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# Optimization of modal shift and container (re-)positioning at Maersk Line

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The aim of the research is contribute to the field of research and support Maersk Line with recommendations to improve their business processes.

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# Executive Summary

In this thesis project the modal shift - distribution between transport modalities - of hinterland transport and (re-)positioning of empty containers is studied at Maersk Line. The former is nowadays in the spotlights by policy makers. The general idea about multimodal transport is that it is more sustainable than truck transport and could lead to cost savings. This will lead to stronger regulations as could be found in the tender of Maasvlakte 2. The latter will be more and more important for cost savings in the future and a more efficient transport network.

Two actual projects at Maersk Line are a shift from truck transport towards rail & barge transport and savings on empty (re-)positioning. The following central question is formulated: *“How can a modal shift towards rail and barge transport contribute to cost savings in the hinterland transport operations of Maersk Line?”* Three research questions were setup to support this question. The first question focuses on modal shift: *“In which way is it possible to shift truck transport towards rail/barge at Maersk?”*. The second question includes the repositioning: *“How can a good balance be found between asset management and logistics in order to improve empty container repositioning?”* At the end the last question combines both aspects mentioned before: *“In which way could a shift towards a higher modal share for rail/barge and a cost reduction of empty container positioning reinforce each other?”*

The problem is studied from point of view of Maersk Line, a container shipping company. A model is set up to study the effects of different scenarios. These scenarios are used to answer the research questions, these scenarios differ in order deadline, stock levels and container reuse. The situation at the shipping company will lead to certain assumptions that will have an impact on the results. In the model capacities on transport services and storage locations are unlimited and all costs are linear. The current network of hubs of Maersk Line is used as network. The dataset used is derived from historical transportation figures of Maersk Line of September 2012. The objective function used is the minimization of total transportation costs, this includes handling costs, storage costs and transportation costs.

The answer to the first research question is that the modal shift could positively be influenced for multimodal transport by three aspects. The first aspect is the order deadline. When more time is available to transport the container from deep-sea terminal towards the customer with use of intermodal transport the modal shift of intermodal transport rises with 33.7% and 6% is saved on transport costs. The second aspect is the truck transport tariff from inland depot towards customer. It showed up that these tariffs have a big influence on total transportation costs. It is advisable to negotiate sharper tariffs. Economies of scale could be maximized at inland depots with a rise for intermodal transport. The gravity center of truck transport is not the Port of Rotterdam but moving towards the inland depots. This could be an opportunity for procurement. With a decrease of 40% on the costs for the last truck leg in intermodal transport this

modal shift will rise with 12.4% and 7.3% on transportation costs are saved. The third aspect is that rail transportation mode is promising in the model due to lower transit times compared to barge, and lower costs compared to truck. In practice this mode has not the highest priority in multimodal transport due to higher costs compared to barge transport. Because transit time is faster than barge, especially for destinations in Germany, more attention for rail corridors could be lead to a higher modal shift for this transportation mode. With the case study in this research a maximum modal share of 8.5% is achieved for rail transport on import transport.

For the answer to the second research question - (re-)positioning - the most important conclusions have influence on storage locations and container reuse. Minimum costs are achieved when storage options on inland depots are maximum exploited. Storage on an inland depot is 58% less expensive. With storage in the hinterland containers are furthermore already at the locations where they are needed for export freight. It turned out that this will lead to cost savings of 15% on total transportation costs. For container (re-)positioning merchant haulage volumes are important. It is an recommendation to include this information in the input data for more realistic model output in this scenario.

It is possible to combine both aspects to answer the third research question. In the scenario about stock levels it turned out that a slightly higher expense on transportation costs of 6.2% resulted in total cost savings of 15.2% due to lower storage costs. A model setup with as scope the total supply chain with linkage between volumes and transportation costs is advisable. When fixed and variable costs are taken into account, full and empty transportation could be combined. With such a model setup the aspects of full and empty container positioning could be combined. This is a direction for further research.

The answers to these research questions lead to some recommendations towards Maersk Line. It is a challenge to provide recommendations towards a operational department with a strategic model, but three strong recommendations are made. The first one is a better internal collaboration between the customer service, sales and operations department. For aspects as order deadline and finding export customers in locations with empty container surpluses both departments have to work together. This is on a tactical planning level. One level higher, at strategic level the second recommendation is advisable to use better software packages. With the tool created in this project some simply relations could be detected. With professional software packages the results will be more in line with the practice situation. Also on operational level it is unimaginable that in a time with all powerful computer systems transports are planned manually. More efficiency could be achieved with such a system. It is demonstrated in the model that this is possible to plan hinterland transport automatically. Professional software packages could catch up the limitations that are made in the tool due to simplifications. The third and last one is to maximize the effects of economies of scale. This is a direction for further research to establish a strong hinterland network.

In this study the problem is analyzed from the perspective of Maersk Line. This has many consequences in the way tariffs are applied and the case of unlimited capacities. When the perspective of the total supply chain is chosen and barge costs are split in more detail other results will show up. Benefits will contribute to the total supply chain instead of Maersk only. It could interesting to see which aspects are important for the market and change business conditions to this optimal situation. This could lead to distinguishing of the brand Maersk Line in the modern container market. This is in line with the new Maersk Line strategy to attract more customers who want to pay for the extra services Maersk Line is offering.

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# Glossary

**80/20 Rule** A term referring to the Pareto principle. This principle suggests that most effects come from relatively few causes; that is, 80% of the effects (or sales or costs) come from 20.

**Accessibility** A carrier's ability to provide service between an origin and a destination .

**Attributes** A label used to provide additional classification or information about a resource, activity, or cost object. Used for focusing attention and may be subjective. Examples are a characteristic, a score or grade of product or activity, or groupings of these items, and performance measures .

**Backorder** The act of retaining a quantity to ship against an order when other order lines have already been shipped. Backorders are usually caused by stock shortages .

**Barge** The cargo-carrying vehicle which may or may not have its own propulsion mechanism for the purpose of transporting goods. Primarily used by Inland water carriers, basic barges have open tops, but there are covered barges for both dry and liquid cargoes .

**Box** Another (less formal) name for a shipping container.

**Capacity** The physical facilities, personnel, and processes available to meet the product or service needs of customers. Capacity generally refers to the maximum output or producing ability of a machine, a person, a process, a factory, a product, or a service .

**Carrier** A firm that transports goods or people via land, sea, or air .

**Consignee** The party to whom goods are shipped and delivered. The receiver of a freight shipment.

**Container** A box, typically 10 to 45 feet long, which is primarily used for ocean freight shipments. For travel to and from ports, containers are loaded onto truck chassis or on railroad flatcars.

**Container Depot** The storage area for empty containers.

**Customs** The authorities designated to collect duties levied by a country on imports and exports. .

**Customs Clearance** The act of obtaining permission to import merchandise from another country into the importing nation .

**Demurrage** The carrier charges and fees applied when rail freight cars and ships are retained beyond a specified loading or unloading time .

**Economy of Scale** Reduction in cost per unit resulting from increased production, realized through operational efficiencies. Economies of scale can be accomplished because as production increases, the cost of producing each additional unit falls.

**Equipment** The rolling stock carriers use to facilitate the transportation services that they provide, including containers, trucks, chassis, vessels, and airplanes, among others.

**FEU** Forty-foot equivalent unit, a standard size intermodal container.

**Forecasting** Predictions of how much of a product will be purchased by customers. Relies upon both quantitative and qualitative methods .

**Freight Forwarder** An organization which provides logistics services as an intermediary between the shipper and the carrier, typically on international shipments. Freight forwarders provide the ability to respond quickly and efficiently to changing customer and consumer demands and international shipping (import/export) requirements .

**Handling Costs** The cost involved in moving, transferring, preparing, and otherwise handling inventory .

**Hinterland** Hinterland is a land or district behind the borders of a coast or river. It is applied to the inland region lying behind a port.

**Hub** A reference for a transportation network as a "hub and spoke" which is common in the airline and trucking industry. For example, a hub airport serves as the focal point for the origin and termination of long-distance flights where flights from outlying areas are fed into the hub airport for connecting flights .

**Intermodal Transportation** Transporting freight by using two or more transportation modes, such as by truck and rail or truck and oceangoing vessel .

**Inventory** Raw materials, work in process, finished goods, and supplies required for creation of a company's goods and services. The number of units and/or value of the stock of goods held by a company .



- Just In Time** An inventory control system that controls material flow into assembly and manufacturing plants by coordinating demand and supply to the point where desired materials arrive just in time for use. An inventory reduction strategy that feeds production lines with products delivered just in time. Developed by the auto industry, it refers to shipping goods in smaller, more frequent lots .
- Leg** A leg has an origin, destination, and carrier and is composed of all consecutive segments of a route booked through the same carrier .
- Multimodel** A system whereby standard-sized cargo containers can be moved seamlessly between different 'modes' of transport, typically specially adapted ships known as containerships, barges, trucks and trains. Because the cargo does not need to be unloaded from the container every time it is moved from one mode to the other it is a very efficient and fast system of transportation.
- Node** A fixed point in a firm's logistics system where goods come to rest; includes plants, warehouses, supply sources, and markets .
- Optimization** The process of making something as good or as effective as possible with given resources and constraints .
- Order deadline** The order deadline set in Shipping releases shipping for a specific date and at the same time stops order processing for that shipping date.
- Origin** The place where a shipment begins its movement .
- Shipper** The party that tenders goods for transportation.
- Supply chain** The material and informational interchanges in the logistical process, stretching from acquisition of raw materials to delivery of finished products to the end user. All vendors, service providers, and customers are links in the supply chain .
- Surcharge** A carrier's charge for accessorial services such as loading, unloading, pickup, and delivery, or any other charge deemed appropriate .
- Tender** The document which describes a business transaction to be performed .
- Terminal** An area designated to be used for the stowage of cargo in containers that may be accessed by truck, rail, or ocean transportation.
- TEU** Twenty-foot Equivalent Unit.
- Vessel** another word for a boat or ship. Container ships are sometimes referred to as vessels.

The definitions are quoted from:

[www.inboundlogistics.com/cms/logistics-glossary](http://www.inboundlogistics.com/cms/logistics-glossary)

[www.investorwords.com/1653](http://www.investorwords.com/1653)

[www.worldshipping.org/about-the-industry/glossary-of-industry-terms](http://www.worldshipping.org/about-the-industry/glossary-of-industry-terms)

# Chapter 1

## Introduction

Transport is one of the key elements of an economy. As long as humanity exists transport is essential to fulfill primary needs, Maslow (1943). The production process of food is an clear example; farmers took their agrarian products from farmland towards the center of a city or village to provide the population with food. In the beginning of civilization this was totally done by manpower. When primary needs were fulfilled demand for luxury goods was growing. These products were scarcer so they had to be transported over longer distances. Water transport was very efficient for these transports because each ship could contain a lot of different items although dimensions were non-standardized. This resulted in a labor intensive process for loading and unloading of a ship. A big change in cargo transportation was made at April 26, 1956 when the first ship loaded with containers sailed from Port Newark to Houston, Salvatore and Mercogliano (2006). Nowadays, 57 years later, this transport can be seen as a milestone in the shipping and transportation history. Without the usage of containers the current global economies with extremely cheap products due to low wages in particularly East Asia is unimaginable.

### 1.1 Worldwide container shipping

Since the first transshipment, container transport went into an extraordinary growth. An important step was the standardization of container sizes; twenty-foot equivalent unit (*TEU*) and forty-foot equivalent unit (*FEU*). The equipment used for container handling on terminals improved with cranes specially designed for lifting containers; instead of using cranes designed for loading bulk goods. Also vertical frameworks were installed to ships to make the stacking process more easily. All these improvements were made in several years after the first container was transported by ship. Broadly the shipping process nowadays is the same as in the late sixties, besides the technological improvements on equipment (increased capacity, speed and reliability). Scale-enlargement was since that moment one of the most important growth factors in container transport. Nowadays scale-enlargement is still one of the most important growth factors for container shipping companies, because it helps to reduce slot costs on these ships due to economies of scale.

In figure 1.1 an overview of different container ship classes is given, Ashar and Rodrigue (2012). Meanwhile the ship with largest capacity in the market is the CMA CGM Marco Polo with 16.000 TEU. This is slightly larger than the Emma Maersk with a capacity of 15.000 TEU. The

limits for container ship capacities are still not reached with the introduction of the Triple E vessel of Maersk Line in Q2 2013 with a capacity of 18.270 TEU.

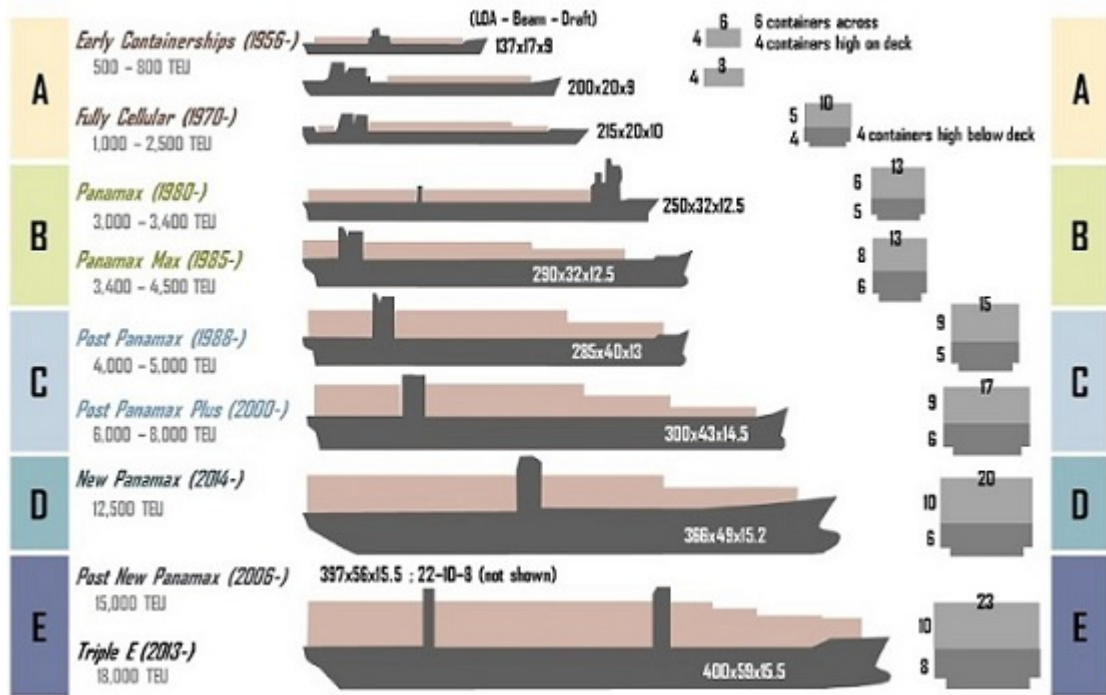


Figure 1.1: Overview of container ship sizes (TEU)<sup>1</sup>

No other load unit has seen such a rapid growth as containers have had. The total amount of containers handled in the port of Rotterdam is shown in figure 1.2. Data is available from 1970 until 2010. Container volumes grew exponentially from 1995, PortofRotterdam (2011). WorldShippingCouncil (2011) and Amerini (2010) stated that there is a strong relation between performance of a world economy and container transport volumes. This can be seen in figure 1.2. Around the year 2000 (*internet crisis*) and 2009 (*debt crisis*) container volumes stabilized or even decreased. The drop in transport volumes is an indication that the container shipping business is strongly dependent to the status of world economy.

This growth is not only limited to the port of Rotterdam. A total figure for container transport in Europe is given in figure 1.3, Forum (2012). In this figure the exponential growth is even more clear.

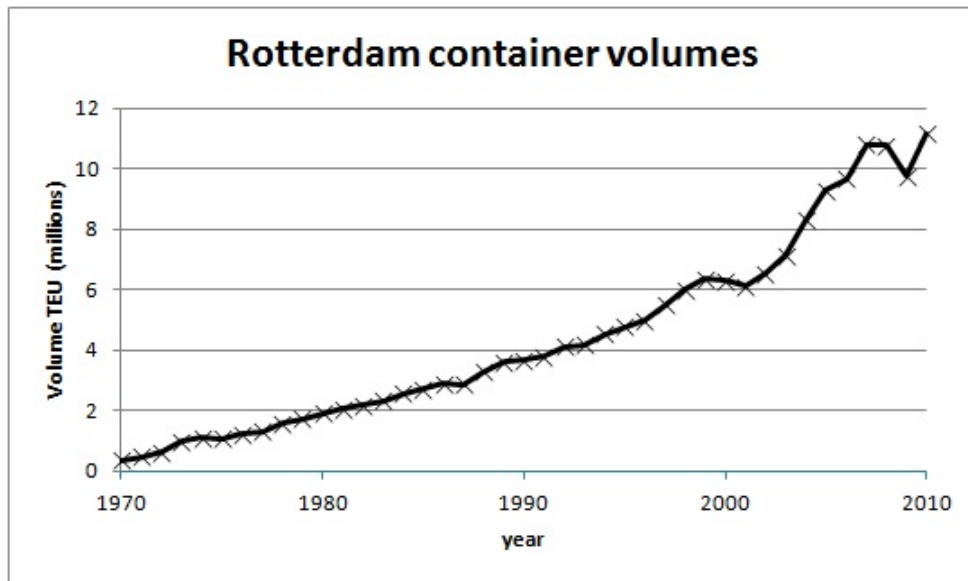
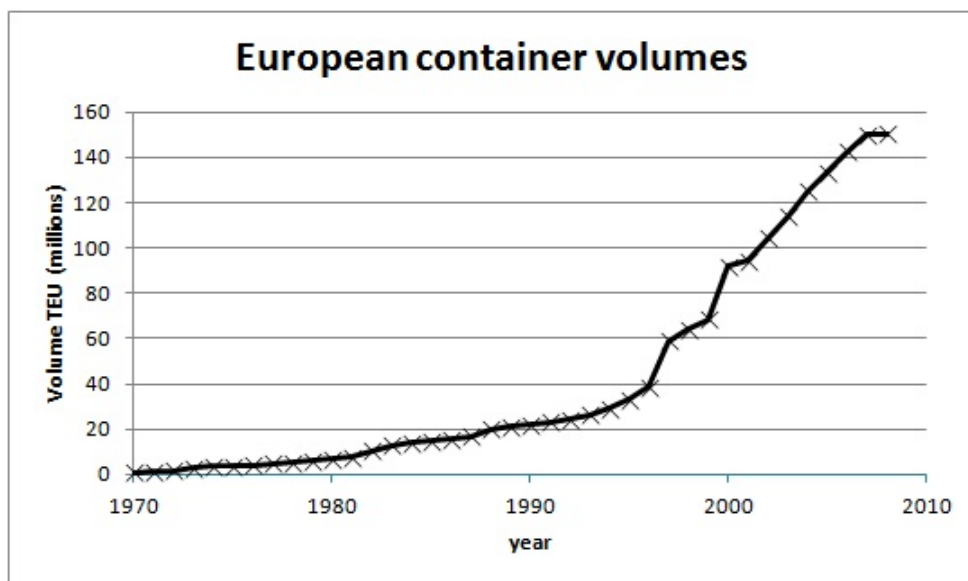
## 1.2 Towards European container shipping

The container market in Europe is characterized as a surplus area of containers in worldwide shipping. This is shown in table 1.1, ContainerTradeStatistics (2010). One of the reasons are low wages in East Asia and the unavailability of enough labor forces, this makes production very

<sup>1</sup>Asharand Rodrigue, 2012

<sup>2</sup>Port Figures, Port of Rotterdam, 2011

<sup>3</sup>International Transport Forum

Figure 1.2: Transport volumes Port of Rotterdam (TEU)<sup>2</sup>Figure 1.3: Transport volumes Europe (TEU)<sup>3</sup>

cheap which results in a big import stream of goods towards Europe. The consequence is a trade imbalance for Europe, more containers are imported than exported, this is result of globalization in world economies.

When a container hits ground in Europe it has to be transported from a deep-sea terminal

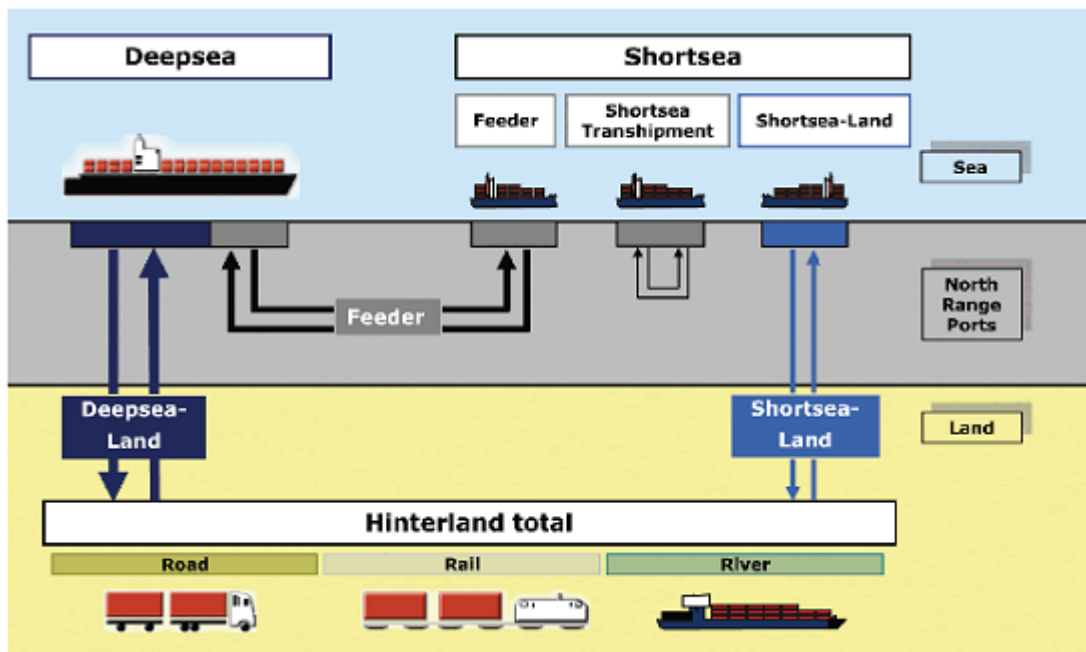
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<sup>4</sup>Container Trade Statistics, 2010

Table 1.1: Container transportation volumes Europe<sup>4</sup>

| Continent               | export     | import     |
|-------------------------|------------|------------|
| Asia                    | 5.458.298  | 11.493.357 |
| North America           | 2.824.503  | 2.495.460  |
| Middle east             | 2.483.922  | 1.527.035  |
| Intra Europe            | 1.026.767  | 736.689    |
| South + Central America | 940.262    | 1.497.517  |
| Australie + Oceania     | 374.901    | 181.527    |
| Africa                  | 1.093.687  | 591.975    |
| total                   | 14.202.340 | 18.523.560 |

to the consignee, this is illustrated in figure 1.4. Multiple modes of transportation are available for hinterland transport: barge, rail and truck. In the early days of container transport hinterland transport was principally executed by truck. When volumes increased, and total costs associated with hinterland transport also rose, other modes as rail and barge came up because the benefits of economies of scale. Truck transport has some negative side-aspects from social point of view. First it causes congestion on the road network for all traffic using that specific network. Second, a freight truck has a lot of pollution, both noise and air. Especially people living close to important freight corridors have a lot of hindrance by this form of transport. Third, freight transports are often heavily loaded, this will lead to sustainable damage to infrastructure. The last negative aspect is traffic safety; imagine the result of a collision between a 40 ton freight truck and a shopping car of nearly 800kg, the result may be clear. Intermodal transport by barge and rail is very interesting from the point of view of society. And even from point of view of the shipper costs could be saved through usage of other transport modes.

Figure 1.4: Overview transport<sup>5</sup>

Both aspects mentioned above - container imbalance and choice of modality - will be studied in this thesis project.

### 1.3 Towards the Benelux

With Rotterdam, Antwerp, Hamburg and Bremerhaven in the top four of busiest container harbors in Europe, DeutscheBankResearch (2005), it is clear that the gravity center of container transport in Europe lies in this region. Other important container terminals are centered in the Far East. The scope of this thesis project will be in Western Europe.

This will be the Rhine basin; this area is served form Maersk Office in the Netherlands. Terminals of Antwerp, Rotterdam and Zeebrugge will be included as well as the inland-depots used in the Maersk hinterland transportation network. All possible modes used in this network will be studied.

A first insight into the container shipping business is provided in this introduction. Starting with the transportation of the first container in 1956 followed by the worldwide growth in transport volumes. Through the effects of economies of scale capacities of transport modes increased (scale enlargements). The Far East <> Europe trade is one of the most important corridors for most shipping lines. This was made clear in the second subsection where the low-wages countries are highlighted. At the end there is a zoom-in on the scope of this thesis project.

The problem description is provided in the next section of this chapter. This is followed by the set up of one central question and three research questions. After this the research goal is explained and the geographical scope of research is described. The first chapter will finish with the outline with the structure of this report.

### 1.4 Problem Description

Modality choice has always been a point of attention for the hinterland transport. For inland container transport in the Netherlands these modalities are barge, rail (cross border) and truck. These modes differ in terms of costs, reliability, transport speed, sustainability and transport safety. For an average transport direct truck transport is most expensive, barge cheapest and rail somewhere in-between. Each transport mode has its own risks in terms of reliability. Truck transport is threatened by delay due to congestion on the highway network; with the reconstruction of the A15 this congestion will only be bigger in the next years. Rail transport is affected with the negative aspects of split organizations and the consequences that different rail companies are not collaborating. At the end barges are sensible for water levels, for example low-water levels in the Rhine, and waiting times at deep-sea terminals.

Besides reliability and costs, environmental performance is more and more an important performance parameter for shipping companies. Container transport by truck will result in more CO<sub>2</sub> and NO<sub>x</sub>R emissions in comparison with transport by barge with a high occupancy. A high modal share for rail/barge transport will not only save costs but will also result in a better market position of shipping companies. This is one of the actual subjects where Maersk Line

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<sup>5</sup>[intermodal.transportation.org](http://intermodal.transportation.org)

is focusing on. APMT is constructing a new terminal on Maasvlakte 2 at the moment. Strict requirements for the modal split are set up by the Port of Rotterdam. With the current modal split these requirements are not met so towards 2035 a change in modal shift is needed to fulfill the requirements.

Some shipping companies offer a total transport package to their clients (carrier haulage(CH). Maersk Line is one of these carriers. The modality choice of carrier haulage is broader, from point of view of the shipper, when larger volumes are transported. Because rail/barge is more favorable with respect to costs, carrier haulage could have a costs advantage, due to economies of scale, above merchant haulage(MH). If one of the aims of Maersk Line is to shift more volume from MH to CH this can be a good initiative to change modal shift.

The modal shift can be seen as an optimization problem with some constraints as order deadline, natural limitations and service level. Variables are for example transit times and costs. The objective function can purely be based on costs, but also other criteria could be used to reach an optimum, e.g. sustainability or minimum transport distance. This depends on the requirements of the shipping company or market situation.

Another problem at Maersk Line is the empty container repositioning. The origin can be found in the container imbalance between Europe and the Far East. More containerized cargo is imported into the continent than exported. A lot of money is spent on repositioning of these empty boxes. All these handling costs and movements generate extra costs without extra earnings. There is a logistic optimum to manage the equipment in the most cost effective way but customers also have certain wishes in terms of availability of equipment (containers). A good balance between container stock levels at the deep-sea terminals and inland depots has to be found. During my internship at Maersk Line an interesting point of attention was where to drop an empty box after a one-way truck trip. If a depot with a shortage is chosen instead of a depot with a surplus costs could be saved. This is an interesting direction for research.

Both aspects described above - modal split & empty container positioning - will be combined in the thesis project. They will both lead to certain conclusions and recommendations. However it is even more interesting to see if the one process change could improve the other process. This can be done in two ways, to create a more efficient and fluent way of transport in the first place. In the second place it is interesting to see if it is possible to save costs if both aspects are combined, this in favor of the Back to Black strategy of Maersk Line. This strategy focuses upon costs savings and increased revenues to get back in the positive financial figures.

## 1.5 Research goal and Research Questions

Container transport has changed the world with an amazing speed. In the Western world it contributes towards the wealth we have nowadays. For the Far East container transport contributes to sustained economical growth. After the financial crisis in 2008 freight tariffs decreased rapidly and transport volumes dropped. After the crisis market circumstances improved but market is highly volatile. Shipping companies have the focus on cost savings to try to make some profit in the challenging market circumstances. Two projects on cost savings at Maersk Line are a better empty container positioning and a shift towards rail and barge instead of truck transport. Besides the intention for cost savings these projects will contribute to a more sustainable way of container shipping. Not only the shipping industry will have benefits but also the society as whole will benefit from such a shift.

This thesis projects has two research goals. The first one is the application of the research done on empty container positioning in a case study at Maersk Line. The second one is contribute to the research field with some new insight in the empty container modeling. Since the dominant opinion in literature is that the empty container positioning cannot be analyzed seen without the full container positioning the full container allocation will be included.

There are a lot of different models which could be used to support these business processes. In this chapter used techniques used for the decision support system (DSS) for empty container positioning and modal split at Maersk Line is described. There is a distinction between different types of DSS's. In the thesis project a model-driven DSS will be used. This model could support the empty container repositioning and modal split of hinterland transport on a strategic level. One of the results of the thesis project is to come up with recommendations for Maersk Line about how to make the business process more efficient. The model that will be created is also a good demonstration of how a software package could contribute to better decision making. Interesting for research is to focus upon different commodities as a lot of journal papers only describe one type of commodity. In some studies a distinction is made between a 20ft. and 40ft. container but for instance a difference between a dry box or reefer is not made. The introduction of the collapsible container is also interesting in this perspective.

The central question in this thesis will be: *How can a modal shift towards rail and barge transport contribute to cost savings in the hinterland transport operations of Maersk Line.*

Three research questions are set up to help answer the questions. These questions are based upon the literature study, see chapter 2

**In which way is it possible to shift truck transport towards rail/barge at Maersk Line?**

Converting direct truck transport into rail/barge transport will be the first part of the thesis project. There are recent developments about concepts as extended gate concepts and a better utilization of the rail network. Barge transport is very interesting but not possible in every country due to natural resources and barriers. The literature study will result in an up to date overview of which research is done for intermodal transport. Different point of views by several researchers will be examined and set out in time perspective.

Besides the literature study the modal share at Maersk Line will be investigated. Multiple systems are used in the organization for planning, financing and container tracking. The information in these systems will be checked to find the current modal split and to check if these systems support each other. With this information it is also possible to distinguish in which situations rail/barge is used instead of truck, and vice versa.

Based upon data available at Maersk and information about the different freight corridors the situation at Maersk Line could be analyzed. This could tell if there is unnecessarily truck transport at the moment. This offers opportunities to shift towards barge or rail.

**How can a good balance be found between asset management and logistics in order to improve empty container repositioning?**



A container transported from the Far East to Europe is stuffed in Asia, than loaded on a deep-sea vessel and transported to Europe. When it arrives at the terminal the container will be transported to the final destination. At this destination the container is stripped and the empty container is ready for reuse. Dry boxes could be reloaded with export goods but there is a trade imbalance between Europe and Asia. This means that there is not enough demand to reload every container, empty containers have to be dropped at a terminal or depot. This problem costs shipping companies a lot of money every year because empty boxes have to be transferred from Europe to Asia. The slow steaming strategy to save on bunker costs will also result in an extra demand for containers because the transportation legs to Asia will have a longer transit time. Other effects due to slow steaming at the total supply chain are studied by Streng (2012).

The research will include a literature study with the aim to check which models already exists and which parts have to be adjusted to have a model for the situation at Maersk Line. Also an overview of the actual methods to calculate costs for empty container positioning will be included. An actual overview of the known optimization models is provided. From this point of view the extra steps needed for Maersk Line could be placed in the already known research.

**In which way could a shift towards a higher modal share for rail/barge and a cost reduction of empty container positioning reinforce each other?**

This research question will be answered with support of the mathematical model. The assumption is that there is a relation between empty container positioning and modal shift. If barge is used more frequently this could have an effect on the container repositioning. Another scenario the tariff structure could be changed and this will have results for the modal shift, which will have an impact on the repositioning. Because of the complexity of the network every change in costs, capacities and network design have an influence on all aspects of container transport. In this research question it is tried to melt the other two research questions.

## 1.6 Research Scope

The scope of the thesis project is explained by use of a visualization, this can be seen in figure 1.5. This will be further explained in the model development in chapter 3. All operations in the dashed box are included in the thesis project.

Geographically the thesis project will be limited to the area serviced by the office of Maersk Line Netherlands. This includes the Rhine area, that contains parts of Belgium, Germany and the Netherlands. The total network is described in chapter 4.1.5.

## 1.7 Set-up

In this paragraph the structure of the report will be described. The first chapter of the thesis is the introduction. This is followed by the literature overview in which a general overview of the shipping industry is provided together with future opportunities for the container shipping industry. It is made clear in which context this thesis could be placed and which issues are addressed, which are not or less well elaborated in other studies. The third chapter provides the model development. The most important part is the mathematical model description. This will be the basis of the transformation into an optimization program as described later in that chapter. The input data for the case study is described in chapter four. This will lead to the

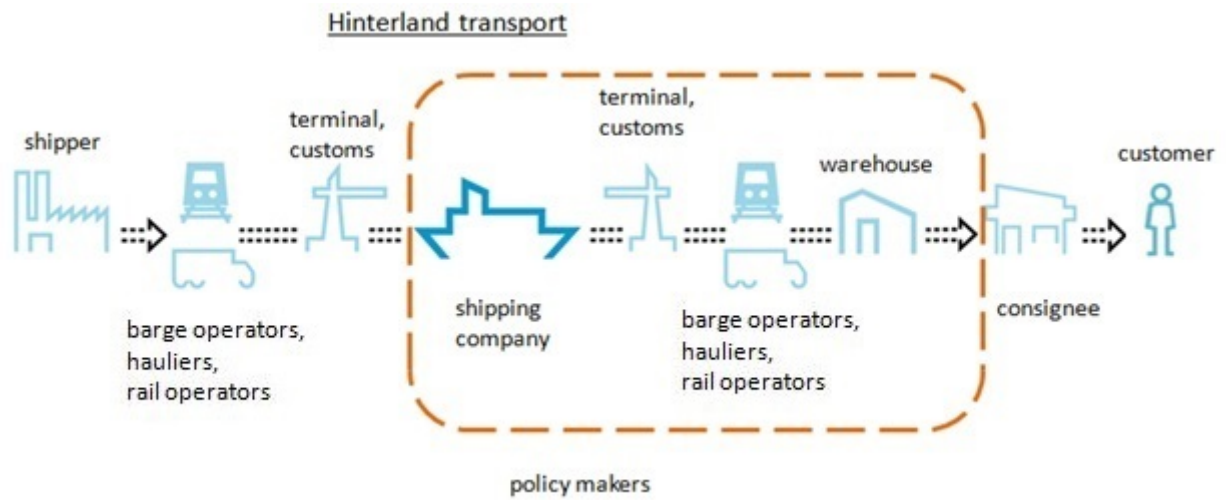


Figure 1.5: Scope of thesis project (own work)

results that will be presented in chapter five. This will be the basis for the conclusions and recommendations towards the research field and Maersk Line in chapter six. At the end four appendixes are added. The first one focuses upon research methodology, the second enlight the literature study. The third appendix covers the model verification and validation and the last appendix include the evaluation.

The structure of the report is shown in figure 1.6.

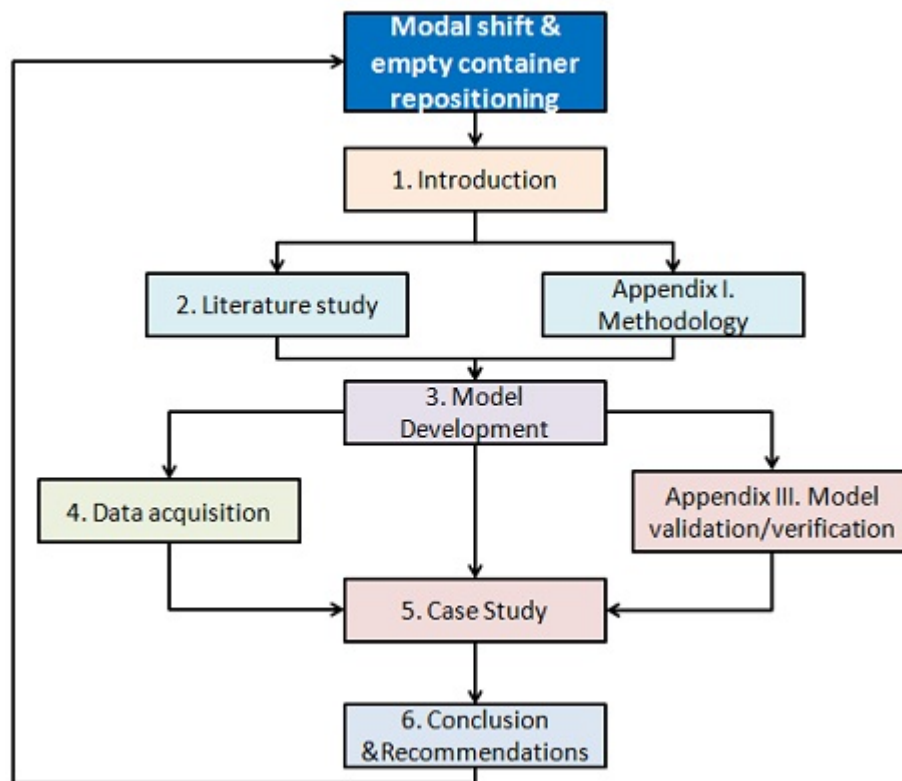


Figure 1.6: Structure of report

## Chapter 2

# Literature Overview

This literature study serves two purposes: provide an overview of research done in the past in the field of empty container repositioning plus modal shift and to show the contribution of the thesis project. (Re)positioning of empty containers is an on-going issue since the beginning of container transport. In the glory days of liner shipping it was known that repositioning had a big impact on operational costs but it was difficult to manage streams, and optimization models were difficult to use due to lack of computer power and complex problem formulation. Now market circumstances are getting more challenging; a more efficient way of repositioning in terms of saving on operational costs, is attracting more attention in the business.

### 2.1 Setup of literature study

This chapter is divided into several sections. First, a concise introduction towards container transportation in general is given. The second section encloses future challenges for the container market. In the third section the empty container handling and its consequences for different actors in the shipping process are explained. The fourth section provides an overview of earlier research towards empty container positioning, modal shift and other articles relevant to the thesis project. The model that will be created during the thesis project will be projected against the already known research. At the end of this chapter a link towards the case study at Maersk Line will be described.

### 2.2 Introduction to container transport

The empty container repositioning and modal shift is a part of the total container supply chain. Several authors studied this supply chain. Work from Steenken et al. (2004) and Heaver et al. (2001) is used in combination with the internal learning system of Maersk Line (LMS) to get a good overview of the container shipping process. This is founded by conversations with specialists and reading of news articles, this helps to complete the insight into the container market. In this section a concise overview is provided to the reader.

Transportation is all about the movement from goods from location A to location B. In its most basic way there is a shipper that produces goods and a consignee that has a demand for the same commodity. The shipper is an export customer, the consignee an import customer. There are multiple ways to transport a commodity from location A to B. In case of container

transport goods are stuffed into a container and transported to the destination via nodes in a transportation network. A node is a fixed point in a transportation network. There the container is unloaded, but before a container is unloaded multiple actors, infrastructure and processes are involved in transportation. As an example the transport of a series of new plasma televisions. These goods are stuffed into a container somewhere in the Far East. In these countries labor is still cheap and the total cost price of production will be lower when compared to production in Europe, although the workforce is available in these countries. Therefore an empty container needs to be transported from a deep-sea terminal or depot to the producer of televisions (shipper). From the factory the full container is transported to a deep sea terminal. This is particularly done by truck in Asia. The terminal operator is the second company handling the container. When the container arrives at the terminal a transport company, in this case a shipping line, will take responsibility for transportation towards an European deep sea terminal. This trip on a large container ship will take about three to four weeks time. When the container hits ground in Europe there are three possible modalities for hinterland transport, barge rail and truck. The shipping company could take care of the hinterland transport, this is carrier haulage (CH). The customer itself could arrange its own transportation or call in a freight forwarder, this is merchant haulage (MH). The last option is that a customer uses a freight forwarder to arrange the hinterland transport. The processes are shown in figure 1.5.

### 2.2.1 Interests of actors in container transportation

In the previous section different actors are mentioned, they are listed in table 2.1. The shipper and consignee are actors responsible for a certain supply and demand in a trade route. Effects on modal split or repositioning have no impact on their business processes. The shipping line will still deliver the containers in line with the agreed order deadline. Since the last leg nearly always has to be executed by truck nothing will change in customer perspective. The only negative consequence of a change in modal shift is a possible delay when there is low water or a river is blocked for barge transport. This is also the case when rail transport is blocked by strikes. A change in container repositioning makes no sense for the customers if they still receive their import or export containers on the agreed order deadline. The limited barge capacity at the deep sea terminals could also be a cause for delays.

The interests for barge/rail and truck operators are clear. The larger the volumes the more turnover these companies could achieve. Repositioning is an interesting point of attention since this can change the volumes that have to be transported.

For terminals a change in modal shift has a more direct effect in terminal lay-out since every modality is served from another location at the terminal. Effects of repositioning are important for terminals since this will change the storage of containers at the terminals.

For shipping lines modal shift and repositioning are important for total container transport volumes. The faster containers are transported the less containers are needed in the network since empty boxes are faster available for reuse. Container repositioning is also important, with a better repositioning throughout the network less containers are needed. This has a big impact on container asset costs.

Freight forwarders are interested in reliable hinterland transport when order deadlines are met and empty containers are available on time. Parties as barge, rail or trucking operators benefit from higher volumes and thus a modal shift into their direction has a positive effect for them.

Table 2.1: Overview influence of different actors

| Actor                     | effect modal shift                 | effect repositioning      |
|---------------------------|------------------------------------|---------------------------|
| shipper/consignee         | reliability                        | -                         |
| barge/rail/truck operator | transport volumes                  | changes for more volume   |
| terminal operators        | terminal lay-out                   | terminal lay-out, storage |
| shipping line             | costs savings hinterland transport | less container assets     |
| freight forwarder         | advantage of volumes               | drop off location         |

## 2.3 Future opportunities for container transportation

In this paragraph different challenges for container transport are described. Using available scientific and professional literature interesting challenges show up. Next to it newspapers, websites and daily talks are sources to identify trends in the container market. Eventually conversations with specialists along are an eye-opener for new challenges and opportunities. In this section these four actual challenges will be described:

- Challenging market circumstances in relation with global economy;
- Scale enlargement in ship and terminal size and effects of slow steaming;
- Change modal shift towards rail and barge;
- Collapsible containers (included in appendix II).

### 2.3.1 Challenging market circumstances

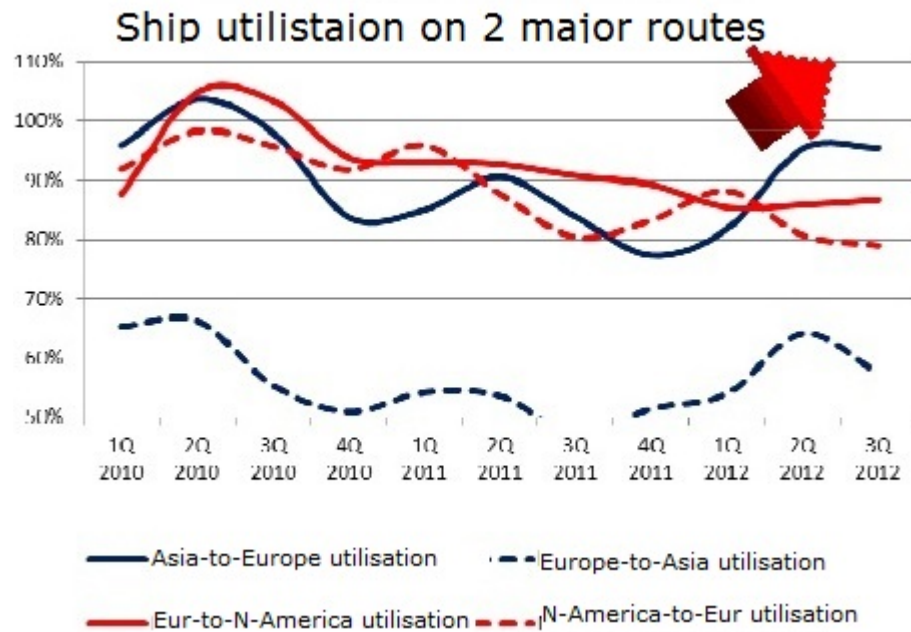
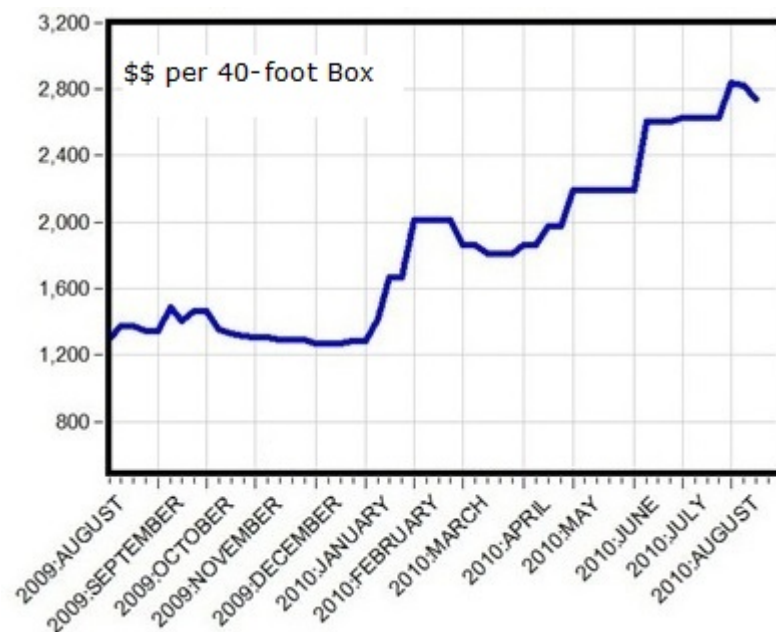
The first challenge for the container market described in this chapter is the strong change in market circumstances over time. A proverb is that after some years of economic growth a period of lesser or zero growth should be expected before a new period of economic growth starts. This is a circular process which has a time span of about seven years. Since the debt crisis of 2008 the container market is more volatile than ever. Periods of good and bad economical circumstances are switching fast. Two indicators are used to indicate this phenomenon. The first one is the utilization rate. This can be seen in figure 2.1.

This graph shows data from 2010 till 2012. 2009 was a weak year for container shipping industry with low utilization rates. In reaction to low utilization rates is that shipping lines reduce capacity on certain corridors and this will lead to a wave pattern. Also seasonal influences are important as Q2-Q3 is always the weakest period of the year for the container market. A utilization rate of 80% is enough to recover costs. The last 20% is to gain extra profit upon trade routes. Next to utilization rate tariffs are important, in figure 2.2 the spot tariffs are shown. There is a gap in the data between Q2-2011 and Q4-2011 because no data was available in this period. In Q2010 and Q3-2010 the ship utilization is more then 100%. In theory this is not possible but in practice more ship capacity was brought into the market to ship those volumes.

The tariff data is from August 2009 till August 2010. In one year prices increased by 133%. However in a shorter time interval, January-10 till February-10, freight rates even increased by 66%. Also nowadays there is a big difference in spot tariffs. Although all shipping companies

<sup>1</sup>Drewry's Container Forecasting, 2012

<sup>2</sup>Drewry's Container Rate Benchmark, 2011

Figure 2.1: Ship utilization<sup>1</sup>Figure 2.2: Shipping rates<sup>2</sup>

try to increase the rates, the market is going in the other direction. It is essential to have a high utilization rate to be competitive these days. When ships are fully loaded it is important that tariffs are at a sustainable level so investing in the shipping business will be interesting again.

### 2.3.2 Scale enlargement & slow steaming

The second actual aspect in the container shipping industry is scale enlargement of ships and terminals. As shown in the introduction ship sizes are still increasing, this can be seen in figure 1.1. Nowadays the CMA CGM Marco Polo is the biggest container ship with a capacity of 16.020 TEU, LloydsList (2012). Other shipping companies have also ordered even larger ships, for example the Triple E vessels of Maersk Line that will be delivered in Q2-2013 <sup>3</sup>. This will lead to an advantage due to economies of scale. Cullinane and Khanna (1999) did some research in the beginning of the previous century into the benefits of ships with larger capacities. He concludes that especially for longer corridors ships with larger capacities are beneficial. When terminals that are called have a high productivity the benefits of economies of scale will be even stronger according to this research. These ultra large container carriers (ULCC) have a longer (un-)loading time than smaller ships because of the higher volumes so only high tech terminals must be called. Especially for the Far East <> Europe trade line these ships have an enormous potential. On this line distances are large, terminals are state of the art and volumes are high. These three ingredients are important to make the ULCC profitable, companies who invest in these ships have the advantage of lower slot costs in comparison with their competitors. Especially with market circumstances as described in section 2.3.1.

Next to the introduction of the ULCC's slow steaming is more and more a way of saving costs for container shippers<sup>4</sup>. In 2007 shipping lines had even no information about fuel consumption for speed lower than 16 knots. In 2010 73% of the Maersk Line fleet was slow steaming at engine loads below 40%. This achieved a lot of savings upon operational costs. The new Triple-E vessels are specially designed for slow steaming. Instead of the V-shaped hull of the Emma Maersk a U-shaped hull is applied to the Triple-E vessels, this is shown in figure 2.3. The consequence of the other hull shape is that there will be more space below deck for containers. The shape is especially designed for slower steaming. Instead of one big propeller two smaller ones are used, the engines are smaller and have less power when compared to the Emma Maersk class.

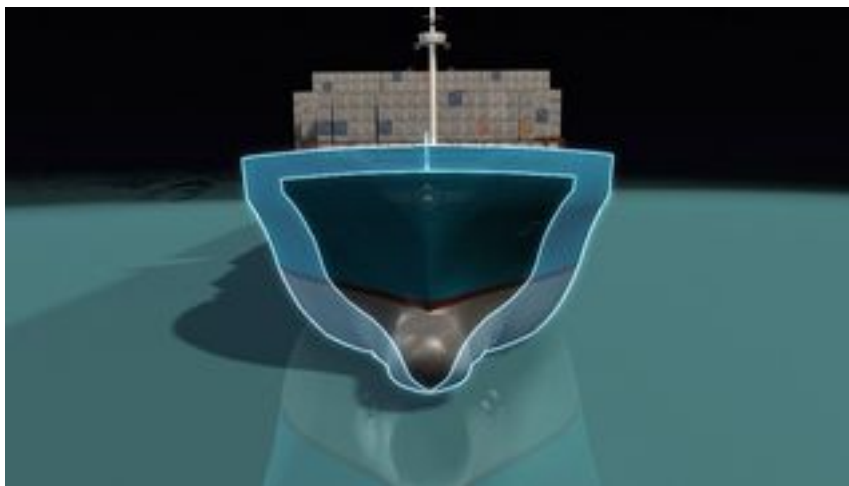


Figure 2.3: Difference Emma Maersk <> Triple E<sup>5</sup>

<sup>3</sup>Maersk Line ([www.worldslargestship.com](http://www.worldslargestship.com))

<sup>4</sup>[www.maersk.com/Innovation/WorkingWithInnovation/Documents/Slow%20Steaming%20-%20the%20full%20story.pdf](http://www.maersk.com/Innovation/WorkingWithInnovation/Documents/Slow%20Steaming%20-%20the%20full%20story.pdf)



Besides ship size terminals become bigger and bigger. Maasvlakte 2 will handle the first container in 2013, Port of Rotterdam 2003<sup>6</sup>. Through all new technologies mother vessels could be handled in a faster and cheaper way. The result will be higher peak volumes on terminals at the moment an ultra large container ship calls at a terminal. This will influence the terminal lay-out and capacities of existing barge and rail terminals. APMT is constructing a new terminal at the Maasvlakte. At the moment there are negotiations with suppliers of terminal equipment to create a state of the art terminal. For an outsider the container business is huge but this business will grow even further.

### 2.3.3 Change of modal shift towards rail and barge

The third opportunity mentioned in this chapter is further improvement of the modal shift in hinterland transport. Research that contributes in this field of study is done by Blauwens et al. (2006) and Konings (2009). There are two main aspects for modal shift, first of all costs could be saved by choosing another transport mode; on the other hand barge and rail transport is in general more sustainable than truck transport, Ricci and Black (2005). Also other authors contributed to this research field but still a lot of work has to be done for sustainable transport. A point of attention is that input data for emissions (e.g. amount of emissions per transport km) is difficult to find and often contradictory and hard to compare due to different assumptions. There are some life cycle analysis packages with useful data but this information has a very high cost and is strictly protected. Next to it the load factor is very important for CO<sub>2</sub> emissions. This load factor is specific for every corridor and freight operator.

Modal shift is very important in combination with the development of Maasvlakte 2 (MV2). Without further improvement of the modal shift the A15 will be heavily congested in the future, Verkeersonderneming (2012). From the perspective of a customer hinterland transport looks the same as a few years ago. A container is transported, as it has been done in the past, by truck towards a warehouse. When unloaded this container was picked up, if possible filled with a return load. Furthermore since last decade sustainability has become more and more important. Particularly for big customers who want to make their products unique from their competitors. Their *'quality products'* must be associated with sustainability for the customer group. In the beginning of the last millennium the use of inland depots was a new development in the market. A lot of effort is put on using inland depots for the hinterland transport of the European ports. Especially the authority Port of Rotterdam and ECT were front runners in this process, Veenstra et al. (2012). Other shipping companies followed these initiatives, also in other regions. For customers not that much has changed, a container is delivered by truck. More and more the first leg from deep sea terminal towards customer is done by barge or rail. This is called a barge/rail combined trip. These modes are in general more sustainable and have lower transport costs, although there is a minimum distance before rail/barge could benefit for the lower transport tariff per km (break-even point). An overview of the modal shift in the port of Rotterdam from 2006 till 2010 is given in table 2.2.

During this time period the modal shift has developed negatively for barge and rail transport. Truck transport increased these years. This data is related to the total throughput of the Port of Rotterdam. In the same period transport from and to the hinterland increased while feeder

<sup>5</sup>Maersk Line ([www.worldslargestship.com](http://www.worldslargestship.com))

<sup>6</sup>[tinyurl.com/bfhftmu](http://tinyurl.com/bfhftmu)

<sup>7</sup>Port Figures, Port of Rotterdam, 2010

Table 2.2: Modal shift Port of Rotterdam<sup>7</sup>

| Mode - year | 2006 | 2007 | 2008 | 2009 | 2010 |
|-------------|------|------|------|------|------|
| Barge (%)   | 33   | 33.2 | 30.2 | 30.4 | 30.5 |
| Rail (%)    | 10   | 10.9 | 12.7 | 11.1 | 10.9 |
| Truck (%)   | 57   | 55.9 | 57.1 | 58.5 | 58.6 |

throughput decreased.

To sum up, modal shift is one of the main attention points in modern container transportation. In the last decade on initiative of ECT several inland depots and extended gates were set up. A balanced network of nodes is essential for barge/rail combined transport and will be more important in the development of MV2.

### 2.3.4 Opportunities in relation with thesis project

In the previous sections different opportunities for future container transport were explained: change in modal shift, collapsible container, challenging market conditions, scale enlargement & slow steaming. This thesis project will contain some elements of these subjects. It is out of the scope of the thesis project to study all these new concepts. But it plays an important role in the broader perspective of the market and should be taken into mind. It also determines the assumptions that have to be made in the model that will be set up.

## 2.4 Empty container repositioning

Empty container positioning is studied in a lot of other research work. In this literature overview a lot of articles are studied. They are included in the Appendix II. In this overview the most important articles are studied. These articles could be divided into two categories. The first category focuses upon the mathematical approach, the second category has a more practical approach. In the mathematical studies a lot of attention is based to a strong mathematical formulation and it is tried to include as much parameters as possible. This in contrary to the practical approach where a basis model is used but a strong dataset is used to imitate real world processes. In this section the lessons learned from the literature study will be explained. In the first part the lessons from repositioning models will be explained. The application of these model in case study will be clarified and tested with the scope of this thesis project. It will be explained in which perspective the thesis project must be placed. In this section the empty container repositioning at Maersk Line is described in a global way. For the complete overview the reader is referred to the appendix. The most important conclusions are provided in the next section.

## 2.5 Lessons from other modeling studies

A lot of literature has been studied for the thesis project and some important lessons are learned that could be applied in this research. This paragraph contains three sections. The first section describes lessons learned from literature about mathematical model building. The second section will explain different scenarios used in other literature. This is useful to determine which scenarios could be used to answer the research questions that were described in section 1.5. At the end of this chapter the thesis project is placed into the perspective of other research work.

### 2.5.1 Experiences from other mathematical models

When a birds-eye perspective is taken distinction between the models described in this section could be made. The first category are the models where the mathematical process is most important or a new method of solving the repositioning is used. A pioneer in positioning models for container transportation is work by Crainic and Laporte (1997). The second category contains articles that set up a mathematical model with the focus of an application to a real world network. In these articles the model and data is more accurate, the network larger and based upon a geographical area. A point of attention is that input data is very important to achieve good model results. In some articles one may question whether the data used were just simulated instead of taken from real life. It is easy to calibrate a model by adjusting input data, especially when the objective function is to minimize costs. This has to be taken into account.

The objective function used in all models - except Shintani et al. (2007) - is to minimize operational costs. In the exception profit (turnover - costs) is maximized. In all models costs for transportation from  $A$  to  $B$  are inserted. Some models included extra costs for handling and storage of containers. Models that deal with leasing of containers have extra leasing costs. Other models also introduced cost penalties for opening new services or arcs. An arc is the connection between two point in a network. These points could be a terminal, inland depot or customer location. No model included surcharges in the costs function for sustainability. The only way sustainability is mentioned is that barge or rail transport should be more sustainable than road transport, this is indicated by Ricci and Black (2005). No author estimated sustainability with figures. Obviously it is not that easy to obtain reliable data about sustainability.

Each of the models is solved with help of heuristics to make it easier to solve the model. Also almost every model omitted some variables to solve the model. With all variables included the model was too complex to solve. This should be kept in mind when developing the model. When too much variables are included it will not be able to solve the model in a efficient way. Particularly models with an extensive case study and a lot of data make a lot of assumptions. In the case study of Maersk Line a lot of data has been used so in line with literature, simplifications should to be made to end up with a model that still could be calculated.

The most important aspects to include in a network model according to literature are:

- full + empty (re-)positioning;
- single- or multi-commodity;
- single- or multi-modality;
- single or multiple time periods;
- in- or excluding leasing containers;
- handling/storage costs for containers.

### 2.5.2 Different scenarios in other literature

In the literature different scenarios are distinguished. Olivo et al. (2005) and Francesco et al. (2009) mentioned the importance to analyze different scenarios. Arnold et al. (2004b) and Shintani et al. (2007) introduced some example scenarios that could be analyzed. Choong et al. (2002) did research to the planning interval and came up with different networks that were analyzed as scenarios. For the thesis project different scenarios are set up to check whatever is

the result of the input data in the model. First of all the different scenarios encountered in the research are listed:

- variations in transport costs;
- variations in transshipment costs;
- technical international compatibility;
- new network design: locations of additional terminals and depots;
- optimization of the location of existing terminals.

### 2.5.3 Time horizon

For a strategic optimization model it is important to select the right time horizon. According to Choong et al. (2002) longer planning horizons give better model results, a too short planning horizon is chosen in the following situations:

1. Concentration of the activities in the network: high variation in demand just after the end of a planning period has influence on the model performance (e.g. when in time period  $t$  after the last model period a new customer enters the market with high volumes);
2. Transit time of container movements: a model with a modality with a long transit time needs a longer planning horizon;
3. End-of-horizon effects: uncertainties at model end.

The planning horizon has to be at least the longest barge transportation duration. The time period chosen in the thesis project will further be explained in section 4.4.3.

### 2.5.4 Scope of thesis work in relation with other research work

First of all the model that will be created in the thesis project will be on a strategic level. This is because such a model could provide best answers and insights into the research questions which are on a strategic level. Next to it the input data could be more of a general nature. For a tactical and operational model all information about the day of the week, manpower, exact costs and transit times should be known. It is not practical to collect all the data in the thesis project correctly due to inaccuracy in Maersk Line systems and for example the totally opaque structure in freight tariffs. Furthermore the more data inserted into the model the larger solving times. Modeling a container model with full and empty (re-)positioning could lead to some problems with supply and demand in time periods close to each other. This is described by Bandeira et al. (2009). Especially when boxes are reused the practice works in a different way compared with theory. In the section about model development, chapter 3 this phenomenon will be further explained.

In a lot of other models multi commodity is mentioned as an important aspect since the inequality in container sizes strengthens the container imbalances. Although important all authors excluded multi-commodity in their final model description due to difficulties to solve the model. In this thesis project the intention is to include multi-commodity.

A lot of other models are built from theoretical point of view. The aim of the model for this thesis project is to combine theory with a practical situation at Maersk Line. More accurate

input data will be used and a existing network will be used instead of a fictitious network. The goal is to give Maersk Line an advice in which way they could optimize their processes.

## 2.6 Conclusion

In this chapter interests for different stakeholders in the shipping process are described. Next to it four important challenges for the container transportation are mentioned. This are the challenging market circumstances, scale enlargement, change in modal shift and the collapsible container. In the last part of this chapter the most important conclusions of the empty positioning are mentioned.

## Chapter 3

# Model development

In this chapter the mathematical model for empty container positioning is formulated. In the first section the problem is described in words to form a model formulation. This is illustrated with a schematic overview of the network. Next to it the assumptions made in the model formulation will be described. In the second part the mathematical model is formulated. The model objective, sets, parameters, (decision) variables and constraints will be explained. The third part of this chapter explains how the mathematical model is transformed into the optimization software package AIMMS<sup>1</sup> is used for this. This chapter is based upon the research methodology, this is included in Appendix I. In this section different model types are explained even as data requirements.

### 3.1 Conceptual model of empty container repositioning

Transport systems are never balanced. It is not a circular process where an item or process passes several stages before it comes back to the original starting point. In the case of transport there is a supply of a good  $X$  at location  $A$  and a demand of the same good  $X$  at location  $B$ . A transport system is used to transport good  $X$  from  $A$  to  $B$ . For the backhaul,  $B$  to  $A$ , costs are made to reposition empty equipment without making revenues. Such a system is in general a transport network consisting multiple transport modes.

In specific for container transport the network exists out of nodes that are connected by arcs. The nodes are represented by transshipment hubs. These hubs could be terminals, inland depots, warehouses or customer locations. Arcs represent transport streams between transshipment hubs. In the model an arc is the connection between hubs with different system parameters. In practice an arc could be seen as a physical transport route, e.g. an highway from terminal to customer or a railroad from terminal to inland depot. Different transport modalities could serve on one and the same arc, as for example an inland depot that is accessible by barge, rail and truck. Without one of the elements mentioned before, transshipment hubs, arcs or transport modes efficient transport is not possible.

In figure 3.1 an overview of the container shipping process is schematically shown. In this figure processes run from left to right, from shipper to consignee. A container is loaded at the

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<sup>1</sup>Advanced Integrated Mathematical Modeling System ([www.aimms.com](http://www.aimms.com)).

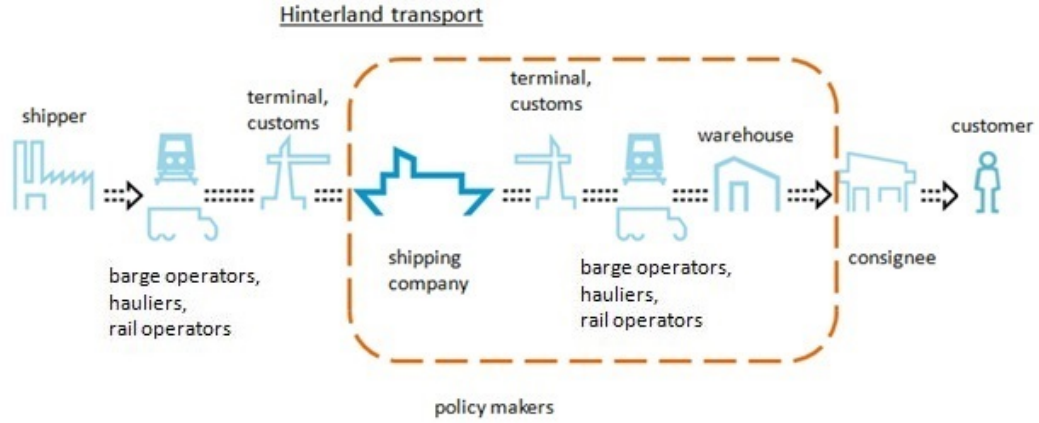


Figure 3.1: Overview of container shipping process (own work)

shippers location and transported to a deep sea terminal. From there the container is loaded on a mother vessel and transported to the deep sea terminal in the country of destination. The last leg from terminal to consignee is performed by a (combination of) transport mode(s) (barge, rail or truck) and if necessary with intervention of an inland depot. The scope, chapter 1.6, of the model is indicated by the orange striped box. This includes all transport processes from the moment a container hits ground in a Benelux terminal up to the its final destination at the customer.

A schematic overview of the network used in the model is shown in figure 3.2. The blue dots with the  $H$  inside represent the deep-sea terminals; inland depots are indicated by the green dots with a  $d$  inside. The final customers are displayed by the orange rounded rectangle with a  $c$  inside. The transshipment hubs in the network are the inland depots, the arcs are shown as arrows. On these arcs transport modes carry goods.

In the model itself there will be a set of nodes. This set of nodes has the three different subsets as mentioned above: deep sea terminals, inland terminals and customers. The arcs are all connections between these nodes. Three modalities will be used (barge, rail and truck). For the best output data quality these arcs will be modeled as separate variables for every transport mode. This is further explained in section 3.2.1.1.

### 3.1.1 Modeling approaches

In this section different modeling choices are described. First the type of model class is explained, second the difference between a deterministic and stochastic model is clarified, and at the end the set of parameter ranges is discussed.

There are two main classes for a mathematical model, namely optimization and simulation models. The former is mainly used for problems that could be optimized. The most important elements in these models are the objective function, (decision)variables, parameters and constraints. With an optimization program these models could be solved. Kroon and Zuidwijk (2003) defined this the *'how-to'* models. Next to those *'how-to'* models they identified the *'what-if'* model. This is a simulation model that describes realistic situations. This situation could be modeled under different conditions with different time intervals with changing input

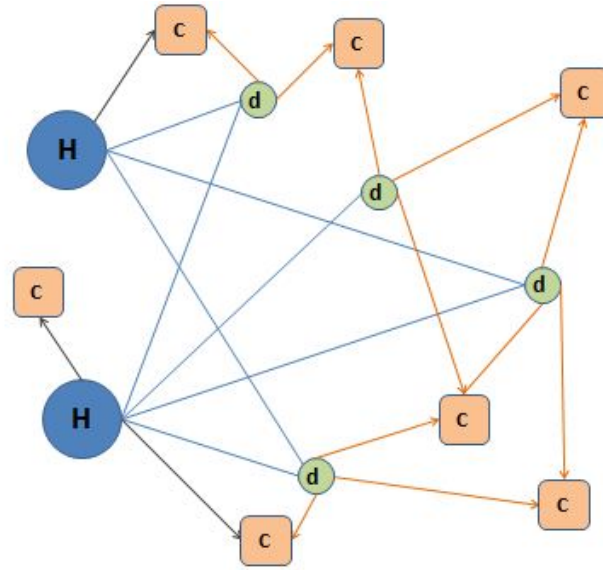


Figure 3.2: Terminal and depots in the network (own work)

data. Different alternatives could easily be examined in this type of model. The advantage of an optimization model is that solving is more simple compared to simulation and easier to setup. A second advantage of an optimization model is that computation times are shorter. The main advantage of a simulation model is that it could deal with dynamic and interactive systems. Uncertainties in the input data could lead to several different model results. For this container allocation problem the optimization model is chosen due to an easier model setup and better fit to input data.

Next to the distinction between the classes of the model, as described in the previous paragraph, there is a difference between deterministic and stochastic models, Hoogendoorn (2007). In a deterministic model all information is assumed to be available and fixed. In a realistic world not all parameters are fixed and known. If there is an uncertainty with a certain variety this could be handled in a stochastic model. Because the supply and demand data is uncertain in the empty container repositioning process, a stochastic model will be used to predict future scenarios. A strategic model will be used so a long time horizon has to be taken into account and this will result in more uncertainty in parameters. This is why a stochastic model will be used. If a stochastic optimization model is chosen no simulation is needed and uncertainties will be taken into account. Another option is to choose for a deterministic optimization model. The advantage of this is that it is less complex in comparison with a stochastic model.

Finally the type of parameters is clarified; discrete and/or continuous, Verhaeghe (2007). Both types are necessary in this model. Variables like the volumes of containers and number of trips should be modeled as a discrete parameter thus only whole quantities can be transported in practice. Other variables like costs or transport distance should be modeled as continuous parameters since all values are possible in practice. They are not limited to divisible units as the number of containers, or the number of transports.



The model will be based upon a deterministic stochastic optimization model and will contain both discrete and continuous parameters. The model will be a network model where the nodes will be the terminal and depots and the arcs will represent the transport by different modalities.

### 3.1.2 Assumptions

In theory it is possible to model the transportation process with respect to all small details. As read in the literature study, section 2, optimization software and computer hardware is limited to solve a total transportation system. There are two more reasons why not all processes are inserted into the model. The first one is that the planning level of this model is on a strategic level. The second is that not all input data for a total modeling is available in good quality. At the end of this chapter the assumptions used are shown.

Crainic et al. (1993) distinguish three different planning levels: strategic, tactical and operational. A strategic model is a long term planning model at firm level. At this level decisions about locations, facilities, tariffs and resource acquisitions are made. A tactical model operates on a medium term, basically one time period in advance. The last level is the operational level, this is a short modeling period and day-to-day activities are planned. A strategic DSS will be built in this project to see what the effect of depot choice and tariff structure. This is in line with the research questions and time horizon as explained in section 1.5.

Second, is that not all input data is available in an acceptable quality to achieve realistic results. Every modeling step will lead to some noise in the model outcome. Especially with small variations or small volumes in a network (e.g. open top containers) optimization will not improve the solution. Therefore assumptions are made in the modeling process. Smaller time periods require more detailed information and are more complex to model.

The assumptions could be split into two categories. The first category is set-up before the mathematical setup. The second category are the assumptions made during the transformation from mathematical model towards the optimization software. These additional assumptions are described in Appendix III. These assumptions are made for the setup of the mathematical model:

- Geographical scope will be limited to the Benelux and Rhine delta:
  - Deep sea terminals: Rotterdam, Antwerp, Zeebrugge;
  - Inland depots: Maersk Line depots in BEL, NL and GER.
- Multi commodity flow problem:
  - 20ft;
  - 40ft;
  - reefer.
- Multi modality:
  - barge: services with contracts Maersk Line;
  - rail: services with contracts Maersk Line;
  - truck.
- Customers (grouped in regions):
  - Belgium:  $\pm 10$  regions;
  - Germany:  $\pm 90$  regions;

– Netherlands:  $\pm 10$  regions.

- No capacity restriction for transport modes barge & rail <sup>2</sup>;
- Linear cost function for transport modes: costs independent of volumes;
- No minimal volumes required to open an arc or transshipment hub <sup>3</sup>;
- Truck capacity is one container for every transport, independent of commodity;
- Stock levels for inland depots based upon Maersk Line forecast;
- Each time period is one day, planning with regard to frequencies of services;
- Customers are grouped into regions, based upon postal code system.

## 3.2 Mathematical model formulation

In this section the transportation problem will be transformed into a mathematical formulation.

### 3.2.1 Model Objective

The objective is to *minimize* total transportation costs for both full and empty container positioning. These costs are build up in different aspects: transport costs, handling costs and storage costs. Depending on the modal split transport costs for a specific container transport can differ during the planning interval. Transport costs and speed have a strong relationship.

The decision variables are the amount of containers transported on each arc represented by the different transport modes, measured in TEU. For each terminal and depot pair there are multiple options for modality choice. When the number of terminals and depots increases in the network the amount of decision variables will increase rapidly and this will affect the model performance.

#### 3.2.1.1 Indices

The following indices are used in the model:

- |                                            |                                      |
|--------------------------------------------|--------------------------------------|
| • $h \in \mathcal{H} = \{1, 2, \dots, H\}$ | set of deep sea terminals            |
| • $d \in \mathcal{D} = \{1, 2, \dots, D\}$ | set of inland depots                 |
| • $c \in \mathcal{C} = \{1, 2, \dots, C\}$ | set of customer regions <sup>4</sup> |
| • $m \in \mathcal{M} = \{1, 2, \dots, M\}$ | set of modes (barge, rail, truck)    |
| • $p \in \mathcal{P} = \{1, 2, \dots, P\}$ | type of commodity                    |
| • $t \in \mathcal{T} = \{1, 2, \dots, T\}$ | time period                          |

The network includes all terminals and depots and could be described as:

- $\{\mathcal{N}\} = \{\mathcal{C}\} \cup \{\mathcal{H}\} \cup \{\mathcal{D}\}$

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<sup>2</sup>Out of scope for Maersk Line

<sup>3</sup>According to rate agreements Maersk Line

<sup>4</sup>Customers are grouped in regions

This set of nodes can be partitioned into several other subsets. Each terminal is at the same moment an origin and destination, the former for full containers and the latter for empty containers. The set of destinations, build up from the regions in Belgium, the Netherlands and Germany have two directions, import & export. The depots will serve as transshipment hub, dummy variables are added here for stock levels to guarantee equilibrium in every time step.

The arcs connecting terminals and depots can be described as:

$$\bullet \mathcal{A} = \{a = (i, j, m, p, t) | i, j \in \mathcal{N}, m \in \mathcal{M}, p \in \mathcal{P}, t \in \mathcal{T}\}$$

This will include all possible routes between origin and destination. It is also possible to model the container flow in the terminal or depot itself (when  $i$  and  $j$  are equal (re-use of containers)). The origin of a transport is indicated by  $i$ , the destination by  $j$ . These are subsets of the total set of nodes  $\mathcal{N}$ .

The network will cover the nodes and arcs. In mathematical formulation:

$$\bullet \mathcal{G} = (\mathcal{N}, \mathcal{A})$$

There are multiple arcs in the network. In the mathematical model they will be divided in four categories. The first category is the transportation of the container from terminal to customer. The second category is the transport of the empty box back towards a storage facility. This could be an inland depot or deep sea terminal (in Maersk terms this is still import transport). The third stream is the (re-)positioning of empty containers. The fourth category is the transport of export boxes of customer back to the terminal. In figure 3.3 an graphical overview of the streams is presented. The different types of movements are listed below. The symbols will be a subset of  $i$  and  $j$  in the predefined definition of arcs.

$\mathcal{A}1$  (black)

- $\mathcal{H}, \mathcal{D} \rightarrow \mathcal{C}$  (full)
- $\mathcal{H} \rightarrow \mathcal{D}$  (full)

$\mathcal{A}2$  (purple)

- $\mathcal{C} \rightarrow \mathcal{H}, \mathcal{D}$  (empty)

$\mathcal{A}3$  (green)

- $\mathcal{H}, \mathcal{D} \rightarrow \mathcal{C}$  (empty)
- $\mathcal{H} \rightarrow \mathcal{H}$  (empty)
- $\mathcal{D} \rightarrow \mathcal{D}$  (empty)
- $\mathcal{D} \leftrightarrow \mathcal{H}$  (empty)

$\mathcal{A}4$  (orange) (full)

- $\mathcal{C} \rightarrow \mathcal{H}, \mathcal{D}$

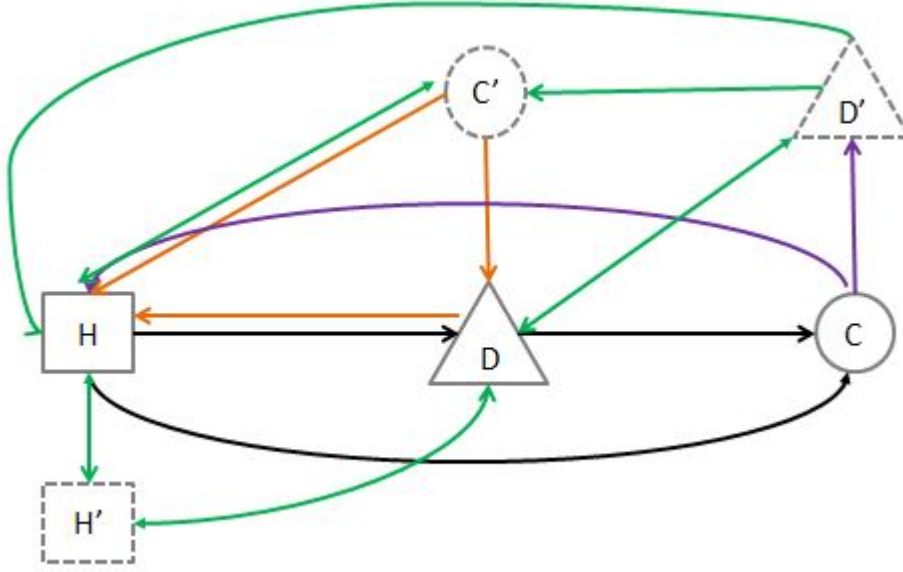


Figure 3.3: Overview of arcs in the network (own work)

- $D \rightarrow H$

The total set of arcs could be described as:

- $\mathcal{A} = \{\mathcal{A1}\} \cup \{\mathcal{A2}\} \cup \{\mathcal{A3}\} \cup \{\mathcal{A4}\}$

The arcs are separated to give the possibility to extract data in the data processing.

### 3.2.1.2 Decision variables

The flows of container type  $p$  moving over the arc  $(i, j)$  by a certain modality  $m$  in time period  $t$  is indicated by the decision variable:  $x_{i,j,m,p,t}$ .

$$x_{i,j,m,p,t} \geq 0 \quad \forall a \in \mathcal{A} \quad (3.1)$$

$x_{i,j,m,p,t}$  could also be notated as  $x_a$  since all indexes are in the set of arcs. This is an integer variable.

### 3.2.1.3 Path/arcs

An important decision for the model building is the choice for an arc- or path-based network transportation model. A network model contains different nodes and arcs as said before. On an arc transport volumes could “move” through the network. A path-based network model uses, as the name indicates, paths from origin to destination. Such a path could contain different nodes connected by different arcs (for example path A that indicates transport from *Rotterdam* via *Venlo* towards *Kempen* using arc “*rot-ven*” + “*ven-kmp*”). Without the definition of the correct

of paths, which arcs are in which path, the network model will not be practical. When a path is not predefined the model will not include a potential forgotten path. All paths used in the model should be pre-defined.

The alternative of a path-based network model is an arc-based network model. Each arc has a origin and destination. This could be every node in the network. Between all these nodes flows are possible. In theory every arc in the network could be used for a flow from *Rotterdam* to *Kempen*. An optimization tool could be used to minimize the objective function. Each arc could have different parameters in terms of costs, reliability or ease of use. The model could be optimized in each possible direction.

The advance of an arc based network model is that freedom in the network is larger and easier to manage. For example if costs are defined for every arc all possible solutions could be taken into account by the optimization software. For a path based model only paths that have been defined by the user are taken into account. For a big transportation network it is easier to only describe arcs instead of paths. The amount of possible paths will explode in large networks. Another difference is the way data could be retrieved from the model. In a path based model it is easy to see which path is used. In an arc based model flows on every arc are known but it is not exactly known which route a container will take through the network.

In this network model an arc based approach has the preference. Particularly because every possible connection will be taken into account by the model. This will help to get full advantage of the economies of scale that occur in the transport business.

#### 3.2.1.4 Supply and demand explanation

Important parameters in the model are supply and demand. This could be subdivided into empty and full containers. Firstly there is a demand and supply of full containers due to the full container allocation problem. Supply of containers will show up in the deep-sea terminal to fulfill the demand of customers in the hinterland. There are two dimensions of freedom for the full container transport problem, modality and route choice. Because the begin and end location are already known each container has a fixed OD-pair (origin - destination), although the specific route is unknown (which nodes and arcs are used for transport).

When a container is transported towards a customer it will be stripped. At this moment there will be a supply of an empty container at this location, it is assumed that there is no storage capacity on a customer's location. When a customer needs an empty container for exporting goods there will be a demand for an empty container at the customer location. Instead of full container positioning, where the origin and destination is already known, there is an extra degree of freedom for empty positioning. It does not matter which depot or deep-sea terminal is used for repositioning. Likewise it does not matter from which depot an empty container is delivered to a export customer. There will be an extra degree of freedom for empty container positioning compared to full container positioning, this makes the problem more complex.

In mathematical formulation the demand and supply per commodity in different time periods will be described as below.  $\mathcal{F}$  is the subset of full commodities and  $\mathcal{E}$  the set of empty commodities.

$$\bullet S_{n,p,t}^f \quad \forall n \in \mathcal{H}, p \in \mathcal{F}, t \in \mathcal{T} \quad \text{Supply of full containers}^*$$

- $S_{n,p,t}^e$        $\forall n \in \{\mathcal{H}\} \cup \{\mathcal{D}\}, p \in \mathcal{E}, t \in \mathcal{T}$       Supply of empty containers
- $D_{c,p,t}^f$        $\forall c \in \mathcal{C}, p \in \mathcal{F}, t \in \mathcal{T}$       Demand of full containers \*
- $D_{c,p,t}^e$        $\forall c \in \mathcal{C}, p \in \mathcal{E}, t \in \mathcal{T}$       Demand of empty containers

\*: These sets will be equal since begin terminal and end-location are fixed locations and have a fixed OD-pair.

For each import container there is an arrival terminal known. With the current description above there is no distinction between terminal 1 or terminal 2. Given the supply and demand an extra supplement from terminal of origin could solve the problem. (for example from Rotterdam could have an additional "R" in commodity type).

### 3.2.2 Constraints

Different constraints are used for the container positioning model. First of all the demand has to be fulfilled. Second, order deadline, has to be fulfilled. Third and last, only modalities that have access to a certain depot should be used.

#### 3.2.2.1 Supply and demand constraint

Each time period  $t$  there are constraints for both import and export customers. Firstly the demand for full containers by import customers has to be fulfilled, equation 3.2. This is the same as a supply constraint since the OD matrices are reversed. Summations are made over the subset full containers ( $\mathcal{F}$ ) and customers nodes ( $\mathcal{C}$ ). Secondly, a demand for empty containers at export customers has to be fulfilled, equation 3.3. In mathematical terms this will lead to:

$$D_{c,p,t}^f - \sum_{i \in \mathcal{N}} \sum_{m \in \mathcal{M}} x_{i,c,m,p,t} = 0 \quad \forall i \in \{\mathcal{H}\} \cup \{\mathcal{D}\}, c \in \mathcal{C}, p \in \mathcal{F}, t \in \mathcal{T} \quad (3.2)$$

$$D_{c,p,t}^e - \sum_{i \in \mathcal{N}} \sum_{m \in \mathcal{M}} x_{i,c,m,p,t} = 0 \quad \forall i \in \{\mathcal{H}\} \cup \{\mathcal{D}\}, c \in \mathcal{C}, p \in \mathcal{E}, t \in \mathcal{T} \quad (3.3)$$

Although both formulas 3.2 & 3.3 contain the same sum over all arcs ( $\sum x_{i,c,m,p,t}$ ) the difference between both equations is the subset of commodities ( $\mathcal{F}$  = full;  $\mathcal{E}$  = empty) and direction component of  $i$  in equation 3.2. In the chapter about the transformation of the model into the software package it will be explained that different arcs will be used for separate transport streams.

#### 3.2.2.2 Order deadline full equipment

A customer has a certain demand for a container on a specific data and time. If a certain modality could be used depends upon three factors. Firstly, arrival time of the deep-sea vessel at the terminal. Secondly, the expected delivery date and time, finally the total transportation time of an optional transport mode. Not only transport speed determines the total travel time but also customs clearance, frequency of shipping and possible traffic blockages.

As earlier explained an arc based modeling approach is used for flow conservations. To get

the total transportation time is difficult because for intermodal transport a barge leg and truck leg have to be combined to get total transit time (including handling and waiting time). It is difficult to combine the two legs with the current notation of arcs. When a path based method was chosen this was easier because the transit time between  $i$  and  $j$  is known for a path while multiple arcs could be in a path. Therefore it is decided to sum up all transportation times and to assign this parameter in the arc from depot to customer (this is a truck leg since most customers are not accessible by barge). When the transit time in this last leg is too large no truck transportation is allowed. Because there is a flow conservation that the input of full containers in a depot is equal to zero the equivalent barge or rail leg is also omitted. There is only one case in which this is not correct, when a depot is both accessible by barge and rail the software package will always check for the largest type of transport (in most cases barge). Therefore an extra parameter should be included to check whatever there is transportation by that kind of modality. First of all in the preprocessing the total transportation time is assigned to the last truck leg.

$$TT_{d,c,t,m} = TS_{d,t,m}^* + TS_{d,c,t,m} + TC_m + TP_m + TH_m \quad (3.4)$$

*\*: It is assumed that transit times from all harbors are the same to a certain depot*

In mathematical terms the following constraint must be fulfilled for every box in days. Because of the distinction between barge two constraints are used in the model. Equation 3.5 is used for barge transport, equation 3.6 for rail.

$$(OD_{c,t}^e - OD_{c,t}^a - TT_{d,c,t,m}) * x_{d,c,m,p,t} * \gamma_{d,t,barge} \geq 0 \quad (3.5)$$

$$(OD_{c,t}^e - OD_{c,t}^a - TT_{d,c,t,m}) * x_{d,c,m,p,t} * \gamma_{d,t,rail} \geq 0 \quad (3.6)$$

Whereby  $\gamma_{d,t,m}$  a binary parameter is to check if a depot is in use by a certain modality or not. This is notated in 3.7. This parameters gets the value of 1 once a depot is in use or a zero once a depot is not in use by a certain modality.

$$\gamma_{d,t,m} \in \{0, 1\} \quad \forall d \in \mathcal{N}, t \in \mathcal{T}, m \in \mathcal{M} \quad (3.7)$$

- Variable decelerations:

|                  |                                                               |
|------------------|---------------------------------------------------------------|
| $OD_{c,t}^e$     | moment a container is expected by customer                    |
| $OD_{c,t}^a$     | moment a container arrives at the terminal                    |
| $\gamma_{d,m,t}$ | decision variable to check if a depot is in use by a modality |
| $TT_{d,c,t,m}$   | total transport time for a certain modality                   |
| $TS_{d,t,m}$     | transport time for modality $m$ to node $d$                   |
| $TC_m$           | custom clearance time for modality $m$                        |
| $TP_m$           | penalty for extra time delay for modality $m$                 |
| $TH_m$           | penalty for extra time delay for modality $m$                 |

## 3.2.2.3 Accessibility constraint

Not all modalities could use every inland depot. Without a rail- or waterway connection transport by respectively rail or barge is not possible. This will lead to the following constraints:

$$x_{i,j,m,p,t} * b_{i,j,m,t} = x_{i,j,m,p,t} \quad (3.8)$$

$$b_{i,j,m,t} \in \{0, 1\} \quad \forall i, j, m, t \in \mathcal{A} \quad (3.9)$$

Where  $b_{i,j,m,t}$  is an indicator if an inland depot is accessible by a certain modality. In chapter 4 the set up of this accessibility matrix is explained.

## 3.2.2.4 Capacities

Each depot has a maximum storage capacity that should not be exceeded.

$$L_{n,p,t}^{min} \leq S_{n,p,t} \leq L_{n,p,t}^{max} \quad \forall n \in \{\mathcal{H}\} \cup \{\mathcal{D}\}, p \in \mathcal{P}, t \in \mathcal{T} \quad (3.10)$$

Where  $S_{n,p,t}$  is the actual amount of containers at inland node  $n$  on time  $t$  (equation 3.11),  $L_{n,p,t}^{min}$  is the minimum stock level based upon Maersk Line stock levels.  $L_{n,p,t}^{max}$  is the maximum stock level. The amount of containers at a storage location could be described as:

$$S_{n,p,t} = S_{n,p,0} + \sum_{i \in A2} \sum_{m \in M} x_{i,n,m,p,t} + \sum_{i \in A3} \sum_{m \in M} x_{i,n,m,p,t} - \sum_{j \in A3} \sum_{m \in M} x_{n,j,m,p,t} \quad (3.11)$$

- Declaration

$$S_{n,p,0} \quad \text{initial stock on depot}$$

The summations over the subsets A2 & A3 relate to the different arcs explained in figure 3.3. A1 & A4 are not included in the stock level equations since these transports are full boxes and do not change stock levels directly.

## 3.2.3 Cost declarations

The objective of this model is to minimize total transportation costs. These are the costs for full and empty positioning of containers. This include transport, handling and storage costs. The costs are declared as:

- $CT_{i,j,m,p}$  Transportation costs between  $i$  and  $j$  for mode  $m$  and commodity  $p$
- $CS_{n,p}$  Storage costs for (inland-)terminal  $n \in \{\mathcal{H}\} \cup \{\mathcal{D}\}$
- $CH_{n,m}$  Handling costs for terminal  $n \in \{\mathcal{H}\} \cup \{\mathcal{D}\}, m \in \mathcal{M}$



### 3.2.4 Costs container transportation

Costs for barge and rail are fixed and described in rates sheets. These tariffs will be used for transport between deep sea terminal and inland depot. For the last leg from inland depot towards consignee an average of transportation costs, based upon historical Maersk Line data, will be used. For truck transport a matrix is set up that relates distance and the truck transportation rate sheets.

The total transport costs will be the amount of transports multiplied by the costs factor. For the different transport streams these costs are described in equation 3.12— till 3.13

$$CT_{A1} = \sum_{i,j,m,p,t \in A1} (x_{i,j,m,p,t} * CT_{i,j,m,p}) \quad (3.12)$$

$$CT_{A2} = \sum_{i,j,m,p,t \in A2} (x_{i,j,m,p,t} * CT_{i,j,m,p}) \quad (3.13)$$

$$CT_{A3} = \sum_{i,j,m,p,t \in A3} (x_{i,j,m,p,t} * CT_{i,j,m,p}) \quad (3.14)$$

$$CT_{A4} = \sum_{i,j,m,p,t \in A4} (x_{i,j,m,p,t} * CT_{i,j,m,p}) \quad (3.15)$$

### 3.2.5 Container storage & handling

Equation 3.16 displays the storage costs. Handling costs are included in the transport tariffs.

$$FCS = \sum_{n \in D,H} \sum_{p \in P} \sum_{t \in T} S_{n,p,t} * CS_{n,p} \quad (3.16)$$

### 3.2.6 Total transportation costs

Total transportation costs become:

$$FCT = CT_{A1} + CT_{A2} + CT_{A3} + CT_{A4} \quad (3.17)$$

$$FCT = \sum_{i,j,m,p,t \in A1} (x_{i,j,m,p,t} * CT_{i,j,m,p}) + \sum_{i,j,m,p,t \in A..} (x_{i,j,m,p,t} * CT_{i,j,m,p}) + \sum_{i,j,m,p,t \in A4} (x_{i,j,m,p,t} * CT_{i,j,m,p}) \quad (3.18)$$

This could also be shown as distinction between empty and full flows through the network:

$$FCT = \left\{ \sum_{i,j \in N} \sum_{m \in M} \sum_{p \in F} \sum_{t \in T} (x_{i,j,m,p,t} * CT_{i,j,m,p}) + \sum_{i,j \in N} \sum_{m \in M} \sum_{p \in E} \sum_{t \in T} (x_{i,j,m,p,t} * CT_{i,j,m,p}) \right\} \quad (3.19)$$

The total transportation costs will be:

$$F = FCT + FCS \quad (3.20)$$

Finally the objective function can be written as:

$$Z = \min\{F\} \quad (3.21)$$

$$Z = \min\left\{ \sum_{i,j \in N} \sum_{m \in M} \sum_{p \in F} \sum_{t \in T} (x_{i,j,m,p,t} * CT_{i,j,m,p}) + \sum_{i,j \in N} \sum_{m \in M} \sum_{p \in E} \sum_{t \in T} (x_{i,j,m,p,t} * CT_{i,j,m,p}) + \sum_{n \in D,H} S_{n,p,t} * CS_n \right\} \quad (3.22)$$

### 3.3 Conversion into optimization software

A mathematical model could describe the reality with a high accuracy, but transformation into an optimization tool can be difficult. Without the experience with optimization software some concessions have to be made to achieve an acceptable performance. The software package AIMMS is used. This is an acronym for *Advanced Interactive Multidimensional Modeling System*. The developer describes the package as: “AIMMS offers an all-round development environment for the creation of high-performance decision support and advanced planning applications to optimize strategic operations.” This fits with the thesis project where a model will be set up for a strategic optimization model. The progress chart in figure 3.4 will clarify the way different aspects come together.

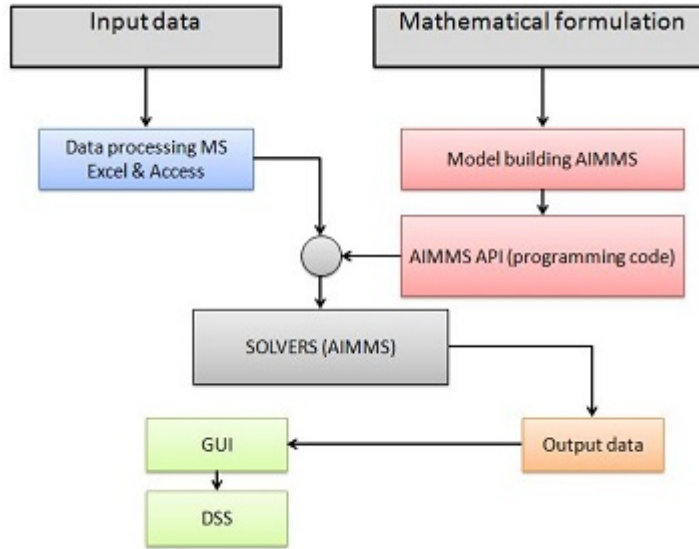


Figure 3.4: Usage of AIMMS (own work)

#### 3.3.1 Experiences with optimization software

The experiences with the software package of AIMMS were both positive as negative. When following the tutorials to learn how the program works it was clear to me that this software

package has a great potential value. Particularly the great possibilities in the GUI were clear. But it was hard to find help when things were not running in the way as expected. For a program as Matlab a big online community is available with solutions for certain problems. For AIMMS the user commodity was more or less closed. The solver used in AIMMS is the CPLEX (version 12.4)

Important aspects that are not included in the model but explained before are the stochastic aspect of the model. This has left out because the normal modeling process was more time consuming than expected. Another aspect that is left out is the multi-commodity aspect, this due to memory issues. More experiences with the software package is described in Appendix IV.

### 3.4 Conclusion

In this chapter the model formulation is given. The problem is made clear and the modeling setup is provided. The assumptions that are made due to different reasons are explained. In the second section the mathematical model is explained.

## Chapter 4

# Case study Maersk Line Benelux

In the introduction the problem description, research goal and scope of research were defined. In chapter two the literature study was described. This knowledge is the basis for the model set up for the transportation problem; this is described in chapter three. This chapter is the link between theory and practice. It is described how the model is filled with input data and which data sets are used.

In the first section it is explained which terminals, depots and customers are included in the network. The second section describes the different modalities used in the network. The different commodities used in the network are described in section three. Section four focuses on the time horizon in the model, order deadline and transit times. All previous aspects will come together in the arcs used in the network. These are the decision variables of the model and indicate transport volumes on an corridor; this will be described in section five. At the end after the optimization these variables will contain the most valuable information: in which time period  $t$  will a commodity  $p$  be transported from  $i$  to  $j$  by modality  $m$ . But without demand for full or empty containers no transport is necessary. The acquisition of transportation data is explained in section six. All sections combined will lead to a practical model that could optimize a transportation network. The model will have some assumptions, they were described in section 3.1.2.

### 4.1 Nodes in the transport network

The basis of a transport network are the nodes in the network. The model created in AIMMS will contain different nodes, this set will be subdivided in deep-sea terminals, inland depots and customer locations. How different nodes are selected is described in this section.

#### 4.1.1 Deep-sea terminals

As seen in figure 1.5 the begin location for transport of import containers, in the model, is the deep-sea terminal. The geographical scope is limited to the Rhine Delta and locations served by Maersk Line Netherlands. This includes the deep-sea terminals of the Netherlands and Belgium: Antwerp (*ANT*), Rotterdam (*ROT*) and Zeebrugge (*ZEE*) in alphabetical order. From these deep-sea terminals carrier haulage transports are planned by Maersk Line Netherlands. These three terminals are included in the several corridors between the Far-East and Europe. In figure 4.1 an example of a worldwide loop is provided, an overview of corresponding transit times is

shown in figure 4.2. In the Asia - Europe (AE1) westbound trade route ports of Rotterdam and Zeebrugge are hit. Antwerpen is included in other westbound trade routes. In total Maersk Line offers 10 westbound trade routes in which Rotterdam is served 5 times, Zeebrugge 2 times and Antwerp 1 time. The deep-sea network is continuously changing due to changing market conditions.



Figure 4.1: Westbound Asia - Europe (AE1) service<sup>1</sup>

| Port                       | Arrives | Departs | Transit |
|----------------------------|---------|---------|---------|
| Kobe, Japan                | TUE     | TUE     | --      |
| Nagoya, Japan              | WED     | THU     | 1       |
| Yokohama, Japan            | FRI     | FRI     | 2       |
| Ningbo, China              | MON     | TUE     | 6       |
| Shanghai, China            | WED     | WED     | 7       |
| Hong Kong, Hong Kong       | SAT     | SUN     | 10      |
| Yantian, China             | SUN     | SUN     | 12      |
| Tanjung Pelepas, Malaysia  | THU     | FRI     | 16      |
| Suez Canal, Egypt          | TUE     | TUE     | 27      |
| Felixstowe, United Kingdom | TUE     | TUE     | 34      |
| Zeebrugge, Belgium         | THU     | THU     | 36      |
| Rotterdam, Netherlands     | SAT     | SAT     | 38      |
| Bremerhaven, Germany       | SUN     | MON     | 40      |
| Wilhelmshaven, Germany     | MON     | TUE     | 41      |

Figure 4.2: Transit times AE1 service<sup>2</sup>

<sup>1</sup>Maersk Line

<sup>2</sup>Maersk Line

Other deep-sea terminals in the Northern part of Europe such as Bremerhaven or Willemshaven are not included in the model since these are serviced by Maersk Line Germany and fall out of the geographical scope.

In these three harbors areas (ANT, ROT and ZEE) different terminals are available to handle the mother vessels. The METS+ system (Maersk Electronic Transport Solution). This is the planning tool for hinterland transport at Maersk Line, more information in section 4.5, is used to see which terminal locations are most important for a certain area. Since the METS+ data contains all transport data some filters have to be used to get the correct information. Empty transports are not taken into account since these will be a result of a repositioning model and must not be used as an input variable. Next to this every transport occurs in multiple records in the METS+ database (for example when road tolls, waiting time or other surcharges have to be paid or multiple modalities are used). For all these inaccuracies adjustments are made or data is filtered out. When only import volumes are taken into account, since these will be fixed in the model because of the fixed OD-pair (origin - destination), the following locations are most important based on historical data from Q1 and Q2 2012.

**Rotterdam:**

- NLROT01: APM Terminals Rotterdam
- NLROT10: Uniport
- NLROT22: ECT Delta terminal

**Antwerpen:**

- BEANT913: Noordzee Terminal Quay 913
- BEANTDGD: DGD Kaai1742

**Zeebrugge:**

- BEZEE01: APM Terminals Zeebrugge

Because there is no fixed return terminal for export containers, empty transport is not included in the selection above. To validate if this assumption is also valid for export containers a check is made for export transports. It turns out that the same terminals have highest volumes for export boxes. These terminals will be used to determine transport volumes, this is explained in section 4.5. In the model itself the locations of the different terminals are modeled as one point, each port has one node in the network. Although this is not in line with practice this approach meets the requirements of the strategic model. When multiple terminals in a harbor are selected very detailed information has to be put into the network since inter-harbor transports have specific constraints and agreements.

#### 4.1.2 Inland depots

The end location of the transport an import box is in the end the consignee. Transport could take place directly between deep-sea terminal and consignee by usage of truck. Another possibility is to transport a container by barge or rail from deep-sea terminal towards an inland depot. The last leg from depot towards customer could be executed by truck, this is multimodal transport. For such transport movements an inland depot is needed. As explained in section 2.3.3 ECT

was one of the front runners in this project. Nowadays each container shipping company with a carrier haulage service offers customers the service of an inland depot. Not only for carrier haulage but also for merchant haulage these inland depots are important for drop off. Since there is no information available about merchant haulage only carrier haulage is considered in this research.

In the case of Maersk Line multiple inland depots are used. Not every inland depot available in the Rhine Delta is used by Maersk Line. The strategy is not to have a very wide spread network but a selected range of depots with very strong rate agreements. For some big customers of Maersk Line special deals are set up with some depots that are only used for transport of these suppliers. All depots with rate agreements with Maersk Line and carrier haulage transport volumes in the first seven months of 2012 are selected to be used in the model. This results in the following network of inland depots:

**Belgium:** Avelgem AVCT; Meerhout; HTS Gent; TCA Athus; Willebroek.

**Germany:** Neuss; Mannheim; Emmerich RWT; Duisburg; Duisport; Germersheim DPW; Keulen CTS; Karlsruhe Contargo; Bonn AZS; Frankenbach.

**Netherlands:** Tilburg; Den Bosch BCT; Nijmegen CTH; Amsterdam CTVrede; Utrecht; Moerdijk; Wanssum.

These inland depots all have their own rate agreements. These are described in the section about modalities, this is section 4.2.

### 4.1.3 Customers

As said in the introduction of this paper, transport is one of the key elements of a modern economy. A modern economy is not limited to certain areas, this will result in a appearance of customers everywhere in the network. For a network model it is not practical to have a large set of all potential customers since all distances or costs should be known to optimize a certain transport problem. Only when in a certain grid all locations are known it is possible to include every customer location with corresponding costs. This is not the case in the network of Maersk Line. Rate agreements are based on linear costs functions and it is hard to find a way to locate each customer. Therefore it is desirable to create regions in which customers are clustered. It is easier to calculate attributes for one large customer group instead of every customer separately. When the regions are large the model will lose accuracy while small regions will decrease model performance. The optimal size is dependent of the spread of inland depots, supply and demand data and availability of data METS+ data to cluster customers automatically in one region.

In Belgium, Germany and the Netherlands the postal code is a system that is used from historical point of view to automatize the sorting process of mail by postal services. For mail services this coding is not necessary anymore since optical character recognition is nowadays able to ‘read’ full addresses. But in especially the Netherlands this system is also used to link demographic figures at neighborhood level or for navigation services. It is easy to separate postal codes from Germany from those of the Netherlands and Belgium since the former uses five numbers and the latter only four. With some additional data from the METS+ database it must be possible to separate data between these countries. This will be explained later on, first the clustering of Germany will be explained.

Starting from scratch the strategy to divide the customers in Germany into clusters is to check where import customers are located. This will be linked with the availability of inland depots, since these are all in the Rhine Delta area. With this information clusters in the network are formed.

Transport data from the METS+ database forms a subset of information about customer locations. The same criteria in METS+ are used as mentioned before to determine terminal locations. A data processing tool ([www.batchgeo.com](http://www.batchgeo.com)) is used to generate two maps of customer locations in Germany, these can be seen in figure 4.3 and figure 4.4. The first map is a plot with some random selected destinations in Germany (source METS+ database). Because postal codes are used worldwide some of the selected data is plotted in other countries, no country data could be added to batchgeo. This has an influence on the locations of customers, but the goal of using this tool is to find out in which regions most transports took place in Germany. Although somewhat inaccurate the tool is useful for its purpose. In the second figure the 100 biggest customer locations from the METS+ database, based on transportation volumes, are grouped after some data processing.

When both maps are combined it can be concluded that most transports in Germany occur in the German industry districts near Dortmund, Frankfurt, Stuttgart and München. In the North East part almost no transports are planned from Maersk Line Netherlands since this falls under the German representative of Maersk.

In figure 4.4 the German industry districts are well represented. The spread of regions should be larger in these districts to achieve more accurate model results. In districts with less transports spread could be smaller to give a good comparison between model performance and accuracy. When combining the map of customer locations and inland depots is combined this will become more clear. A useful tool to create clusters is the map in figure 4.5. This is a map with German postal codes (first two figures). These figures could be linked with the postal codes in METS+ and so regions could be linked to the data in the transportation system. The blue numbers are the regions of customer groups that will be used in the model. In more crowded areas as can be seen in figure 4.3 & 4.4 no regions are used but the small districts are used (this is district 40-60).

Because the postal code information in Belgium and particularly the Netherlands is more detailed the density of the network is higher when the same strategy is applied. But the surface of the Netherlands and Belgium is much smaller than Germany. Also the terminals are closer together. It is chosen to use more or less the province borders to make clear clusters. The regions in Belgium and the Netherlands are shown in figure 4.6 and figure 4.7.

#### 4.1.4 Overview of the nodes in network

In this chapter it is explained which nodes are used. In AIMMS this will result in different sets of data. There are three subsets that contain the total set of nodes in the network. Subset  $h$  is used for deep-sea terminals,  $d$  for inland depots and  $c$  for customers. This will result to the set  $n$  that contain all nodes. Two subsets,  $i$  (origin) and  $j$  (destination), are used in the decision variables as origin and destination index. An overview of nodes is shown in figure 4.8, overview per country in figure 4.9 and a map is included in figure 4.10.

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<sup>3</sup>[www.zipcodelookup.me](http://www.zipcodelookup.me)

<sup>4</sup>[www.zipcodelookup.me](http://www.zipcodelookup.me)

<sup>5</sup>[www.zipcodelookup.me](http://www.zipcodelookup.me)







Figure 4.4: Detailed overview (100th largest regions) (own work)

network were described: barge, rail and truck. An important variable in the model is the transport tariff between nodes. From other literature about repositioning models two useful lessons are learned. First a separate data source has to be used for transport tariffs. These cannot be deduced from the same data source as the input data for tariffs. This will lead to unreliable data and the model will be sensitive for other input data sets. The second lesson is that most other research using cost functions for calculation of transportation costs. These are based on fixed and variable costs in the transportation network. With a given distance is easy to calculate costs. When a route planner is linked to the optimization model for all possible combination of nodes transport rates could be calculated. In the case study this is different. At Maersk Line tenders are used to acquire competitive rates between deep-sea terminal and inland depot for barge, rail and truck transport. Therefore it is not possible to use costs functions. In other literature aspects as fuel consumption, waiting time and interest are taken into account.

Figure 4.5: Detailed overview ZIP codes in Germany<sup>3</sup>

Maersk only pays a fixed tariff for transport from  $i$  to  $j$  without considering all these aspects, only some surcharges could be added to a tariff. For truck transport these rates are based on a km-price. In this chapter it is described how rates are extracted from the Maersk files, exact rates are left out due to confidentiality.

#### 4.2.1 Barge

Rate agreements are set up with inland depots for barge transport. There is a big variation in the rate structure from depot to depot. The most important component is the tariff for transportation from  $i$  to  $j$ . This is transport from deep-sea terminal towards the depot itself. For some depots handling costs are included in the rate for others these are calculated separately. These two costs components determine the costs, associated to barge transport. A third component for the total transportation is the last leg from depot towards customer. For every depot band



Figure 4.6: Detailed overview ZIP codes in Belgium<sup>4</sup>Figure 4.7: Detailed overview ZIP codes in the Netherlands<sup>5</sup>

rates are set up for certain distances. This will be explained more in section 4.2.3 about tariffs for truck,.

There are some extra surcharges for barge transport. This could be extra handling costs for reefers, low water surcharges and services on a inland depot. For sense of simplicity these factors are not taken into account in the rate structure of barge transport.

A remark has to be made for using these rate structures in the model. From perspective of a

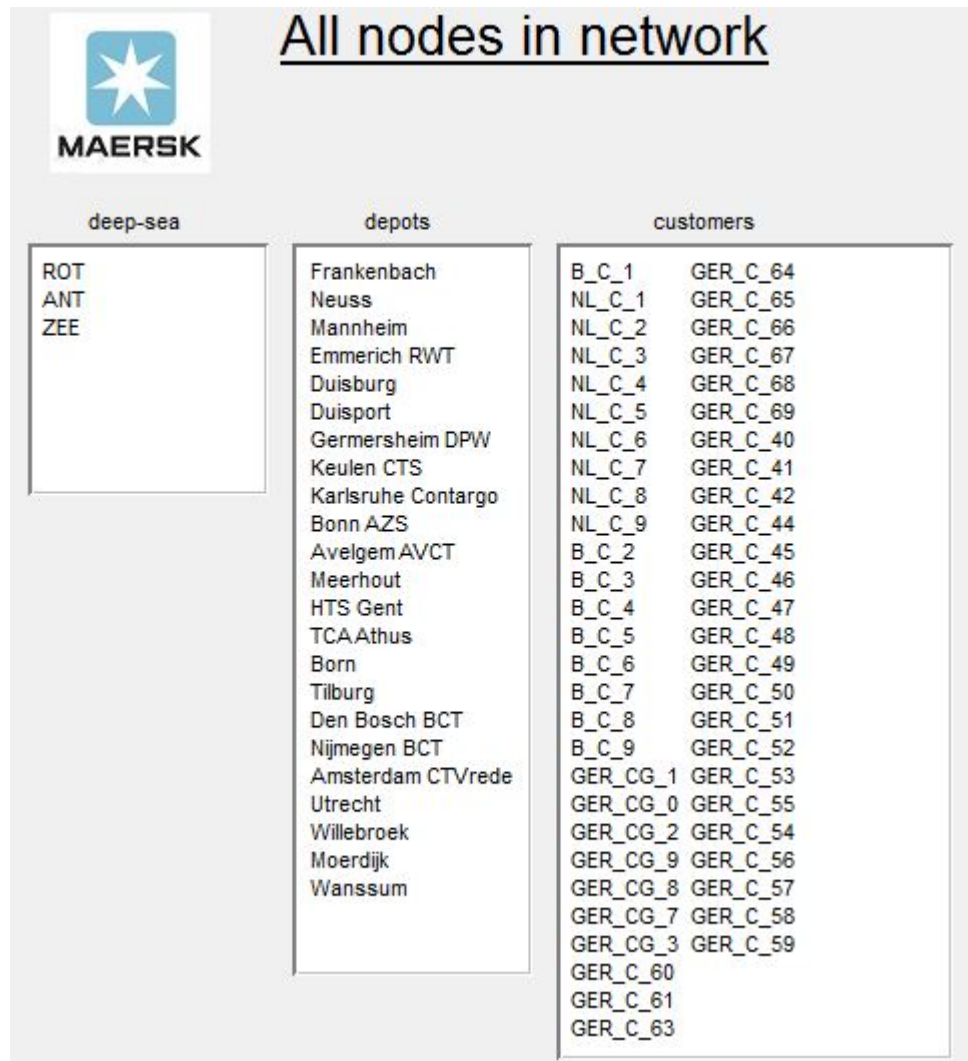


Figure 4.8: Nodes in network (own work)

barge operator costs are determined by ship capacities and revenues by the volumes on the ship. A specific barge category has a certain fuel consumption, maintenance costs and labor costs etc. At Maersk Line there is one single slot price. Barge capacity is unlimited since there is overcapacity at the barge market at the moment.

#### 4.2.2 Rail

Rail tariffs are based on the same principle as barge. For certain corridors rate agreements are set up with fixed rates. Handling costs are not included in rail tariffs and are added to the tariffs. Not for all inland depots rail agreements are made. The amount of tariffs imported into the model is very low in comparison with barge transportation. This is because barge is used more in the real world.

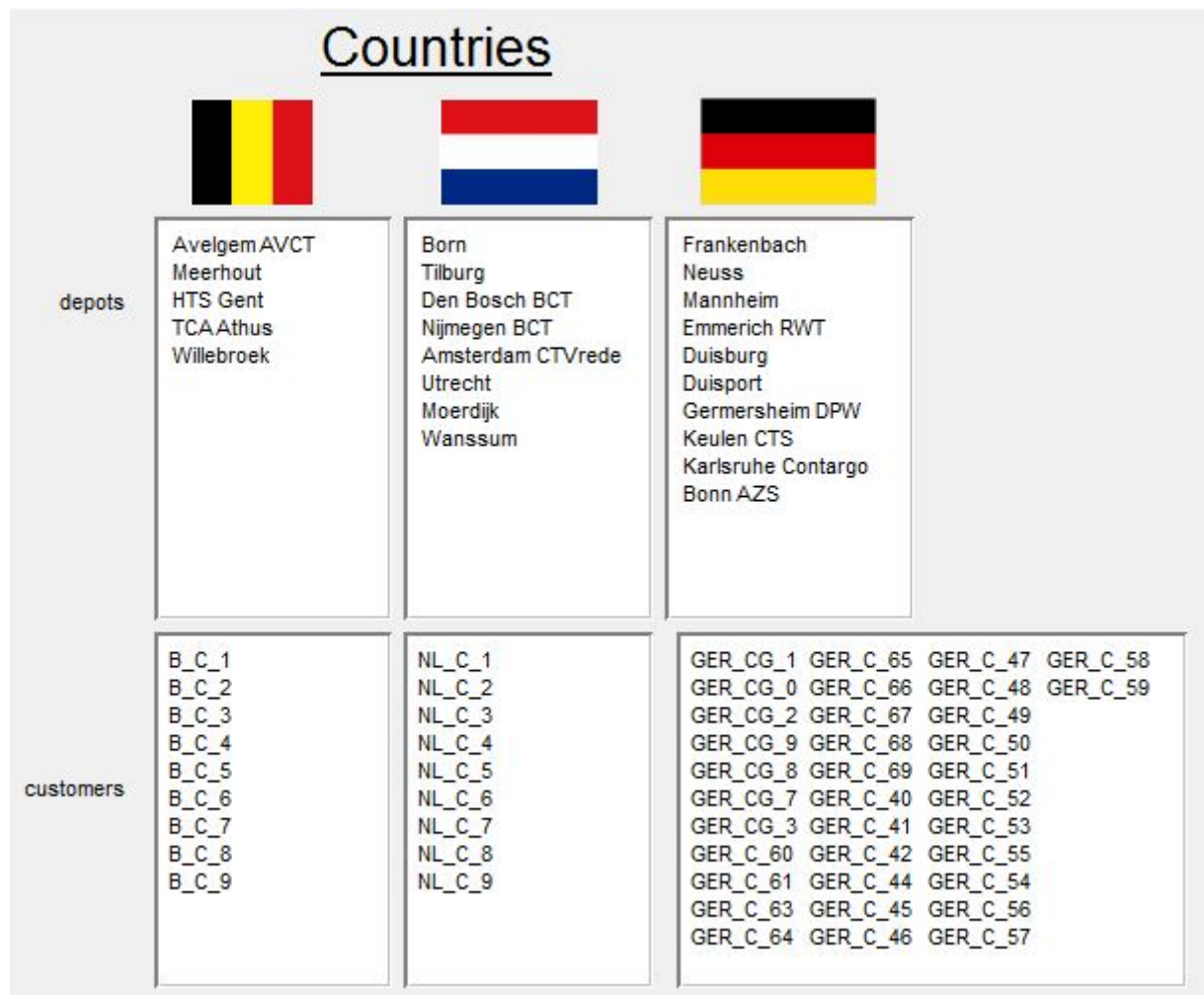


Figure 4.9: Nodes in network - country (own work)

### 4.2.3 Truck

Compared to barge and rail transport, in truck transport has more freedom in tariffs. Costs are calculated based on distance and location of origin and destination. A good accessibility is one of the advantages of truck transport. Since between every node in the network transport by truck is possible all tariffs should be included to make all routes available.

At Maersk Line a tender is used to achieve sharp transport rates. For separate corridors different transport rates are set up, each deep-sea terminal has slightly different rates. For truck transport different types of transport exists: import/export roundtrip, one way transport and triangulation. Triangulations are under certain circumstances most beneficial, followed by one way transport. In the Netherlands itself the band rates of Maersk are used to calculate transport tariffs, this is a roundtrip tariff. For cross border transports a one way transport tariff is used. For inland transport a bandwidth with steps of 10km is used. The rate is for a roundtrip; transport from terminal towards customer and back towards terminal. For this project this holds for

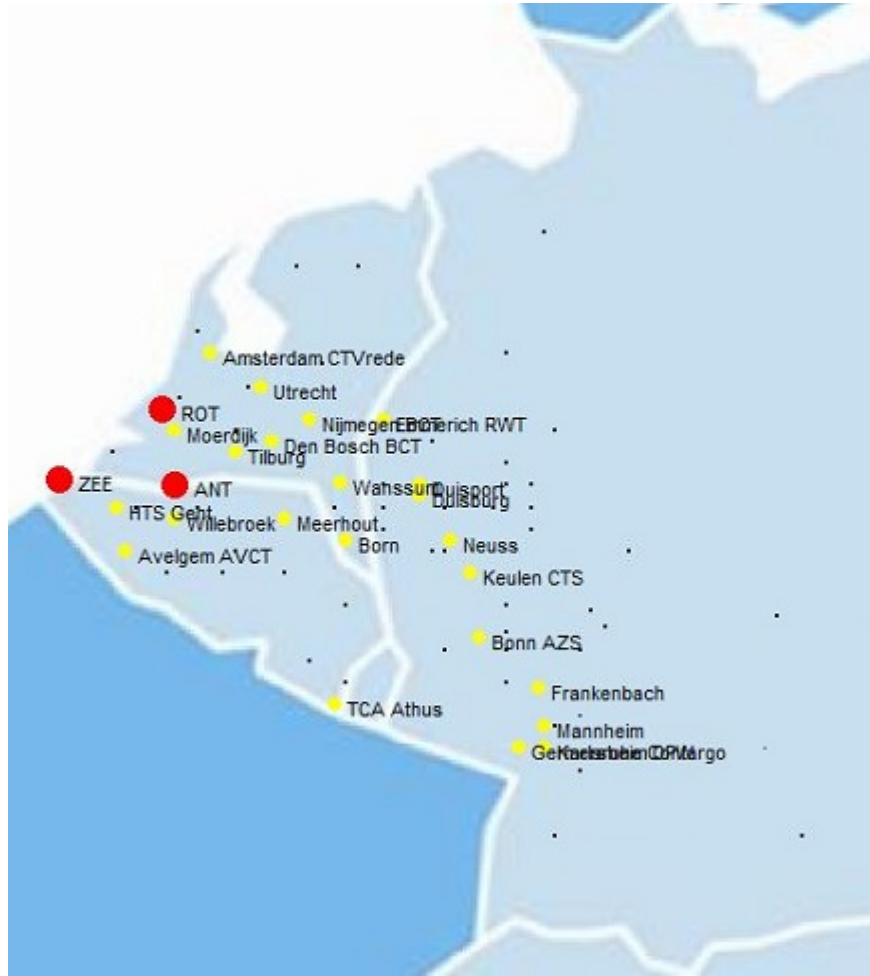


Figure 4.10: Nodes in the network - map (own work)

inland transport in the Netherlands and Belgium. For cross-border transport, for example from Rotterdam to Frankfurt, there is a km rate with respect of a minimum tariff. This is summarized in table 4.1 (bi-directional).

Table 4.1: Calculation method truck rates

| From | To  | Calculation  | Comment                                                       |
|------|-----|--------------|---------------------------------------------------------------|
| NL   | NL  | Band rate    | Band rates till 200 km; longer distance km tariff; steps 10km |
| BEL  | BEL | Band rate    | Band rates till 200 km; longer distance km tariff; steps 10km |
| GER  | GER | Price per km | Minimum rate; km-price                                        |
| NL   | GER | Price per km | Minimum rate; km-price                                        |
| NL   | BEL | Band rate    | Band rates till 200 km; longer distance km tariff; steps 10km |
| BEL  | GER | Price per km | Minimum rate; km-price                                        |

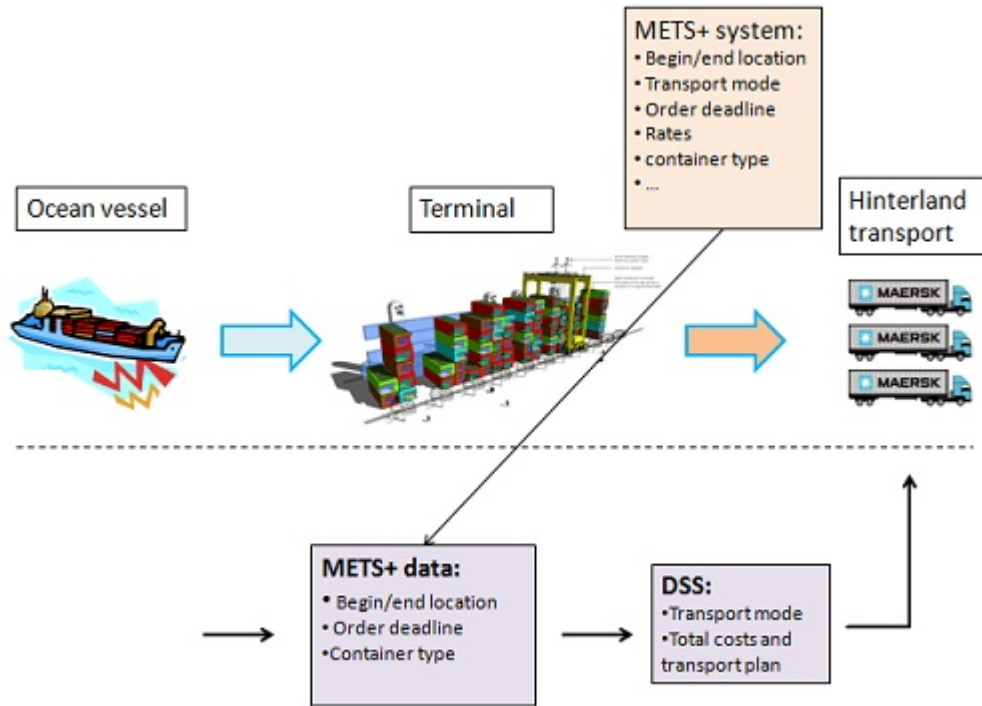


Figure 4.11: DSS (own work)

Besides the transport costs for a specific distance additional surcharges exist. These surcharges include waiting time, additional stops, reloading, equipment, MAUT and other taxes. All these costs have an influence on total transportation costs. In practice these surcharges have an influence on transportation costs but they are not included in the model. Special tariffs are set up between some interdepot corridors. These rates are included into the model.

The distances used for the calculation of tariffs are based on the TLN route planner. This route planner only supports an input of one origin <> destination pair. Therefore it is not practical to calculate a large set of distances between nodes. Since there are 26 nodes (terminals + inland depots) in the network, for 325 OD pairs distances have to be calculated ( $n = *n(n-1)$ ). This corresponds with the distance of the arc for truck transport. For every OD the reverse distance could be difficult,  $A > B$  is not equal in every case to  $B > A$ . Therefore the amount of different transport distances will be larger. Finally not only connections occur between terminals and depots nodes, but also between customer locations and terminals or inland depots. With an extra 30 customer locations, more than 1500 distances should be calculated. It is possible to send a standard operation procedure (SOP) with all routes to India and let the general service center (GSC) calculate the distances with TLN route planner. This will have a big impact on the reliability of input data since there will always be some errors.

Another, more practical, solution is to use Google Maps. With a macro distances could be calculated from the web application of Google maps. A user is allowed to calculate 2500 routes a day without paying any fees. Although this route planner is not designed for truck transport it is allowed to use this data in a strategic model. When the model is designed as strategic or



Table 4.2: Comparisson of TLN and Google Maps

| From     | To              | TLN (km) | Google (km) | Diff (km) | Diff (%) |
|----------|-----------------|----------|-------------|-----------|----------|
| APMT ROT | Amsterdam       | 117      | 117         | 0         | 0.0%     |
| APMT ROT | Tilburg         | 118      | 117         | -1        | -0.8%    |
| APMT ROT | Born            | 208      | 208         | 0         | 0.0%     |
| APMT ROT | Neuss           | 261      | 258         | -3        | -1.1%    |
| APMT ROT | DPW Germersheim | 542      | 539         | -3        | -0.6%    |
| APMT ROT | Frankenbach     | 469      | 466         | -3        | -0.6%    |
| APMT ROT | Zeebrugge APMT  | 228      | 213         | -15       | -6.6%    |
| APMT ROT | Athus           | 373      | 375         | 2         | 0.5%     |
| APMT ROT | Kaaij 742       | 128      | 134         | 6         | 4.7%     |

operational level this uncertainty in data could have a strong effect on the model outcome. For 9 locations a comparison between Google Maps and TLN is made (3 NL, 3 BEL and 3 GER). For the locations in the Netherlands there was almost no difference. For Belgium there is some difference, because some roads are not allowed for 40T trucks. Therefore a detours has to be made. For Germany the difference is positive for Google maps, but very small. At the location of the city of Venlo the TLN routeplanner choose for a route close to the city (a regional road) while Google Maps is using the highway. The results are shown in table 4.2.

The accuracy of Google Maps lies within the certainty range of 95% with a deviation of 3.7 km based on these 9 observations. Therefore no big differences in rates will occur due to the usage of distances in Google Maps. The equation below is used to calculate the accuracy.

$$n > \frac{Z^2}{d^2} \sigma^2 \quad (4.1)$$

With Google Maps all distances required are calculated. Because truck transport is always possible all arcs should have a costs value (without costs, these routes will attract a lot of volumes). In total there are 26 depots (inland + deep sea) in the network. With the known formula to calculate amount of routes:  $n(n-1)/2$  this means 325 different costs. Furthermore all clients are connected to all depots. Because there are 74 regions this means an additional 1248 costs. This will lead to 1573 different freight tariffs that are imported into the network model.

Surcharges are not included in the model, including MAUT in Germany.

#### 4.2.4 Conclusion

Transport tariffs are not as easy as they look like. There is a standard rate for transportation from A to B for barge and rail transport. Besides this rate additional surcharges are added such as handling costs, reefer surcharge, low water surcharge and waiting time. This makes it difficult to implement everything in detail into the model. The model created is on strategic level. For tactical and operational models the level of detail should be higher. For such kind of models information about all different surcharges should be added. In total 1750 different freight rates are imported into the model. For empty transportation some changes occur in barge an rail tariffs according to the rate sheets.

In AIMMS the modes are stored in the set  $m$ . Next to costs an important aspect for the modalities is transit time, this is explained in section 4.4.3.

### 4.3 Commodities used

In the Maersk Line transportation network different commodities are used. The largest transport volumes are the 20ft, 40ft and reefer containers. For empty container repositioning it is important to identify these different container types due to different rates and storage conditions. For truck transport it makes no difference if a 20ft or 40ft container is loaded. It is not possible to load two 20ft containers on a truck because of weight limitations. For barge and rail transport different tariffs are used for 20,40 and 45 ft. containers. For reefer containers an extra surcharge has to be paid.

For empty container repositioning it is important to consider multiple commodities since some regions have a deficit for one commodity while other commodities have a surplus. The Maersk Line stock levels for inland depots also consider different commodity types.

During the verification phase of the model it turns out that memory usage was too high to solve the model. For full container transport already three different container types are used to make sure the begin terminal is correct (ROT, ANT and ZEE). Therefore multi commodities are left out the model. But for more realistic optimizations multi commodities should be included especially for the empty container positioning. For full container transport the three different commodities (ROT, ANT and ZEE) are stored in set  $p$ .

#### 4.3.1 Storage costs

For container storage three main items are important. Storage costs per TEU per day, maximum capacity at a depot and demurrage and detention. When an import container is transported towards a customer the empty container is again available for export. Because of the global container imbalance not all containers could be reused in Europe. This effect is enlarged by the local imbalances and commodity choice. As a result not every container could be reused in the hinterland. Containers stored somewhere in the network are transported towards deficit areas. This could be export clients in the hinterland or shippers in the Far East. In a situation a container is stripped at an import customer at time moment  $t$  and the same box is reused after  $t + t_{transport}$  a container has to be stored somewhere in the network. An assumption is made that storage at a customer is not possible. Therefore storage is only allowed in all depots and terminals.

For inland depots storage is included in the rate agreement. There is an amount of free days for full and empty containers. This varies from zero till 14 days. After this period a certain storage fees has to be paid. The fee in deep-sea terminals are considerably higher than an inland depot. The costs for storage at an inland depot are used in the model. In the model no free storage days are included.

Next to storage costs capacities are important for inland depots. When a depot is in a surplus area the amount of empty containers will increase. Maersk Line set up stock levels for each depot. This is the desired amount of containers that should be available at a depot. The figures about desired stock levels are for the total level, also considering merchant haulage volumes. Because origin and destination of MH is not know it is not possible to include these transports in the system. Therefore a minimum of 10 boxes is used as stock minimum and 30 boxes as

stock maximum at inland depots based on Maerk Line data. For deep-sea terminals there is an unlimited storage. At customer locations there is no storage available. But because it is assumed that every container is available after one day of transport there is a dummy variable at a customer location with a maximum  $t$  of one day.

## 4.4 Time period used

For transportation, time is essential. More and more industries are depending on just in time deliveries. To save on inventory costs companies try to minimize the amount of products in stock. For example in the car industry just in time deliveries are very important. When one part is missing a whole production line could come to a halt. This will have big consequences for a factory.

In this chapter it is first explained which time horizon is included into the model and which time period is chosen. In the second section the order deadline is described. In the last section the transit times of different transportation modalities are explained.

### 4.4.1 Horizon and period length

Time horizon is very important for mathematical models. Learned from the literature study some effects have to be taken into account. The startup period of the model is important since all input data and constraints have to be set, this will take at least one time period. The end of horizon effects have to be taken into account that will also affect one time period. Next to it the time period must be at least as long as the slowest transport modality. In this case that is barge transport which takes more or less a week for the longest transport leg.

Next to the time horizon, the duration of one period is important. The duration of one time period has to be realistic. When this period is too long differences during time are hard to see and patterns are smoothed out by the larger data stored in one time period. When the time period is too small the amount of detail will be too high for a strategic model. An important aspect is the amount of details available in the input data. The smallest possible time duration is equal to the smallest time duration in input data. Information about order deadline is available on an hourly basis. Transit times are available on a daily basis. The minimum time period is one day. A time duration longer than one day will lead to less accurate results, particularly for the order deadline as explained below. All input parameters are available for a one day time period so this will not lead to disturbances. The time duration in the model will be one day.

The amount of time periods is depending on the amount of time that will be studied. A large amount of data is available. The basis used for transports is the METS+ database. This will lead to the demand of full and empty containers. To get information about the order deadline this system has to be combined with the RKEM system (equipment management system). To extract large data sets from this system is difficult. Therefore only one terminal with a maximum of around 100 days could be selected for one terminal. To take startup and finish effects of the model into account a time period of around 1/3th of 100 is perfect, to make sure 90% of METS+ orders have a fit in the RKEM data. This is in line with the duration of a month. September 2012 is chosen as time period for the model in AIMMS.

### 4.4.2 Order deadline

Each container should be delivered before the moment of order deadline to the customer, both for import and export. At the moment a container arrives at the deep sea terminal different

processes affects the total transit time for a container in hinterland transport, this differs for each modality. The order deadline of an order is stored in the METS+ database. To calculate the time between arrival at the terminal and this moment of delivery the linkage with RKEM is used where all gate-in and gate-out moves are stored. The amount of days available for transport is stored into a parameter in AIMMS. There is one disadvantage of the model. The demand is grouped into AIMMS. That means that for example there is a demand of 10 containers in time period  $t$ . Although all these 10 containers could have another order deadline only one value could be assigned to the days available for transportation. Therefore the average is used in the SQL-query to achieve the data for each customer in a certain time period. This will lead to less model accuracy since in one time period only one type of modality could be used for one customer.

#### 4.4.3 Transit times

When a mother vessel arrives at a deep sea terminal the containers must be unloaded. The custom clearance time is 4 hours for truck and globally one day for rail/barge. This has to do with the fact that it is known which container is loaded on a single truck. On a rail/barge service multiple containers could be loaded and therefore it is a requirement from the harbor authority that all containers are unloaded from the mother vessel first. Next to customs clearance there is the time need from transportation on the terminal itself. A container has to be stored on the terminal and transported towards the barge terminal or rail terminal. In practice this time has no influence on total transport time. Truck transport is the fastest option and chosen when other modalities are not able to achieve the order deadline.

For rail and barge services the transportation time is different. Besides transit time frequency is important to determine the total transportation time. Just like transport tariffs the frequencies and transit times are highly unclear. Some barge operators state that they have departures every day from the Rotterdam area but Maersk can only book for two or three departures a week. The following information is acquired at the planning desk. Information is based on experiences of the planners and timetables of transport suppliers. Each planner has different insight into regions. Transit time for rail services is one day. When a booking is made at day  $t$ , transport will take place on  $t + 1$  and delivery date is  $t + 2$  (when  $t + 2$  is weekend delivery date is on the first work day).

In table 4.3 the values are shown that are used in the model.

For a tactical or operational model it is important that all information is in line with reality. Although an operational model has the same requirements some simplifications are made. Because Maersk Line has a lot of volume it should be able to enforce services that are useful for the shipping company. Therefore not the average waiting time is used to determine frequency. This will lead to the transit times in the table above for barge transportation. For rail transportation a transit time of 2 days has been taken into consideration.

A remark is that an additional two days in advance of the booking period is required. This can be achieved when the mother vessel is still at the deep sea. This will not be included into the model since it falls out of the model scope.

### 4.5 Supply and demand

Two methods of data input are distinguished from the literature study. The first method uses total transport volumes, this can be all historical transport data from a certain geographical

Table 4.3: Transit times barge transport

| <b>Depot</b>       | <b>freq</b> | <b>transit time day</b> | <b>totaltime</b> |
|--------------------|-------------|-------------------------|------------------|
| Neuss              | 2           | 2.5                     | 5                |
| Mannheim           | 2           | 4                       | 5                |
| Emmerich RWT       | 2           | 4                       | 5                |
| Duisburg           | 2           | 4                       | 5                |
| Frankenbach        | 2           | 4                       | 5                |
| Duisport           | 2           | 4                       | 5                |
| Germersheim DPW    | 2           | 4                       | 5                |
| Keulen CTS         | 2           | 4                       | 5                |
| Karlsruhe Contargo | 2           | 4                       | 5                |
| Bonn AZS           | 2           | 4                       | 5                |
| Avelgem AVCT       | 2           | 2                       | 3                |
| Meerhout           | 2           | 2                       | 3                |
| HTS Gent           | 2           | 2                       | 3                |
| TCA Athus          | 7           | 2                       | 3                |
| Willebroek         | 2           | 2                       | 3                |
| Born               | 3           | 1                       | 2                |
| Tilburg            | 1           | 1                       | 2                |
| Den Bosch BCT      | 2           | 1                       | 2                |
| Nijmegen BCT       | 3           | 1                       | 2                |
| Amsterdam CTVrede  | 3           | 1                       | 2                |
| Wanssum            | 3           | 1                       | 2                |
| Utrecht            | 3           | 1                       | 2                |
| Moerdijk           | 1           | 1                       | 2                |

region or time period (e.g. 40% of total volumes have throughput terminal Rotterdam for transports to Germany in 2012). This will lead to a large amount of data, which could be subdivided into smaller parts, but the data is not very detailed. It is not known what kind of commodity is transported or in which time period transport took place. This is a very efficient way to give input in a model and to predict large scale effects. Another method is to use a known dataset from a company. This data is adapted with some factors to achieve reliable results.

For this research transport data of Maersk Line Netherlands is used. This has some advantages and disadvantages. The main advantages are that every detail is known, a lot of data is available. The disadvantage is that multiple software systems are used to extract data. Transport data is available in the METS+ database. All delivery times are registered in RKEM. These systems have no internal link. Files could be linked manually by comparing container number and week number. When data is not stored in the right way data could not be linked and there is a data loss. Every detail that is missing in the transportation data will result in a missing transport order. But for every transport in the network it is sure that is executed by Maersk Line. This will give reliable results.

The demand for full containers are the import boxes. These are attracted from the METS+ database, some filters are applied to get the right data. First of all only import boxes are selected. It is made sure that every transport is selected only once by filtering the amount of surcharges to 0, in this case there will be only one entry. 'Orderfinancialscope' is selected for the region where transports took place. With this option a distinction between Netherlands, Germany and Belgium could be made. Next to the items before time is limited to week 35 towards 39 (september 2012). As begin site the terminals are used as mentioned in the section about deep-sea terminals. This results in the input data of the model for a specific harbor towards country. Because there are three harbors in the model and three countries 9 extracts had to be made.

For export data the same time and amount filter is applied, instead of selecting import boxes the option export boxes is selected. The 'orderfinancialscope' is also selected for the country for which the data was needed. The begin site is only different since the notation in the database is not in a correct way for all means of transport. All end locations are selected to get the total data set.

## 4.6 Arcs

Nodes and arcs are the basis of a network transportation model. The declaration of nodes is provided in section 4.1. In this chapter the arcs will be described. These items form the connection between the nodes as explained in the model development, chapter 3. Four different types of transport could be distinguished in the network, they will be explained in this section.

### 1. Full container transport (deep-sea terminal > customer)

The first one is the transport from deep-sea terminal towards customer, this is full container transport with a fixed OD pair. The decision variable linked to this flow is defined as  $flowoverarc_{full}(i, j, m, p, t)$ . Five indexes are used. The first index -  $i$  - is the origin, this is one of the deep-sea terminals. The second index -  $j$  - is the destination, this could be every other terminal, depot or customer in the network. The index  $m$  is used for the modality, barge rail or truck.  $p$  Is used for the commodity type. Although there is only one commodity in the network this parameter assures that containers unloaded at Rotterdam are also transported from Rotterdam. The last index -

$t$  - is used for the time period in which a transport will take place.

With this decision variable a container could flow throughout the whole network, using every possible modality in every time period. Next to the decision variable some parameters are applied to ensure a movement will take place (a certain demand at customers  $demand_{full}(n, p, t)$ ) and every transport will result in costs  $costs_{full}(i, j, m)$ . Not all indexes are used in these parameters while during testing there were memory errors. Therefore different tariffs for different commodities or time periods are left out of the costs parameter. Next to the costs and demand a third parameter is added, accessibility, to ensure only depots which truly have a barge or rail connection could use these modes.

Without some connections nothing will happen in this network transportation model since the objective function is to minimize costs. Every transport will result in costs. So the first constraint in the model is that demand is fulfilled. When barge or rail is used there will be flow conservations that guarantee in is out at the inland depots. The third constraint is the accessibility so only realistic transport could be executed. A fourth constraint is added to make sure no full container flow is starting from a customer (in theory it is possible to transport the full container from customer  $i$  to  $j$  without returning it to its depot).

The decision variable is multiplied by costs and these are the costs used in the objective function for full container transport.

## 2. Return of empty container (customer > inland depot/deep-sea terminal)

The second one is the transportation of the empty boxes from customers towards an inland depot or deep-sea terminal, this is empty container transport but in Maersk terms still falls under the full container movement. There is no fixed destination for this kind of transport, it is only known that an import box arrives at the terminal. In the next period ( $t = t + 1$ ) this container should be transported back to a storage location. The same indexes are used for the decision variable, in this case  $flowoverarc_{bt}(i, j, m, p, t)$ . Also the costs and accessibility parameter were defined. Constraints are that all boxes that arrived at a customer location in time period ( $t = t - 1$ ) should be transported back to a storage location in time period  $t$ . The second constraint is added to make sure no transports took place with  $j$  in the set of customers to make sure this second decision variable is only used for transport backwards with as origin the customer (instead of moving empty boxes). A third constraint is for the accessibility (only realistic transports).

## 3. Empty container transportation (inland depot/deep-sea terminal > customer)

The third transport stream is the supply of empty containers. This leg is quite familiar to the full movements. Again a decision variable is used  $flowoverarc_{empty}(i, j, m, p, t)$  with parameters for costs, accessibility and demand. The same constraint is used to ensure empty demand is fulfilled and only possible routes are chosen.

## 4. Empty container transportation (customer > deep-sea terminal)

The forth and last arc looks quite familiar to the second one. The backbone transport from customer towards deep-sea terminal in this case. The decision variable used is defined as  $flowoverarc_{bh}(i, j, m, p, t)$  with usage of the same parameters. It is made sure that all transports are executed (all empty demand is returned to the terminal).

All information generated in the model is visible in an overview page. The start screen is shown in figure 4.12. With the navigation panel all information could be made visible. In this chapter all information about the input data of the model is given. The results will be described in chapter 5

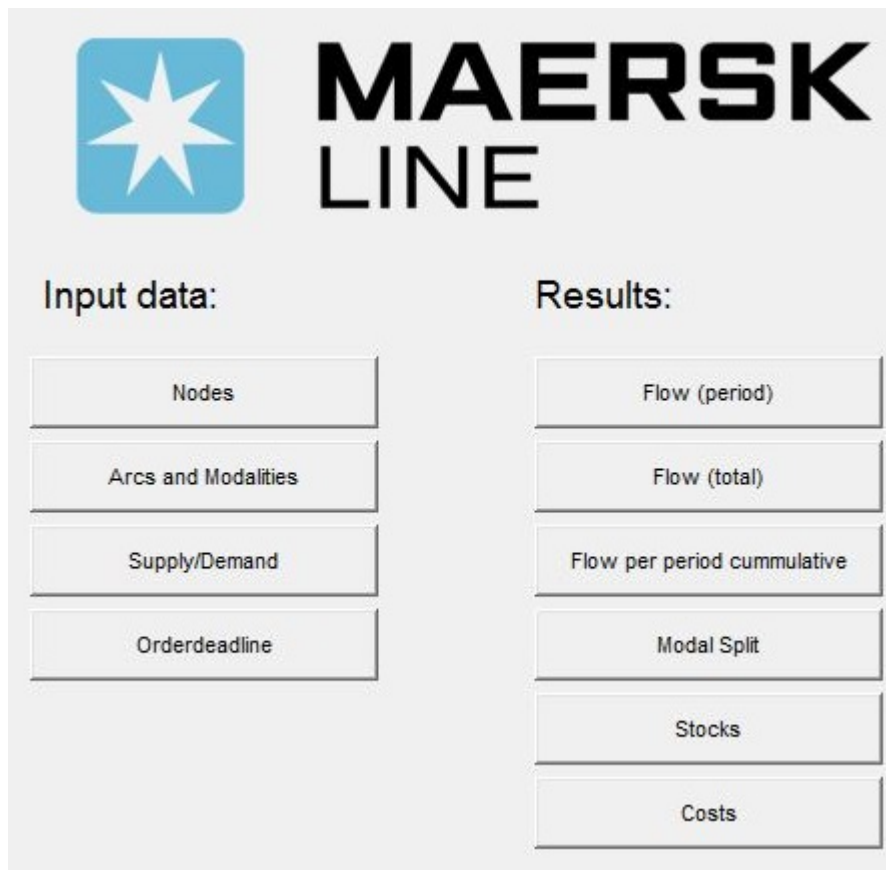


Figure 4.12: Overview of GUI start screen AIMMS(own work)





## Chapter 5

# Results of the Case Study at Maersk Line

This chapter will provide an overview of the model results. The mathematical model in AIMMS generates a lot of data during the solving process. All this data is stored in the variables and parameters and could be extracted out of the system for analysis. With the GUI of AIMMS it is easy to give an overview of these results. This chapter is divided in different parts. Initial the research questions are shown and a short explanation is given which information is needed to answer the research questions. A link towards the software systems Maersk Line is using is provided in this section. In the second section the different scenarios that will be studied are described. It is made clear why these scenarios are chosen and what the advantages are of studying different scenarios. In the third section the model results of the basic scenario are provided. It is possible to analyze every single detail in the GUI of AIMMS. The most important aspects are included in this chapter. With these overviews a first insight into the possibilities of the GUI of AIMMS is given as well as the most important model results. These results are not included for every scenario since exactly the same data formats, even in higher detail, could be viewed into the software package. Therefore only an overview of the most important results are included in the fourth section of this chapter. The answers to the research questions are provided in the chapter 6: Conclusions and Recommendations.

### 5.1 Research Questions

In the introduction, chapter 1.5, three research questions are defined. A concise overview of these research questions is provided, in combination with the information needed to answer these research questions.

*RQ1: In which way is it possible to shift truck transport towards rail/barge at Maersk Line?*

Before anything could be concluded from the model results the current modal shift at Maersk Line should be known. There are different ways to calculate the modal shift of the hinterland transport. Inside the company different systems are used for different business processes. All these systems could extract a distribution between modalities. These three software packages, all developed by Maersk Line are:

- FACT (Finance & Accounting for Container Transport)
- METS+ (Maersk Electronic Transport Solution)
- RKEM (Rederiets Kontainer Equipment Management)

The first system is used as the finance system platform for all container related activities of the Maersk Group. This also includes Damco and APM Terminals. METS+ is the planning tool for hinterland transport. At the end RKEM is a container tracking system. It is possible, although with some data quality challenges, to extract a figure for the modal shift with all these systems. One important aspect in comparing data is that apples should be compared with apples and pears with pears. When apples are compared with pears the results will not tell anything. In this case study the input data is extracted from METS+. Some filters are applied to filter out unreliable data, see chapter 4.5. Only with the METS+ system an equal comparison could be made. It is made sure that exactly the same transports in the same time horizon will be compared.

For the different scenarios - these will be described in chapter 5.2 - the results for the modal shift will be analyzed. In the model all transports are stored in decision variables (also repositioning). This has strong effects on the total modal shift of the transport network. Therefore a distinction is made between full and empty containers in the modal shift. To give more insight for this research question the different scenarios will provide insight into a change in modal shift with a certain intervention. This will become more clear in the upcoming part of the report.

*RQ2: How can a good balance be found between asset management and logistics in order to improve empty container repositioning?*

In the shipping business a distinction could be made between carrier haulage (CH) and merchant haulage (MH), the difference between both is explained in paragraph 2.2. As read in paragraph 4.1 customers are grouped into customer regions. This is one of the ways to model the transport streams in the network. For CH all transport information is known, for MH begin and end location of transports are unknown and therefore these transports are not included in the model. Since for the modal shift only CH transports have to be known the first research question could be related towards figures at Maersk Line. In the case of asset management the MH boxes are also important since they are dropped at the different inland depots in network. To include all these streams in the model would have made this model far too complex. Since the MH volumes are around 80% of total transport streams and CH only 20%, the MH has a dominant influence on the asset management. If a certain inland depot has a surplus due to the CH transport it could be that there is a big MH export client so the depot will be a deficit depot and vice versa in practice.

Maersk Line the SAFE tool (Stock Analyzer and Forecast Estimator) is used to estimate stock levels at the nodes in the network. These estimations are based upon a difficult calculation with a Gauss distribution. Since the people who developed this system are no longer working for the company it is hard to retrieve how this system works (black box system). It could be that this system will be replaced by a model that is easier to understand. At the end the SAFE tool is used to give an insight into the distribution between surplus and deficient depots and stock levels. These are used to make an estimation of stock levels. But no comparison could be made between the model results and real world situation.

It is hard to compare the model output with the current situation at Maersk Line. Therefore an extra decision variable is added tot the network. This is the stock level at all different depots. With the implementation of such a decision variable it is possible to see the effects of the container asset management in the stock levels at different depots. Different price strategies can be tested and the effects of different scenarios will be analyzed.

*RQ3: In which way could a shift towards a higher modal share for rail/barge and a cost reduction of empty container positioning reinforce each other?*

The last question is a very ambitious research question. While there were some thoughts about how to answer the first two research questions before the project started this last question had more uncertainties. A link between the full container transport and repositioning should be created to let both different problems influence each other. This research question has no direct results in this chapter, therefore the reader will be redirected to chapter 6. It has to be taken into mind that merchant haulage has also a strong influence on the answer to this this research question.

## 5.2 Scenarios

The aim of this section is first to explain why scenarios are used. Next it is explained which scenarios will be executed in the model. One of the business tools to analyze the effects of uncertain future developments is to use scenarios. In relation with the thesis project these scenarios are based upon the basic situation. Some changes in the input parameters are made to see the effects when a change to the original situation is made. This could be done by changing input parameters for instance, to make some constraints less rigid.

As read in the previous section some ideas about different scenarios already rose up while setting up the research questions. Some examples were provided in a presentation at Maersk Line. The results were presented and with the input data from this meeting the scenarios were finetuned. Some other interesting scenarios were also mentioned about network design. It could be possible to create a scenario to see the effect of a new network design (which depot should be included in the network and which ones could be left out). The model created for the thesis project has another purpose. Therefore the situation is explained to the person who asked for that scenario and explained why an other model type is better to tackle that problem. With some adjustments the scenarios were presented at a meeting for the graduation committee. With the feedback from this meeting it turned out that the scenarios were a good way to study the problem.

A scenario could only be analyzed when there is a basis situation to compare with. This basis situation is the model set up in AIMMS as described in chapter 3. Because the input data is very extensive an infinite number of scenarios could be created. All transport tariffs could be adjusted by different percentages. This will not provide better insights to answer the research questions. Therefore the next scenarios are included in the model:

1. No order deadline constraint;
2. No order deadline but change in truck transport rates hinterland transport;
3. No order deadline and no truck transport allowed from terminal towards hinterland;
4. No stock level constraints at the inland depots;
5. No stock level constraints and no order deadline constraint;
6. No reuse of empty containers at inland depots;
7. No reuse of empty containers at inland depots and no order deadline constraint.

For each scenario a short description is given. The scenarios are set up before a meeting with the Maersk Line Management Team to see which aspects were interested to study for the intermodal department. First of all there were some thoughts about the order deadline constraints. This is tested with the first scenario. The second scenario is set up after the validation phase of the model, 6.8.4. Together with the third scenario these three scenarios will be used to answer RQ1. The remaining four scenarios are used to answer RQ2. In the model the decision parameters that influence the storage of containers are the stock levels and figures about reuse. Therefore these aspects are studied in a scenario. For all these scenarios the input data of supply/demand and costs is chosen as fixed. This is done because the historical data of September 2012 is studied and these transports occurred in this time period. Cost of the main corridors are fixed due to the sharp tariff negotiations of the procurement department. The aspects of order deadline, stock level and reuse have been taken as scenario because in the business process these processes could be steered.

The first scenario will not take the effects of transit times into account. In the basic situation barge has the longest transit time of multiple days, rail a somewhat smaller transit time around two days and at the end there is truck transport without a transit of a few hours. Without this extra constraint there are less restrictions in modality choice without the order deadline constraint. There are two possible ways to adjust this scenario in the model, to ignore the order deadline constraint or to set the transit times to zero. The result will be equal but the first one will lead to shorter computation times. Therefore this option is used.

In the second scenario next to ignoring the order deadline the truck rates are adjusted. After the meeting at the MT of Maersk Line it turned out that the result of ignoring the order deadline was too small. It turned out that this was due to the effects of the truck rates. This is explained in the validation section, chapter 6.8.4. Therefore two scenarios are created. One with a decrease in truck rates of 20% and one with a decrease of 40%. These scenarios could also indicate the effect of the truck rates on intermodal hinterland transport.

The third scenario is a situation in which no direct truck transport is allowed between terminal and hinterland. The general opinion is that truck transport is way more polluting when compared to intermodal transport. The Port of Rotterdam has some strong requirements upon the modal shift in the new Maasvlakte 2. All new terminals must have a certain modal shift. The first idea was to use these percentages as extra constraint for the modal split. Because all transport streams are represented by the decision variables this should be possible in theory. In practice AIMMS was not able to solve this problem in an acceptable time horizon (not even for two time periods). Therefore it is chosen to simplify this scenario and eliminate all truck transports. This is simpler because less iterations should be made to achieve a solution. The results will not be the same but some conclusions could be generated with the results.

Scenario number four and five have to do with the stock levels at the depots and are more focused towards the second research question. In the normal situation the stock levels at the inland depots are bounded by a minimum and maximum stock level. Without stock levels there is totally freedom in the equipment management. This is more in line with the situation at a container shipping company where containers could be stored relatively easy on inland depots. To make also a comparison with the previous scenarios this scenario is also executed without the order deadline constraint.

The last scenario will focus upon the situation where the inland depots only have the func-

tion of throughput station. Only boxes are lifted from one to another modality. No storage is allowed. This is the function of the deep-sea terminal. This scenario is included to give more insight into the processes and help to answer the second and third research question. Also the order deadline is ignored in order to compare the results of this scenario to the other scenarios.

Table 5.1: Different scenarios

| Scenarios      | OD constraint | stock level (min/max) | truck costs | reuse |
|----------------|---------------|-----------------------|-------------|-------|
| Basis          | yes           | 10 / 30               | 100%        | yes   |
| 1              | no            | 10 / 30               | 100%        | yes   |
| 2              | no            | 10 / 30               | 60%-80%     | yes   |
| 3 <sup>1</sup> | no            | 10 / 30               | 100%        | yes   |
| 4              | yes           | - / -                 | 100%        | yes   |
| 5              | no            | - / -                 | 100%        | yes   |
| 6              | yes           | 10 / 30               | 100%        | no    |
| 7              | no            | - / -                 | 100%        | no    |

### 5.3 Model Results

In this section the model results of the normal situation are presented with all constraints and no adjustment in tariffs or stock levels. The desired approach is to show the most important output data. In AIMMS a special graphical user interface (GUI) is generated to present the data. It is not possible to include this tool in the report and therefore the most important aspects of this tool are highlighted. The first user interface is shown in figure 5.1.

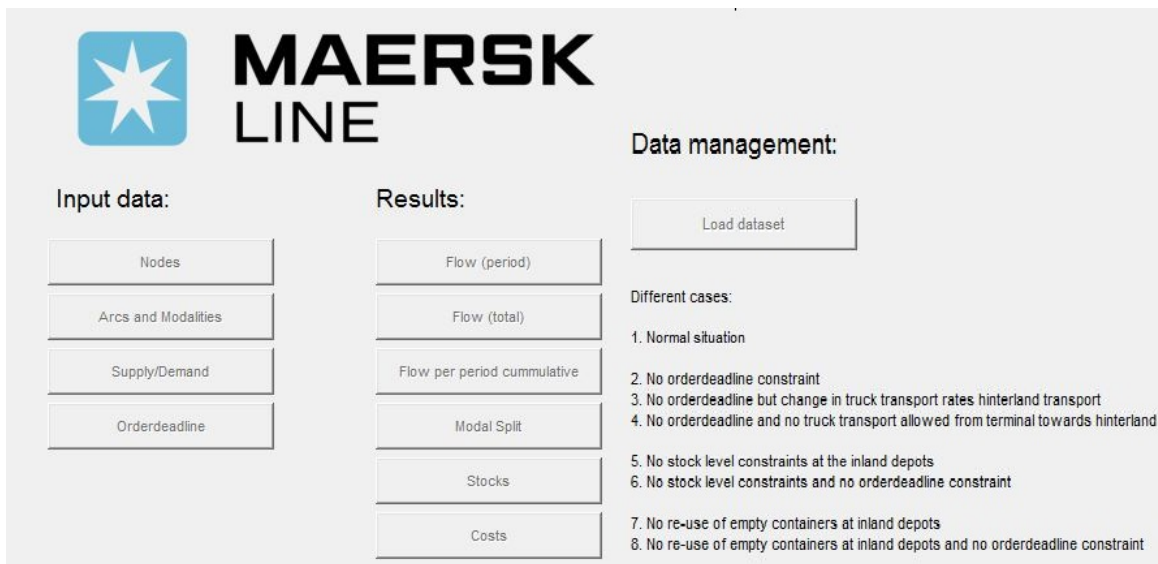


Figure 5.1: Overview GUI in AIMMS

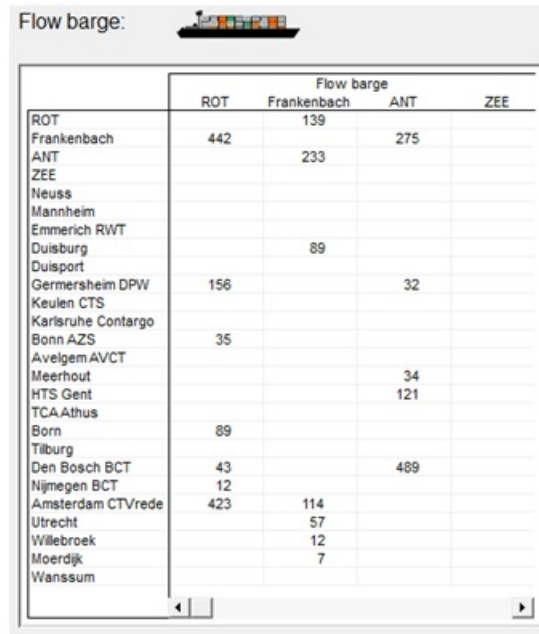
<sup>1</sup>no truck transport at deep sea terminal

There are roughly three sections: input data, results and data management. The first item is described in chapter 4. In this section the results will be shown. The third part allows a user to select multiple scenarios. As said only the basis situation will be shown, the other scenarios could be loaded into the software in the data management section.

### 5.3.1 Overview of transports in network

All data used in the solving process is stored into the decision variables and parameters. For every transport it is known what the origin  $i$  and destination  $j$  is, which modality  $m$  is used in which time period  $t$ . This information is stored in the decision variable of container transports. In figure 5.2 the accumulated flow of barge transports is displayed. On the left side the origin is shown, on top of the table the destination. With the scroll bars all information could be made visible. The figures illustrate the amount of containers transported in the total time horizon. This information is also available in a more detailed overview per time period or per movement type (full or empty (re-)positioning) by use of element parameters in AIMMS. With these overviews every transport could be tracked easily in the network.

Flow barge:



|                    | ROT | Frankenbach | ANT | ZEE |
|--------------------|-----|-------------|-----|-----|
| ROT                |     | 139         |     |     |
| Frankenbach        | 442 |             | 275 |     |
| ANT                |     | 233         |     |     |
| ZEE                |     |             |     |     |
| Neuss              |     |             |     |     |
| Mannheim           |     |             |     |     |
| Emmerich RWT       |     |             |     |     |
| Duisburg           |     | 89          |     |     |
| Duisport           |     |             |     |     |
| Germersheim DPW    | 156 |             | 32  |     |
| Keulen CTS         |     |             |     |     |
| Karlsruhe Contargo |     |             |     |     |
| Bonn AZS           | 35  |             |     |     |
| Avelgem AVCT       |     |             |     |     |
| Meerhout           |     |             | 34  |     |
| HTS Gent           |     |             | 121 |     |
| TCA Athus          |     |             |     |     |
| Born               | 89  |             |     |     |
| Tilburg            |     |             |     |     |
| Den Bosch BCT      | 43  |             | 489 |     |
| Nijmegen BCT       | 12  |             |     |     |
| Amsterdam CTVrede  | 423 | 114         |     |     |
| Utrecht            |     | 57          |     |     |
| Willebroek         |     | 12          |     |     |
| Moerdijk           |     | 7           |     |     |
| Wanssum            |     |             |     |     |

Figure 5.2: Overview of transport flow barge

The data is available in databases and could also be extracted to generate a table. This is done for an overview of the usage of the terminals in the network. An overview of terminal usage is shown in table 5.2. The terminals names on the left represent the origins, the terminals on top destinations. Not all data is included in this table, the complete table is visible in AIMMS. From this table it can be seen that the three deep-sea terminals have highest import volumes. This is logical because every import box has to pass a deep-sea terminal. Rotterdam has the highest volumes followed by Zeebrugge and Antwerp. The inland depots in the Netherlands are used most frequently. This is one of the consequences of the demand for import boxes that is highest in the Netherlands. For export containers the harbor of Antwerp is most popular as evacuation harbor. It can be seen that there is a big difference between the usage for inland depots for

import and export boxes. This is one of the consequences of the order deadline constraint and cheaper storage costs at these depots.

Table 5.2: Transports from terminals in network

| <b>Terminal</b> | <b>full</b> | <b>empty</b> |
|-----------------|-------------|--------------|
| Rotterdam       | 2368        | 292          |
| Zeebrugge       | 947         | 4            |
| Antwerp         | 785         | 532          |
| Den Bosch       | 586         | 92           |
| Wanssum         | 175         | 80           |
| Amsterdam       | 149         | 13           |
| Moerdijk        | 110         | 7            |
| Born            | 107         | 57           |
| Athus           | 96          | 152          |
| Utrecht         | 92          | 430          |
| Willebroek      | 65          | 83           |
| Neuss           | 65          | 375          |
| Duisburg        | 54          | 170          |
| Keulen          | 34          | 19           |
| Frankenbach     | 27          | 761          |
| Bonn            | 25          | 278          |
| Nijmegen        | 18          | 619          |
| HTS Gent        | 13          | 85           |
| Germersheim     | 8           | 43           |
| Meerhout        | 1           | 10           |
| Karlsruhe       | 0           | 6            |
| Duisport        | 0           | 28           |
| Mannheim        | 0           | 39           |

One of the powerful tools of AIMMS is to display the flow variables on a map. A map has to be imported and coordinates of all nodes have to be assigned. The result is a graphical overview of all transports in the network. In figure 5.3 an overview of all transports in the total model horizon is shown.

Different colors represent the different transport streams as explained in chapter 4.6.

- Black: import boxes terminal > customers;
- Pink: import boxes customers > depot;
- Green: export boxes depot > customer + repositioning;
- Orange: export boxes customer > terminal.

When seen for the first time all these transport streams might look very confusing. Therefore the streams are separated in figure 5.4.

This could also be done for the different modalities. This is shown in figure 5.5



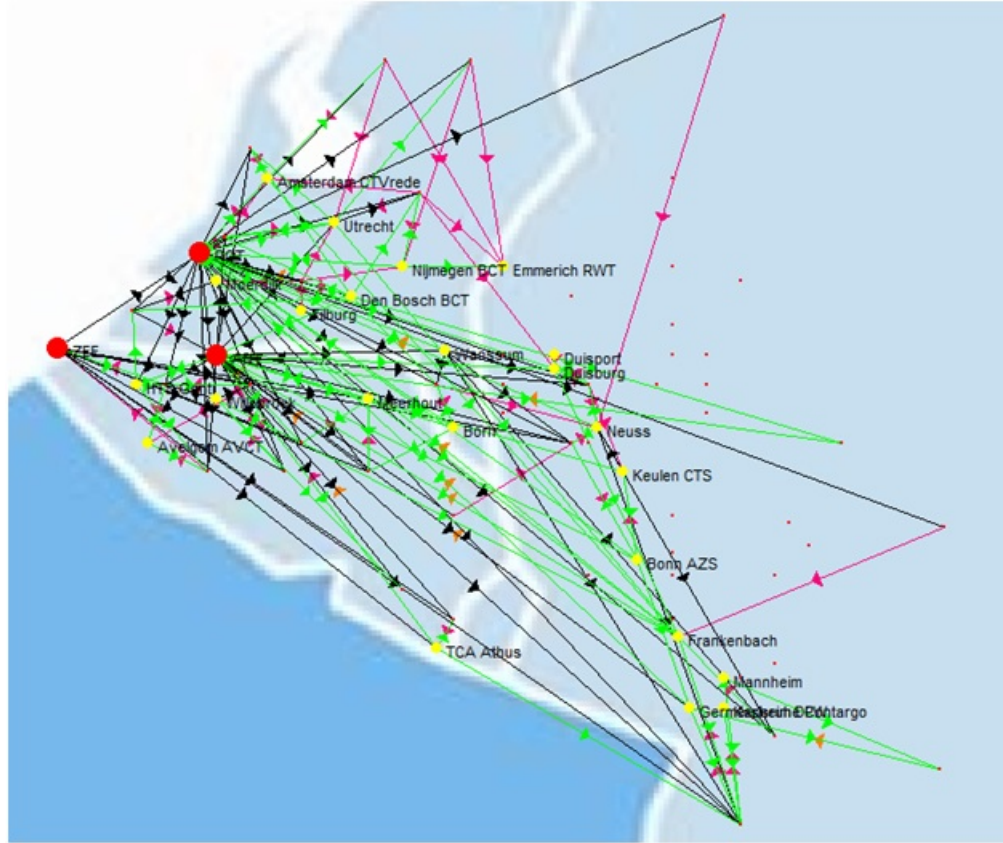


Figure 5.3: Overview off all transports in the model horizon (own work)

These figures still could look quite confusing. In AIMMS itself it is easier to select one time period so less data is shown on the map. This is shown in figure 5.6. In this figure it could be seen that the period 9 is selected. It is also possible to extend this towards the choice of one specific modality (e.g. barge or truck). An extra element parameter could be used to let the user select the information that is required.

In this section different overviews of transport streams were shown. These maps could be used for the analysis of the transport streams. Especially the overview in AIMMS where mode and time period are selected are widely used when the different scenarios are executed. From these maps it could be seen that for transport with free modality choice in most cases the depot is chosen that is close to the customer. This is because the last truck leg has the highest share of the total hinterland transport costs. From figure 5.5 it could be seen that rail is used on very specific corridors. This is because the optimization tool uses minimum costs. On these corridors rail is more competitive than barge transport.

This chapter illustrated different maps that give an example of which data could be extracted from the system. These tools are used to analyze the network.

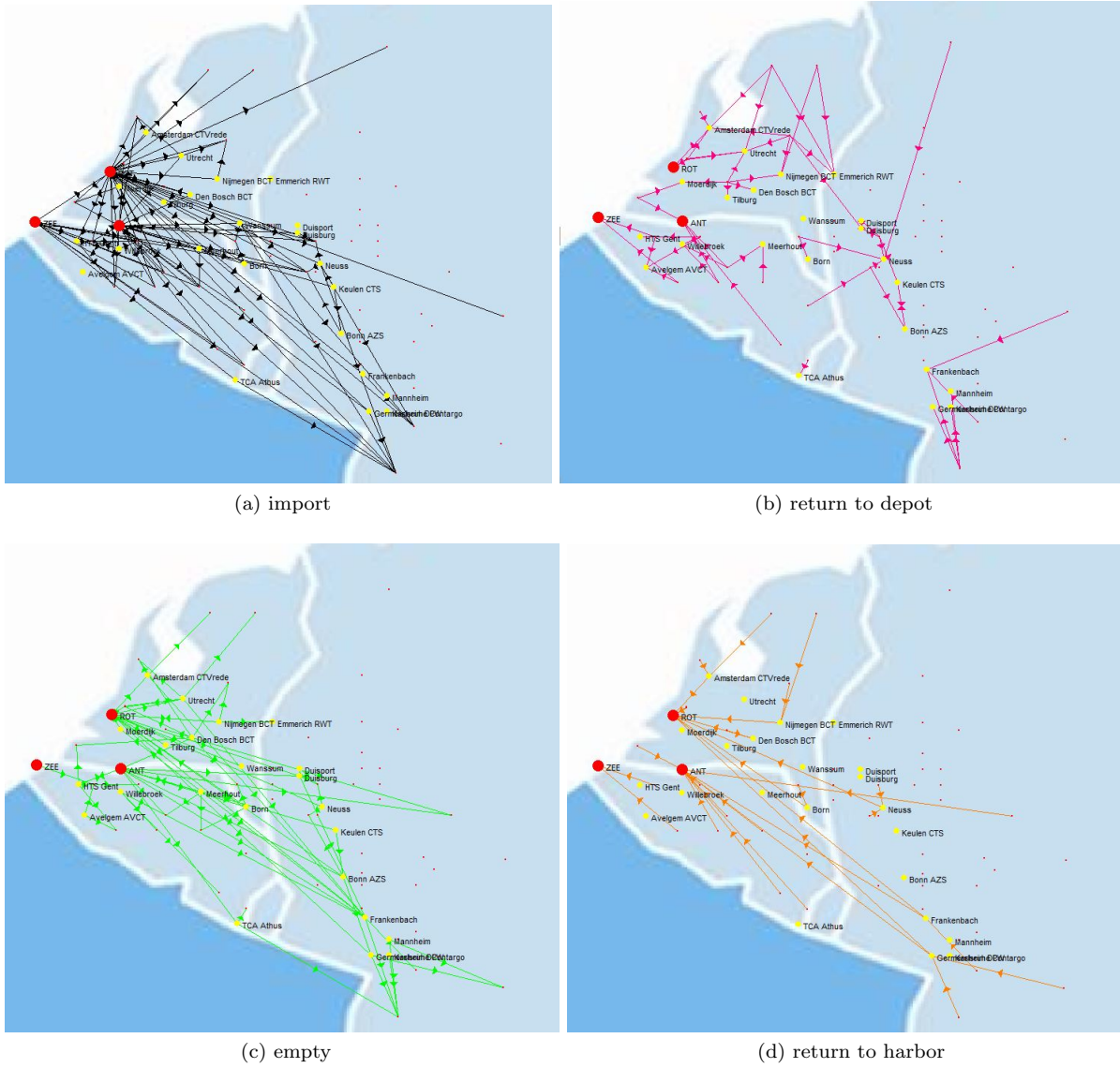


Figure 5.4: Overview of transports in the network per direction (own work)

### 5.3.2 Modal shift

In the previous section the transports are shown with the help of different tables and maps. To get more specific information to answer the research question, a closer look at the modal shift is made.

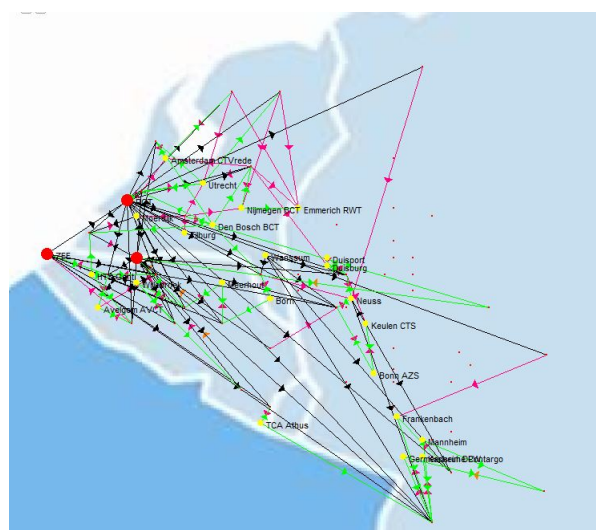
In section 5.4 the results and comparison between the scenarios will be provided, this also includes the figures about the current modal shift at Maersk Line. In this section the modal shift for the four different streams is made clear.



(a) barge



(b) rail



(c) truck

Figure 5.5: Different modalities, import and export (own work)

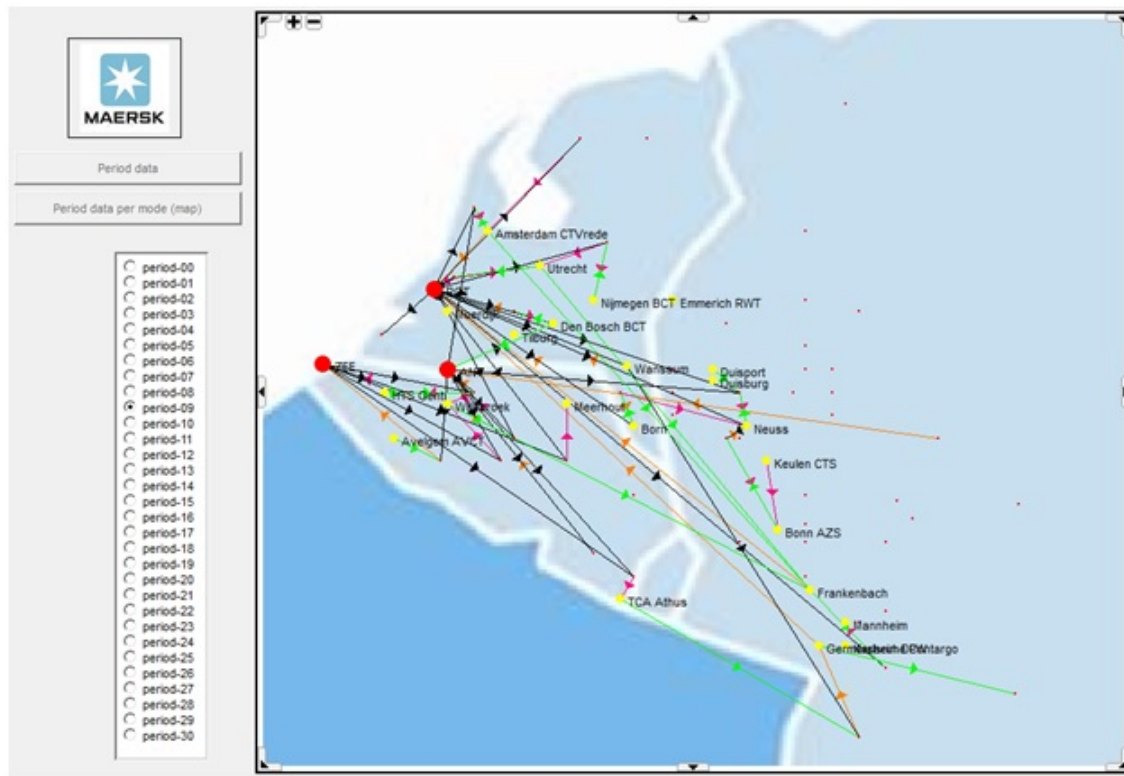


Figure 5.6: Selection of time period (own work)

The modal shift of different transport directions for the basis situation is shown in figure 5.7. The difference between streams is highlighted in section 3.2.1.1 and 4.6.

The first figure shows the modal shift of the import boxes in different time periods. It can be seen that there is a big difference in time periods, this is caused by the different order deadlines. In the second figure the transports back to the terminal are shown. These are all executed by truck since there is no barge or rail connection between a depot and customer. The third image shows the empty container positioning. It is interesting to see the differences in time periods. This is strongly dependent on the availability of export boxes. The last leg is the return of the boxes to the harbor. In this case only truck is chosen when other modalities are more expensive, this is only the case for customer locations very close to a harbor or without a nearby inland depot.

When all data is combined this will lead to the total modal shift for September 2012, this could be seen in figure 5.8.

The total modal split will be 62.7/31.4/5.9 (%) for truck/barge/rail based on the figures extracted from the model. When only import boxes are taken into account this split will be 61.2/35.1/3.7(%). The reason why the modal share of truck is higher is that truck transport is the only option due to order deadline. For more results see the section on results, section 5.4



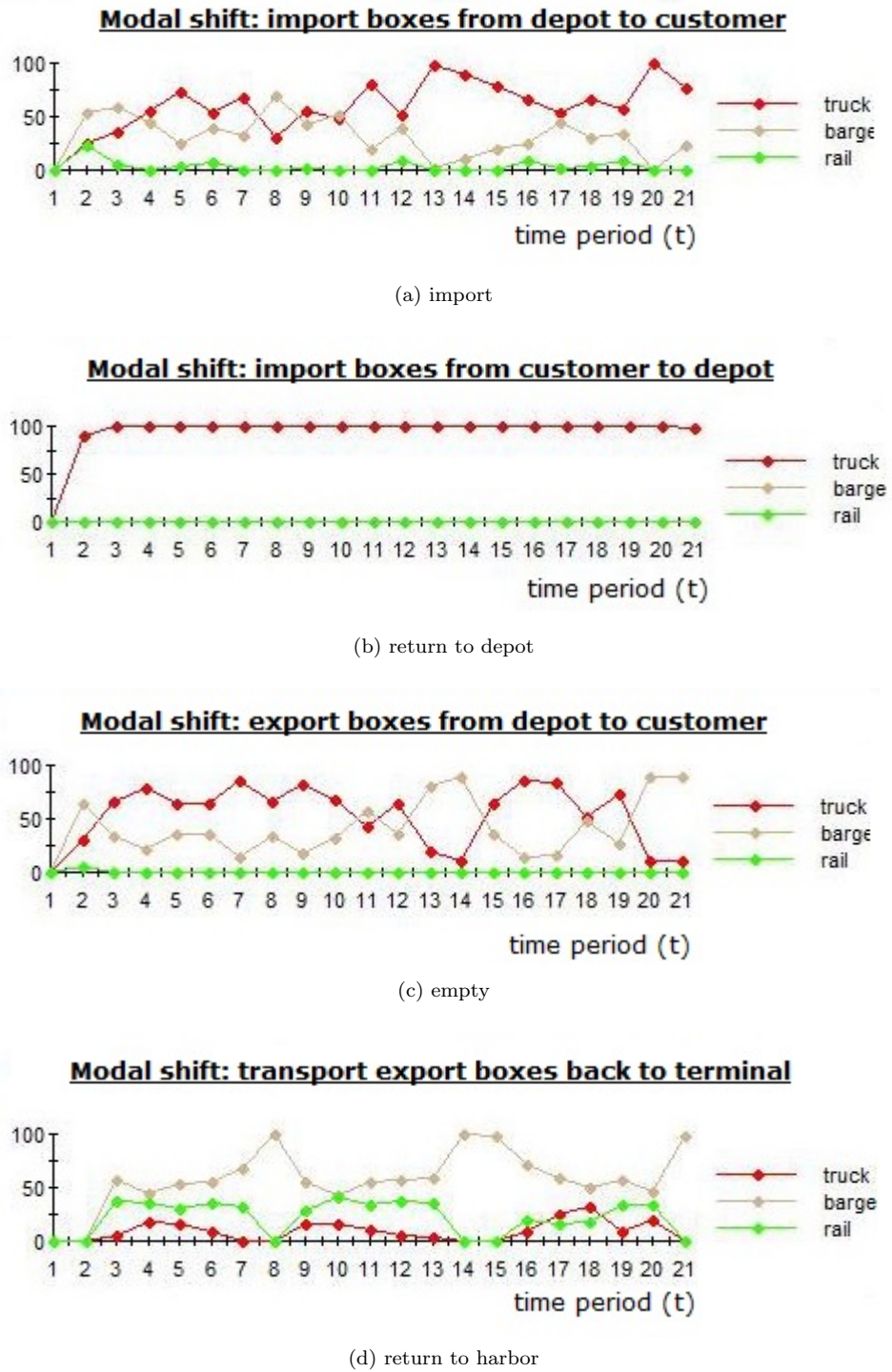


Figure 5.7: Overview of transports in the network per direction

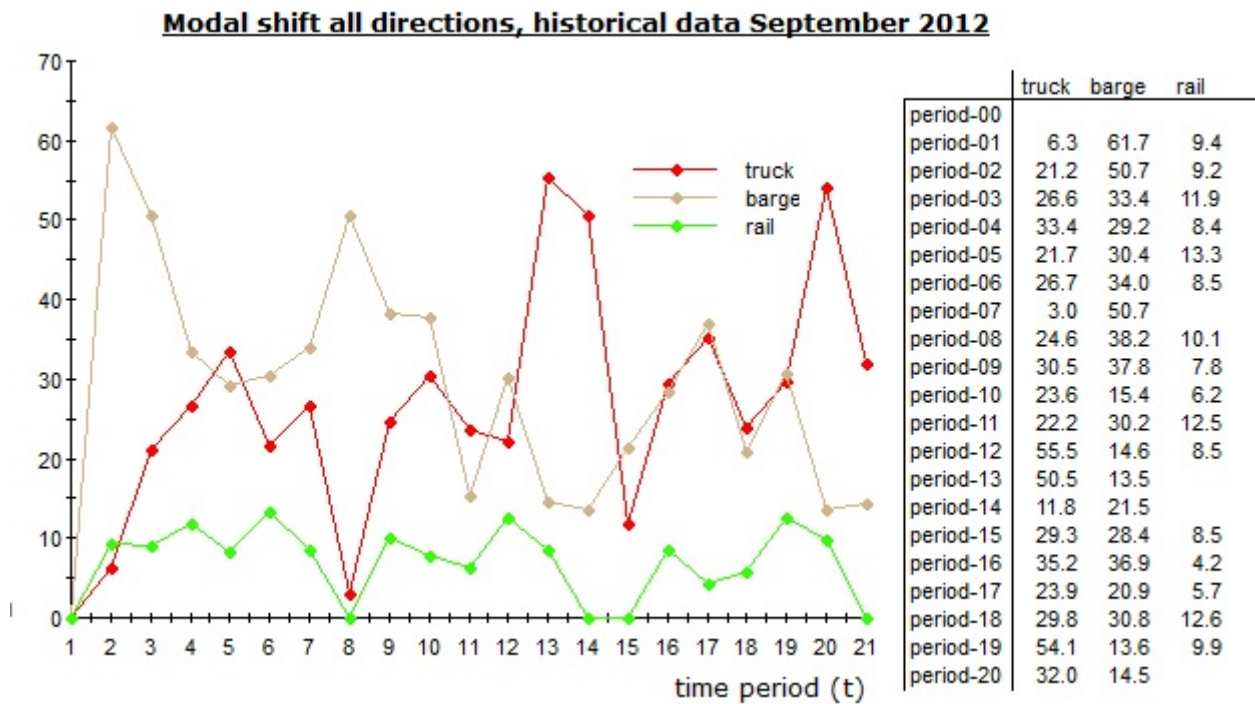


Figure 5.8: Total modal shift

### 5.3.3 Stock levels

With all transport data known the stock levels at different terminals could be calculated. This information is plotted in three different charts. In the first chart, figure 5.9, the stock levels of the deep sea terminals are shown. It is clear that the port of Antwerp is in favor for return boxes. This is due to the cost input parameters. Transport to the port of Antwerp tends to be the cheapest option for empty boxes.

For the inland depots a minimum stock level of 10 containers is used and a maximum stock level of 30 containers. These figures are estimated by information from the SAFE tool of Maersk Line. Storage at an inland depot has lower rates in comparison with a deep-sea terminal. Therefore it is not surprising that in the beginning a lot of transport will occur during the inland depots. An optimum between transportation and storage costs have to be found and this is clearly visible in the figure. All stock levels will be at the maximum capacity at the end of the time period of the model, but the way the maximum amount is reached is different. Some are filled from the first planning period, others reach the maximum due to transport in the last period. The overview is given in figure 5.10. In AIMMS these figures will be better readable.

At the end the figure with stock levels at the customer locations is presented. One of the assumptions was that there is no storage at a customer, although the containers are delivered in time

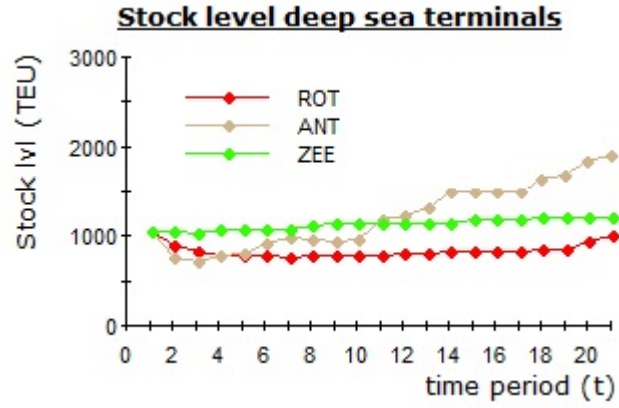


Figure 5.9: Stock levels at deep sea terminals

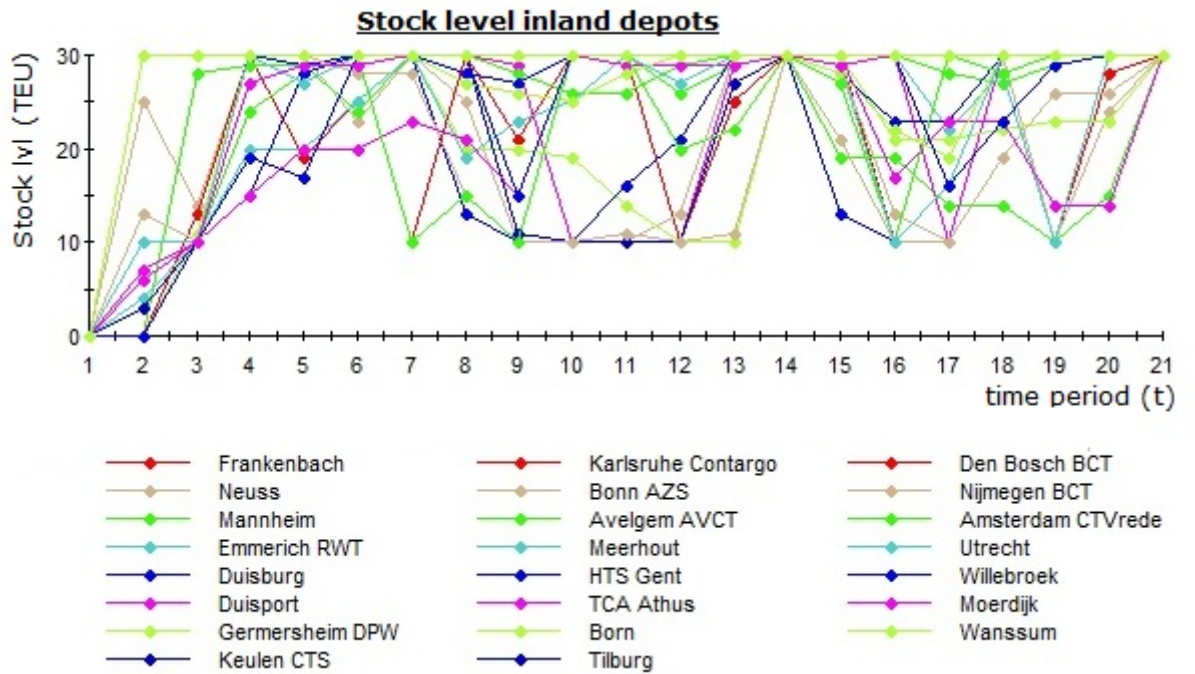


Figure 5.10: Stock levels at inland depots

period  $t$  and evacuated to an inland depot in time period  $t+1$ . This will lead to a dummy storage at customer locations. A penalty function is used for storage costs at customers to eliminate the amount of futile trips. These figures are shown in figure 5.11.

Some of the scenarios have very interesting charts (especially when there storage limits are not bounded).

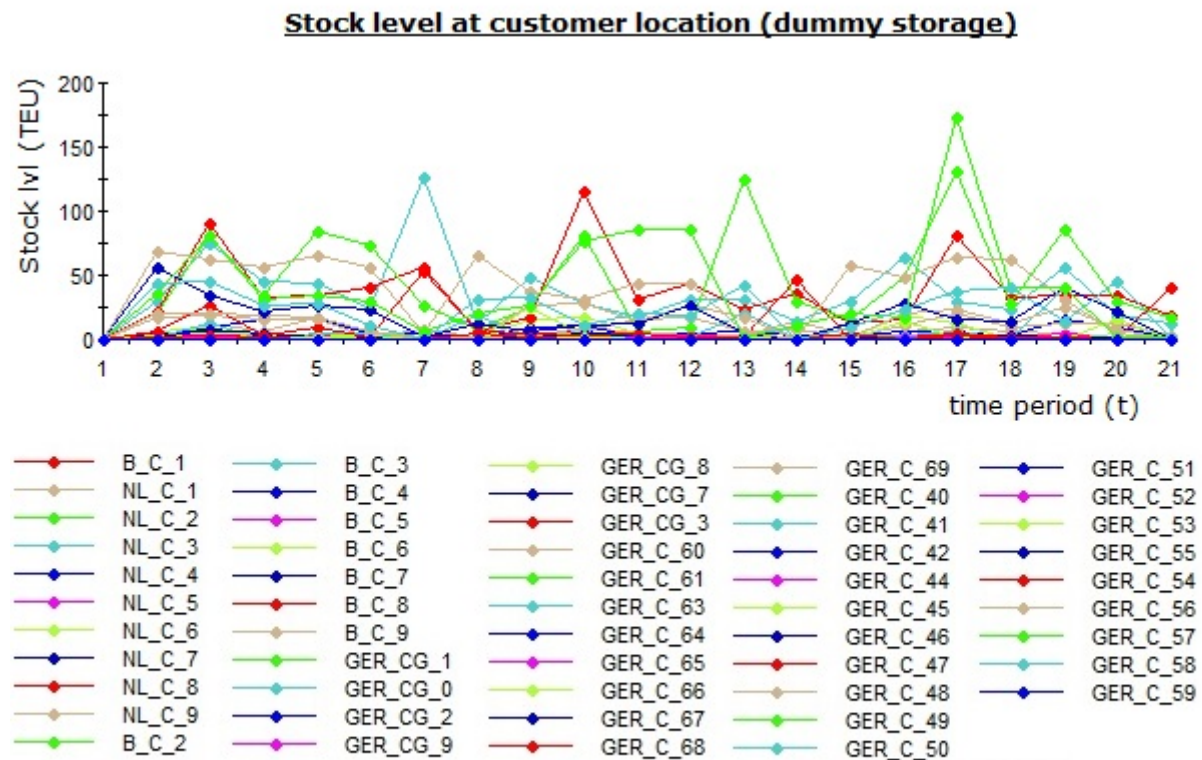


Figure 5.11: Stock levels at customers

### 5.3.4 Costs

One of the most important decision parameters for a change in strategy at Maersk Line are costs. Especially during hard market circumstances it is important to save on expenses and try to increase revenues. This section will focus upon transportation costs. In the software package a clear overview of the costs is generated. Therefore this is included into the model. A distinction is made between the different time periods. The GUI of AIMMS for the costs is shown in figure 5.12.

Next to this total overview it is possible to split the costs per direction per mode. This is shown in table 5.3.

Table 5.3: Cost per modality per transport direction

| Mode  | Full      | BT      | Empty      | BH      |
|-------|-----------|---------|------------|---------|
| truck | 1.027.861 | 658.613 | 266.297.48 | 258.090 |
| barge | 110.110   | 0       | 142.060    | 108.870 |
| rail  | 23.584    | 0       | 3.834      | 68.744  |



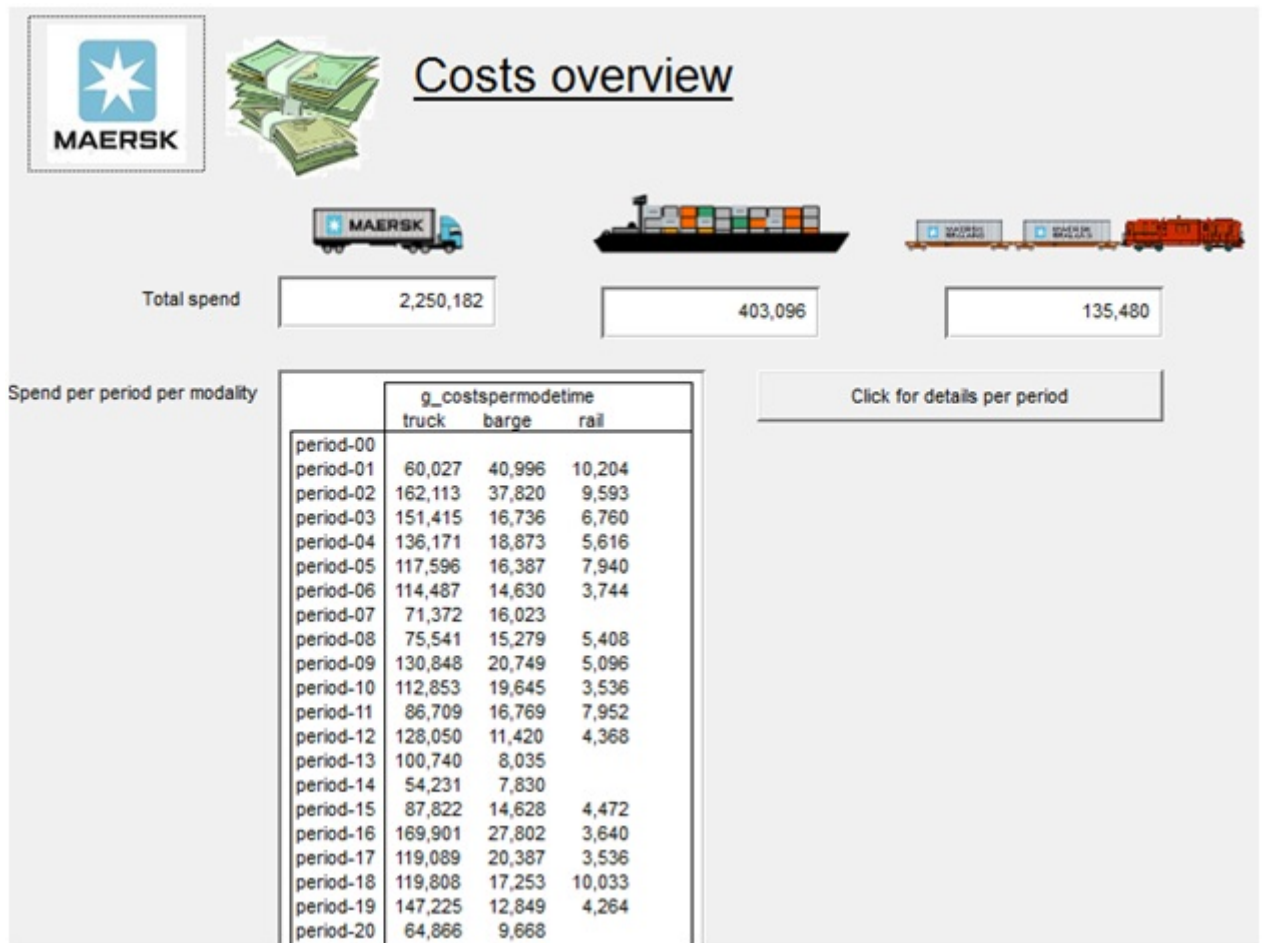


Figure 5.12: Overview of costs in AIMMS

In the GUI of AIMMS it is possible to give an overview as detailed as possible. For every modality in every time period for every direction exact costs are compared with the corresponding flows. It is too much information to provide every overview.

## 5.4 Results & analyses of scenarios

After the results that were shown in the previous paragraph the results of different scenarios will be presented in this paragraph. This section will be divided in four sections. The first section focuses on the change in order deadline and accessibility of the harbor areas. Second, the change in stock levels will be analyzed. In the third section the effects of container reuse will be analyzed. At the end of this section the differences in amount of transports movements will be analyzed for all scenarios. These scenarios are explained in section 5.2. Next to these analyses figures about modal shift and costs are provided. These results will be used, together with the data available in AIMMS, to answer the research questions, this will be done in chapter 6.

### 5.4.1 Effects of order deadline

In this section the first four scenarios will be analyzed, all these scenarios are used to analyze the effect of the order deadline. In the first scenario the total order deadline is excluded, in the second scenario truck rates from depot to customer were decreased with respectively 20% and 40% and in the last scenario no truck transport from the deep sea terminal is allowed. In these scenarios order deadline is totally excluded so all modalities could be used. The first idea was to give some extra days in the delivery window to see the effects when the order deadline constraint is less strict. These effects were too small to make significant conclusions. Therefore the total order deadline is excluded. It is chosen to change the truck rates from depot towards customer after a meeting with the management team at Maersk.

For these scenarios it is interesting to see the effect on modal shift and costs associated with transport and storage. These are shown in the table 5.4 and 5.5 (No OD = no order deadline)

Table 5.4: Change in modal shift in different scenarios (percentages)

| Scenario         | barge | change | rail | change | truck | change |
|------------------|-------|--------|------|--------|-------|--------|
| Maersk           | 59    | -      | 4.3  | -      | 36    | -      |
| Basis            | 35.1  | -23.9  | 3.7  | -0.6   | 61.2  | 25.2   |
| No OD            | 68.8  | 33.7   | 8.5  | 4.8    | 22.7  | -38.5  |
| No OD (20% TD)   | 69.8  | 34.7   | 8.5  | 4.8    | 21.7  | -39.5  |
| No OD (40% TD)   | 81.2  | 46.1   | 8.5  | 4.8    | 10.3  | -50.9  |
| No OD (no truck) | 91.5  | 56.4   | 8.5  | 4.8    | 0     | -61.2  |

Table 5.5: Change in costs different scenarios

| Scenario          | Transportation costs | difference (%) | Storage costs | Total costs |
|-------------------|----------------------|----------------|---------------|-------------|
| Normal situation  | 2.735.868            |                | 1.364.463     | 4.100.331   |
| No OD             | 2.582.284            | -5.6           | 1.364.463     | 3.946.747   |
| No OD (20% truck) | 2.485.267            | -9.2           | 1.364.463     | 3.849.730   |
| No OD (40% truck) | 2.382.867            | -12.9          | 1.364.463     | 3.747.330   |
| No OD (no truck)  | 2.688.974            | 4.1            | 1.364.463     | 4.053.437   |

First of all it can be seen that there is a big difference between the modal shift observed in the METS+ system of Maersk Line and the mode results. The reason for this difference is caused by the assumptions made in the mathematical model. A lot of simplifications are made

and due to the elimination of surcharges and MAUT other rates are used. Next to it the planning at Maersk is not as it should be in an ideal situation since a lot of manual work is done. Also all containers are taken out with data inaccuracies, these are particularly multimodal transports.

It is interesting to compare the basis situation with the scenarios. In this situation 35.1% of transports are moved by barge, 3.7% by rail and 61.2% by truck. When the order deadline is removed the amount of barge transports rise to 68.8% and truck drops towards 22.7%. Rail will rise to 8.5%, it turned out that this was the maximum amount of rail transports. One of the remarks of the MT of Maersk Line was that the change in modal shift for excluding order deadline was too small. When the truck rates were adjusted the modal shift of multimodal transport increases as could be seen in table 5.4. Without truck transport all transports are executed by barge or rail.

When the table of costs is studied more in detail the normal situation is most expensive. The total spend is not that interesting since all the assumptions and limitations of the model make it not possible to make a 1 to 1 reflection of the real world situation. The relative changes between scenarios are interesting. It can be seen that due to neglecting the order deadline the transportation costs decrease with 5.6% due to a more efficient route choice. Storage costs will be the same since there are no changes to the empty positioning processes. Decreasing the truck rates will also lead to lower transportation costs, 9.2% and respectively 12.9%. When no truck transports are allowed from the port, transportation costs increase with 4.1%. This will be caused by destinations close to the port that have to be served by barge, which will lead to a large detour. More transports are executed but total costs are lower than the basis situation, this is because the order deadline constraint is not added in the third scenario. The storage costs are equal in this analyses due to the fact that transit time is not included in the availability of containers.

#### 5.4.2 Effects of change in stock level

In this section the results of the scenario with multiple stock levels is shown. Even as the previous section an overview of the model split for different scenarios is shown in table 5.6 (No Stock lvl = no stock level).

Table 5.6: Change in modal shift different stock levels

| Scenario           | barge | change | rail | change | truck | change |
|--------------------|-------|--------|------|--------|-------|--------|
| Maersk             | -     | -      | -    | -      | -     | -      |
| Basis              | 31.3  | -      | 7.5  | -      | 61.2  | -      |
| No Stock lvl       | 42.3  | 11     | 6.1  | -1.4   | 51.6  | -9.6   |
| No Stock lvl No OD | 52.5  | 21.2   | 7.5  | 0      | 39.9  | -21.3  |

In the previous section the modal shift of the full transports is shown. In this section the modal shift of all transport combined is analyzed, this also includes (re-)positioning. Because the stock levels have no influence on the full allocation problem (from terminal to customer) there should be no change in the modal shift study in the previous section.

It can be seen that without a stock level, this is scenario four and five, the total modal shift of barge transports rise with an extra 11% and 21.2%. This is caused by the effect that more containers are repositioned in the network. At the same time the modal shift of rail and truck transport decreases. The relatively decrease in rail volume is the result of a higher total amount

of transports with an almost equal amount of rail transports. It can be seen that barge is essential for (re-)positioning. The costs for these scenarios are shown in the table 5.7.

Table 5.7: Change in costs different stock levels

| Scenario                        | Transp. costs | diff. (%) | Storage costs | Total costs | diff. (%) |
|---------------------------------|---------------|-----------|---------------|-------------|-----------|
| Normal situation                | 2.735.868     |           | 1.364.463     | 4.100.331   |           |
| No Stock lvl                    | 2.906.333     | 6.2       | 567.589       | 3.473.922   | -15.3     |
| No Stock lvl No OD <sup>2</sup> | 2.752.749     | 6.6       | 567.589       | 3.320.338   | -15.9     |

It can be seen that without stock levels transportation costs increase with 6.2%. But storage costs will reduce by almost 60%. The total amount of cost will decrease with 15%. This is an interesting phenomenon, especially for Maersk Line, where one process could lead to higher costs but another alternative process more costs could be saved. In the case of the neglecting of order deadline transportation costs will be even lower through a more efficient route choice. The total amount of “cost savings” will be higher.

In figure 5.13 a new overview of the stock distribution at the inland depots is provided, the legend is taken out for a better visibility. Three interesting observations could be seen. The first is shown in the purple and blue line on top. These depots are the cheapest storage option (depots close to the terminal with minimum transportation costs). It could be seen that all superfluous containers are transported to these depots. The red line is the second aspect, at this depot there is a lot of empty demand. All containers needed during the model horizon are transported in the first period. At the end the amount of storage is equal to zero. The total amount of transportation and storage costs will be minimal. The red and blue line are depots without an initial storage. But in these regions there is a surplus of import containers. Without a maximum level these containers will not be evacuated and storage levels increase during the model. The combination between transport costs and storage costs is interesting to see in this graph.

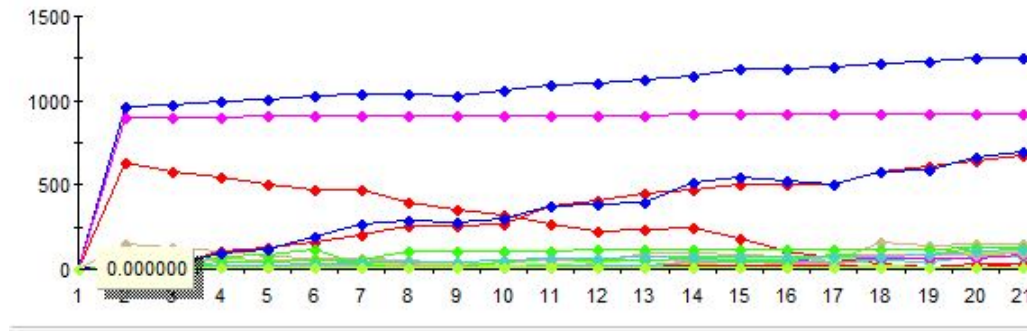


Figure 5.13: New stock level

<sup>2</sup>The difference is calculated with scenario one instead of normal situation

### 5.4.3 Effects of container reuse

In the basis model all containers could be reused. In this scenario reuse and storage at depot is not allowed and all containers should be transported back the the deep sea terminal. This is shown in table 5.8 & 5.9. Although transportation costs increase with 1.3%, because the rates are higher on a deep sea terminal, storage costs decrease bt 11% because no positioning movements have to be made. The total solution will be more expensive, 2.7% when no reuse is allowed.

Table 5.8: Change of modal shift and reuse of containers

| Scenario        | barge | change | rail | change | truck | change |
|-----------------|-------|--------|------|--------|-------|--------|
| Maersk          | -     | -      | -    | -      | -     | -      |
| Basis           | 31.3  | -      | 7.5  | -      | 61.2  | -      |
| No Return       | 35.1  | 3.8    | 3.7  | -3.8   | 61.2  | 0      |
| No Return No OD | 68.8  | 37.5   | 8.5  | 1      | 22.7  | -38.5  |

Table 5.9: Overview influence off different actors

| Scenario                     | Transp. costs | diff. (%) | Storage costs | Total costs | diff. (%) |
|------------------------------|---------------|-----------|---------------|-------------|-----------|
| Normal situation             | 2.735.868     |           | 1.364.463     | 4.100.331   |           |
| No Return                    | 2.698.929     | -1.3      | 1.515.120     | 4.214.049   | 2.8%      |
| No Return No OD <sup>3</sup> | 2.545.345     | -1.4      | 1.515.120     | 4.060.465   | 6.8%      |

### 5.4.4 Amount of transports in different scenarios

The amount of transports differs strongly in all scenarios. For some scenarios it is clear that the amount of transports increases, when no truck transports are allowed from harbor, all transports are multi modal. Two movements (barge/rail + truck) are needed for one import order. From a social point of view more transports are not desirable. The amounts of transports is shown in table 5.10.

It can be seen that the amount of transports is lowest in the normal situation. In all other scenarios the amount of transports increases. Without an order deadline constraint the amount of transports is increasing because there is more freedom in modalities. A transport includes in this situation two movements (one barge/rail leg and one truck leg). It can be seen when the amount of transports increases, the costs per transport drops. This is caused by a increase in barge transports that have in general lower rates compared to truck. Nothing could be concluded about the sustainability performance since no emission factors are included in this research. When on each arc an emission value for modality is added this problem could be minimized from environmental point of view. This is interesting for further research.

<sup>3</sup>The difference is calculated with scenario one instead of normal situation

Table 5.10: Costs per transport

| Scenario           | Transports | Costs     | Costs per transport |
|--------------------|------------|-----------|---------------------|
| Normal situation   | 12.936     | 2.735.868 | 211                 |
| No OD              | 14.475     | 2.582.284 | 178                 |
| No OD (20% truck)  | 14.520     | 2.485.267 | 171                 |
| No OD (40% truck)  | 14.987     | 2.382.867 | 159                 |
| No OD (no truck)   | 15.414     | 2.688.974 | 174                 |
| No Stock lvl       | 15.126     | 2.906.333 | 192                 |
| No Stock lvl No OD | 16.731     | 2.752.749 | 165                 |
| No Return          | 17.708     | 2.698.929 | 152                 |
| No Return No OD    | 18.307     | 2.545.345 | 139                 |

#### 5.4.5 Overview of results

In this chapter the results of the model are provided. The model provides an overview of all transport details in a historical time period (September 2012) at Maersk Line. With the assumptions and limitations of the model these results are not a 1 to 1 reflection of the real life process but the results could be used to compare different scenarios. This is done in the second part of this chapter. The answers to the research questions are provided in the next chapter: Conclusions and Recommendations.



## Chapter 6

# Conclusions & Recommendations

The last chapter of the thesis contains the conclusions and recommendations of the thesis project. The research questions will be answered in the first section. This is the contribution to the theoretical part of the thesis project. In the introduction the next question is stated as central question: *How can a modal shift towards rail and barge transport contribute to cost savings in the hinterland transport operations of Maersk Line?*. With help of the three research questions this question will be answered. In the second section of this chapter the theory is less important and the focus will move towards the practical situation at Maersk Line. Hereby some recommendations towards the company are given.

### 6.1 General conclusions

In this subsection the three research questions will be answered.

#### 6.1.1 Research question 1

*In which way is it possible to shift truck transport towards rail/barge at Maersk Line?*

- The current modal shift at Maersk Line is a distribution of 59% barge, 36% truck and 5% rail, (multimodal 64%). This information is extracted from the METS+ database with the same filters as used in the selection for input data for the model. The model results of the basis situation, with all constraints and normal tariffs, has a modal shift for full transportation of 35.1% for barge, 61.2% for truck and 3.7% for rail, (multimodal 38.8%). The difference between the data from the METS+ system and the model outcome is very large. This difference is particularly caused by the constraint of delivery windows. There are some special customer deals where the order deadline is manually adjusted after the arrival time in the database. Such MIG deals are transported by rail or barge in practice but in the model the transport needs to be transported on truck due to an infeasible transit time. This can be seen in the scenario where order deadline is excluded from the model. In this case the percentage of multimodal transports rises with 38.5% towards 77.3% (with a distribution of 68.8%, 8.5% and 22.7% for respectively barge, rail and truck). This is an indication that order deadline has a strong influence on the modal shift. This will be further discussed in the section about recommendations towards Maersk Line.

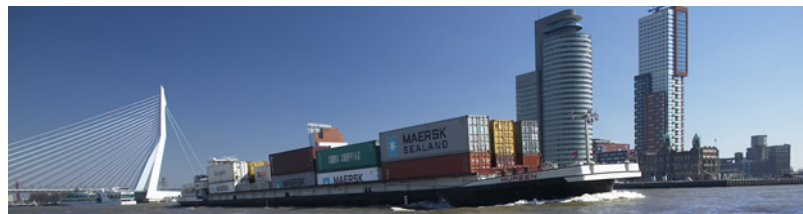
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<sup>1</sup>source: Maersk Line



Figure 6.1: Truck<sup>1</sup>

- The objective function is a minimization of total costs. For full container positioning the cost aspect is the sum off the transports needed to transport a container from  $A$  to  $B$ . For truck transports there are direct truck costs, for multimodal transport this is the summation of a barge or rail leg and a truck leg. The effect of a change in rates is examined for this last truck leg. It turned out that this last leg has a strong influence on the modal shift of full container positioning. A price drop in truck transport of hinterland transport with 20% or even 40% will lead to a increase in multimodal transport with respectively 1% and 12.4%. Total transportation costs will rise by 9.2% and 12.9%. The higher modal share for barge and rail is due to lower transportation costs for multi modal transports. It turns out that for the Netherlands the break even point between truck transport and multimodal transport is quite close. Better truck rates from inland depot to customer have a strong influence on modal shift. This is one of the new projects of Maersk Line, the inland CY product. In this product containers are delivered to an inland depot instead of deep sea terminal.

Figure 6.2: Barge<sup>2</sup>

- For the new Maasvlakte 2 strong restrictions are set up for the modal shares for the new terminals (truck: 35%; barge: 45%; rail: 20%). When a terminal is used by different shipping companies or freight forwarders it is hard to set a modal share target. It was the aim to see the effects when Maersk Line has to meet these requirements, to implement a maximum percentage for truck transport. This was not possible due to computation limitations. Instead of this scenario no truck transport from ports is allowed. This will lead to a modal shift for multimodal transport of 100% (barge 91.5% and rail 8.5%). When the figures about costs are compared with the normal situation costs will rise with 4.1%. In this case there is no order deadline constraint since barge/rail has longer transit times. The 4.1% rise in costs is a negative result for a shipping company, for locations close to the terminal it will also has a big influence on total transit time. For MV2 a modal as set

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<sup>2</sup>source: Port of Rotterdam

up in this thesis could be used to see which transports could be shift towards intermodal transport with the least negative influences for the company.

- Barge capacity is not included in the model since Maersk Line uses fixed rate agreements. The effects of bundling of streams could not be studied and has no influence in the current model setup.



Figure 6.3: Rail<sup>3</sup>

- The maximum modal shift for rail transport in the current dataset is 8.5%. The amount of corridors for rail transports is low compared to barge; although tariffs are competitive in the current market with DistriRail. There might be changes for rail transport when more corridors are included in the Maersk Line transportation network.

To answer this first research question, there are multiple ways to improve the modal shift at Maersk Line. The first one is to loosen the order deadline constraint, this will lead to an increase of intermodal transport of 33.7% and a cost reduction of 6%. Next to it a decrease in rates for the last truck leg will lead to a higher modal share for barge/rail of 12.4%. Furthermore the usage of rail is limited by the availability of this service, the model results show a modal shift of 8.5%. Adding more corridors could lead to a higher modal shift. A total embargo for trucks in the port area is possible but will lead to higher transportation costs. Further research could be done by optimizing towards environmental performance.

### 6.1.2 Research question 2

*How can a good balance be found between asset management and logistics in order to improve empty container repositioning?*

The total amount of containers in the network have to be stored somewhere in this network. There is storage capacity at the deep-sea terminal and at the inland depots. For these terminals different storage costs have to be paid. This is strongly simplified in the model since the

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<sup>3</sup>source: Maersk Line

free storage days, amount of free storage boxes and storage fee differs strongly from terminal to terminal.

- The storage costs at the deep-sea terminal are more expensive than the tariffs at inland depots. It tend out from the model results that storage should be minimized at the deep-sea terminals. In the normal situation there is a minimum and maximum storage limit at the inland depots and therefore additional boxes should be stored at the deep-sea terminal, since this is the only remaining option. In this scenario the storage costs are 1.364.463. When the maximum storage levels at inland depots are removed this amount of storage costs will drop to 567.589, this is a decrease of 58%. Therefore inland depots are preferable for container storage.



Figure 6.4: APMT<sup>4</sup>

- In the 6th and 7th scenario the effects of reuse of empty containers is studied. Reuse is the process where a import box is transported towards an inland depot and from there transported towards an export customer. With reuse of containers transportation costs will decrease with 1.4%. Storage costs will increase since the containers will be transported back to the deep-sea terminal with high total costs. Reuse is beneficial for the shipping company.
- Merchant haulage is important for the stock levels at inland depots. When data from SAFE is studied the amount of incoming boxes from merchant haulage customers is high. When the origin of these boxes is known a more efficient reuse strategy could be set up with pickup and drop off charges. Graphically this could be imagined by a map where all customers are located with a dot. When there are twice the amount of customers the density of dots is doubled. It is clear that a better fix could be created with more freedom. This is illustrated in figure 6.6. It is clear that it is easier to combine transports in the right scenario than the left scenario. Because there is no data available about the merchant haulage transports it is not possible to give a quantified conclusion, attracting more MH to CH will lead to better reuse.
- As can be concluded from the model results some depots are more used than others. As in many cases there are benefits through economies of scale. This will also be the case

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<sup>4</sup>source: Verkeersonderneming, 2011

<sup>5</sup>source: Port of Rotterdam, 2010

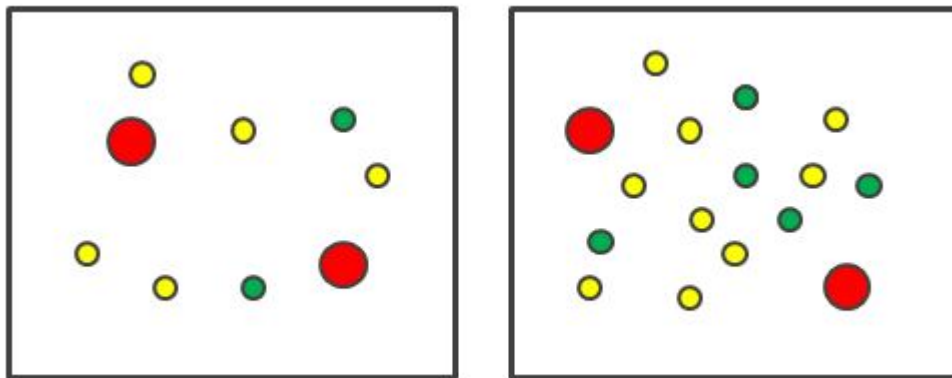
Figure 6.5: Inland Depot<sup>5</sup>

Figure 6.6: Amount of customers in network (red: depot; yellow: import customer; green: export customer)

for container storage. When there are high volumes at certain inland depots better rates could be negotiated. For inland depots free storage is a strategy to attract volumes to the terminals. When volumes are bundled also the capacity of barges could be optimized. This is difficult to distinguish with the current model since capacity is unlimited and costs are linear.

The answer to the second research question shows that storage costs have an influence on the total spend of a shipping company. In the case study storage costs are responsible for 33% of the total costs. Storage on deep-sea terminals is far more expensive than storage at inland depots and should be prevented as much as possible, difference of 58%. Merchant haulage has a big influence on stock levels and it will be an additional value to add the MH as input data in the model. The more customers available in the network the more containers could be reused. A good collaboration between the operations and customer service department is needed to gain maximum profit.

### 6.1.3 Research question 3

*In which way could a shift towards a higher modal share for rail/barge and a cost reduction of empty container positioning reinforce each other?*

This is an ambitious research question and with the model output hard to answer. In the model the input data of supply and demand is taken as fixed value even as transport tariffs. From a helicopter perspective it is easy to distinct opportunities to combine both aspects. It could be possible to attract volumes to barge and because all equipment has to be returned empty transport could be cheaper. It is also a possibility to have slightly higher truck tariffs for import trips. Empty equipment has to be returned and so sharper tariffs for repositioning could be negotiated. In the current rate agreements at Maersk Line these aspects are already in the tariffs. To answer this research question it is more interesting to look from a broader point of view and study the whole supply chain.

- A minimal change in the rates has big consequences for the modality choice. When the rates for truck transport from inland depot to customer decrease the modal share of barge and rail rises. This could be seen in the analysis of the scenarios. There is no linkage between the equipment (barges/trains) in this model but in practice these vehicles have to be returned to another location where the ship could be loaded. In case of container transport this is often the deep-sea terminal. In this way empty equipment could be returned with very attractive rates back to the terminal.
- In some aspects higher tariffs and rates will lead to a cheaper total solution. This could be seen in the scenario where storage costs decreased but transportation costs increased. At Maersk line a lot of processes are approached as a processes that stands on itself. But almost every process has influence on other processes. This could be the case when a container is not dropped to the nearest inland depot but transported a little but further towards a depot with a deficient. Transportation costs for empty transportation will be saved (2x). A better collaboration between departments is desirable.

It is hard to answer this last research question. It could be answered but the model created is not the best model to answer this question. A model with another scope, the total supply chain instead of one shipping company, will have stronger relations between the modal parameters and will provide better results. In the rate agreements of Maersk Line all aspects as benefits of economies of scale are already implemented. When the costs for operators are used as model input and capacities are taken into account a more realistic transportation network is created. It is wise to only include depots when they are beneficial (a minimum amount of containers per year). This will provide a better model output so a better analysis could be made. At the end of the thesis project the desired output of the model is a strategic advice, but some of the input information is more tactical or operational.

### 6.1.4 Central question

*How can a modal shift towards rail and barge transport contribute to cost savings in the hinterland transport operations of Maersk Line?*

In this last part the first subsection of the conclusion will be ended with the answer of the central question. It turns out that a combination of intermodal transport in combination with direct truck transport is the cheapest option. Cost savings in hinterland transport will occur due to lower rates for barge and rail transportation. When the sum of all costs for all legs and

handling costs is lower than direct truck transport, hinterland transport is beneficial. This could only be achieved in a network of inland depots and transport services between the nodes in the network. These inland depots could also be used for storage of empty container positioning since storage rates are lower than those at deep-sea terminals. The constraint of order deadline has a big domination in modality choice. When this constraint is loosened or truck rates drop from inland depot towards customer, costs savings in the hinterland will be higher. A positive effect is that multimodal transport is more sustainable than direct truck transport in most cases. This could be studied in further research by adding a sustainable performance parameter.

## 6.2 Recommendations

In the previous section the research questions are answered with the help of a model analysis. In this section some recommendations towards Maersk Line will be described, this is more focused upon the practice and also based upon personal experiences.

- The first point of attention is the intransparent rate structure. There is a difference between the setup of barge and rail contracts and the band rates of truck transport. The former uses fixed rates between a origin and destination. For every depot different costs aspects are included or excluded and every depot has its own surcharges. For example the handling costs, for some depots these are included in the rate agreement while for others these costs were excluded. The reason why the rates are so confusing is due to the negotiations in the procurement of all contracts in order to achieve minimum costs. Depot specific agreements could be set up for handling costs or storage. Nevertheless it is a disaster to create a model with such rates because it is not a good idea to process every little detail in an strategic model. A uniform rate structure is much easier to implement in a tool. For the planners an overview in one file is also better in order to have a good overview of the different rates instead of multiple rate sheets.
- The influence of the order deadline could be seen in the different scenarios. The amount of cost savings compared to the real world situation is difficult to give due to the assumptions made in the model. From the analyses of the scenarios it is clear that without the order deadline constraint the percentage of intermodal transports increase by 38.5%, with a cost reduction of 5.6% on transportation costs. In the model a transport is only executed by intermodal transport if the sum of transit times is less or equal to the time between arrival on terminal and delivery moment at customer, no penalty for late transports is used. It is advisable to do more research in this direction, particularly to filter the MIG customers and use better tariffs for truck transport from depots. With a better overview, if possible on the client level, it is know what is the space to negotiate with customer service about a new order deadline. For the model the order deadline could be modeled as decision variable. This could lead to some guidelines for customer service in selling the hinterland transport.
- The model created in this thesis project is part of the learning curve for modeling of freight transportation systems. In a demonstration the possibilities of the model are shown. In AIMMS it is easy to change input data. In figure 6.7 this is illustrated with a graph of the costs from a terminal towards customer. In AIMMS it is possible to select the bar and to move it upwards and downwards. For the management team of Maersk Line such a tool is quite useful to predict future situations. Now decisions are often based upon guesses and gut feelings. With a tool like this the effects of decisions could be better analyzed.
- The TLN planner is used for calculating distances. With the model created in the thesis all transports could be calculated in the most efficient way. With some more accurate costs

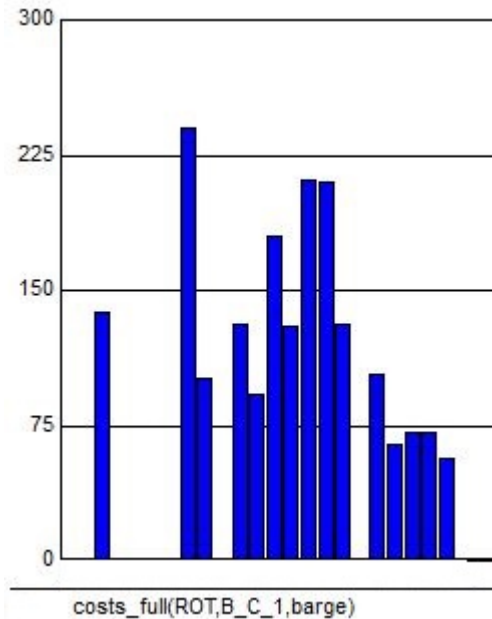


Figure 6.7: Easy change of input parameters

that include surcharges a tool could be made that automatically plans the majority of transports. Because of the rate structure of the barge contracts all costs could be included. When a route planner is combined with an optimization tool all transports could be planned automatically. Because the transport distance could automatically be calculated by Google Maps all information is known beforehand. It is not necessary that this is calculated by hand. The time the planners save by using this tool could be used to find good intermodal transport combinations.

- During the thesis project an interesting conversation with Simon Bosschier from Holland Container Innovations led to another insight in the collapsible container. During the whole shipping process a lot of cost savings could be achieved. Not only for the transport from hinterland back to the deep-sea terminal but also during the steps for transport back to the Far East. Especially for the CY product where a close look is taken at specific customers this could be an opportunity to run a pilot with the collapsible container. With the CY product the conditions for transport are more in favor of the collapsible container than with other transport products.
- Next to the business processes at Maersk Line it was remarkable to notice the difference between student life and working life. At Maersk Line the difference is bigger than I experienced at other companies. During my period as board member of WTOS I learned that a group of people are working as a group of individuals till they have a common experience. Such an experience could be the suffering in a race, adventures at a holiday or have some drinks in the pub. After such an experience a group of individuals is working as a team and in almost all situations this will lead to better results. For Maersk Line communication between departments is difficult. To have more common experiences will help to have also better communication during work. This will be beneficial for the business

processes. It is hard to build a good team with so many different people but it certainly will lead to better results.

## 6.3 Follow up research

There are many lines of approach for further research in the subject of modal shift and empty container (re-)positioning. The first section focusses upon the mathematical model improvements. It is explained which aspects are desirable to add to the model but are left out due to different reasons. In the second section it is explained which information and theories are missing more in general. Examples and guidelines for further research will be provided.

### 6.3.1 Remarks and steps for further research in general

A lot of literature had been studied for this thesis project. A distinction could be made between pure mathematical journal papers on the one hand and papers with more details about a case study. It was surprising to me that a combination with a very strong analytical model and a case study was not present. The first idea was to create a strong analytical model and combine it with a perfect input dataset. During the thesis project this was more difficult than it looked at first. Theory is different from practice and this occurs when importing the input data and the model is ran with large datasets.

The transformation of the mathematical model from paper towards software package is one step of modeling. To use correct input data is another important requirement for a reliable and accurate model. In this thesis project it is chosen to use the Maersk Line databases for rates, supply and demand and delivery windows. All these data systems are not ideal as described in the recommendations towards Maersk Line.

The perspective in the current research from point of view of a shipping company. This will result in linear cost relationships between an origin and destination, no capacity limits and no fixed costs for opening or closing depots. When a social point of view should be chosen other rates will be used. Than there will be a minimal load volume before a barge is more beneficial for truck and no depots will be opened with very limited volumes. It will be a additional value to study the problem from a broader perspective and give a best solution for the whole supply chain. Not only a shipping company will have benefits but also the customers or operators. In transport it is often that costs on the one side will lead to benefits on the other side. But costs will lean to one party and benefits to another. The total solution might be cheaper, or maybe more eco friendly, but because of the diversity of interests such a solution will not be chosen. It is preferable to study this problem without the perspective of someone with an own interest. From a social point of view this will be very valuable.

In the model created for Maersk Line there is no linkage between the full and empty container transport directly. It is assumed that capacity is always in the market. As always in transport, equipment (vehicles, railers, barges, trains) operate between an origin and a destination. Empty type of equipment has to be returned to an area where it could do further research in this direction, from a helicopter point of view instead of on a company basis since costs and benefits are not achieved at the same companies. From a global point of view both parties could benefit more.

Another interesting thing to study is to let the export demand for empty containers be a decision variable. For certain customer groups a demand will be generated. For the sales department of Maersk Line this could be interesting to see in which regions more attention has to be paid to



attract new customers.

In the first model setup multicommodity was included in the model by index  $p$ . This indexed is removed due to memory issues. It is interesting for further research to add this parameter in the software package.

As earlier said in this chapter it is interesting to change the minimal costs objective function for an environmental performance function. With usage of such a function practical information about the sustainability could be provided.

A last interesting aspect is the collapsible container. It will have some excess value to use this type of commodity in the network. Particularly on corridors with limited volumes and unequal container balance. At Maersk Line the CY product is set up to deliver containers towards a customer by multimodal transport. For these corridors a collapsible container might be a solution to serve customers in regions without export freight. The effects of such a collapsible box could be studied. With the attention for a low CO<sub>2</sub> footprint nowadays this might be promising.

To conclude this section there are multiple directions for further research. First of all the improvement of the model itself. This can be done by better modeling and more accurate input data. Next to this aspects as multi-commodity and a longer time horizon could be added. Other aspects such as multiple truck directions, better transit times and container reuse could be taken into account in the model when the AIMMS package was easier to implement. This is still part of the modeling. When looked at the problem from a broader perspective the scope in this research was Maersk Line. It is preferable to study this problem from a social point of view since costs and benefits are conflicting. This will lead to a better solution for society as a whole.

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# Appendix I: Research Methodology

In this chapter research methodology will be described; first in general, followed by a focus towards the specific thesis project. In section 6.4 the general research strategy will be described. Although this is not the key element of this thesis it contributes towards a good process for steps that have to be taken to execute accurate research. A good knowledge of research methodology will also help to avoid commonly mistakes made in previous research work; therefore this part is included into the thesis report. In section 6.5 an overview of general modeling techniques is provided with a link towards freight transportation modeling. This is followed by section 6.6 where data requirements are described. At the end the structure of research will be described, with the steps that will be taken to finish the thesis project.

## 6.4 Research methods

In this section an introduction into scientific methodology is given. The general concepts are explained and some definitions are given. In the last section the relation with the thesis project is sketched.

### 6.4.1 Scientific method

The scientific method describes how science should be executed, in theory. This method has been used for hundreds of years and is still under development. Science generates new knowledge with help of research done in the past and is always in motion. For different research fields (formal, empirical and social science) different research methods are developed. The origin has been found in the field of exact sciences, this is adopted by other research fields. Whewell (1837) has set up a five step scientific research method. These steps will be described below.

1. Formulation of a set of questions about a problem or process. These questions are based upon observations in real world and based on own experiences. In this step work of other scientists has to be taken into account to form a framework for the new research.
2. Set up a hypothesis. According to businessdictionary (2012) a hypothesis is : "*A supposition or explanation (theory) that is provisionally accepted in order to interpret certain events or phenomena, and to provide guidance for further investigation*". The hypothesis could be very specific, a distinction is made between a null-hypothesis and an alternative hypothesis. The null-hypotheses is tested whatever a conjecture of a statistical hypothesis met requirement  $y$ . The alternative hypotheses stated the desired output of research. A scientific hypothesis must be falsifiable, an outcome must be tested by criteria to examine if it is true or not.
3. Prediction of hypothesis. In this step a prediction method is selected for further testing of the hypothesis. The less likely this prediction the stronger the evidence will be.
4. Test of the prediction of hypothesis. In this step it is checked if real world conditions will behave as the predictions of the hypothesis. This could be done by experiments, observations and with usage of other models.
5. Analysis to study the results of experiments or observations. The predictions of the hypothesis are compared with the null-hypothesis, this can be done by falsification and

verification methods. In this step some statistics could be used to see how reliable experiment outcomes are, particularly when iterations are performed in the fourth step. New steps for research are also set up in this stage. In research it is important to prevent confirmation bias, people think in a way that they expect a phenomenon will be. For the thesis project about container positioning this is an important aspect since there are strong expectations in the business while there is no evidence for some assumptions.

All together those five steps form the scientific method set up by Whewell (1837). He concludes that the most important step in research is to formulate good questions. This will be kept in mind for the set up of questions for the thesis project at Maersk Line. Some definitions in the scientific method above are explained below.

### **Falsification & Verification**

In step five of the scientific method of Whewell (1837) a distinction is made between verification and falsification. The first term is a procedure to check if a process or system meets its requirements and specifications and for which criteria a theory can be proven if the outcome is fulfilled. The second term, falsification, is devised by Popper (1963). If it is possible to define criteria before an experiment to reject the outcome, than a theory is falsifiable. An example is the gravity theory, or the black swan pool. A theory is proven until evidence is found that it could not be true.

### **Validity & reliability**

Validity and reliability are important terms for accuracy of research. Validity describes if the outcome of research reflects the original problem. The reliability describes if a solution is consistent or not. This can be explained by some images shown in figure 6.8, based on Shuttleworth (2009). Four boxes are shown; the desired goal of each research should be in the middle of each box. The first figure shows a solution that is reliable, because the results are close together, but not valid. The second box has a low reliability (high separation of results) and low validity. The third is both not reliable and valid. This is in contrast to the last figure where results are reliable and valid. This is how the outcome of research should be (ideally).

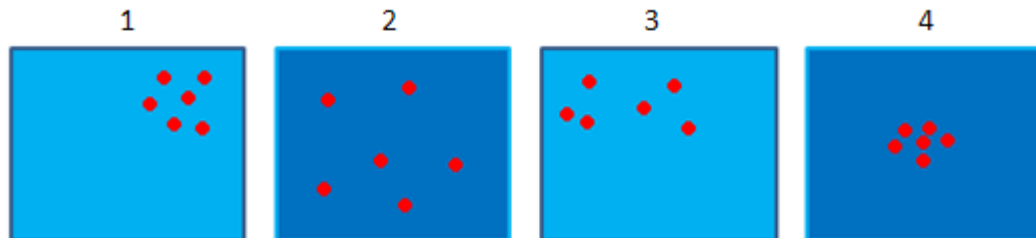


Figure 6.8: Validity & Reliability (own work)

## **6.4.2 Fundamental and applied research**

Research is executed in many different ways. On the highest level a distinction could be made between fundamental and applied research. The former has no intention for direct practical usage and is focused upon gaining new knowledge. The outcomes are often published in scientific papers. After a while fundamental research could lead to applied research. This has its focus for a more practical usage. The set up is often multidisciplinary between research fields. Results

are published in journals or could lead to new patents for industry. For the empty container positioning applied research is chosen. There is already some research done towards repositioning, although the application at Maersk Line is new and some company specific aspects are included, so this research project contributes to the research field.

### Hourglass figure

The process of an applied research project could be described as an hourglass. This concept is shown in figure 6.9, based upon Shuttleworth (2008) & Crawford and Stucki (1990).

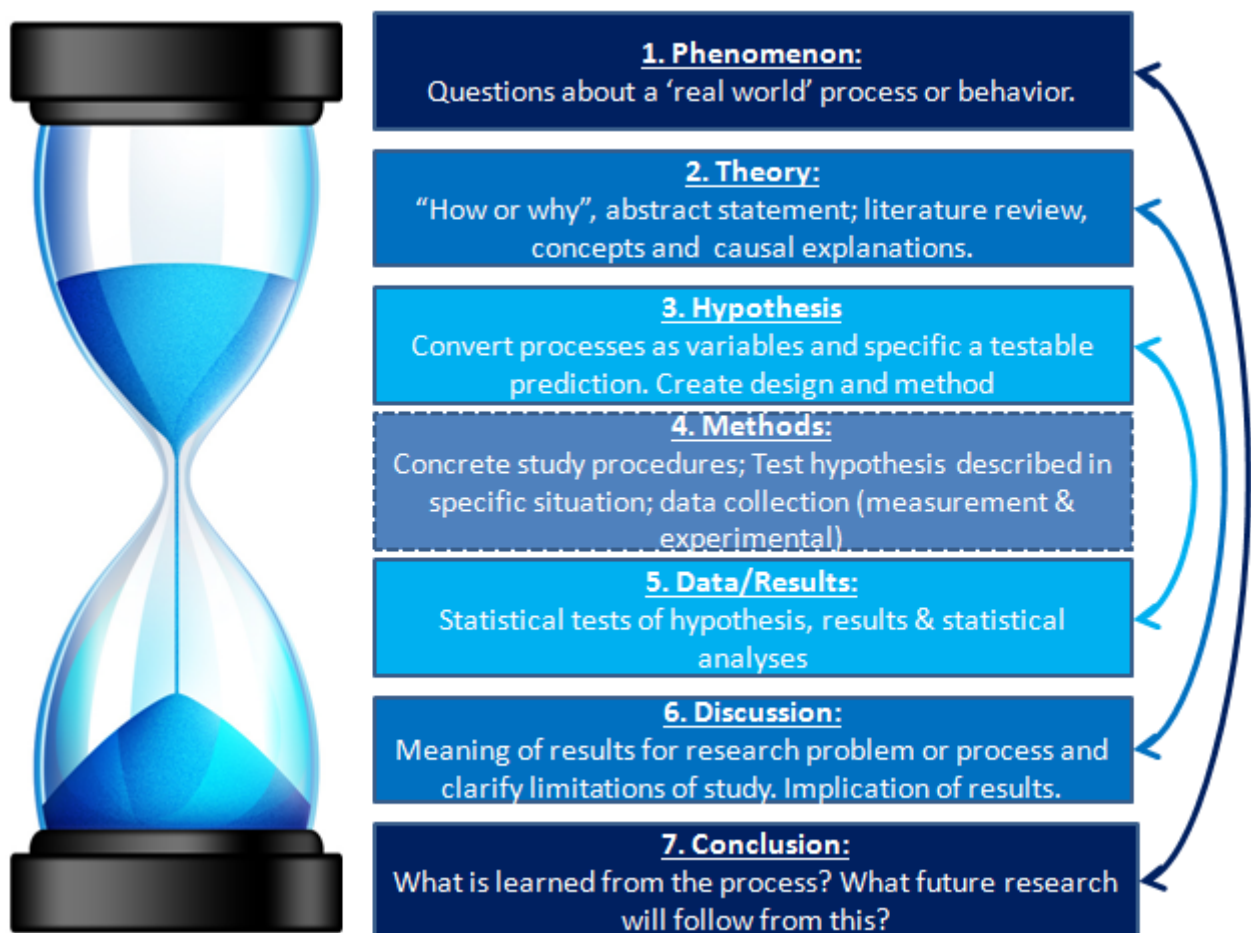


Figure 6.9: Hourglass figure of research (own work)

Research starts with a broad perspective of the problem and focuses upon an actual process or behavior. Literature will be used to find relevant information in the same field of research. With help of the literature study a hypothesis will be formed. In this stage the scope of the research is narrowed (follows the form of the hourglass). When the hypothesis is set up the hypothesis could be tested with measurements, experiments or model building. This will lead to a certain amount of data; this could be statistically tested with the hypothesis and will lead towards a discussion

about the implications of the results. After some steps the research will end with a broad scope with conclusions and recommendations. A proposal for further research will be shown.

In the thesis project all steps described will be taken. The first problem considered is transport of empty containers - high costs and no revenues. In the literature study other studies of empty container positioning are analyzed. Plus literature study will help to formulate a clear mathematical model. The literature will be used to learn which aspects should be included in the model and which should be let out or simplified. After this is done the hypothesis is set up, this will lead to the research questions. Then a model is built of the problem discussed in the upper box of the figure (1). The result of the model is a dataset about transports and empty container repositioning. Next, the outcome will be examined in a broader scope. At the end a conclusion for the empty container positioning will be given in step 7. If necessary steps for further research will be provided.

### **Research types**

Applied research could be divided in different types: exploratory research, constructive research and empirical research. Exploratory research focuses upon research areas that have not been studied before. This type of research helps to set up a new problem and is used if someone has new ideas in a certain research field. Constructive research is mainly focused upon the preparations for the setup of new research projects or new policies. The last type of research is empirical research where (in-) direct observations are used to test hypotheses. A side category is descriptive research where a lot of information and knowledge about a phenomenon is gathered it will lead to an up to date overview. This thesis project could be placed into the empirical research field because the recommendations will lead to changes in business processes at Maersk Line.

### **Primary and secondary research**

There are two research levels. Primary research focuses upon the collection of new data. Questionnaires, interviews, experiments or observations are used. This kind of research is in general very expensive because a lot of new data has to be acquired. Secondary research on the other hand also known as desk research, uses data gained from other publications. Data is already accessible before research starts. But before the data is ready to use some pre-processing steps should be executed. Because the data is already known this kind of research is less expensive. This is also the case for the project at Maersk Line.

### **Qualitative & quantitative**

In qualitative research the set up of hypotheses is very important. It gives insight in the way people think and can typically answer the 'why' questions. It could be used to find new ideas, background and motives. Methods used in this type of research are in depth interviews, group meetings and desk research. No quantitative relationships between observations are made. This kind of research is often used as a step up for later quantitative research.

Quantitative research is strongly associated with measurement. New data must be found such as percentages or size of a specific group in relation with a total group. Relations between quantitative properties are investigated. Statistics are important to check for relationships between different variables. Because measurement usually costs a lot of time and money, it is important to formulate research goals. A lot of methods for data acquisition could be used to accurately collect data. The thesis project at Maersk Line is quantitative research and data is processed with use of the model that will be built.

### Induction & Deduction

In research there is a difference between induction and deduction. In case of induction, a generalization is found based upon some specific observations. The conclusion is plausible with a certain probability. Induction is commonly used in qualitative research. An example for induction is that for the first process A holds, for the second process A holds and for a third process A holds. So for all different processes A holds, although there could be a process for which A is not holding but B is holding, in this case the conclusion is falsified. Statistics are important to prove that sample sizes are big enough to draw conclusions.

Deduction on the other side is more commonly used, particularly in quantitative research. It is often called a proofing technique. Assumptions are the basis of deduction. These are used to form reasons for which conclusions are logically. As an example, in general it is known that it will snow when it is raining when it is freezing outside. If it is known that it is raining and that it is freezing it logically follows that it must snow. For the thesis project deduction will be used. On bases of assumptions, that are the outcome of the model that will be built, logically conclusions will be deducted.

### 6.4.3 Summary research methods

In this chapter some of the most important research methods relevant for this research project are summarized. Since research already exists hundreds for years it is not possible to provide a complete overview. This is also out of the scope of the thesis project. First the scientific method based upon work of Whewell (1837) was described. Next to it the hourglass figure was explained. The processes in research are following the shape of the hourglass, starting with the problem definition and ending up with the conclusion and recommendations. In section 6.4.2 all steps are explained in more detail. The research for the thesis project at Maersk Line focusses upon empty container positioning and modal shift has chosen to be relevant research methodology to carry it out.

First of all the research that will be executed is applied science. It can be categorized as research. Because a lot of data is already known from the company the research falls into the category of secondary research. Because a model is built and this data is studied it could be classified as quantitative research. Deduction is used as argumentation technique.

## 6.5 Modeling approaches

In this section modeling approaches are explained. This section is divided into two sections. The first section focuses upon general issues. The second section is about modeling approaches at Maersk Line.

### 6.5.1 general

In all research fields modeling is very important. Modeling is the process of understanding the real world with help of a simplified model, this is a helpful tool to understand real world processes. According to businessdictionary (2012) a model is defined as: *"Graphical, mathematical (symbolic), physical, or verbal representation or simplified version of a concept, phenomenon, relationship, structure, system, or an aspect of the real world"*. There are different kinds of models such as scale models, maps, mathematical models, calculations for construction strengths and flowcharts to describe a process. Models are used because a full scale analysis is often too complex or too expensive to study.



A specific model type is a mathematical model. Such models are generally used in quantitative analyzes. The next five model choices have to be made to build a mathematical model:

1. Linear vs. nonlinear
2. Deterministic vs. stochastic
3. Static vs. dynamic
4. Discrete vs. continuous
5. Deductive vs. inductive

Although most definitions should be clear for the reader a short explanation is provided. The first choice is whether relationships between variables are modeled as linear or nonlinear. In case of a deterministic model all information is certain, for a stochastic model uncertainties should be taken into account. A static model does not have a time component; a dynamic model has a certain time component. Instead of a continuous model a discrete model has no outcome on every possible time moment (e.g. only measurement once a hour/week/month). The difference of the last item is described in section 6.4.2.

The specific model built for Maersk Line is a linear, deterministic, dynamic, discrete and deductive model. Some additional aspects are described in the section about model development, e.g. the difference between optimization and simulation models. In the next part a concise overview of the model elements is given.

A mathematical model, an optimization model in particular, consist of different aspects: The most important one is the objective function. This function describes what should be the solution of the optimization. An optimization model minimizes or maximizes a objective function. This choice depends upon whatever the problem is and what the user wants to know about the phenomenon studied. The objective function will contain different parts. There will be decision variables and (scale) parameters that determine the total objective function. Besides the elements in the objective function there will be other elements to build the model. The most important elements in a mathematical model are:

- (Decision) variables (state/random)
- Parameters
- Sets
- Constraints
- Operators

Important issues for model building are the objective and which aspects will be taken into account or not; this is the scope. Another choice is if a process should be modeled as separate system or as a system in total; maybe subsystems could be practical to use. Input data, section 6.6, will be very important. For a mathematical model it is important to choose the right model language and programs to build the model.

The setup of a good model is described in a concise overview. First of all information has to be gathered. Estimations of what has to be predicted with the model and what is already known. The second point is to sketch flow diagrams of all processes that are going on. Linking these flowcharts together might be a good idea to simplify processes. When a model already exists

there is no need to redevelop it, but all assumptions and the scope has to be totally known before it can be used. The next step is to handle data streams. This will be described in section 6.6. An important lesson is to start with a simple model before attempting to model the whole process. When this model is finished and outcomes are acceptable the model should be as simple as possible. This will improve computation time for a real world problem, and possible errors could be prevented. When a model is working it is important to check what the relation is between the variables. What is the relation between input and output variables? Which constraints are 'active' in the model? For the parameters used it is important how to estimate the values from the original data. A possible solution would be to link the data source with a set of equations. The model outcome has to be compared with a data set that is not used to build the model. This helps to prevent circular processes where input data affects the output data strongly. Testing, validation and verification are important steps in model development.

There are multiple reasons why a model will be built for the case of empty repositioning at Maersk Line. The first reason is the aim of Maersk Line to change the modal shift. The current situation at Maersk Line will be compared with a possible future situation. For the difference in figures possible reasons and relations will be tried. With the enormous amount of transports at Maersk Line an optimization tool is the only thing that would work properly.

## 6.6 Data requirements (general)

In this paragraph a focused overview of data requirements is given.

First of all there will be two main types of data, input and output data. The former is the data that will be imported into the mathematical model. This kind of data is the network used for the case study, different modalities, commodities, costs, order deadline and stock-level. The latter is the output data of the model. This is the information stored in the decision variables. It contains how much flow there will be on each different arc in which time period and how the storage will develop over time. In the next sections these aspects will be illustrated.

It is important to combine all data before a model is built. In most cases there will be gaps in the data sources. It is useful to think about such aspects before the model is actually built. Quantifying of the uncertainties within the data file is important.

### 6.6.1 Input data

For input data the expression *garbage in, garbage out* is self explaining. All data stored in parameters to optimize the transportation problem must be correct. In general an old data set is imported into the mathematical and outcomes are checked with real transportation data. Input data and the test data set must not be equal. Explicit data will be there in the form of transportation costs, accessibility, stock levels and network data. The validity of all these sources could be checked easily, although it could be time consuming to do this. The transport data on the other hand will be divided into regions; this is explained in section 4.1.5. It is possible to insert every customer as a separate node in the network but the extra work (notation of location and costs towards location) does not lead to a higher accuracy. Some regions are in districts where much more transport is expected (Ruhr area) so volumes will differ along each region. For a good comparison between regions the average distance from distribution center towards customer in that region should be about the same. If regions become too big it might be advisable to split them into smaller ones.

Because all data such as costs, stock levels, modalities and containers are explicit, the accuracy of splitting the customers, depots and other nodes into clusters determines the modal accuracy.

Beforehand no requirement of accuracy is given, this will be done after the implementation of the model. This will be done in chapter seven.

### 6.6.2 Output data

The mathematical model generates a lot of data. There will be a lot of nodes and arcs in the network and with the availability of three modalities the amount of decision variables will be about a factor three higher. The outcome of the model must be statistically significant. This means that the model outcome is no lucky guess but a previous hypothesis must be accepted. The accuracy of a statistically significant result is the p-value. With a p-value of 1 the result is based on luck, when the p-value is 0 the outcome is statistically significant. Normally a value of 0.05 is chosen. Because the model is deterministic each model outcome has the same outcome, this in contrast with a stochastic model. Multiple runs are not needed to achieve stable results. In case of a stochastic model multiple model runs would be needed. This not the case with the thesis project.

### 6.6.3 Structure for thesis project

In this chapter the research methodology has been explained. First an overview of the research methods and terms is provided. Further on it is explained what are the reasons for model development and in which way a mathematical model could be built. In the third part the data requirements are made clear. All these processes are relevant for the thesis project.

The idea of combining the aspect of modal split in container transport and empty container repositioning evolved from startup meetings. This is the first step in the hourglass, figure 6.9. This figure will be the framework on which the thesis project rests. The second step that should be taken is to search for relevant research work. Not only in the literature but also at Maerk Line a lot of information is available. In the third step, with the help of the literature study, the research questions could be set up. These questions are the basic structure of the research. In this step the freedom will be limited towards a minimum. At this stage, step 4 in the figure, the model will be built with the scope set up in previous steps. Literature will help to contribute to an efficient model building. All knowledge gained before will be used. When there is a model that is working in the way it can contribute towards a solution of the research questions, the project could continue to the next step in the analysis of the data and results. Statistical tests will be performed to check if the results are valid. The results will help to answer the research questions. Different scenarios could be modeled in which a cost uncertainty could be built in; an uncertainty in demand or supply or a new network design could be implemented. When conclusions are drawn and recommendations are provided it will be time to defend this project to the graduation committee.

## Appendix II - Literature overview

A lot of journal papers are studied at the start of the thesis project. From all articles the most important aspects are summarized. The overview is too large to include in the report therefore it is included in this appendix.

### 6.7 Learning from other research projects - modeling approaches

In this section several articles about model building are described, most of them focusing on container (re-)positioning. For the thesis project it is tried to find a represent set of articles that describe the current state in this research field. Besides the empty container repositioning some research about network configuration, the optimal length of time periods and empty vehicle routing are examined. All this research has no direct influence upon the model that will be built, but some lessons could be learned.

In this section other container allocation models are explained. They are grouped according to two different criteria, pure mathematical journals and more general container shipping businesses articles. Each section has the same structure. It starts with a description of the article itself. The most important and unique items are highlighted. At the end of the section the value to the thesis project is explained.

#### 6.7.1 Planning models for freight transportation

This paper, by Crainic and Laporte (1997), is cited in a lot of other articles that deal with empty container repositioning and freight transportation planning. Crainic indicates three classical decision-making levels: strategic, tactical and operational. In general strategic planning is long term planning, tactical planning is medium term planning and operational planning is short term planning, this will be explained more in detail in section 3.1.2. The level of freedom in planning is affected by each decision-making level even as the time planning.

Strategic decisions determine the general development policies and shape the strategies of a firm. Typical questions are where to locate facilities (depots and terminals) and which transport modes should be used. These are location models on the one hand and network design models on the other hand. The first one focus on locating different facilities to facilitate movements of goods. The second one, network models, are a generalization of location models. These networks consist of nodes and vertices and are connected with links. These are represented by arcs, which include multiple transport modes. Each arc could have different costs and transport times. Another point of attention mentioned in the paper is the regional multimodal planning. This is the impact of changes to the system. These are changes in new facilities since barge and rail transport always need an inland depot, quantities of moved goods and changes in communities. Finally government and industry policies are important, they have a strong influence on growth percentages in the future and relations between transport streams. This is not explained in the paper itself but the regulations around the modal shift for MV2 is a good example, even as tax levels for fuel.

The tactical planning problem has different dimensions. The first one is the service network design problem and the second one is the vehicle routing system. The first one concerns the difference between long distance transport and less-than-truckload. Vehicle routing consists of the routes chosen by a vehicle. Tactical planning appears as a vital link in the planning process

of a freight transportation carrier. The output of such a concept is a transportation plan to serve the day-to-day policies. The main decisions made at the tactical level concern:

- Service network design (route selection and frequency of services);
- Traffic distribution (routing distribution of each OD-pair);
- Terminal policies (efficient allocation between terminals);
- Empty balancing (empty vehicle repositioning);
- Crew and motive power scheduling (how to allocate people and vehicles for the next planning period).

One of the topics of operational research is transport planning, undoubtedly this is one of the examples of great success. In this paper different model set-ups based upon different levels are discussed. The paper was written in 1997 and since then a lot has changed in computation power of computer systems. The information described in this section is somewhat outdated.

An operational level is the third planning level. On the smallest scale this includes processes as such as human resource planning, truck operations, exact transit times, et cetera. A lot of detailed information is needed and the time period studied is very short, could be on minute basis.

For the thesis project it is important to distinguish the different planning levels. The case study will be executed in collaboration of Maersk Line. The department where the model is created is the operations department. For Maersk Line an operational model is very interesting and the mindset of a lot of people is directed into operations. The model that will be created is a strategic model. Some assumptions upon data usage and details of the network could be taken out. For example the gate-in movement data is available on minute basis, this is too detailed for a strategic model and will eventually reduce the model complexity. This has to be taken into account. The conclusions and recommendations are not an end to end solution for the planning processes at the operations department of Maersk Line.

### 6.7.2 A survey of optimization models for long-haul freight transportation

Crainic is mentioned in a lot of other research work in empty container positioning models. Crainic can be seen as one of the pioneers in empty container modeling. Two important aspects are setup by Crainic (1998). Firstly, three different planning levels for model building are explained. Secondly a basic mathematical model for container allocation is proposed. He focuses upon long-haul, intercity freight transportation. In relation with this thesis project this paper is useful for the choice of the planning level and the type of model. Also the mathematical model will be used as a reference for the mathematical setup.

Next to the planning levels Crainic (1998) provide a method for strategic system analysis. This focus is: strategic planning issues at the international, national and regional level, where the movements of several commodities through the transportation networks and services of several carriers are considered simultaneously. An accurate reader will notice that this is very close to the thesis problem formulation. The main components the author addresses are: supply modeling, demand modeling and assignment of multi-product flows. The first component is everything that makes the transport possible, so infrastructure, nodes and vehicles. The second component includes the shippers, consignees and demand choices. The last step combines step 1 and 2; the demand is assigned to the supply.

For the second step countries developed input/output models. Since the open borders of the European Union these statistics are less accurate. Another model used is the spatial price equilibrium model. CITE. These two types of models are used to set up an origin destination matrix.

Crainic stated that random utility models are used for mode choice. They are also widely used in passenger transportation systems. The question is if a freight transportation network could be compared with an transportation network. There is a big difference between passenger transportation and freight transportation. The former has to do with a lot of individuals who all have their own preferences and uncertainties. The latter is planned by planners from different companies. They have a better insight into networks and have to optimize the transports. The randomness factor should be a lot lower in case of freight transport than in the case of passenger transport. In the latter the uncertainty in route choice is much larger

When the OD-matrix is known and the mode is determined transport could be assigned to the network. Route mechanisms and network optimization models are named in this article. This is schematically shown in figure 6.10.

Lessons learned from this article in relation with the thesis project is particularly the clear

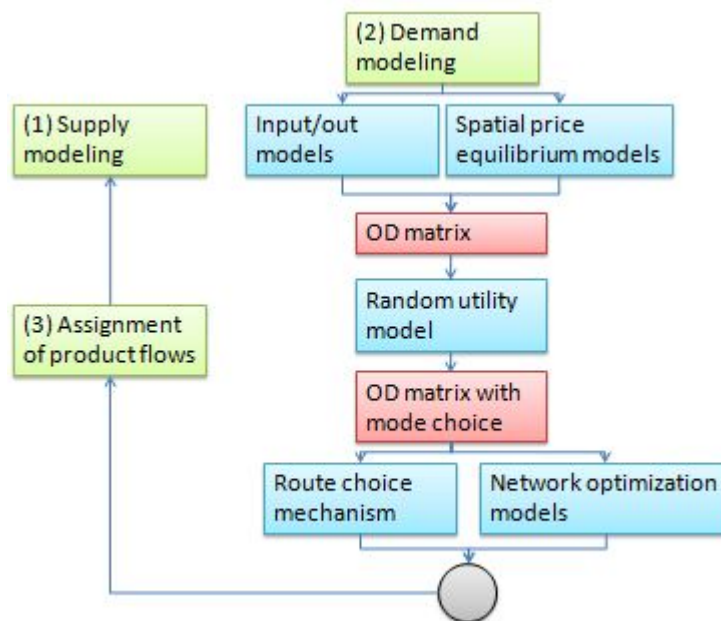


Figure 6.10: Flowchart of Crainic's model

overview of processes. At the TU Delft in the master Transport and Planning a lot of attention is paid in passenger transport. To create a passenger transport model is different from a freight transport model. But there are some equalities. From supply/demand a OD matrix is created, this will lead to a certain route choice and transports could be assigned to the network. This strategy will be used in the model development section.

### 6.7.3 Relation with branch-and-bound parallelization strategies

Bourbeau et al. (2000) present branch-and-bound (BB) parallelization strategies applied to the location and allocation problem with balancing requirements. BB is a widely used algorithm to find an optimal solution in optimization problems. Upper and lower limits are used to discard large subsets of candidate solutions, Land and Doig (1960)

A multi-commodity network flow structure is used to explain this method. The objective function

comprises fixed and variable costs. The bounding procedure embedded in the branch-and-bound algorithm is complex and time-consuming. Therefore parallelism is used by dividing the search tree among processors and performing operations on several subproblems simultaneously. The parallelization strategy is tested by a representative location/network design formulation with balancing requirements and multi-commodity (MLB). The general goal is to locate depots for empty container to satisfy customer requests while minimizing total operating costs. The mathematical model used in this case is derived from earlier work of Crainic et al. 1989.

In general this is a network with a number of terminals and depots. Flow is represented by volumes moving on arcs between these nodes for multi commodities. Supply and demand restrictions are taken into account for every node in the network. There is only one modality considered.

Two Lagrangian relaxations of the MLB may be used in order to efficiently compute tight lower bounds on the objective function. The upper bounds are determined by solving a location model with unlimited capacities. These values are used to determine the upper bounds. The conclusion of this article is that B&B algorithms could improve computation time of a model. Nothing is concluded about a better way of container repositioning. For the thesis project a good insight into mathematics is provided in this article. This can be used in the optimization program. It is interesting to read it because it is the basis of how to solve a model in a efficient way, although the focus is too much upon mathematics compared to this project.

#### 6.7.4 A DSS for integrated distribution of empty and full containers

In this article the setup of a decision support system (DSS) for full and empty container transshipment operations is provided by Bandeira et al. (2009). The intention is to build a DSS, or at least a mathematical model that describes the repositioning process, in this thesis project so in this perspective research could be useful. General by the mathematical model is interesting to learn how to formulate the own problem definition. The network used in this article consists of nodes and arcs. Nodes represent harbors, warehouses, customers and leasing companies and arcs the transportation routes. This is schematically shown in figure 6.11.

In circles the harbors and warehouses are shown, in the rectangle the leasing company. Customers are divided into four round rectangles, each for a role a customer could have (supply and demand of full and empty containers). With arrows the streams between the nodes are displayed. Direct transportation between customers is not allowed in this model.

Existing literature considered both problems of empty container repositioning separately. Combining both problems makes the problem far more complex but gives the opportunity for re-use of empty containers and thus more accurate and useful results. According to Bandeira et al. (2009) no optimal solution was presented so far for a total transportation network. The main contribution of this research according to the authors is combining models developed in the past. The mathematical formulation is based on work of Crainic et al. (1993), although there is no reference to that article. The objective is to minimize deadheading costs, these are the costs for empty repositioning, and full distribution equally. Constraints ensure that all transports are executed and demand is satisfied without running out of stock in depots. Only one commodity is assumed and cost functions are linear.

An unique aspect of this article is the decomposition of the model into a static and dynamic part. The former is a static model; this model is responsible for the movement and allocation of full and empty containers. This model requires input from the dynamic model and updates the forecasting of demand and supply of full containers. This model is based upon heuristic methods. This model deals with transportation time and transportation costs. even as futile

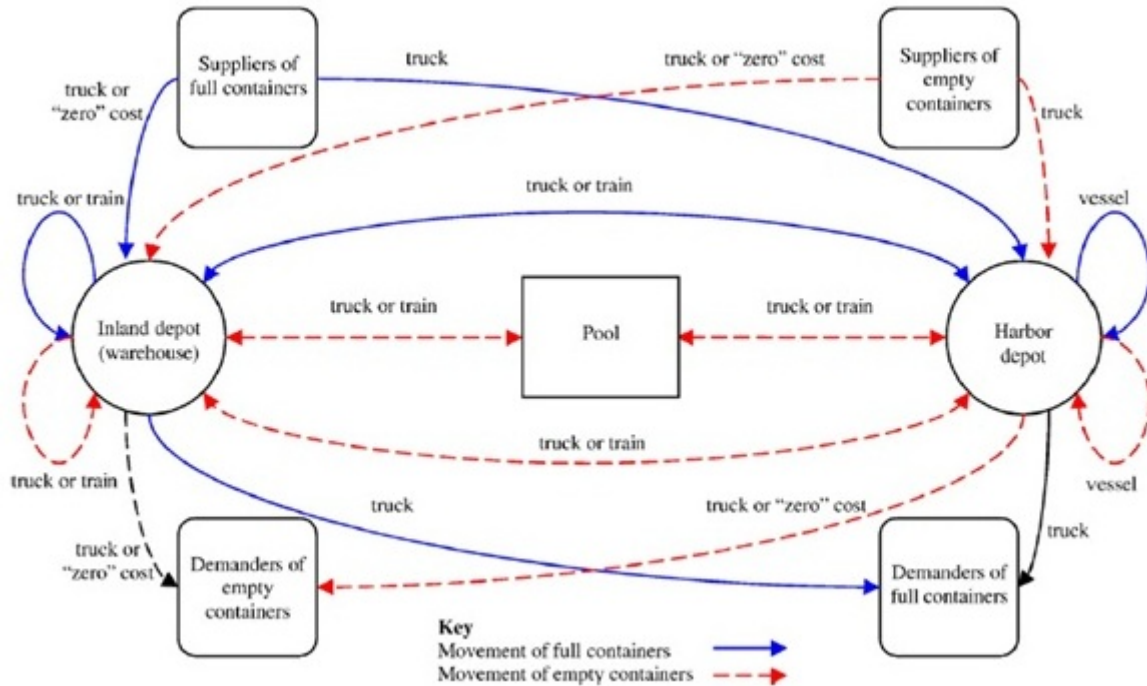


Figure 6.11: Overview of container flows between nodes

supply & demand. The authors indicate that full container allocation makes the model more complex since the origin and destination are fixed. For empty repositioning there is one extra degree of freedom (origin could be every depot with stock) and thus easier to formulate. Some of the most important parameters, decision variables, constraints and objectives are provided in the model formulation. An interesting part about the fixed origin & destination is not provided in the article. As said, the objective is to minimize costs for both empty and full container repositioning.

A disadvantage of the usage of two sub-models is that the static part is unfeasible because supply and demand of containers is unbalanced in a time period. Therefore a part of the demand in time period  $t$  is postponed to the next time period ( $t + 1$ ). The problem is which demand should be postponed to achieve the best model result. The following order is used:

1. ODD - Older orders have priority, retain service level;
2. ETC - Orders with lowest estimated costs have priority, goal cost reduction;
3. ETT - Orders with lowest estimated costs have priority, minimize flows.

The DSS is build in a Microsoft Windows environment, Lindo is used as the integer programming solver, this solver is not developed by the authors themselves but it is a commercial product. A simple case study is executed with a maximum of 8 customers, 216 containers and 50 time periods.

The conclusion of this article is that container allocation in real life is extremely difficult, particularly when both costs and service levels are considered together. In this model multiple transport modes and multiple commodities are not considered. Authors advise to use heuristics and decomposition to solve such models. During the modeling phase some variables are left out, with use of heuristics, to make the problem less complex. Surprisingly the authors did not



mention which ones exactly.

For this thesis project this article is very interesting because it also considers the problem of empty and full container allocation. Lessons learned from this article are that transportation networks are very complicated and complex to analyze. Some sub-problems even make the model more complex than others; for example the difference between fixed origin destination pairs for import boxes. The case study examined in this article is very simple, only one commodity and modality is modeled. Therefore this model is much 'easier' to solve than the proposed model in this thesis project where multi commodities and modalities are modeled in a situation of a larger case study with more movements, customers and volumes.

### 6.7.5 Positioning empty containers among multiple ports

In this article Moon et al. (2010) develop a model for positioning of empty containers with respect to leasing and purchasing of containers. Only empty container positioning is considered. Nodes in this model are called ports, it is not clear if these are deep-sea terminals or inland terminals. In figure 6.12 this process is schematized.

In figure 6.12 the situation of empty container positioning is described. Continuous arrows represent the empty container flows on arcs in the network, the dashed line the full containers. The container inventory is divided into two categories: owned and leased containers. In the figure these different categories are shown. The  $I$  symbol denotes the owned containers,  $L$  leased boxes. The inventory in the ports itself are showed with the arrows intern ( $I$  to  $I$  and  $L$  to  $L$ ). The arrows from the inventory from one port tot the demand node of another port represent the flow of full containers ( $I > D$  and  $L > D$ ). When containers arrive at the port of destination depends upon the transportation time. The costs of transport are separated in fixed and variable costs.

The mathematical model is to set up with the assumptions that no backlog is allowed. Capacity of vessels is unlimited and no limit to the purchase of containers is set. Different commodities are considered. The mathematical model is a mixed integer programming model. Two meta-heuristic algorithms are developed to improve the solving time of the model. The algorithm used to solve the LP problem is based upon a method developed by Pedroso.

In figure 6.13 the process of Moon is shown in a flow diagram. The amount of container demand is calculated. In the second step a check is done to see if all ports are considered. When this is successful the empty containers will be repositioned. In the figure below the flowchart the empty container positioning is shown. One remarkable point is that the containers are randomly assigned to the network while the objective is to minimize cost, in relation to container leasing, and every arcs has thus other costs. To plan empty transport as efficient the total costs for empty repositioning should be minimized. For the model simplicity this could be useful but it will not be practical in practice.

Different solving techniques are discussed in the article. LP-based GA and the hybrid GA are capable of solving problems of larger size. The hybrid GA is more efficient than the LP-based GA in terms of computation time. Solving a very large problem has detected some limitations of the model. Some simplifications could be made, this is done by omitting some constraints from the model. Omitting variables make the model less powerful but it dramatically reduces computation time. Heuristic methods could help to find a feasible solution without omitting variables.

For the thesis project this article is interesting because the mathematical model description is detailed. Although the attention to the problem of leasing boxes will not occur in the thesis

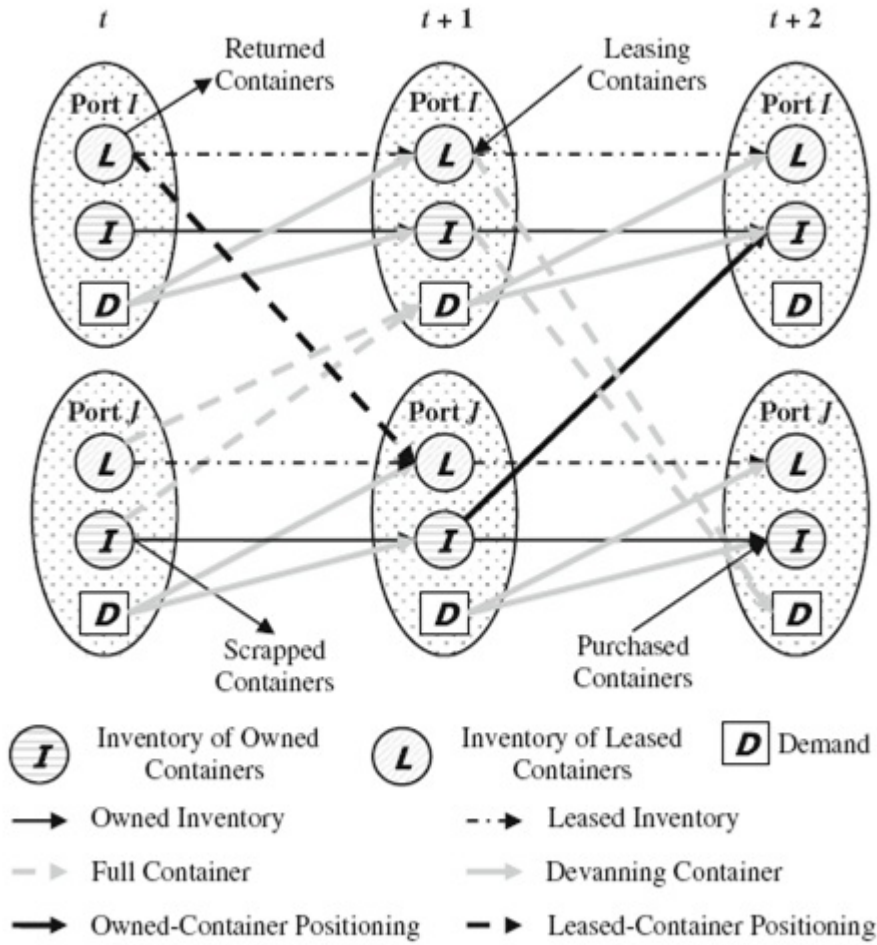


Figure 6.12: Container flow in different time periods

project, the basis will be the same. Even as other authors the complexity of this problem is huge and variables have to be omitted from the model. The focus of this article is at the mathematical solving process instead of a case study. An important lesson learned is to keep the model simple.

#### 6.7.6 An operational model for empty container management

Empty flows are not only a problem for container transport, for vehicle routing this presents also an interesting optimization problem. Olivo et al. (2005) reviewed and combined research done in empty vehicle transportation either as main subject and as a sub-problem of a larger transportation study. They conclude that efficient empty positioning has to do with decreasing the costs of empty transport while satisfying the demand adequately. Despite that repositioning empty (rail) vehicles container transport is characterized by different sizing, ownership or leasing, multi-carrier transportation, fleet sharing, Olivo et al. (2005) stated that other authors took a deterministic approach to the problem (dynamic in time). Another interesting problem mentioned by the author is that there is a lack of appropriate and reliable information about

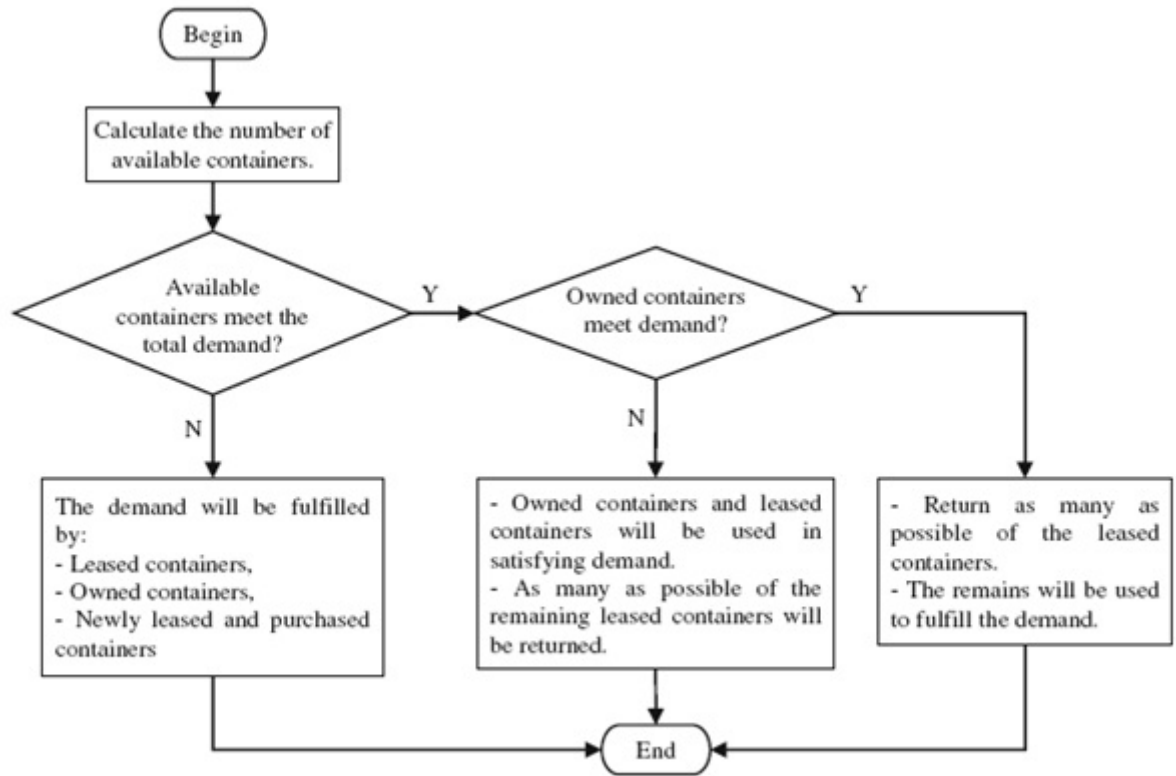


Figure 6.13: Flow diagram of container demand

the availability of backhaul transports. For all levels of operation it is better to approach empty repositioning as a combined problem, both loaded and empty. It is also recommended to include transit time between terminals for empty transports.

Olivo et al. (2005) proposed a mathematical programming approach for empty container management. An hourly time-step is used in a dynamic network. Two implemented algorithms are used to compile good results. Freight transportation has transformed from a port-to-port to a door-to-door service. Multi-modality is more and more important in recent years, particularly in a market of empty repositioning where origins and destinations are not fixed. Another difference between empty and loaded containers is the difference in economic value of time. Olivo et al. (2005) indicate some interesting aspects of the imbalance: commodity flow imbalances, vehicle specialization, inter company agreements and government regulation.

A deterministic dynamic multimodal network is presented for the operational management, this is work of Crainic et al. (1993). Olivo et al. (2005) uses a hourly time-step, he mentioned the importance of good quality data when applying a small time interval. An interesting point, particularly for the model creation in the thesis project, is the usage of dummy variables. When demand of one container type is greater than supply, dummy arcs are used. In this case it is known how much containers should be leased in the network. It prevents that the model stuck in a infeasible solution. A recommendation of the author is that scenarios could be used to

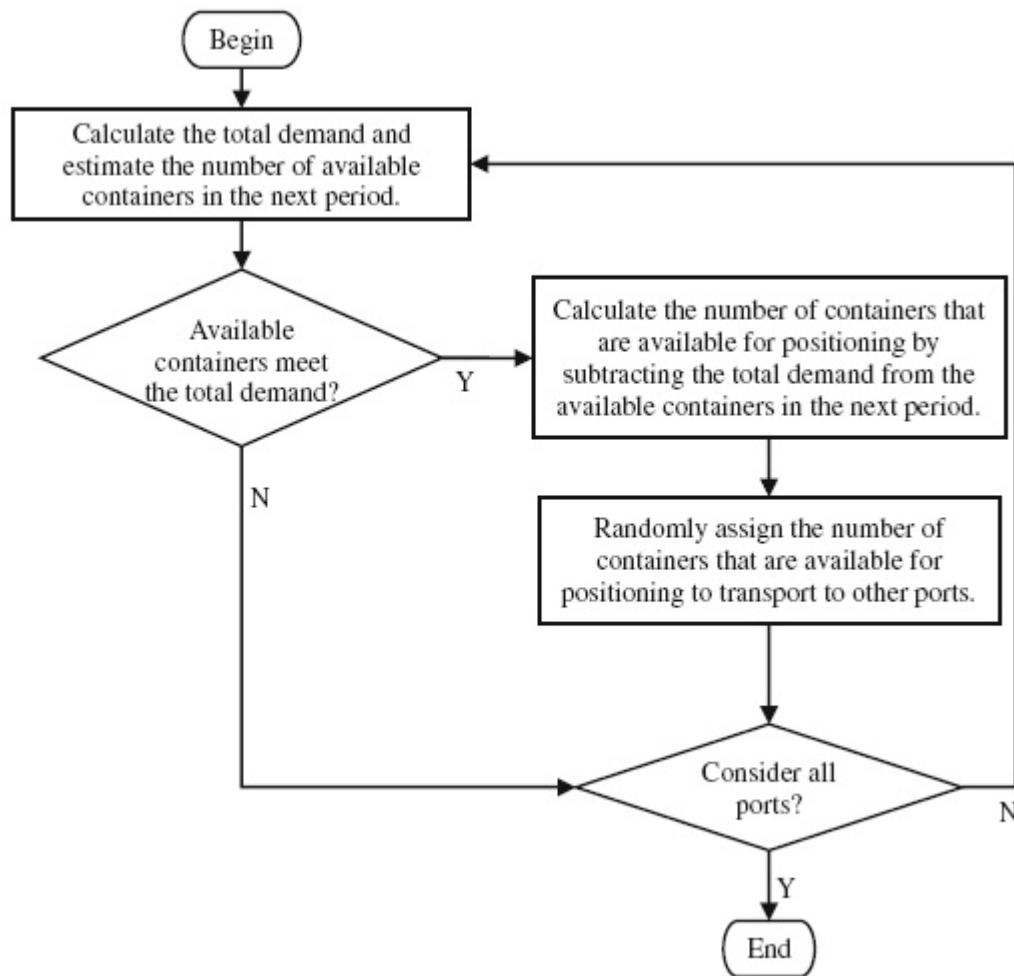


Figure 6.14: Flow diagram empty containers

represent a more detailed overview of the randomness in such a empty vehicle model.

### 6.7.7 The container shipping network design problem

This paper addresses the design of container liner shipping service networks in combination with empty container repositioning. Shintani et al. (2007) reviewed some literature and wondered why both subjects were studied separately instead of combined. The problem is formulated as a two-stage problem and a genetic algorithm-based heuristic is developed to solve this problem. For the container shipping industry this combination is interesting because there are a lot of investments into Ultra Large Container Carriers (ULCCs), see also section 2.3.2. Freight transport usually generates a significant number of empty movements. This amount will increase with the introduction of larger ships. Optimizing the containership routing by designing the network with respect to full and empty container transport is superior to dealing with two separate models.

Authors state that full and empty traffic is modeled separately because of the complexity of the model.

The objective in this paper, differently from other literature, is to maximize profit instead of minimizing costs. Decision variables are the optimal cruising speed, slow steaming is very actual nowadays, and amount of ships available in a service network. This is the so-called location routing problem. Assumptions made are:

- Demand for empty containers at a port, at a specific point of time, is the difference between the total traffic originating from the port and the total loaded container traffic arriving at the port for that specified time period;
- All cargo traffic emanating from a port is satisfied if a port is selected on route;
- In case of shortage this will be solved by leasing containers;
- Total loaded and empty containers must not exceed ships capacity.

The problem is defined as a Knapsack problem (definite). This problem contains two parts; the lower-problem and upper-problem. The former identifies the optimal calling sequence of ports. The latter chooses the best set of calling ports that associate with the calling sequence found in the former problem. Because the objective is to create maximum profit costs have an important role (since profit = turnover - costs). These are split in-between operating and capital costs. Besides the costs for shipping extra penalties are added in case of imbalances for repositioning empty containers.

An example in Southeast of Asia is appended. A small case with 5-8 ports within the trade area is used. The time horizon is 52 weeks, turnaround time is 21 days with ship sizes up to 2000 TEU (this is not deep-sea shipping nowadays). Handling and storage costs are 200/300 USD per TEU, for all ports the same figures are used due lack of data. All these figures make no sense in the actual container market.

Different scenarios are used to compare alternatives, with and without considering empty containers. Different penalty cost coefficients are used. Two cases, one with and one without empty container repositioning. The author conclude that the most profitable ship size is 1000 TEU. Case 1 (with empty containers) is more profitable than case 2. The main reason behind this was that there was a saving in handling time due reuse. Therefore shipping speed could be lower to handle the same volumes.

In practice there is a strong competition between shipping companies. Load restrictions are not considered in practice, inclusion of this load restriction is a direction for further research.

The case study used in this research is so different that it is not possible to compare the situation in Southeast Asia with Europe. An important conclusion is that empty positioning has a strong influence on the model outcome. This underlines the importance of a good container repositioning. Lessons learned from this article are the cost functions described. All relevant issues are include. This might be useful for the cost function in the model set up.

### 6.7.8 Modelling a rail/road intermodal transportation system

In this paper Arnold et al. (2004a) studied an optimal location for new rail/road terminals for container transport. The problem is solved by a heuristic approach. Hub network design problems are one subset of problems that have recently gained prominence in scientific research. *"A hub is defined as a nodal point for collecting, dispatching and redistribution of flows"*, Arnold et al. (2004a). A container terminal can be defined as a hub so the research to hub locations could be extended towards depot locations.

The formulation used is based upon Magnanti and Wong (1984) and based on multicommodity fixed-charge network design. The paper is written in 2004 and at that time computer systems had not sufficient resources to solve such systems. Therefore the authors use an alternative formulation. A terminal is considered as an arc in a graph instead of a vertex. This will reduce the number of decision variables in a dummy network.

As in many other the objective is to minimize transportation costs between origin and destination (no empty container repositioning included). Constraints used are that every transport uses two nodes (so there is intermodal transport). Some flow conservations are used to ensure containers will reach this destination in the model. Transfers could only be made at terminals that are included into the network. Transfer arcs are always bi-directional.

The heuristic used in this paper is noted as ITLSS (Intermodal Terminals Location Simulation System). Dijkstra's algorithm is used to determine shortest paths. Several additional indicators are provided by ITLSS:

- Total transportation costs;
- Modal split;
- Shortest path;
- Distribution of transport costs;
- Traffic load on each arc and through terminal.

A case of the Iberian (Spain + Portugal) multimodal network is used to test the model. Five scenarios are taken into account:

1. Variations in rail transport costs;
2. Variations in transshipment costs;
3. Technical international compatibility;
4. Location of additional terminals;
5. Optimization of the location of existing terminals.

The European road network defined by ECMT is used in this model as reference (in total 2191 arcs and 1745 nodes) railway (1706 arcs and 1745 nodes). There are 175 existing rail/road terminals. Every city with more than 50 000 inhabitants is treated as node. The OD matrix is made of 21816 OD pairs. Transportation cost functions also imply that transport units are always full (no return) and that the transshipment costs are independent of the quantities. The model results are discussed for each scenario:

1. For long distances rail is more competitive than road transport. With environmental bonuses rail could be promoted;
2. As guessed the modal share is very sensitive to changes in transshipment costs. This will mean that differences in transport costs are low;
3. New terminals have a very small impact on modal shares. Adding new terminals in the network lead only to an increase of 3% in the international combined traffic.
4. Location of additional terminals;
5. Reposition the nodes has no big influence.

Arnold et al. (2004a) concludes that intermodal transport can be a worthwhile alternative to uni-modal transportation systems. Especially for transports that are executed by truck nowadays barge en rail could lead to costs savings. The author stated that solutions are very sensitive to variation of the relative costs of rail in the case study examined. Consequences can be in terms of local congestion or changes of freight lanes is not considered.

For the thesis project this article is interesting because a network, in south Europe, is studied. Useful items are the scenarios named in this article. Some of them will come back in the model that will be created. Also the conclusions are interesting of this case study. Prior to the model development the results are in line with the assumptions set up by myself.

### 6.7.9 Empty container management for intermodal transportation networks

In this article Choong et al. (2002) studied the effect of planning horizon on intermodal transportation networks. A lot of research is done about planning horizon in production planning but little research is done about container management. Only simple research is already done in this field of study. Crainic et al. (1993) suggest an optimal time horizon of 10 and 20 time periods, but do not indicate how long a time period should be. It is important that all information available on the future supply and demand levels of empty containers should also be considered, even if there is a uncertainty in this information. Cheung and Chen (1998) conclude that a longer planning horizon is not necessarily better than a shorter one, in their research the results for a longer time period were even worse in comparison with a shorter time period for some test cases. Holmberg et al. (1998) concluded that the time horizon should be longer than the longest transportation time for all modalities.

The mathematical model set up by [authors] minimizes the total cost of for empty container repositioning. The basic structure of empty container positioning is adapted from the deterministic single commodity model by Crainic et al. (1993). The disadvantage of this model is that it does not include delivery windows, capacities are not recognized. Finally all costs are linear; in real life this will be different since barge/rail transportation have not a linear cost function.

Another assumption that is made in this article is that supply and demand is exactly known. The availability of containers is instant and dummy spots are used if customers want to store containers longer than 1 period. One commodity is taken into account and backorders are not allowed. The last assumption is that there are no repairs in the model so every container is always available.

A case study is examined for the Mississippi River basin, minimum transport cost is chosen as objective. There are three scenarios of 3, 5 and 7 container pools and 12 customer locations. Not all locations are used in all scenarios. Three different modes are considered: barge, rail and truck. An average transportation speed is used but handling costs on terminals are not considered. AMPL is used as modeling language and CPLEX as solver, these are commercial products.

The conclusion of this article is that a longer planning horizon can give a better result for empty container positioning in earlier periods. The reason for this is that slower transport modes could be better utilized. The planning horizon has to be at least the longest barge transportation duration. Three conditions are distinguished for a too short time period:

1. Concentration of the activities in the network: high variation in demand just after the end of a planning period has influence on the model performance (e.g. when in time period  $t$  after the last model period a new customer enters the market with high volumes);
2. Transit time of container movements: a model with a modality with a long transit time needs a longer planning horizon;
3. End-of-horizon effects: uncertainties at model end.

A recommendation by the authors is to do further research into the combination of empty and full container allocation in a single model. This is done, for example in 6.7.4, but the research has a fixed period length. The uncertainty in demand and supply could be taken into account, the effect of the first end of horizon effect in the list above.

For the thesis project this article is very useful. It is not the scope of research to check whatever time period is suitable but a time period has to be chosen. When the model is developed the three points of attention mentioned above could be used in the phase of validation and verification. With this information it can be said if a certain time period is not too short that results aren't reliable anymore.

#### 6.7.10 Research on the optimization of intermodal empty repositioning

In this paper the intermodal empty container repositioning of land-carriage is investigated with integer programming by Wang and Wang (2007). The objective is to minimize distribution costs on three levels: port to port, supplier to port and port to customer. An interesting thing is that the author predicts that the costs of empty container reposition will be beyond 50 billion dollars until 2010, no source of these costs is mentioned unfortunately. The author, state that not earlier problems related to time management have been solved yet.

In this article a mathematical model is explained. All parameters, variables, objective and restrictions are explained. The second part of the article is a numerical experiment. A network with five time periods, one port and one inland terminal is used. There are two customer clients, three suppliers who all have a demand/supply in only one time period. This is a very simple network and could be solved manually but Lingo is used as solver. Great for the mathematical overview but for the rest this article is not convincing. The conclusion of the author is that cost for empty container distribution is reduced, but for me it was not clear which point was the reference of the author. Lessons learned from this article is that it is possible to build a model that predicts something. But when applying the model to a case study there must be a relation between model and practice. In this thesis project the relation with Maersk Line is very important, this has to be taken into account. It is not that easy as it likes to combine both aspects.

#### 6.7.11 The effect of multi-scenario policies on empty container repositioning

This paper, by Francesco et al. (2009), presents a repositioning model with the application of a case study. On three points it contributes to the already existing literature. The first point is that different ports have been considered. Two types of with different restrictions are used for the ports (based upon different tariffs for storage and handling). The second point is to execute a case study with a data shortage. A set of scenarios is created to determine with decisions have to be taken. The last and third aspect is to illustrate the importance of policy changes. This provides more insight into future uncertainty.

An decision has to be made about the scenarios. Only negative aspects have been studied, no extra growth perspectives have been added, e.g. only when some political decisions are made that reduce transport volumes (for example additional VAT or other taxes). Another remarkable point is that the authors indicate all possible effects of multi-modality and multi-commodity. But at the end all these items are excluded from the model in small letters. This has a negative impact on the usability.



The conclusion by the authors is that shipping lines have a lot of choice in ship size and network design. It is up to the shipping line to choose which parameters should be considered, this is very important for the network design and ship size. The basis of the network design is the input for ship size selection.

For the thesis project it is an eye-opener that the three scenarios are explained. The first item of different rates for ports will be applied to all inland depots. Data shortage is not the case at Maersk Line, although this might be useful for an total market overview. At the end multi-scenarios regarding policies are important but they are subordinate to the changes in the economy, see section 2.3.1.

## 6.8 Learning from other research done - container businesses

In this section an overview of literature is given not about mathematical models but about the container businesses in general. The authors of previous articles focuses upon a market phenomenon and tried to formulate a mathematical model around it. The articles in this section also focus upon an interesting phenomenon in relation with the thesis project without a mathematical formulation. Also some literature about data in transport is included. This literature is useful to form a good overview of the container transportation market.

### 6.8.1 Container terminal operation and operations research

Steenken et al. (2004) describe and classify the main logistics processes and operations in container terminals. An overview of methods for terminal optimization is given. Neither this is in the scope of the research of empty container repositioning or modal shift but still it is interesting because the terminal processes have a practical influence on the model. Terminal operations determine handling time at the deep sea terminal and possibilities for storage. It is not necessarily to know the exact procedures but the basics are important to keep in mind. When all processes are clear this is also good to know the limitations from the shipping side.

The article begins with an historical overview in which growth rates are shown, in chapter 1 some of these aspects are described. The second chapter describes the terminal processes and all different equipment used on the terminal (cranes, AGVs and straddle carriers). In the third chapter optimization methods are described for terminal operations. In relation with this thesis project it is interesting to study which objectives and models are used. Although the objectives are completely different the modeling approach and reasoning might be useful.

The process that hits the scope of the thesis project is ship (un-)loading. There are three ship planning processes: berth allocation, stowage planning and crane split. The first, berth allocation, is important since not all terminal facilities are all over the terminal. In case of delays this could have big impact on handling times, since containers are stacked on the different terminal locations. Especially for barge and rail transportation this could have a big influence. The second, stowage planning, is split into two parts. Stowage on a deep-sea vessel itself and the stowage at a deep sea terminal. There is a difference between both operations. In the first situation it does not matter what is the destination of the container. If attributes are the same than containers are treated as if they are equal. On a terminal each container has its specific customer destination so here a distinction is important. The last one, crane split, is very interesting due to different objectives. One could be the minimization of the total delays or to maximize one ship's performance. When terminal and shipping operator have different interests

this could be harmful. Especially with the introduction of the ultra large container carriers, this is explained in chapter 2.3.2, this is an interesting point of attention. At the end the conclusion of the authors is that a lot of new challenges are ahead. Transponders and other useful tools could have big impact on a new optimization.

For the thesis project these terminal operations are not that important in the way of optimization. This article is useful to learn which processes occur on the terminals and which parameters are used for terminal operations models. With this background the input and output of the model (container stream from and onto the mother vessel) have a better background.

### 6.8.2 The social costs of intermodal freight transport

Freight transport is essential for the world economy but has a lot of negative side-aspects that are difficult to quantify. This paper is interesting because Ricci and Black (2005) focus upon the social costs of transport. From a shipping company point of view minimal costs have the highest priority. But from a social point of view other aspects are also important, such as minimal delay on the road network or noise hindrance. From a research point of view it could be interesting to investigate also a best solution based upon the social objective. One important remark is that this paper is written in 2005, since then a lot has changed for sustainability. A lot of these initiatives are based upon cost savings (since less fuel consumption means less emissions).

An interesting overview of costs is shown in figure 6.15.

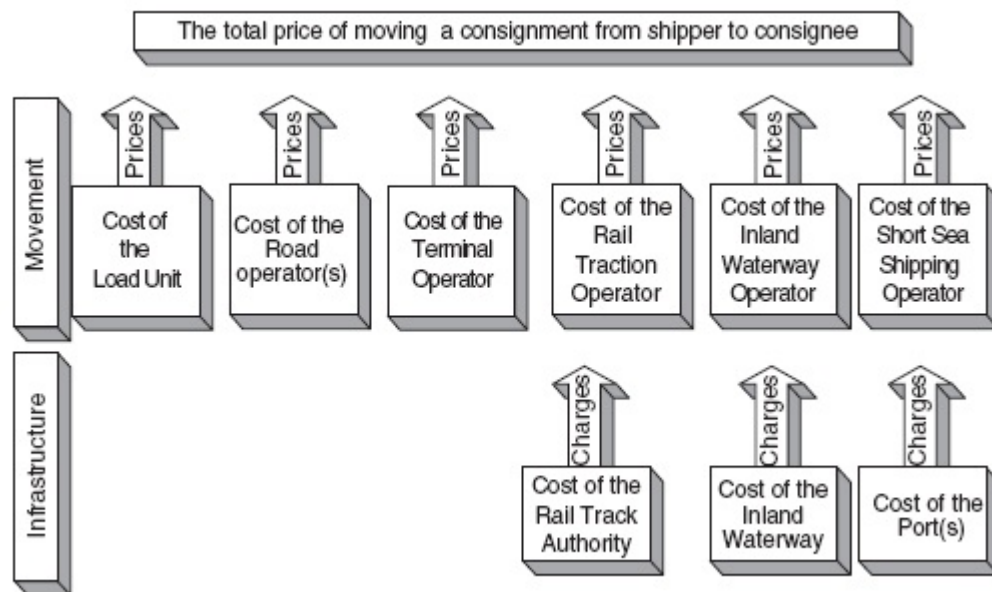


Figure 6.15: Overview transport costs

Not all aspects are relevant for the scope of this thesis project. A lot of simple assumptions are made because of the strategic model approach, this is explained in chapter 6.7.1. For example a short distance transport is relatively more expensive than a long distance transport

distance per km and has relatively more emissions. The conclusion of this report is that it is very complicated to determine social costs due to the large number of components, variability of costs and different locations. Although it is found that full internalization of external costs will lead to a benefit of intermodal transport, no figures are given to provide a prove for this, but it is said that intermodal transport is more sustainable, this confirms their assumption.

In relation with the thesis project no quantitative data could be provided with this research. The model that will be created in the thesis project minimizes transportation costs. In most cases with a minimum transportation distance barge and rail combined transport have more costs compared with truck, due to extra handling costs. In line with ethics it is important that this alternative is not harmful for the environment.

### 6.8.3 Intermodal freight transport on the right track?

One of the challenges for the project is to find a way to describe sustainability in a mathematical way if something has to be concluded about sustainability of transport. This is not an easy task because a lot of data is used in black box systems that are used for Life Cycle Analysis. It is very expensive to collect data about emissions, and moreover often data is secured because calculations in such systems can have big consequences.

In the work of Kim (2010) a lot of work is done to try to find  $CO_2$  costs per km. There are a lot of variables that influence these figures, the author concludes that there are a lot of uncertainties. Therefore simplifications are made and data loses its reliability. This is not a good basis to use in an optimization model as objective function.

This report is interesting for the model that will be created. Not in the way of contributing to useful figures that could be imported into the model but in the way that environmental data is difficult to achieve. This is a separate study so it will not be included in the thesis project.

### 6.8.4 A review of intermodal railtruck freight transport literature

Bontekoning et al. (2004) reviewed 92 publications related to freight transportation to identify the characteristics of the intermodal research field. The goal of this review is to seek directions for future research. For the thesis project it is interesting to read this paper because an overview of the actual state is given and directions for further research are indicated. This document is set up in 2002, this date has to be taken in mind when reading this article. Since then computer systems became more and more powerful so restrictions formulated in this article could be solved nowadays. Further on is the network design of a lot of container carriers changed in the last decade. The amount of inland depots increased rapidly in combination with extended gate concepts.

To give a summary of the article in the literature study will not contribute to a better solution. Although the conclusion is interesting, in 2002 the modal split research was still in a pre-paradigmatic phase. Small research groups are studying different processes. A better cooperation is desirable according to the authors. Nowadays this has changed as there is more collaboration but still shipping companies work on their own. Only freight forwarders combine containers from different terminals to one end location. Another point figured out is that more attention has to be paid to barge-road and short-sea-road combined transport, but very specific for certain corridors where volumes are high. In the last decade a lot of work is done in this field and nowadays there is a network with inland depots for rail and barge.

For this thesis project it is interesting to see that since 2002 some questions are answered. There is an inland network of depots for rail and barge and better collaboration. Although there is work to do, the network given could be optimized and there are still containers transported by truck which could be transported by rail and barge. With the larger performances of computer systems these problems could be analyzed.

## Appendix III: Model verification and validation

In this chapter the model verification and validation is described. The former is the process to check if the model is programmed correctly, if algorithms are applied in the right way and to check the model for bugs and mistakes. This is not a test if the model has a result that is in line with the problem stated before. The latter, model validation, is the check the model outcomes are in line with reality. Is the outcome of the model as it had to be and in line with processes at Maersk Line. This will be done with a check with current Maersk Line transport data and a presentation for a team of specialists. At the start of the thesis project there was an idealistic view on how a business process could be transformed into a model that describes reality perfectly. After the literature study and the first attempts to program an optimization model it looked harder than expected to fully describe the reality. The structure of this chapter is divided in two parts. The first focuses upon different aspects of model verification and the second part on model validation.

### 6.9 Verification

As noticed in the introduction the model verification is the process where the model is tested to see if the model is programmed correctly. A general rule is that it is easy to test a small model, large models are very hard to verificate since many processes influence each other. So the first verification steps are made with a small data set. Such a model could be solved on the back of a cigar box or scratch of paper by hand.

The strategy of the model verification process is to first test the model with a small data input. It could be tested if all constraints and variables work in the way it is expected. To force the model into one direction a change in input data was made or certain parameters were left out of the model. After every change the model was compiled and optimized again to see if results were still in line with the model requirements. When errors or mistakes were detected the model was improved in that direction.

The first variables that are checked in the model are the decision variables that represent the volumes on arcs in the network. When all these flows met specific requirements the stocks levels are set up and checked. After this step another check on the decision variables of the arcs is made to make sure these were still correct. After the check upon stock levels the order deadline constraint is implemented in the model and checked. When all these aspects worked properly the whole model was removed from unnecessary ballast. For testing purposes a lot of extra parameters were added to see the effects of measures. At the end this simple model was tested with a lot of different input scenarios to force the model into specific directions. Everything worked fine. The test network consists of two nodes, three inland depots and four customer locations. Only one commodity type was used and during testing other commodities were added. Six time periods were used during testing, excluding the first start up period. Network design, demand data, costs and transit times were not based upon Maersk Line data for the test network.

Not all changes in the model during the verification phase will be described in this chapter because most of them were just simple programming errors or ignorance of the optimization software. Some highlights are picked out in the next sections that were difficult to solve in the software.

### 6.9.1 Full container transportation - begin terminal

One of the requirements of the model is that a full container transportation has a fixed OD pair. When a container is unloaded at the port of Rotterdam it has to be transported with this port as origin location. In a general network optimization model there is a supply and demand. For example five factories have a certain production and 20 customer locations have a certain demand for the same commodity. The model has to find an optimum between those two parameters. In this case study there is not a uniform supply of goods. In a path based network model it is easy to add an extra constraint since the origin and destination is in the same decision variable. In case of an arc based model there is more freedom and the origin and destination do not have to be a supply and demand pair (when an inland depot is used). To solve this incorrectness multiple solutions were tested which all failed at a certain moment during testing. A simple idea was just to set the amount of outflow of containers of commodity ROT for the ports of Antwerp and Zeebrugge to zero. All containers of commodity type ROT have to be transported from the port of Rotterdam. The same constraints could be added for other streams, resulting in six additional constraints. This solution worked well for every constraint individually. When all constraints were added simultaneously the model had an infeasible result. When the constraints were removed the model still had an infeasible solution. The reason never showed up, the only variable that was affected by this constraints was the flow over arcs, with each execution these arcs were reset so it is not clear why the model failed to solve. The eventual solution was to add an extra index in the accessibility constraint for commodity type. Only transports with commodity type ROT are allowed for the deep-sea terminal of Rotterdam, the same holds for other terminals.

### 6.9.2 Stock levels + time periods

Another big problem occurred while the stock levels were calculated. To calculate the stock levels only integer variables are used. But the result of stock level was not an integer value. After a lot of checks and adjustments of input data it appeared to be an issue with the amount of periods in the network. The horizon  $t$  included all time periods. This horizon was bound by the maximum amount of periods in the model and the chosen amount of periods in the model. But a startup period (initial period) was used to let the model start up and fill with all basic data before the first time period. This was done due to lessons learned from literature. After removing this initial period the stocks were calculated as integer values. The lesson learned is that no special exceptions should be created in the model. When all time periods are the same someone could find out that the first period is different from other periods, no special time periods should be added. This makes the model unnecessarily difficult.

### 6.9.3 Order deadline and modality choice

The third big issue is the order deadline of the model for full container transport. The model uses decision variables for the different arcs. So for full container transport the decision variable  $flowoverarc_{full}(i, j, m, p, t)$  is used. This means that every transport between  $i$  and  $j$  could take place with respect to the constraints in the model. For example the barge move from a transport from Rotterdam to NLC (customer cluster in the Netherlands) consists of two parts. The first part is the barge movement from Rotterdam towards Utrecht, the second the truck transport from Utrecht towards NLC. There is no linkage between those movements. The first transport leg cannot be executed without the last leg and vice versa. Therefore it is not an option to easily sum up the transit times and compare them with the order deadline. Only for direct transports this method will hold, and thus no arc based network should be used but a

path based network. A solution was to use some algorithms used in vehicle routing problems. These algorithms were difficult to implement into AIMMS, especially due to the random crash moments of the software. In theory it is very clear that the total transportation time between terminal and customer should be smaller than the amount of days available between the arrival of the container at the terminal and the moment expected by the customer. To apply this theory in practice was more difficult.

A solution was to gather all transit times together in the last transportation leg from inland depot towards customer. In that case only transports from inland depot towards customers should be checked for order deadline. And with the available data this was possible because the order deadline is linked to customer location. For the example started above it means that for the leg from Utrecht to NLC the total transit time was taken into account (thus including the time to transport a box towards the inland depot).

This worked all fine but a new problem occurred when also the rail constraint is added to the network. For the same leg ( $d$  to  $c$ ) the same transportation speeds could be used (barge or rail). In practice AIMMS always selects the longest option. Therefore it was not possible to use the alternative proposed before. An extra value is added to ensure that only depots are taken into account where a modality is used. This is done by only selecting depots used by the specific modality.

#### 6.9.4 Testing of input data

Since the 'first' model was tested a lot of issues showed up, but they all could be solved. When the model ran smoothly with the standard data input the model was tested with extreme values. Transport tariffs were some extreme input values, used to check if the model holds for these extreme conditions. Some additional problems were solved in this phase. An example from a model error was the transportation of containers throughout the network without a demand. In that case no storage costs had to be paid.

#### 6.9.5 Testing with a large dataset

After the small model was running correctly the input data was changed from a test data set to a real world dataset. Because all information is gathered by hand a lot of reading errors occurred. As an example the name of inland depot Utrecht was the same as customer location Utrecht. This led to errors in the truck tariffs which led to an infeasible solution. After adjusting the name of the customer location this problem was solved. Some values were multiple times allocated in the model when special truck tariffs were agreed between terminals.

When all input data was read by AIMMS in a correct way the model could be executed. First of all input variables and constraints are read by the software package. A total number of individual constraints is listed in the model as well as the amount of variables. Distinction is made between integer and continuous variables. Also the amount of non-zero coefficients is displayed, these are nonzero coefficients in the Jacobian matrix, this is a matrix with first order partial derivatives. Next to these numbers the type of model is recognized and if the solver has to minimize or maximize the objective function. This is information used by AIMMS to feed the solver. For this purpose the commercial CPLEX solver is used. During the solving process the amount of memory used by the software is shown. At the end if a feasible solution is achieved the amount of iterations is shown. In figure 6.16 the result of a test run is shown. The model type is defined as MIP, this is the Mixed Integer Programming solver. The objective function consists of linear equalities and inequality constraints. One of the requirements is that a part of the variables are

required to be integer. These are all decision variables since containers could not be divided. The first executions of the model were made with limited time periods to ensure computation

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```

AIMMS      : thesis_better formulated.amb
Executing   : MainExecution
Line number : 11 [body]
Math.Program : leastcosts
# Constraints : 3695209
# Variables  : 5529144 (4718196 integer)
# Nonzeros   : 54457685
Model Type   : MIP
Direction    : minimize

SOLVER      : CPLEX 12.4
Phase       : Postsolving
Iterations   : 3547
Nodes       : 0          (Left: 1)
Best LP Bound : 1280097.25 (Gap: 0.00%)
Best Solution  : 1280097.25 (Post: 1280097.25)
Solving Time  : 47.24 sec  (Peak Mem: 3013.6 Mb)
Program Status : Optimal
Solver Status  : Normal completion

Total Time   : 174.50 sec
Memory Used   : 5712.2 Mb
Memory Free   : 4366.6 Mb

```

Figure 6.16: Overview solver AIMMS

time was limited. While the amount of time periods increased to one month the model was not able to solve due to a high memory usage.

In some cases the model was not able to solve a certain dataset with time horizon  $t$ . When all data was erased and the same constraints, parameters and variables were used the error still occurred and the model was not able to solve. After a reboot of the whole system the model in AIMMS ran smoothly with same input data and without changes. Probably this is caused by memory issues in Microsoft Windows. It was tried to clean up the model with unnecessarily variables. Next to have the model as clean as possible the CPLEX settings are adjusted. Particularly the phase of copying the data from the solving process to the postsolving step, in which all variables that violate bounds are rounded to nearest bounds. This step will have a big influence on the computation time. When adjusting some parameters in the CPLEX algorithm the model was able to give a solution.

When all time periods are included into the model the model was not able to solve again. After installing some new memory modules the model ran better. The 32bit version of AIMMS could only handle 4GB of memory. This was not sufficient to run all time periods, therefore the 64 bit version is used that supports 8GB of memory. In the first runnings still some errors occurred. CPLEX was not able to copy the solution found in the postsolving process. The solution was to adjust the solver settings with the error the model came up with. Meanwhile some vague errors occurred which were solved by rebooting the system or with some bad luck so that after a few tries of opening the model it suddenly started working. After a validation step of the input data the model stopped working again. With the warning given, AIMMS is not able to give a



solution, not much information was provided to solve this issue. Learning from literature begin and end periods were examined. The presumption is that there are some memory problems with writing and reading of data. The math program inspector was used to check if there were some infeasible constraints but all constraints were feasible. After reducing the amount of time periods the model started working again.

At the end importing the real database into AIMMS was the starting point of a lot of miseries. Instead of programming faults that have the origin in the person who created the model this were software problems that were hard to understand.

## 6.10 Validation

After the model verification the model validation phase will be entered. It is checked whatever the model is in line with the real situation at Maersk Line. With the feedback from experienced specialists at Maersk Line it is possible to see if strange patterns occur. With the help of this feedback the model parameters could be adjusted.

The first change in the model was that it turned out that multiple barge legs were used for one transport. In practice this was not happening. After a check of the transportation costs, it turned out that handling costs for certain depots were not included in the tariff structure. When these handling costs were added it turns out that only one barge leg was used.

Another mismatch was that all containers were returned to the port of Antwerp instead of Rotterdam or Zeebrugge. This was an error in the input data for empty container costs that were too low for the port of Antwerp. After adjusting these values the problem was solved.

## Appendix IV: Evaluation

In this chapter an evaluation of the thesis project is given. It contains three sections. In the first section the most important lessons learned and new software packages will be explained. The second section focuses upon the general process during the thesis project, the last part upon the modeling processes in detail.

### 6.11 Lessons learned & new software used

The most important lessons learned in this thesis project is to use a good structure. For every little subprocess this will contribute to a better final result. Before a new model should be created it is important to draw a sketch of the situation with all important aspects into it. On a scratch of paper the basis model structure could be created. In such a phase it could be checked if the input data is in line with the requirements for this data. The data processing will also be much easier through a good structure. Before the thesis project I had no experiences with such a big model with all freedoms. To pass through a first project is the best way to learn for future projects.

Next to the lessons learned in the modeling process a few new software packages are used. The most important package is AIMMS that is used to create the optimization tool. Next to AIMMS one of the daily software packages was LaTeX to create this report. The combination with JabRef is very practical to create the bibliography and maintain an overview of all references. Next to these new software packages MS Access and Excel is used a lot to do the preprocessing and to create datasets for the model. The language of SQL is used in combination with MS Access and some simple macro's and VBA is used in MS Excell.

### 6.12 Learning process

. Starting with the thesis project could be compared with a parachute jump. After the first start-up meeting everyone is enthusiastic about the problem and expectations are, as always, on a high level. On this high level a skydiver jump out of the plane into the infinite air. There seem no limits; everything is possible and falling speed is very high. This is the same as starting with the literature study, no borders or signs to guide someone in a good direction. At the same moment I started to look out how to build the model, which data sources are available, how should I describe such a problem in a mathematical way and which software should I choose. The scope of the thesis project is very wide and a lot of areas seem to be important and interesting for the thesis project. Apart from the thesis project there is a big change in daily living and habits when working at a company. Freedom to do everything on your own way will be limited. The study environment is different from an the library of the TU Delft, a lot more distraction by other people walking around, talking and so on. An important lesson learned is that studying at a company, a busy social life and trying to compete at an acceptable level in road cycling is not possible. Not only for me this was difficult but I heard same stories from other students. Talking to other students also busy with their graduation process is always interesting. After a while you recognize the same struggles in other projects. Back to the skydiver, at a certain moment the air resistance is equal to the gravity force. Acceleration is zero and no change in speed will occur.

To prevent from crashing into earth he opens his parachute. In the thesis project I was struggling with the optimization software and reading a lot of literature. Together with trying to write the

mathematical model I was doing stuff but unstructured. But luckily also for me the parachute opened. With a better structure and better definition of goals it was more easily to work towards an end product. At a certain point the literature study was in an advanced stadium, the mathematical model was described in big lines and the optimization software optimized a problem with some outcomes. It was known what kind of works has to been done to achieve the goals of graduating. Since I am not an IT student it was hard to translate the mathematical problem from the sketching table into the computer software. I had in mind how the model should work but without the experience of the software thing were not running as I wished. Without anyone using the same software in my region this was not very motivating for the study progress. Although it was possible to solve the optimization with some dirty programming tricks I tried to solve the problem of network flows in AIMMS in a neat mathematical way. Finally on Boxing Day sitting in the intercity between Zwolle and Amersfoort AIMMS was finally cracked and I found the solution for the network flow problem. When thinks are working on the way you want, and the way you have in mind, it motivates to put more effort in the project.

A skydiver has a moment between opening his parachute and flying into the direction where he wants to land. From that moment on he has very limited moving space and his path is known. For me the moment of fixing the model in the way it come close to the mathematical description and useful for the scenarios is the same. The greatest part of the things I want to study is known, all resources I need for graduating are known and available. The only needed for graduation is the same as the last process for the skydiver. Approach the final landing point in case of the jump or to the final endpoint of the graduation process. After the reflection a lot could be learned from the first model building process.

## 6.13 Experiences in model building

Starting to build a model was something new before I started the graduating process. During the courses followed in the curriculum of Civil Engineering there was some attention to model building. As often with courses at the university there is a lot of information given in the assignments. Starting from scratch is a total new experience. I learned a lot during the thesis project. When I first read an article about empty positioning I know what I was reading and what they meant by all the different symbols etc. I was able to understand. Now I understand what I am reading and, more important, know why they do certain things. When I read the same articles now the point of attentions are more clear to me. I am paying more attention to the broader setup, assumptions and the way the authors created the model. Also the link between the model and case study in an article is much clearer to me at this stage.

Not only by reading my perception of the articles changed. Also the attempts to create the model for the thesis in mathematical way and in the optimization software contributed towards the knowledge. When you are experiencing the problems by yourself it is easier to understand the dilemmas of other authors.

At the end I can conclude that the process of graduating is very important for the last part of the study. All aspects learned in the past five years will come together in the thesis work.

### 6.13.1 Modeling improvements

The first section focus upon the model created in this thesis project. The project in AIMMS will be taken as eventually result of this modeling process. Since this was the first time I created a model by myself I learned a lot. The most important lessons is to take a scratch of paper and draw a figure of the problem. Use this image to create a good structure of information already

known, information that could be reached easily and hard to get data. With this information an overview of parameters, (decision)variables, constraints and objective function could be set up. With such a clear structure the set up of the mathematical model and conversion into the optimization software should be much easier. This is a personal learning curve that could be directly used in a new optimization problem.

Next to set up a better structure to solve the model the notation and programming in AIMMS could be much better. The model is not programmed perfectly. The model works as is has to work and provide the user with correct output data. But a lot more efficiency could be achieved when programmed in a more efficient way. There could be a collaboration with C++, this is a programming language. This could be used for more preprocessing in the model so less information will be sent to the solver. Next to C++ there is the option to store and read data from MS Access databases via the SQL language. Because the 64 bit version of AIMMS does not support MS Access it is not possible to use a database system. Although a lot of C++ will show up for the communication with AIMMS and SQL. When looked at similar software packages special IT specialists are hired to do the programming for such technical parts. It will take too much time to specialize in all these aspects for this thesis project. Although information and reference projects are limited for the AIMMS package. The desired output will be the same but some processes could run more smoothly due to better programming.

The output data could be the same but the solving time could be smaller with a good software package due to more efficient memory usage. In the mathematical section different commodities are introduced but these are removed during the conversion into AIMMS due to memory issues. With a better internal memory usage such commodities could be modeled properly. Next to multi-commodities, more time periods could be included in the final model. Now the limit of the amount of time periods lies around three weeks. With a longer time horizon the CPLEX solver will terminate because of maximum memory and this could be solved by a more efficient modeling. These two aspects are two items I wished to implement in the model but due to software were hard to implement.

Furthermore the constraint of order deadline is hard to implement. Because it is chosen to use a arc-based modeling approach multiple arcs determine a route for multi modal transport. A combination of the first (barge) and second (truck) transport leg determine total transit time. But to assign the first and second leg to one transport is difficult. It will be a subject for further research to find a neater way to solve this problem. Articles about vehicle route choice could be used for this, to implement this into the model specific knowledge of C++ is needed to program it correctly in the model.

Two other aspects could be implemented in the model, these are reuse at customers, truck direction and a better use of transit times. The first point of attention is the reuse. Now all boxes are returned back to a depot before it could be reused for export freight. This is done for the pre trip inspections (PTI). This could lead to cost savings. This is done in a special case of the truck triangulation. This is also the second additional item in the model. Multiple transport directions for truck transport. At Maersk Line truck transport could be planned as one-way, import/export round trip or triangulation. This will lead to a more accurate model result. The last addition is a better modeling of transit times. Now it is assumed that all containers are transported at the moment an order is sent. This is not in line in practice where a container takes multiple days before it arrives at a customer location when barge is used. This will have an influence on the reuse. Especially when storage costs have to be paid. In that situation it could be cheaper to take more transit days to save costs. This could be a interesting aspect for further research.



## Appendix V - Collapsible Container

### 6.14 Collapsible container

In the main text the collapsible container is included. Some more information is provided in this appendix.

The fourth opportunity, described in chapter 2, for container transport is the collapsible container. This item attracts a lot of media attention in recent years. The inventors promise that a considerable amount of money in both the hinterland transport as well deep-sea transportation could be saved. Three companies, *Holland Container Innovations*, *Cargoshell* and *Staxxon* from California invented a collapsible container that is suitable for the maritime shipping industry. Some companies have achieved certificates, Container Safety Convention, so the container could be used in practice, Cargo (2012).

The transportation industry is characterized by the fact that there is always a return leg for empty equipment, however not always sufficient export cargo is available to regain costs for this repositioning. This not only the case for container transport, although container transport has the additional empty box. Worldwide a global trend in container business is that there is a surplus in Europe and deficient in the Far East for empty containers. Maersk Line is transporting 2 million empty boxes to the Far East each year. For the total container business, costs are estimated at 30 billion dollar. 20% of the containers transported via the sea are empty, 40% transported over land are empty. Locally imbalances are even stronger due to market circumstances in certain areas.

Two interesting articles are written about the opportunities for collapsible containers, Konings and Remmelt (2001) & Konings (2005). They conclude that the collapsible containers have an enormous potential to save upon transportation costs and to reduce the  $CO_2$  footprint for transport. Empty container positioning could be separated into a land-side and sea-side. Particularly for the land-side the collapsible container lead to cost minimization. However since the container transportation system is complex and the container market is used to familiar processes it is difficult to implement a new system with collapsible containers. For regions with a permanent imbalance this system is promising. Besides the hinterland leg, S. Bosschietter of HCI indicates big savings on terminal handling and storage costs as well since 4 collapsed containers have the size of one. Especially for corridors with limited volumes and closed loops without export customers this initiative is promising. Rob Konings: *"Expertise, experience and scale advantages are maximized with these conditions"*

The shipping industry is interested in this concept because transports costs are lower, storage costs will decrease and handling costs are only one fourth of the costs compared to a normal box. Ships can carry more containers and there will be lower emissions. But market circumstances are difficult and investments are not made that easy as before the economic crisis. There could be a positive effect for the transportation network as whole, but costs are made by one party while benefits accrue to another. This makes investments difficult. With decreasing transport volumes it is a big guess for a shipping company to invest in this concept. HCI is in contact with shipping lines and have already started some pilots with other shipping lines than Maersk Line. However there are still some drawbacks. First of all the stability during the collapsing should be more stable and sealings, that protect a container against water from outside, must be guaranteed. Cargo in containers has a high value and must not be damaged during transport. A

second drawback is the extra labor needed for the collapsing of the container. This is an extra handling and so extra costs for a shipping line. A theoretical calculation could be made to check if a collapsible container is profitable over time, but only a pilot project could prove how this concepts functions in practice.