory analysis of an upper boundary using an emission-optimized trip assignment. *Transportation Research Record*, pp. 29-37.

Tavasszy, L. A., & Halim, R. A. (2012). *Modeling the global freight transportation system: A multi-level modeling perspective.*

Tavasszy, L., Michiel, M., Jean-francois, P., & Theo, N. (2011). A strategic network choice model for global contianer flows:specification, estimation and application.

Tavasszy, L., Minderhoud, M., Perrin, J.-F., & Notteboom, T. (2011, 11). A strategic network choice model for global container flows: specification, estimation and application. *Journal of Transport Geography*, pp. 1163-1172.

The EU Emissions Trading System. (2013). Retrieved from European Commission: http://ec.europa.eu/clima/policies/ets/index_en.htm

The geography of transport systems. (2009). Retrieved 06 10, 2014, from http://people.hofstra.edu/geotrans/index.html

The International Council on Clean Transportation. (2011). *The Energy Efficiency Design Index (EEDI) for New Ships.*

Transport Intelligence. (2011).

Triple-E Efficiency. (2014, 4 5). Retrieved from MAERSK: http://www.worldslargestship.com/the-ship/#page/efficiency/lower-speeds

UNCTAD Handbook of Statistics 2012. (2012). Geneva : United Nations Conference on Trade and Development .

UNFCCC. (2013, 11 15). Retrieved 1 15, 2014, from United nations framework Conevention on Climate Change: http://unfccc.int/2860.php

Veritas, D. N. (2010). *Assessment of measures to reduce future CO2.* DNV.

Vidal, J. (2007). CO2 output from shipping twice as much as airlines. *The Guardian*.

Visser, J., Konings, R., Pielage, B.-J., & Wiegmans, B. (2007). *A new hinterland transport concept for the port of Rotterdam:organisational and/or technological challenges?* Delft: Delft University of Technology.

Wang, S., Wang, Q., & Sun, Z. (2012, 4 5). Container routing in liner shipping.

Why Size Matters: Container Ship Economies of Scale. (2013, 09 03). *MarineLink.com*. Retrieved from http://www.MarineLink.com

Wikipedia. (2013, 11 15). Retrieved 06 08, 2014, from List of largest container ships: http://en.wikipedia.org/wiki/List_of_largest_container_ships

Wikipedia. (2013, 12 4). *Liquefied Natural Gas*. Retrieved from http://en.wikipedia.org/wiki/Liquefied_natural_gas

World Energy Council. (2011). *Global Transport Scenarios 2050.*

World Trade Organization. (2007). *World Trade Report.*

World Trade Organization. (2013). *World trade report.*

Appendix A. Throughput and transhipment

A.1 Original World Container Model

Throughputs, transhipment and fraction of thirteen ports in Europe have been printed out as examples to show the changes for the original WCM in two scenarios: 2006 and 2040. All the unit of figures is TEU.

HAMBD	Scenario 2006	Scenario 2040	Difference
throughput	4846670.92	11036612.93	6189942.013
transhipment	1610031.56	3722086.77	2112055.208
fraction	33.22	33.72	0.505571762
GENOI			
throughput	4867248.09	11237413.48	6370165.387
transhipment	50377.82	121949.76	71571.94138
fraction	1.04	1.09	0.050174957
VENII			
throughput	1827477.48	3494933.45	1667455.979
transhipment	0	0	0
fraction	0	0	0
BREMD			
throughput	4598960.92	11552947.84	6953986.921
transhipment	1823642.60	4673889.39	2850246.791
fraction	39.65	40.46	0.802887911
ANTWB			
throughput	12217119.89	30961634.20	18744514.31
transhipment	4841676.92	12190793.82	7349116.907
fraction	39.63	39.37	-0.25639369
MARSF			
throughput	1368353.64	3527086.35	2158732.708
transhipment	556036.06	1579895.78	1023859.716
fraction	40.64	44.79	4.157820133
ZEEBB			
throughput	801187.54	1679071.27	877883.7254
transhipment	27565.90	58184.36	30618.45791
fraction	3.44	3.47	0.024639956
BARCE			
throughput	2967013.15	7093560.74	4126547.592
transhipment	438475.82	1188896.29	750420.4634
fraction	14.78	16.76	1.98186067
ROTTN			
throughput	12371384.87	31296252.34	18924867.47

transhipment	3577654.59	8987506.15	5409851.551
fraction	28.92	28.72	-0.201272653
AMSTN			
throughput	11694.01	23999	12304.99127
transhipment	0	0	0
fraction	0	0	0
LASPI			
throughput	2482874.49	5137257.97	2654383.482
transhipment	74862.80	149909.95	75047.15476
fraction	3.02	2.92	-0.097073689
LEHAF			
throughput	1938722.21	4586592.21	2647869.994
transhipment	492266.86	1186106.40	693839.5394
fraction	25.39	25.86	0.468993155
DUNKF			
throughput	126892.62	279440.54	152547.9189
transhipment	205.48	202.93	-2.552401144
fraction	0.16	0.07	-0.08931334

A.2 Extended World Container Model

In the extended WCM, throughputs, transhipment and fraction of thirteen ports in Europe have been printed out as examples to show the difference compared with the original WCM in scenario 2040.

HAMBD	Scenario 2040	New Scenario 2040	Difference
throughput	11036612.93	10948420.77	-88192.15714
transhipment	3722086.77	3656301.72	-65785.05249
fraction	33.72	33.40	-0.329201221
GENOI			
throughput	11237413.48	11241884.05	4470.572333
transhipment	121949.76	122256.59	306.8219435
fraction	1.09	1.09	0.002297718
VENII			
throughput	3494933.45	3587349.34	92415.88868
transhipment	0	0.00	0
fraction	0	0.00	0
BREMD			
throughput	11552947.84	11424462.36	-128485.4791
transhipment	4673889.39	4578276.03	-95613.3521
fraction	40.46	40.07	-0.381925599
ANTWB			
throughput	30961634.20	31171973.44	210339.2383
transhipment	12190793.82	12319338.24	128544.419
fraction	39.37	39.52	0.146688561
MARSF			
throughput	3527086.35	3526515.87	-570.4710254
transhipment	1579895.78	1582757.04	2861.260766
fraction	44.79	44.88	0.088381656
ZEEBB			
throughput	1679071.27	1673350.54	-5720.724553
transhipment	58184.36	58207.07	22.70909391
fraction	3.47	3.48	0.013203908
BARCE			
throughput	7093560.74	7146897.69	53336.94512
transhipment	1188896.29	1291072.75	102176.4619
fraction	16.76	18.06	1.304581056
ROTTN			
throughput	31296252.34	31370100.71	73848.37021
transhipment	8987506.15	9070235.80	82729.65049
fraction	28.72	28.91	0.196117424
AMSTN			

throughput	23999	25748.45	1749.453402
transhipment	0	0.00	0
fraction	0	0.00	0
LASPI			
throughput	5137257.97	4982959.48	-154298.4971
transhipment	149909.95	120836.65	-29073.30357
fraction	2.92	2.42	-0.493095125
LEHAF			
throughput	4586592.21	4653255.69	66663.48484
transhipment	1186106.40	1196589.19	10482.78986
fraction	25.86	25.72	-0.145201258
DUNKF			
throughput	279440.54	279728.42	287.8752901
transhipment	202.93	219.05	16.12347693
fraction	0.07	0.08	0.005689241

A.3 Extended WCM at different speed in 2040

In the extended WCM, throughputs, transhipment and fraction of thirteen ports in Europe have been printed out as examples at different speed in scenario 2040. Compared with the figures at speed 25 knots, the difference are made to show the changes.

HAMBD	25Knots	BARCE	25 Knots
throughput	10938840.23	**throughput**	7054643.93
transhipment	3634670.54	**transhipment**	1278317.52
fraction	33.23	**fraction**	18.12
GENOI		**ROTTN**	
throughput	11197045.42	**throughput**	31270622.05
transhipment	120015.94	**transhipment**	9074185.98
fraction	1.07	**fraction**	29.02
VENII		**AMSTN**	
throughput	3581394.51	**throughput**	25976.04
transhipment	0.00	**transhipment**	0.00
fraction	0.00	**fraction**	0.00
BREMD		**LASPI**	
throughput	11509813.24	**throughput**	4929676.00
transhipment	4610315.15	**transhipment**	120368.91
fraction	40.06	**fraction**	2.44
ANTWB		**LEHAF**	
throughput	31440496.90	**throughput**	4659644.96
transhipment	12312180.57	**transhipment**	1189839.25
fraction	39.16	**fraction**	25.53
MARSF		**DUNKF**	
throughput	3499094.46	**throughput**	281403.26
transhipment	1594031.11	**transhipment**	195.46
fraction	45.56	**fraction**	0.07
ZEEBB			
throughput	1658273.07		
transhipment	58439.93		
fraction	3.52		

HAMBD	23knots	Difference compared with 25knots	BARCE	23knots	Difference compared with 25knots
throughput	10948420.77	9580.539657	**throughput**	7146897.69	92253.75938
transhipment	3656301.72	21631.17793	**transhipment**	1291072.75	12755.23003
fraction	33.40	0.168497659	**fraction**	18.06	-0.055427699
GENOI			**ROTTN**		
throughput	11241884.05	44838.6333	**throughput**	31370100.71	99478.66061
transhipment	122256.59	2240.649893	**transhipment**	9070235.80	-3950.184452
fraction	1.09	0.015656142	**fraction**	28.91	-0.104612819
VENII			**AMSTN**		
throughput	3587349.34	5954.831712	**throughput**	25748.45	-227.5866997
transhipment	0.00	0	**transhipment**	0.00	0
fraction	0.00	0	**fraction**	0.00	0
BREMD			**LASPI**		
throughput	11424462.36	-85350.87754	**throughput**	4982959.48	53283.47391
transhipment	4578276.03	-32039.11505	**transhipment**	120836.65	467.7396306
fraction	40.07	0.018807186	**fraction**	2.42	-0.016722871
ANTWB			**LEHAF**		
throughput	31171973.44	-268523.4642	**throughput**	4653255.69	-6389.267135
transhipment	12319338.24	7157.668381	**transhipment**	1196589.19	6749.94463
fraction	39.52	0.360298514	**fraction**	25.72	0.180119964
MARSF			**DUNKF**		
throughput	3526515.87	27421.41818	**throughput**	279728.42	-1674.838405
transhipment	1582757.04	-11274.0746	**transhipment**	219.05	23.59685374
fraction	44.88	-0.673924307	**fraction**	0.08	0.008851497
ZEEBB					
throughput	1673350.54	15077.47448			
transhipment	58207.07	-232.8630773			
fraction	3.48	-0.04566975			

HAMBD	20knots	Difference compared with 25knots	BARCE	20knots	Difference compared with 25knots
throughput	11021897.73	83057.49514	**throughput**	7325723.79	271079.8612
transhipment	3746074.57	111404.028	**transhipment**	1322389.05	44071.53052
fraction	33.99	0.760362221	**fraction**	18.05	-0.068918195
GENOI			**ROTTN**		
throughput	11299671.44	102626.0203	**throughput**	31652608.14	381986.0895
transhipment	125645.31	5629.372821	**transhipment**	9079090.34	4904.364023
fraction	1.11	0.040084105	**fraction**	28.68	-0.33470006
VENII			**AMSTN**		
throughput	3598872.24	17477.72982	**throughput**	25300.33	-675.7062991

transhipment	0.00	0	transhipment	0.00	0
fraction	0.00	0	fraction	0.00	0
BREMD		0	LASPI		
throughput	11297979.18	-211834.0516	throughput	5082106.45	152430.4501
transhipment	4565113.81	-45201.34262	transhipment	122056.68	1687.766987
fraction	40.41	0.350946664	fraction	2.40	-0.040025895
ANTWB			LEHAF		
throughput	30465151.18	-975345.7179	throughput	4645191.88	-14453.08091
transhipment	12212656.26	-99524.31054	transhipment	1217784.05	27944.8033
fraction	40.09	0.927038288	fraction	26.22	0.68103525
MARSF			DUNKF		
throughput	3572985.40	73890.94521	throughput	276304.45	-5098.808576
transhipment	1559261.07	-34770.04551	transhipment	278.70	83.24198331
fraction	43.64	-1.915245975	fraction	0.10	0.031408643
ZEEBB					
throughput	1722944.50	64671.43206			
transhipment	57949.07	-490.8607538			
fraction	3.36	-0.160769847			

HAMBD	17knots	Difference compared with 25knots	BARCE	17knots	Difference compared with 25knots
throughput	11154072.69	215232.4548	throughput	7502970.28	448326.3563
transhipment	3866703.51	232032.9678	transhipment	1337463.41	59145.89043
fraction	34.67	1.439090902	fraction	17.83	-0.294441584
GENOI			ROTTN		
throughput	11342874.29	145828.8698	throughput	32032954.63	762332.5783
transhipment	141509.78	21493.8401	transhipment	9085101.44	10915.46301
fraction	1.25	0.175711796	fraction	28.36	-0.656511649
VENII			AMSTN		
throughput	3614497.78	33103.26763	throughput	24998.27	-977.7711393
transhipment	0.00	0	transhipment	0.00	0
fraction	0.00	0	fraction	0.00	0
BREMD			LASPI		
throughput	11069107.05	-440706.1822	throughput	5190165.57	260489.5678
transhipment	4500620.92	-109694.2326	transhipment	124065.01	3696.100343
fraction	40.66	0.603778651	fraction	2.39	-0.051334141
ANTWB			LEHAF		
throughput	29640765.38	-1799731.522	throughput	4567718.34	-91926.61506
transhipment	12148048.22	-164132.3527	transhipment	1196079.49	6240.237831
fraction	40.98	1.823998799	fraction	26.19	0.650514659
MARSF			DUNKF		
throughput	3618366.28	119271.8258	throughput	271787.80	-9615.457779

transhipment	1529597.84	-64433.27635	**transhipment**	378.82	183.367012
fraction	42.27	-3.282370618	**fraction**	0.14	0.069924276
ZEEBB					
throughput	1846495.10	188222.0374			
transhipment	64938.71	6498.777207			
fraction	3.52	-0.007280751			

HAMBD	14knots	Difference compared with 25knots	**BARCE**	14knots	Difference compared with 25knots
throughput	11709670.93	770830.6992	**throughput**	7744058.24	689414.3159
transhipment	4381727.39	747056.8455	**transhipment**	1371484.58	93167.06474
fraction	37.42	4.192529191	**fraction**	17.71	-0.410074094
GENOI			**ROTTN**		
throughput	11373346.98	176301.5604	**throughput**	32492804.61	1222182.558
transhipment	169567.54	49551.6036	**transhipment**	9167542.35	93356.36549
fraction	1.49	0.419066692	**fraction**	28.21	-0.804176731
VENII			**AMSTN**		
throughput	3632909.52	51515.00784	**throughput**	24264.76	-1711.275355
transhipment	0.00	0	**transhipment**	0.00	0
fraction	0.00	0	**fraction**	0.00	0
BREMD			**LASPI**		
throughput	10692706.41	-817106.825	**throughput**	5371070.09	441394.0914
transhipment	4389085.23	-221229.922	**transhipment**	159525.37	39156.46083
fraction	41.05	0.991951276	**fraction**	2.97	0.52836493
ANTWB			**LEHAF**		
throughput	28561916.28	-2878580.623	**throughput**	4383754.43	-275890.5305
transhipment	11875853.87	-436326.7008	**transhipment**	1175388.05	-14451.19626
fraction	41.58	2.419070803	**fraction**	26.81	1.27738419
MARSF			**DUNKF**		
throughput	3668476.95	169382.4971	**throughput**	324553.39	43150.13652
transhipment	1489077.89	-104953.2249	**transhipment**	60327.54	60132.08811
fraction	40.59	-4.964357844	**fraction**	18.59	18.51840671
ZEEBB					
throughput	2092459.82	434186.7557			
transhipment	77779.25	19339.31387			
fraction	3.72	0.19297607			

A.4 Extended WCM at different CO_2 price

In the extended WCM, throughputs, transhipment and fraction of thirteen ports in Europe have been printed out as examples with different CO_2 price in scenario 2040. The difference also shows compared with the 0.006 euro per TEU CO_2 price.

HAMBD	CO2 price 0.006 euro/TEU	BARCE	CO2 price 0.006euro/TEU
throughput	10948420.77	**throughput**	7146897.687
transhipment	3656301.718	**transhipment**	1291072.748
fraction	33.39569965	**fraction**	18.06479965
GENOI		**ROTTN**	
throughput	11241884.05	**throughput**	31370100.71
transhipment	122256.586	**transhipment**	9070235.796
fraction	1.087509758	**fraction**	28.91363302
VENII		**AMSTN**	
throughput	3587349.342	**throughput**	25748.45316
transhipment	0	**transhipment**	0
fraction	0	**fraction**	0
BREMD		**LASPI**	
throughput	11424462.36	**throughput**	4982959.477
transhipment	4578276.034	**transhipment**	120836.6502
fraction	40.07432376	**fraction**	2.42499765
ANTWB		**LEHAF**	
throughput	31171973.44	**throughput**	4653255.693
transhipment	12319338.24	**transhipment**	1196589.192
fraction	39.52055928	**fraction**	25.7150965
MARSF		**DUNKF**	
throughput	3526515.875	**throughput**	279728.4174
transhipment	1582757.039	**transhipment**	219.0519902
fraction	44.88160822	**fraction**	0.078308808
ZEEBB			
throughput	1673350.541		
transhipment	58207.07014		
fraction	3.478474396		

HAMBD	CO2 price 0.005 euro/TEU	Difference compared with 0.06 euro/TEU	BARCE	CO2 price 0.005 euro/TEU	Difference compared 0.06euro/TEU
throughput	10946170.11	-2250.662713	**throughput**	7130491.28	-16406.4064
transhipment	3651930.406	-4371.31238	**transhipment**	1288536.585	-2536.163628
fraction	33.36263157	-0.033068076	**fraction**	18.07079672	0.005997074
GENOI			**ROTTN**		
throughput	11235152.98	-6731.068404	**throughput**	31349902.02	-20198.69123
transhipment	121792.4618	-464.1242203	**transhipment**	9070563.076	327.2793434
fraction	1.084030293	-0.003479465	**fraction**	28.93330598	0.019672964
VENII			**AMSTN**		
throughput	3586394.265	-955.0771858	**throughput**	25790.22598	41.77282683
transhipment	0	0	**transhipment**	0	0
fraction	0	0	**fraction**	0	0
BREMD			**LASPI**		
throughput	11434327.69	9865.335368	**throughput**	4972597.517	-10361.96038
transhipment	4578753.016	476.9823811	**transhipment**	120742.0159	-94.63428501
fraction	40.04391984	-0.030403922	**fraction**	2.428147774	0.003150124
ANTWB			**LEHAF**		
throughput	31228649.28	56675.84583	**throughput**	4647521.351	-5734.342276
transhipment	12324405.88	5067.635817	**transhipment**	1188507.934	-8081.258074
fraction	39.46506225	-0.055497038	**fraction**	25.57294188	-0.142154622
MARSF			**DUNKF**		
throughput	3521823.42	-4692.454505	**throughput**	280004.1874	275.7700135
transhipment	1584783.236	2026.197388	**transhipment**	214.4909605	-4.561029713
fraction	44.9989408	0.117332584	**fraction**	0.076602769	-0.001706039
ZEEBB					
throughput	1670253.996	-3096.544962			
transhipment	58258.94613	51.87598904			
fraction	3.488029142	0.009554745			

HAMBD	CO2 price 0.004 euro/TEU	Difference compared 0.06euro/TEU	BARCE	CO2 price 0.004euro/TEU	Difference compared 0.06euro/TEU
throughput	10944194.72	-4226.059368	**throughput**	7113389.093	-33508.59407
transhipment	3648020.006	-8281.712034	**transhipment**	1285915.848	-5156.899688
fraction	33.33292308	-0.062776569	**fraction**	18.07740068	0.012601036
GENOI			**ROTTN**		
throughput	11227034.27	-14849.78301	**throughput**	31330567.17	-39533.53531
transhipment	121370.0012	-886.5847855	**transhipment**	9071192.211	956.4145466
fraction	1.081051312	-0.006458446	**fraction**	28.95316947	0.039536456
VENII			**AMSTN**		
throughput	3585219.67	-2129.672386	**throughput**	25831.60709	83.15393503

transhipment	0	0	**transhipment**	0	0
fraction	0	0	**fraction**	0	0
BREMD			**LASPI**		
throughput	11445816.5	21354.14499	**throughput**	4963243.604	-19715.87285
transhipment	4579360.689	1084.654955	**transhipment**	120665.5942	-171.0560248
fraction	40.00903463	-0.065289132	**fraction**	2.431184197	0.006186548
ANTWB			**LEHAF**		
throughput	31284321.2	112347.761	**throughput**	4649184.142	-4071.55079
transhipment	12329155.69	9817.446992	**transhipment**	1188229.551	-8359.640819
fraction	39.41001504	-0.110544244	**fraction**	25.55780788	-0.157288621
MARSF			**DUNKF**		
throughput	3517033.627	-9482.248047	**throughput**	280327.8731	599.4557413
transhipment	1586900.621	4143.582696	**transhipment**	210.0201613	-9.031828922
fraction	45.12042789	0.23881967	**fraction**	0.074919472	-0.003389337
ZEEBB					
throughput	1667240.621	-6109.920631			
transhipment	58335.17616	128.1060151			
fraction	3.498905643	0.020431246			

HAMBD	CO_2 price 0.003 euro/TEU	Difference compared 0.06euro/TEU	**BARCE**	CO_2 price 0.003euro/TEU	Difference compared 0.06euro/TEU
throughput	10942457.61	-5963.168858	**throughput**	7097561.713	-49335.97398
transhipment	3644046.239	-12255.4792	**transhipment**	1285119.604	-5953.144475
fraction	33.30189954	-0.09380011	**fraction**	18.10649425	0.041694606
GENOI			**ROTTN**		
throughput	11218837.16	-23046.89132	**throughput**	31311941.27	-58159.43866
transhipment	120918.0103	-1338.575685	**transhipment**	9071896.04	1660.243694
fraction	1.077812331	-0.009697427	**fraction**	28.97264006	0.059007042
VENII			**AMSTN**		
throughput	3584194.465	-3154.87735	**throughput**	25873.769	125.3158431
transhipment	0	0	**transhipment**	0	0
fraction	0	0	**fraction**	0	0
BREMD			**LASPI**		
throughput	11454065.32	29602.95691	**throughput**	4953192.602	-29766.87504
transhipment	4577568.761	-707.2730703	**transhipment**	120583.3131	-253.3370592
fraction	39.96457707	-0.109746693	**fraction**	2.434456377	0.009458727
ANTWB			**LEHAF**		
throughput	31342674.5	170701.0614	**throughput**	4651230.324	-2025.369234
transhipment	12336369.01	17030.76558	**transhipment**	1187887.059	-8702.132946
fraction	39.35965646	-0.160902825	**fraction**	25.53920095	-0.175895553
MARSF			**DUNKF**		
throughput	3511791.384	-14724.4906	**throughput**	280660.7193	932.301886

transhipment	1589016.082	6259.04351	**transhipment**	205.6397436	-13.4122466
fraction	45.2480204	0.366412189	**fraction**	0.07326987	-0.005038939
ZEEBB					
throughput	1664482.609	-8867.932142			
transhipment	58337.83127	130.7611266			
fraction	3.504862769	0.026388373			

HAMBD	CO2 price 0.002euro/TEU	Difference compared 0.06euro/TEU	**BARCE**	CO2 price 0.002euro/TEU	Difference compared 0.06euro/TEU
throughput	10941508.06	-6912.715295	**throughput**	7079774.96	-67122.72627
transhipment	3640532.995	-15768.72343	**transhipment**	1282568.841	-8503.90688
fraction	33.27268028	-0.123019366	**fraction**	18.11595493	0.051155286
GENOI			**ROTTN**		
throughput	11209860.24	-32023.80738	**throughput**	31294992.14	-75108.5706
transhipment	120571.1394	-1685.446643	**transhipment**	9072688.862	2453.065658
fraction	1.075581111	-0.011928647	**fraction**	28.99086481	0.077231788
VENII			**AMSTN**		
throughput	3583098.186	-4251.156615	**throughput**	25916.24089	167.7877292
transhipment	0	0	**transhipment**	0	0
fraction	0	0	**fraction**	0	0
BREMD			**LASPI**		
throughput	11498472.28	74009.92466	**throughput**	4943563.849	-39395.62841
transhipment	4612929.501	34653.46651	**transhipment**	120497.7918	-338.8583653
fraction	40.11775988	0.043436115	**fraction**	2.4374681	0.012470451
ANTWB			**LEHAF**		
throughput	31362943.12	190969.6852	**throughput**	4653386.907	131.2144519
transhipment	12305778.01	-13560.23038	**transhipment**	1187535.447	-9053.745034
fraction	39.23668121	-0.283878071	**fraction**	25.51980892	-0.195287586
MARSF			**DUNKF**		
throughput	3506535.659	-19980.21604	**throughput**	280970.2095	1241.792125
transhipment	1591071.534	8314.495157	**transhipment**	201.347604	-17.70438629
fraction	45.37445754	0.492849328	**fraction**	0.071661549	-0.006647259
ZEEBB					
throughput	1661778.037	-11572.50432			
transhipment	58379.61851	172.5483731			
fraction	3.513081604	0.034607207			

Appendix B. Programming by JAVA in Eclipse

B.1 Programming for cost function

The algorithm can be achieved in the World Container Model by Eclipse. The cost of CO_2 emission during transportation is added into the transport cost itself. The pseudo-code of JAVA is listed to explain the counting process as followed:

Input:
marEdge.getLength: length of every link
ptopFlow: the flow from one port to another
valueofCO2Emission: Value of CO_2 emission
factor: Emission factor of maritime transport
marEdge.getCosts: Original cost during transportation

Output:
Costs: Total costs in the process of maritime transport

```
double costs = 0
for AbstractEdge marEdge : shortestPath do
if ptopFlow.containsKey portId
costs+=valueofCO2Emission* ptopFlow *marEdge.getLength*factor*1E-6
end for
costs +=marEdge.getCosts
return costs
```

B.2 Code for extended WCM in eclipse

The main method of modelling is to write a new scenario “OptimalScenario” with the extended calculation instead of the base one.

Main.java

```
public class Main {


	public static void main(String args[]) throws IOException{

		HashMap<String, HashMap<String, Double>> kpi;
		long startTime = System.nanoTime();

		//Rongwei laptop
		String wd = "D:/eclipse/ZRW/WCM_Ori_Lastest";

		WorldContainerModel  model = new WorldContainerModel(wd);

//		String odFileName = wd+"/input_data/TEU_flows_estimated_NSTR1_2006.csv";
		String odFileName = wd+"/input_data/Table_TEU_2040_Highgrowth.csv";
//		ScenarioInterface scenario = new BaseScenario(odFileName);

		ScenarioInterface scenario = new OptimalScenario(odFileName);
		System.out.println(TransportMode.MARITIME.getTransportCostsPerKm());

		kpi = model.runWCM(scenario);
		printKPI(kpi);
		drawMap(model.getMaritimeNetwork());
	}

	private static void printKPI(HashMap<String, HashMap<String, Double>> kpi){
		for (Iterator iterator = kpi.keySet().iterator(); iterator.hasNext();) {
			String portName = (String) iterator.next();

			java.lang.System.out.println(portName);

			HashMap<String, Double> portKPI = kpi.get(portName);
			for (Iterator iterator2 = portKPI.keySet().iterator(); iterator2
					.hasNext();) {
				String key = (String) iterator2.next();
				double value = portKPI.get(key);
				java.lang.System.out.println(key +"\t"+value);
```

```
			}
		}
	}

	private static void drawMap(MaritimeNetwork mar) {
		//additional graphic feature, here the visualization frame is instantiated
		VisualizationFrame vis = new VisualizationFrame(mar);
	}
}
```

OptimalScenario.java

```
	public OptimalScenario(String odFileName){
		this.odFileName = odFileName;
		modifyTransportMode();
	}

	@Override
	public void modifyMaritimeNetwork(MaritimeNetwork marNetwork) {
		// this is a bit strange, but od data requires the countries
		// to be known. these are only known after the maritime network is
		// parsed
		this.odData = new ODdata(odFileName, marNetwork.getCountries());

		//do nothing, this is just a base case scenario
	}

	@Override
	public void modifyServiceNetwork(ServiceNetwork serNetwork) {
		//do nothing, this is just a base case scenario
	}

	public void modifyTransportMode()
	{
		TransportMode maritime = TransportMode.MARITIME;
		maritime.modifyTransportCostsPerKm();
	}

}
```

B.3 Code for routes to and from Rotterdam in eclipse

These codes are used to only display the routs to and from all over the world.

SimpleMakerApp.java

```
//drawing flows from and into Rotterdam

        Collection<AbstractNode> nodes=this.maritimeGraph.getVertices();

        for (AbstractNode originNode : nodes) {
            for (AbstractNode destinationNode : nodes)
            {
                if((originNode.getName().equalsIgnoreCase("rotterdam") &&
destinationNode.getClass()==PortNode.class)

    ||(destinationNode.getName().equalsIgnoreCase("rotterdam") &&
originNode.getClass()==PortNode.class))
                {
                    System.out.println("rendering shipping lines for
Rotterdam");

                    List<AbstractEdge> sp =
this.mar.getPath((PortNode)originNode,(PortNode)destinationNode );

                    for (AbstractEdge abstractEdge : sp) {

                        Pair<AbstractNode> shortestPathEP =
abstractEdge.getEndpoints();

                        Double lineWidth =
(abstractEdge.getAssignedflow()/10000);

                        System.out.println("line width
for"+abstractEdge.toString()+" is: "+lineWidth);

                        if (lineWidth.isNaN()){
                            lineWidth=1.0;
                        }else{
                            lineWidth = Math.log(lineWidth);
                        }

                        if(lineWidth<1&&lineWidth>0)
                        {
```

```
                        lineWidth=2.0;
                    }

                    float mapLineWidth= lineWidth.floatValue();

                    //to ensure that line with no flow isn't visualized
                    if(lineWidth<=0)
                    {
                        mapLineWidth=0;
                    }

                    drawServiceEdges(ServiceEdgeMarkers, shortestPathEP,
mapLineWidth);
                }

            }
        }
    }
```