Delft University of Technology

Faculty of Civil Engineering,
Faculty of Mechanical Engineering
Faculty of Technology, Policy and Management

Transport, Infrastructure and Logistics

Repositioning of empty containers in the Dutch hinterland: How to achieve cost savings at Empty Depots in Rotterdam?

Master Thesis

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Summary

The container shipping business is an ever growing market, resulting in more shipments between locations, where goods are shipped from, and locations, where goods are required. (Shippingwatch, 2014; UNCTAD, 2013; Wall Street Journal, 2014) Shipping companies mainly focus on providing transport between major ports in a global network, yet as customers are not located near the terminal and as the competition from other carriers is fierce, it is necessary for shipping companies to pay more attention to the transportation of containers in the hinterland of a port between the ocean terminals, off-dock empty depots, inland terminals and customer's front door. Containers are a commodity, that generate income when transported full, making it vital to provide empty containers as efficiently as possible to customers with an export demand. A trade imbalance can be observed in all transport scales leading to regions being either surplus (import dominated) or deficit (export dominated), resulting in empty container transport between import and export customers. At a global scale this results in an evacuation flow between e.g. Europe and Asia and at a regional scale this results in a positioning flow between deficit and surplus regions e.g. customers surrounding inland terminals.

The port of Rotterdam and its hinterland is an example of a surplus region. Due to the expansion of the container market the Maersk Group is opening the new Terminal2 terminal at the Maasvlakte, which can handle more containers at a higher frequency and reliability. The opening of this ocean terminal allows for an investigation of the composition of its network of empty depots and inland terminals required to determine the correct course of action with respect to reducing cost on empty container steering. The steering of empty containers is today performed in an *ad hoc* way from inland terminals through off-dock empty depots to other inland terminals or to ocean terminals, to meet demand, which could result in high unexpected costs. Empty container steering results in transport, handling, storage and repair operations, which need to be optimized such that expenses can be minimized and container utilization can be maximized. The problem is that it is unknown what the effect is of decisions made in the steering of empty containers through a set of off-dock empty depots in the port of Rotterdam and which solutions can be applied to improve the efficient handling of empty containers.

To solve this problem the following research question has been formulated. *How can total costs be optimized on the steering of empty containers through off-dock empty depots, while keeping operations in the hinterland and ocean terminals in mind?* The question was answered in a logical way, starting with a system analysis consisting of an investigation of the state of practise and state of art of shipping containers. Based on the results from this analysis phase, a mathematical model has been established. Simultaneously scenarios have been developed and reference datasets have been established. The mathematical model and the composition of the reference dataset has led to the implementation of theory and practice into a Decision Support System tool. This tool was then used to investigate the outcome of the pre-established scenarios, which led to answering the research question.

State of practice of empty container steering

Three scales of repositioning exist, viz. global, regional and local scales, to form a super network, see Figure 1 (Boile et al, 2006; Braekers, Janssens, & Caris, 2011; Rodrigue et al., 2013). The local scale covers repositioning of empty containers between inland terminals or depots and surrounding customers. The regional scale focusses on hinterland transport between inland terminals, off-dock empty depots and ocean terminals. The global scale repositioning focusses on the balancing of international trade imbalance between ocean terminals. Inland terminals serve as gateways connecting the regional and local scale network and ocean terminals serve as gateways to interconnect the global scale with the regional scale network. Meeting demand of customers globally through the positioning of empty containers follows in a hierarchical order from local to regional to global scale until costs exceed the price of producing new containers. (Theofanis & Boile, 2009) The network of Maersk Line, consisting of ocean terminals (1) in Rotterdam, off-dock empty depots (2) in Rotterdam and inland terminals (3) in its hinterland are located in a regional network and its customers and (4) located in a local network. Between the four types of locations in the network a number of flow interactions exist, i.e. repair flows to transport damaged containers to a workshop located at a depot (5), customer flow (6) to meet local demand, positioning flow (7) to meet regional demand and evacuation flow (8) towards a global network to serve overseas deficit areas (9). The ocean terminals considered are Terminal1, Terminal2 and Terminal3. The off-dock empty depots reviewed are Depot A, Depot C, Depot B and Depot D. The regional network considered consist of 14 inland terminals, which are aggregated with surrounding customers.

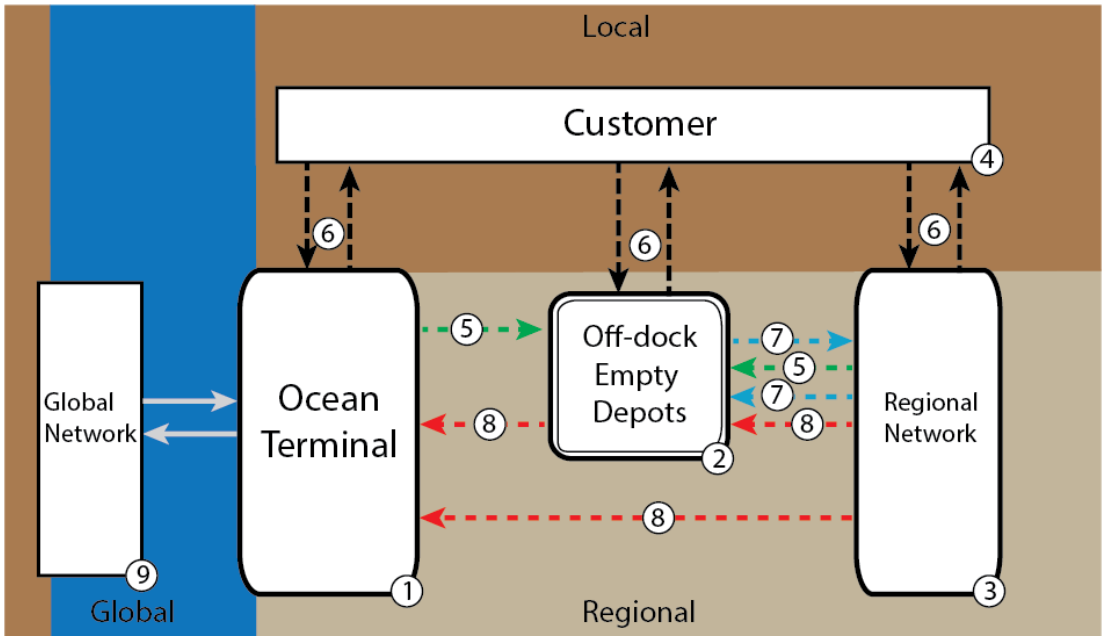


Figure 1: An overview of the regional network of the port of Rotterdam in relation to the transport super-network.

To meet future expected and unexpected demand at each location in the network, stock is required. Per country in the network a Target Stock Level, which is set by the company's headquarters, is known and is divided over the locations depending on where demand originates. The focus of the investigation lies on 4 container types, , specifically 20' dry containers (20DC), 40' dry containers (40DC), 40' highcube dry containers (40HC) and 40' highcube reefers (40HR).

State of art of empty container steering

This study contributes to research by developing a multi-commodity model which takes into account both damaged and non-damaged containers. The proposed model is then used to investigate the impact on different network topologies and the results of applying the street-turn (Furió, Andrés, Adenso-Díaz, & Lozano, 2013) or depot-direct proposed by (Jula, Chassiakos, & Ioannou, 2006) solution to the network. The purpose of the model is to support decision making on empty container steering through a network of inland terminals, depots and ocean terminals. The model takes into account all the described flows in a regional transport network including repair flows. Various scenarios influencing the network composition are investigated. Solutions found in literature showed both advantages as disadvantages, however only the *Depot direct*, (Jula et al., 2006) and *Street turn* (Furió et al., 2013; Jula et al., 2006) solutions have been considered interesting to investigate through the implementation of scenarios, because when applied correctly a full transport leg can be eliminated resulting in large cost savings.

For the development of the mathematical model many papers were studied. (Crainic, Gendreau, & Dejax, 1993) propose a single commodity model, which is much used by a lot of authors. The model serves as the basis for the theoretical model proposed in this thesis. (Choong, Cole, & Kutanoglu, 2002) present a model to investigate the planning horizon and assume containers are always available for demand. The paper provides a better understanding of implementing a container allocation problem to a fixed network, yet no damaged containers are taken into account. (Olivo, Zuddas, Di Francesco, & Manca, 2005) provides a single commodity model which takes container lease into account. They are the first authors who discuss the uncertainty effect of damaged containers on the meeting of demand. The implementation of customers and inland terminals as aggregated nodes, macronodes, will be used for the new model. (Jula et al., 2006) present a single commodity model, which implements the solutions depot direct and street-turn, but leaves out the effect of damaged containers. The implementation methods presented is used to investigate the impact of the solutions on total cost. (Wang & Wang, 2007) present a model, which minimizes cost of empty container positioning for empty containers with a focus on inventory at locations. Empty containers stock is managed through a Target Stock Level, which is implemented as an equality constraint in the model. (Furió et al., 2013) present a Decision Support System tool that reviews street-turn in an model implemented to a case at Valencia port. No evacuation demand to out of scope locations is taken into account. (Moon, Do Ngoc, & Konings, 2013) present a model which investigates the influence of foldable containers on total costs. (Olivo, Di Francesco, & Zuddas, 2013) present a deterministic multi-commodity model, which takes future requirements into account. This aspect is incorporated into the implementation of Target Stock Level.

No papers were found, which take into account damaged containers and the constant evacuation of empty containers, however existing literature did contribute to the development of the mathematical model from existing models to allow the addition of multiple container states and solutions to the empty positioning problem were found. A Linear Deterministic Discrete Dynamic Mathematical Optimization model is developed and implemented to solve the research question for finding an optimal cost solution for the steering of empty containers through the off-dock depots of the Port of Rotterdam, while taking both damaged as non-damaged container into account.

Development and implementation of a theoretical model

A mathematical model is developed to optimize costs of transporting empty containers in a network $G(N, A)$. The problem is known as a minimum cost network flow problem, which optimizes an objective function restricted by flow conservation constraints. The model assigns flow to the various arcs in the network, while meeting demand. All transport in the model is performed by barge with no capacity constraint. A time step of 1 week with a horizon of 52 weeks is assumed to take into account the effect of seasonality. The model is subject to repair capacity. No capacity constraint exist at the other nodes in the network. Damaged containers are repaired either in the network or overseas and when repaired in the network this is performed at a workshop in one timestep and returned to inventory in the following timestep. Depending on a failure rate containers are deemed damaged or non-damaged and based on a local repair rate containers are repaired in the scoped network or outside the network.

The theoretical model is used to develop a Decision Support System tool in Matlab 2014a with the help of the Matlog toolbox (Kay, 2014). The tool is implemented as a linear program, which allows decision variables to be set to fractional values. This is not coherent with reality, but as the goal of the model is to compare results from scenarios in comparison to a base year and both results contain the error induced the simplification is acceptable. The Decision Support System tool is then used to investigate the impact of various scenarios on reference input data from Maersk Line. The scenarios incorporate solutions found from the state of practice and state of art analysis performed. The following scenarios have been implemented on the model;

- Ocean terminal topology (varying in the opening and closing of ocean terminals)
- Empty depot topology (varying in the opening and closing of off-dock empty depots)
- Container steering (forcefully steering empty containers through depots)
- Target Stock Level heuristics (varying ways to divide the national Target Stock Level over the nodes in the network)
- Move type scenarios (altering the network to allow direct transport between inland terminals or inland terminals and ocean terminals)

An empirical setup was established for to reduce the size of the investigation of the scenarios. Ocean terminal topology, empty depot topology and container steering make up the primary investigation. Each setup is applied to the 4 container types investigated in the case study

Results from implemented model

From running the different scenarios and performing sensitivity analysis, a number of results have been identified and consequently this answers the main research question.

- Depending on the transport distance the weight of handling cost with respect to the total costs fluctuates. Resulting in a shift in focus on moves over long distance versus moves over short distance between handling and transport cost.
- Transport and handling cost combined account to roughly 75% of the total cost for the dry containers and 50% for the reefers. Repair costs account to roughly 20% for the dry containers and 45% for the reefers of the total cost paid for empty positioning. Resulting in depending on container type the main focus lies on transport and handling cost or repair costs.
- In any of the future ocean terminal topologies, where Terminal2 is open, When the depots Depot A and Depot D are open the model calculates for ocean terminal topologies that take into account an open Terminal2, the best results. Depot D is a depot offering low cost solutions due to where it is located and Depot A is a depot offering high quality service and high reliability. These depots result in cost saving opportunity range between 3% and 17% depending on the container size and type.
- Closing all depots does result in large cost savings, but as one of the roles of empty depots is to relieve an ocean terminal of empty containers to reduce congestion at its gate and to allow it to focus on the aspect that fuels the income of a carrier, this should be considered a bad decision. However, during daily off-peak moments at the ocean terminal, direct evacuation from the hinterland could be implemented and result in costs savings.
- Cost reductions can be achieved when containers are transported directly from inland terminals to other inland terminals (direct positioning) of around 13%. However, this solution does requires a more intensive planning.
- The Target Stock Level heuristics in respect to a pre-set target stock level applied do not result in cost reductions however it does show it is an important cost driver, which is directly related to the cost of empty container positioning. The pre-set TSL set by Maersk Line experts results in the most optimal cost in comparison to any of the TSL heuristics applied.
- Reducing the failure rate by improving the quality of containers results in cost savings.
- Cost reduction can be achieved by a global collaboration on global repair policy regarding the global transportation of damaged containers. In other words by improving the local repair rate of damaged containers.

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1 Introduction

The container business is an ever growing market, resulting in more shipments between locations, where goods are shipped from, and locations, where goods are required. Shipping companies like Maersk Line offer the means to perform such movements. The core business for shipping companies involves global shipping along the ocean's trade routes. Customers however require a shipment to be delivered to their location, making it necessary for shipping companies also to focus on the shipping of containers into the hinterland. The repositioning of empty containers becomes ever more important as they represent costs and also pose a threat for missing demand.

Within the inland network empty containers are provided to customers with an export demand and full containers to customers with an import demand. As import customers and export customers are rarely located at the same location empty containers need to be repositioned in order to meet transport demand. Balancing the container demand of different types and sizes is a transport activity, which affects all scales of containers transport (i.e. global, regional and local). Throughout the shipping network, all locations are either net export or net import dominated, resulting in that particular location being deficit (export dominant) or surplus (import dominant) with respect to empty containers. Containers are assets for carriers, which enable a more efficient usage of their ships through a higher level of cargo control,(Rodrigue et al., 2013). Even though the business mainly focusses on shipping full containers, it is imperative for the carriers to efficiently manage their empty containers to ensure out-of-pocket costs are minimal. Operational empty container management involves transportation, storage, handling and maintenance of containers, (Lun, Lai, & Cheng, 2010). Empty container repositioning worldwide is expected to cost Maersk Line 1 billion USD (±800 million EUR) yearly,(Wall Street Journal, 2014). Four million empty containers are being sailed around yearly of which two million to Asia,(Shippingwatch, 2014).

From studying the assignment field a number of problems can be identified, which require further investigation. As the container business is a volatile market and there exists a large overcapacity on the Asian-European trade routes there is a constant requirement for improving the container shipping process. Minimizing costs and optimizing revenue are important aspects of this improvement. It is important to understand, what the consequences are of minimizing costs, as a small decrease in costs in one department could result in an increase in costs at another department resulting in a net increase in costs for Maersk Line. Empty container steering is now performed in an *ad hoc* manner to meet sudden changes in demand. This ad hoc movement of containers can result in costly transport moves, which could be minimized by better using available information and by understanding what chain of decisions have an impact on costs. The problem is that it is currently unknown what the effect of decisions made with respect to off-dock empty depots are on the total cost of empty container steering and whether solutions can be found, which reduce those costs. Furthermore with the opening of a new terminal within the Rotterdam port in Q4 2014, a change in the setup of the port and depots is expected. The new depot and port setup might have a different impact on the costs as the current system. It is necessary to determine the optimal operations with

regard to empty container steering through these different network compositions of off-dock empty depots and ocean terminals.

The goal of this study is to provide Maersk Line with recommendations on how to handle the uncertain future and to determine which cost aspects have the most influence on the total costs of relocating empty containers through the off-dock empty depots. A set of scenarios need to be tested in a new developed model taking into consideration damaged and non-damaged containers. The results will be qualitatively judged to identify the positive and negative points of the various scenarios.

1.1 Research Question

The research will focus on investigating the impact of future scenarios on steering empty containers with respect to network topologies consisting of inland terminals, empty depots and ocean terminals

> *How can total costs be optimized on the steering of empty containers through empty depots, while keeping operations in the hinterland and ocean terminals in mind?*

in Rotterdam port, which leads to the following research question:

In order to solve the research question in a logical sequence, the following sub-questions have been developed, which leads to a research methodology for performing this study.

- *What is 'state of practice' with respect to empty container steering in a network of inland terminals, off-dock empty depots and ocean terminals?*
- *What is 'state of art' as described in scientific research papers with respect to optimal empty container steering models, which resemble the current state of practice?*
- *How does the theoretical model look like, which takes into account lesson's learned from state of art and state of practice?*
- *What scenarios/strategies can be derived from comparing the current state of art with the current state of practice?*
- *What are the results of implementing the identified scenarios and what cost drivers can be identified influencing the total cost of empty container steering?*

1.2 Research Methodology

System analysis (state of practice). The system of the carrier Maersk Line is assessed to obtain knowledge of the current state of practice with respect to empty container steering. The findings from this analysis phase can be found in chapter 2

Literature review (state of art). The literature review is performed to obtain knowledge of the current state of art with respect to empty container steering and to identify the gap in literature required to answer the research question. The results from the literature review can be found in chapter 3 and a more detailed analysis of the various papers can be found in Appendix A

Theoretical model development. A model shall be developed and validated towards existing datasets based on historical data from Maersk Line, before it will be used to assess future scenarios. Chapter 4 contains the model description.

Establishment of reference dataset. Reference datasets (flow data, physical network composition and operational cost structures) will be established from Maersk Line's historical flows and rate agreements. Due to confidentiality of the data, this will not be incorporated into this report.

Establishment of scenarios. Scenarios shall be established through cooperation with Maersk Line experts, system analysis and based on the results from the literature review. The scenarios are described in Chapter 5 and in detail in Appendix D.

Model implementation/validation The theoretical model shall be implemented into a optimization software package and will be aimed at supporting the problem owner in decision-making. Afterwards the model will be validated according to Maersk Line results. Both aspects are found in chapter 5.

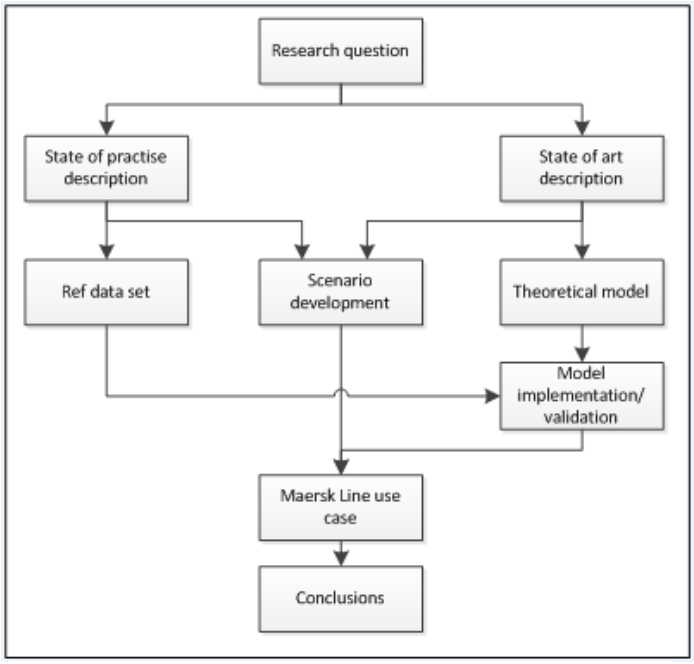


Figure 1-1 Thesis logic

Maersk Line Case study. The theoretical model will be used to determine optimal container steering subject to various scenarios. Chapter 5.5 provide the case study assumptions and results.

1.3 Thesis structure

Chapter 2 gives a system description of empty container steering in Rotterdam and its hinterland, followed by the future changes of the system. Chapter 3 presents a literature review with the purpose of identifying the gap in research to be filled by this thesis work. Chapter 4 describes the model. Chapter 5 gives the implementation of the theoretical model and chapter 6 the application of the model to the Maersk Line case. In Chapter 7 the conclusions and recommendations derived from the model results are presented together with a discussion for further research topics.

2 State of practice of empty container steering network

This chapter gives a description of the current state of practice. From what is known in theory on empty container steering a system logic is derived, which is applied to the empty container steering network of Maersk Line. The purpose of this chapter is to gain an understanding of how empty containers are handled in real life.

2.1 Scale levels for empty container steering network

(Boile, Theofanis, Baveja, & Mittal, 2008; Ishiguro & Mirchandani, 2013; Rodrigue et al., 2013) describe three levels of repositioning existing, namely global, regional and local scales. Through gateway terminals these scale levels are interconnected resulting in a complete network, also known as a super network, see Figure 2-1.

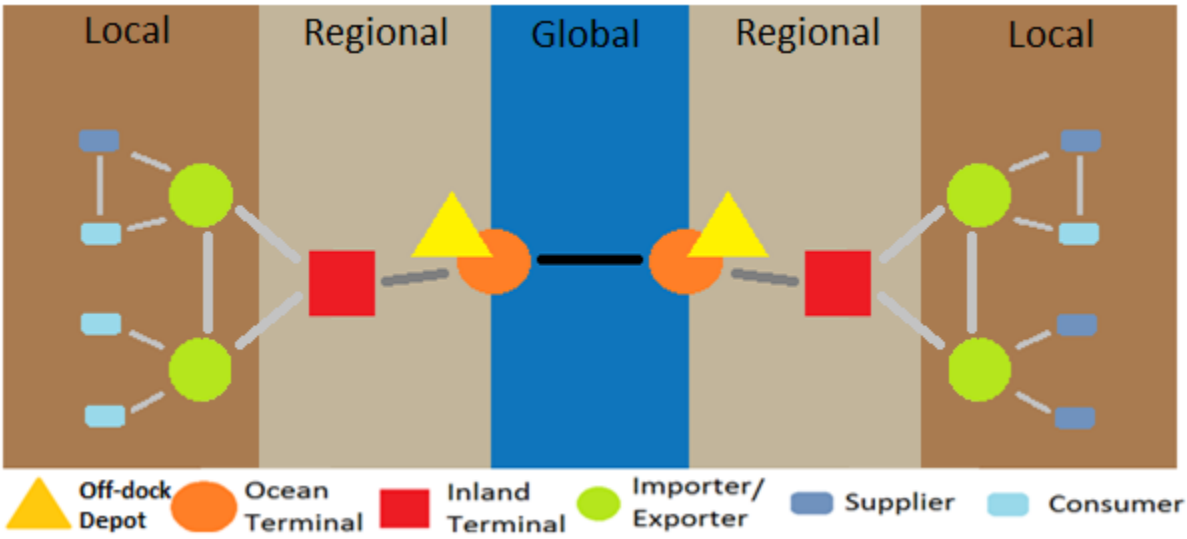


Figure 2-1 Graphical representation of scale levels. Source: based on (Rodigrue, et al., 2013)

2.1.1 Local scale container transport

The local scale (see Figure 2-1) covers repositioning of empty containers between a terminal or empty depot and its surrounding customers, whom either empty or fill a container. As soon as containers are emptied they are returned to an inland terminal from where they can either be picked up or delivered to a customer with an export need or can be returned to the regional scale network (Rodrigue et al., 2013). On a local scale trade imbalance exists due to the existence of business clusters and as such a truck rarely picks up and drops off containers within such a cluster (Rodrigue et al., 2013). The local scale network is primarily served by truck.

2.1.2 Regional scale container transport

The regional scale (see Figure 2-1) focusses on intermodal transport between inland terminals, off-dock empty depots and ocean terminals. (Boile et al, 2006; Braekers, Janssens, & Caris, 2011; Rodrigue et al., 2013). The regional scale tends to be either import or export dominated. The fact

that a location is import dominant does not mean that no exporter customers exist within the network. Due to the existence of exporter customers in an import dominant region (and vice versa), an opportunity arises to reduce empty container kilometres through regional balancing operations prior to global balancing operations.

Empty containers are stored at off-dock depots (off-dock refers to the exact location of a depot with an ocean terminal being on-dock), due to scarcity and the high cost of land at ocean terminals. (Boile et al., 2008). The inland terminals serve as an inland location close to the customer, where containers can be dropped off and picked up by the surrounding customers or delivered by a carrier such as Maersk Line. The inland terminal and empty depots are the gateways that connect the regional scale with the local scale. Containers not required at inland terminals are shipped to empty depots (Rodrigue et al., 2013). Ocean terminals are the gateway node in the regional network that connect the regional scale with the global scale network.

Empty containers are moved by either truck, rail or barge, to depots to reduce operational costs (i.e. transport, storage, handling costs) on empty container steering (Crainic, Gendreau, & Dejax, 1993). Inland terminals provide economies of scale with respect to bundled transport by barge and rail. Inland terminal operators have no influence on the rerouting of empty containers as this is kept by the carrier, yet it could be advantageous as inland terminals have a large amount of knowledge regarding local transport demand. A better cooperation between ocean carriers and inland terminals could benefit both parties (Veenstra, 2005). Empty containers are stored at off-dock empty depots for the low storage costs and for the performing of maintenance on containers. (Rodrigue et al., 2013).

2.1.3 Global scale container transport

Global repositioning focusses on the balancing of international trade imbalance between ocean terminals. The ocean terminals serve as gateways to interconnect the global scale with the regional scale. These gateways are connected by global shipping routes along which large container vessels sail.

(Veenstra, 2005) explains that trade imbalance exist between global trading regions, resulting in the rise of surplus and deficit regions. The Asian market is an example of a deficit area and the European market is an example of a surplus area. On a global scale an imbalance in trade can be observed, which will continue to grow in the future years. UK-based shipping consultant Drewry Maritime Equity Research has predicted that the global container trade will increase by 4.7% in 2013 and 5.7% in 2014, (Ship-Technology.com, 2014). This growth has direct influence on empty container positioning costs. Maersk Line takes care of roughly 15% of the global container shipping capacity and they expect shipping capacity to increase by 9,8% in 2014, resulting in a downward pressure on freight rates in 2014. A.P.Møller-Maersk declares freight rates have fallen 7.2% last year. This drop in freight rates is caused by an overcapacity problem (10%) on the East-West trade routes. Last year Maersk has decreased its capacity and launched its first Triple-E class ships on the Asia-Europe trade routes to supply transport with a higher efficiency through economies of scale(Wall

Street Journal, 2014). Figure 2-2 shows how the container transport market has grown over the last few years (UNCTAD, 2013).

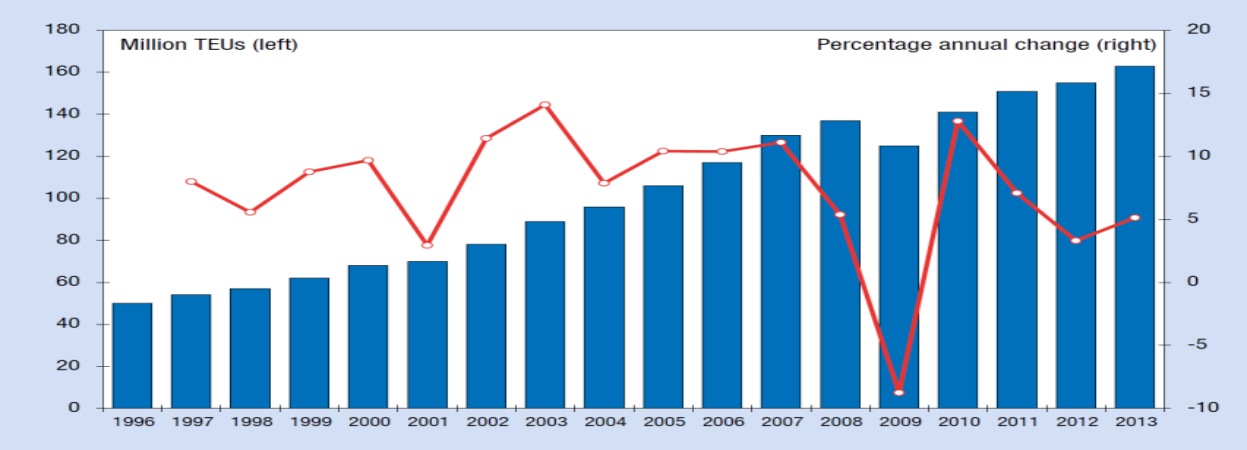


Figure 2-2 Bar chart with Growth trend line of global container market. Blue bar showing million of TEUs moved in each year and red line showing the relative growth per year. source: (UNCTAD, 2013)

Up until 2004, the increasing transportation of containers worldwide and the production of new containers in Asia have added to the amount of empty containers stacking up at major ports where import dominance (surplus) occurs, e.g. Europe. An increase in steel price in 2004 resulted in the increase in manufacturing costs of new containers, making repositioning more relevant (Boile et al., 2006). Carriers have the desire to keep empty containers close to the port to ensure better control of available empty containers for the global balancing activity. A carrier's core competence lies at shipping of containerized goods globally, hence the storage of empty containers is kept close to ocean terminals which connect global scale networks to regional scale networks (Boile et al., 2008; Veenstra, 2005).

2.1.4 Hierarchy of repositioning empty containers between scale levels

Now that repositioning has become more relevant, it is vital to understand in what sequence repositioning needs to be performed and what incentives are required for performing repositioning actions. Figure 2-3 presented by (Theofanis & Boile, 2009) shows when it is desirable to look for repositioning opportunities. The authors identify a number of aspects that influence the feasibility of empty repositioning. The scale of the transport level determines together with unit costs and distance when repositioning is feasible, as long as it remains below the costs of manufacturing a new container.

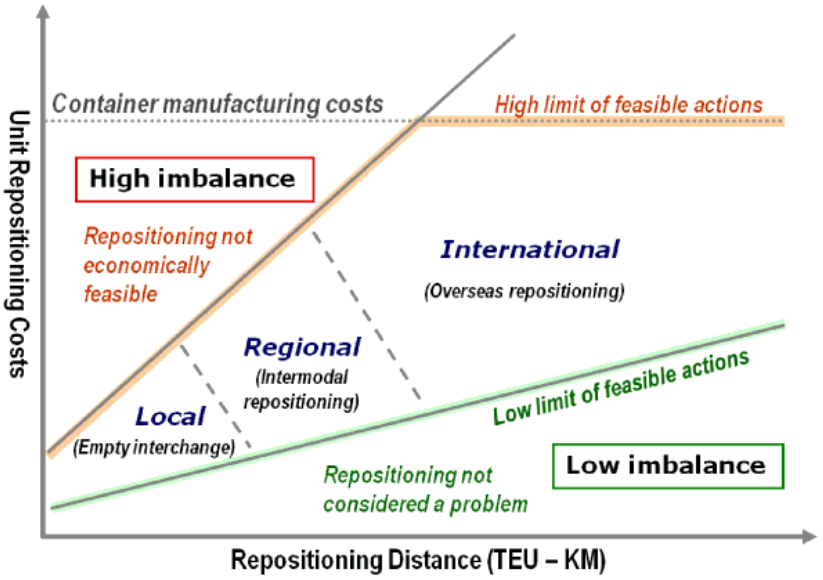


Figure 2-3 Theoretical graphical representation of feasibility of empty repositioning. Source: (Theofanis & Boile, 2009)

The feasibility of empty repositioning at different scale levels also results in a hierarchy in repositioning policy. As stated in paragraph 2.1.1 till 2.1.3, it is important to meet local demand prior to evacuation to overseas markets as this firstly increases the load factor of a container vessel resulting in extra revenues and secondly it decreases empty repositioning costs. When local scale transport requirements are met it becomes more acceptable to pay a higher unit repositioning costs up until the container manufacturing costs limit. The hierarchy thus starts at local scale, followed by the regional scale and lastly the global scale.

2.2 Empty container steering network of Maersk Line

Upon arrival of full containers in the Rotterdam port, inland shipping of containers can be organized by the customer itself or by Maersk Line. A general description of Maersk Line can be found in Appendix A. The former is called Merchant Haulage (MH) and the latter is called Carrier Haulage (CH). A full container picked up according to a particular agreement will be dropped off at a location according to the same agreement.

MH means that the customer picks up the container at the port and organizes the shipping of the container to their location and is then afterwards responsible for delivering the container back to the designated drop-off location. MH containers result in repair and storage costs for Maersk Line. MH containers which have been delivered back to inland terminals are transported to the ocean terminal by the carrier.

CH means that the carrier delivers the container to the customer or to an inland terminal. This type of haulage is performed by truck, when the container is delivered at the customer directly and by barge or rail, when the container is brought to an inland terminal. CH containers result in storage, handling, transport and repair costs.

Figure 2-4 provides a graphical representation, which describes the flow of containers using an empty container depot. Each number is further detailed in subparagraph. It shows the way containers are handled in the Rotterdam port area and its hinterland and will serve as a blueprint for describing the current container handling system. The Port terminals and empty depots are all located at the Rotterdam port.

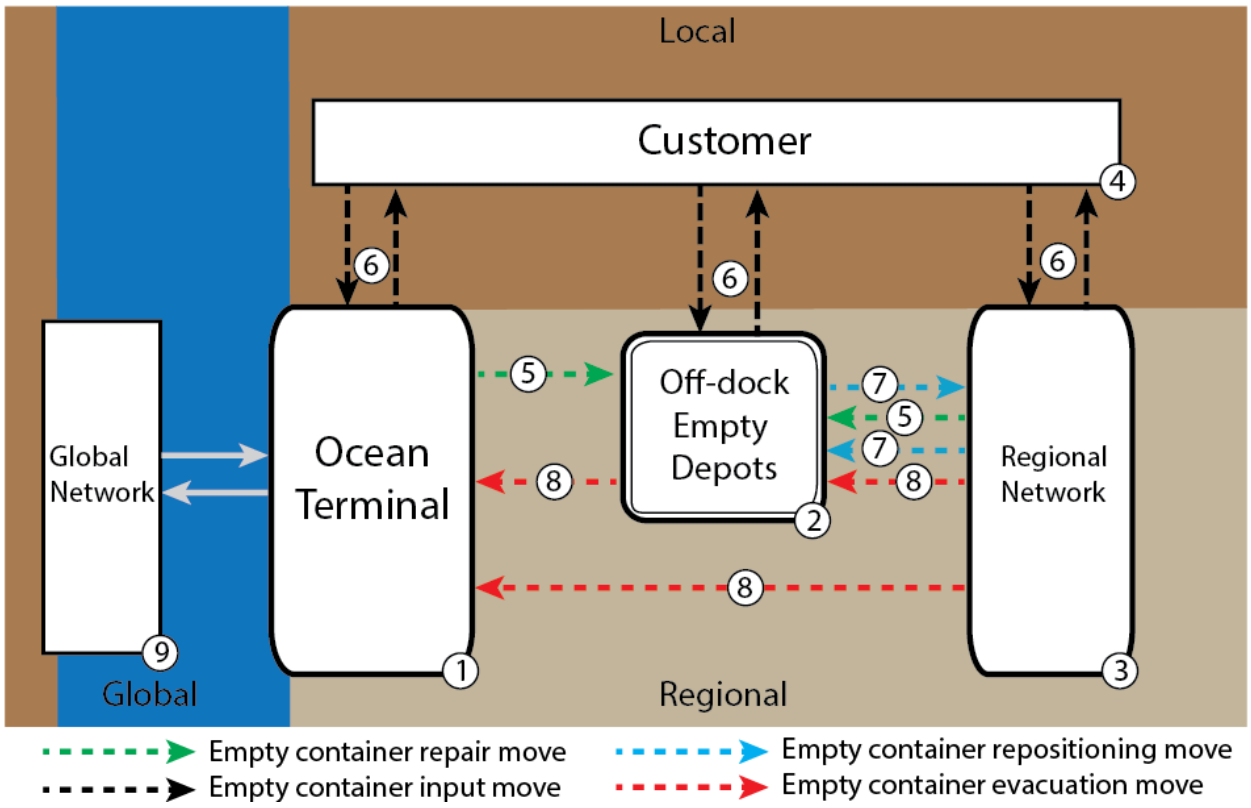


Figure 2-4 Graphical representation of the hinterland empty container flows. 1) Ocean Terminal 2) Empty Off-dock Depots 3) Inland network 4) Customer 5) Empty container repair move 6) empty container input flows 7) repositioning flows 8) evacuation flows 9) global flows (both import as export flow) (Source: own work based on)

2.2.1 Local scale network for empty container repositioning

The local network consists of the customer and the interaction they have with their surroundings, both other customers as local inland terminals. In Figure 2-4 these are identified by the indices 4 and 6.

Customer

Customers can fulfil three roles in the empty container management. They either have an import requirement, an export requirement or both. The requirement of a customer determines the amount of empty containers that are picked up or dropped off at any of the terminals or depots. When a requirement for empty containers exists, a container is repositioned from a surplus location to that customer and vice versa. After the export requirement is fulfilled a full container is returned to the ocean terminal. Customers are responsible for the costs of transporting MH containers back to the

terminal after emptying the container. This terminal can be either an ocean terminal or an inland terminal, depending on the specific agreement between carrier and customer.

Empty container input flow

An importer receives full containers from the ocean terminal or from the inland terminals and delivers the container when stripped back to the location where it initially came from. An exporter picks up an empty container at the nearby inland terminal and returns it after filling to the ocean terminal or the inland terminal where it came from. As the hinterland of the Rotterdam port is an import dominant market, more empty containers will be returned than picked up, resulting in the terminals becoming surplus. This occurs for most of the locations in the hinterland with the exception of a few. These surplus locations have an overflow of empty containers which should be moved to locations where there is requirement of empty containers such that a profit can be made.

2.2.2 Regional scale network for empty container repositioning

The regional network consists of the ocean terminals, off-dock empty depots and inland terminals in a ports hinterland and the flow interactions that exist between them. In Figure 2-4 these are identified by the indices 1, 2, 3, 5, 7 and 8. Both ocean terminals as off-dock empty depots are located in a port and the inland terminals are located in hinterland of that particular port.

Ocean terminal

The ocean terminal functions as a gateway between the global scale and the regional scale. At this gateway deep sea vessels are emptied or loaded with containers to and from the hinterland. Whether or not the cluster behind the gateway is deficit or surplus determines what type of load primarily is delivered. Rotterdam port, the Terminal1 and Terminal3, serves as the gateway for the NL-CH cluster of Maersk Line. This cluster, which is a part of the Northern Europe business unit, is an import dominated market, resulting in a higher demand for full containers than empty containers. Due to the high costs of handling containers at an ocean terminal, the storage of empty containers has been relocated to off dock empty depots, which aren't located on similar prime real-estate. Terminal1 and Terminal2 are located on the Maasvlakte and Terminal3 is located at the Waalhaven, one of the Rotterdam city terminals (see Figure 2-5). Terminal1 and Terminal3 are currently in use and Terminal2 will be taken into operations in Q4 2014. Terminal1 operations include 13 large quay cranes, 1 barge crane, 81 straddle carriers handling a total of 3.3 million containers yearly, of which 1.2 million empty containers, (Terminal1, 2014).

Terminal2 terminal has a berth of 1600m long with a depth of 16,6m (A.P.Moller - Maersk Group, 2014) and will be operated with AGV's (automated guided vehicles), resulting in more automated operations. The quay wall will first be 1000m long and will later be expanded to the final 2800m length and the depth will be up to 20m, allowing the large triple E class ships to moor at the quay wall. Furthermore a 500m barge quay and a direct connection to rail will be built to allow better intermodal connection. The Terminal2 terminal will have an initial throughput of 2.7 million containers(Terminal1, 2014).



Figure 2-5 Layout of Rotterdam port with all ocean terminals (yellow box) and off-dock empty depots in operation for Maersk Line (source: based on (Port of Rotterdam, 2014a, 2014b))

Off-dock empty depot

Empty depots are facilities which offer empty container handling and maintenance at a lower cost than possible at the expensive ocean terminals. Less expensive real estate allows for lower handling and storage costs of empty containers. Furthermore most maintenance work can only be accomplished when the container is empty and requires a container to stay at a location for a longer period of time, making it beneficial to lower storage costs. All containers returned from the hinterland to the terminal of Rotterdam is brought to the depots prior to evacuation towards the Asian market.

Within the Rotterdam harbour 18 depots exist of which 3 depots offer services to Maersk Line. Those 3 depots are Depot C, Depot A and Depot B. Figure 2-5 shows the exact locations of the depots with respect to the harbour and ocean terminals. Depot B is located at the Waalhaven near the Terminal3 terminal and Depot A and Depot C are located on the Maasvlakte in the vicinity of the Terminal1 and future Terminal2. The transportation of containers between the depots and terminals is known as ITT (Inter terminal transfer) at a unit price per container.

EMR (Equipment, Maintenance & Repair), a bundled term for all activities associated with pre trip inspection (PTI), cleaning, repairing and maintenance of containers, are exercised at off-dock empty depots for Maersk Line. Each depot is subject to an EMR capacity limit and per container type/size different EMR operations are required. PTI is performed only on Reefer units (cooling element) for almost all containers prior to delivery to an exporter. Note these operations can also be performed at inland terminals.

Depot A is the largest of the three depots with access to the modalities rail, barge and truck. The depot today takes care of most of the 40’ dry freight containers and some 20’ dry freight containers for Maersk Line. The depot is open 24 hours on 7 days of the week, allowing large customers, such as Heineken NV and Daimler AG, the flexibility of everyday delivery and pickup. Depot C depot is a depot with access to truck modality. By the use of the multi-trailer system (MTS) empty containers are moved between the depot and ocean terminal. Depot C operates all container types for Maersk Line. Depot B is a depot with access to all three modalities, which today handles mostly Reefers and

20' container for Maersk Line. The empty depot is located away from the other depots and terminals. Near Depot B a very large reefer customer of Maersk line is situated, which explains why the reefers are handled there. A new depot will be built at the new Terminal2. This depot will provide a similar service as the other depots, with the added benefit of empty containers not requiring an ITT move when transferred between depot and ocean terminal. Even though today containers are handled in a particular way between the different off-dock depots, all depots offer the possibility to handle all types of containers at each location.

Inland terminals

Inland terminals are located at multiple locations in the hinterland of Rotterdam port, see Figure 2-6. Goods are shipped from and to there, depending on demand a supply of the surrounding pools. An inland terminal can be viewed as a centroid connecting surrounding customers to the gateway to Asia. The customers' businesses determines whether an inland terminal is import dominated or export dominated, or in other words what type of containers are required and if they are full or empty when moving from gateway to inland terminal. Each inland terminal in the Dutch hinterland also serves as an empty depot.

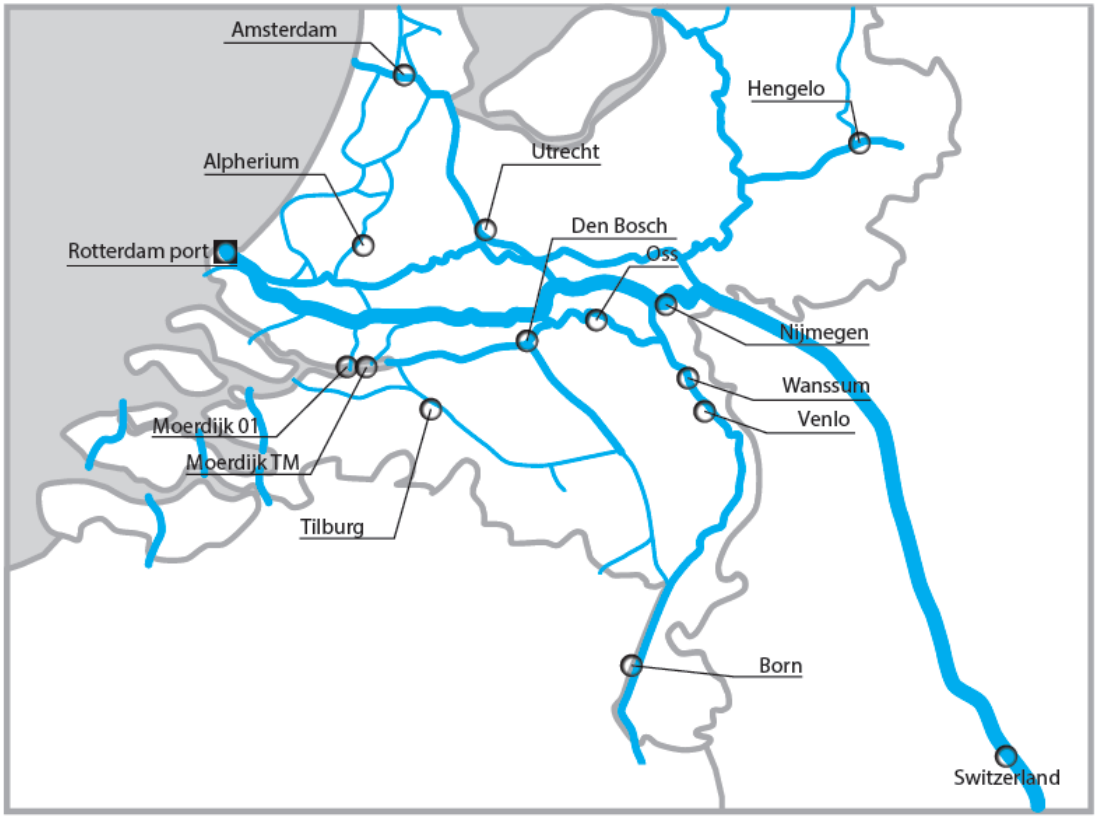


Figure 2-6 map of all inland terminals taken into account. Port of Rotterdam and Switzerland are aggregated nodes (own work)

Within the inland terminal network containers can be repositioned as merchant haulage (organized by either customer or a freight forwarder (MH)) or by carrier haulage (organized by Maersk Line

(CH)). MH implies a container is only brought to a specific terminal and CH implies a door-to-door service is provided.

The inland locations found in Figure 2-6 account for 95% of the total empty containers for export and from import within the NL-CH cluster. Switzerland is shown as an aggregated location, because locations have a large surplus of empty containers and therefore will all shipped to Rotterdam directly for evacuation.

Empty Container Repair flow

Before a container is picked up from a storage facility (depot, ocean terminal or inland terminal) a container receives a quality check and when it is noticed that a container requires maintenance or repair work a container needs to be transported to the off-dock depot where the containers repairers are located. Note that an import dominant region will keep high quality containers and ship poor quality containers to export dominant regions. The threshold for container repair is a lot lower for containers at the ocean terminal, than at the depot or inland locations. Different container types have different requirements, e.g. Reefer containers for export requirements nearly always require a pre-trip investigation (PTI) to ensure the highest quality of the refrigerated containers. Other repair tasks are box repair, unit (the cool installation of a reefer) repair or cleaning. Container repair is an expensive cost aspect of empty containers, which is directly related to empty container steering.

Empty Container Positioning flow

An import dominant area will still have a number of deficit locations and to reduce the cost of moving empty containers it is important to first service the local empty requirements before servicing the regional and global requirements. All empty containers after local balancing operations will be used to balance regional and global imbalances (in that order). Regional balancing are known as repositioning flows. Global balancing flows are known as evacuation flows.

After balancing takes place at the local scale (within an inland terminal's customer pool) the remaining available empty containers can be used to service other inland terminals, which have an empty container requirement. Those containers are moved to the off-dock depot, where most storage is performed. Carriers prefer to keep containers close to the port to have a better control over their stock (Rodrigue et al., 2013) Afterwards containers are moved back to the inland network to fulfil empty requirement of a deficit terminal (indirect positioning). A cost saving can be made by allowing containers to be directly transported between deficit and surplus inland terminals (direct positioning).

Empty Container Evacuation flow

After local and regional balancing operations have been sufficed, a global balancing operation is required. The global deficiency is far greater than the local and regional deficiency, as the Asian market is export dominated. A deficit market will accept any container it can take as it has a large export demand. All containers not necessary for future empty requirement, current empty requirement and currently unavailable due to repair work will be evacuated to reduce global

imbalance. Evacuation can be performed directly from the hinterland to the ocean terminal (direct evacuation) or via the off-dock depot to the ocean terminal (indirect evacuation).

Indirect evacuation is subject to a transport move between the inland terminal and off-dock terminal and a move between the off-dock depot and ocean terminal, the former is done by barge and the latter by ITT (inter terminal transfer). ITT is performed by ECT on the Maasvlakte or by barge operators otherwise and is at an average of €80 per container in comparison to inland transport a costly service. Direct evacuation requires a larger storage of empty containers at multiple locations inland and the availability of moving containers directly from inland terminal to ocean terminal when evacuation is required, however the advantage is that the expensive ITT is eliminated and a cost reduction is expected.

2.2.3 Global scale network for empty container repositioning

Globally an imbalance in trade exists, due to the existence of export dominant markets (e.g. Asia) and import dominant markets (e.g. Europe). Containers not required for local or regional imbalances should therefore be shipped to Asia as excess ship capacity allows. The core business of Maersk Line is full container transport and therefore full containers will always receive priority on available ship capacity. All unused capacity of a container vessel can thus be used to take along empty containers. Four vessels call the port of Rotterdam weekly, each able to take along the available empty containers for evacuation.

2.3 Project scope in a regional scale network for empty container steering

To clarify the study better, the project scope will be divided into two parts. The first part focusses on the interactions between the off-dock empty depots and ocean terminals located in the Rotterdam area. This scope will be known as scope 1A (See Figure 2-7). The second part focusses on the interactions between the port of Rotterdam and Inland terminals and will be known as scope 1B (see Figure 2-8).

Appendix B shows the combined scope of the project (Scope 1A & Scope 1B). The physical connections are based on the actual transport arcs possible for Maersk Line.

2.3.1 Scope 1A: The port of Rotterdam and surrounding empty depots

Scope 1A (See Figure 2-7) is built up out of nodes and arcs, where the nodes represent ocean terminals and off-dock empty depots and the arcs represent the different types of flows between the nodes. Empty containers are generated in the inland network and at the off-dock empty depots and ocean terminals. The ocean terminals Terminal1, Terminal2 (future) and Terminal3 in the Rotterdam port area and the empty off-dock depots Depot B, Depot C, Depot A and Depot D (not currently in operation) are considered.

For scope 1A, the inland terminals have been aggregated and inland operations are considered a 'black box'. This scope focusses on the optimal steering of empty containers through the off-dock empty depots. The containers enter the scope from customers at any node and leave the scope at

ocean terminals through evacuation onto container vessels and to customers at any node. Only handling and storage costs at ocean terminals are taken into account.

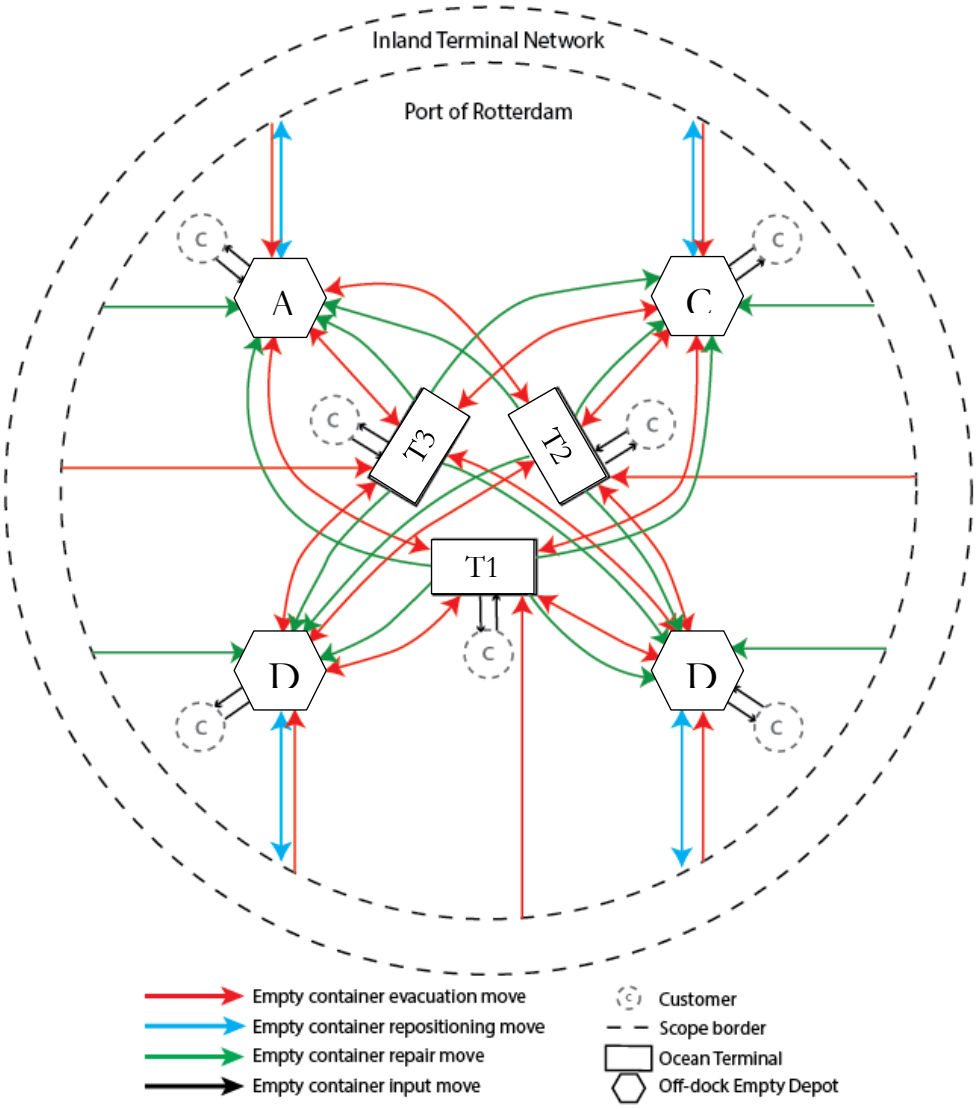


Figure 2-7 Scope 1A, which focusses on the interactions between ocean terminals and Off-dock Depots. (source: own work)

The empty depots provide pre-trip investigations, maintenance, repair, cleaning (EMR) and storage services for the empty containers. Before a container is repositioned or evacuated a container is checked if it requires any type of EMR. Containers arrive from customers (macronode), inland terminals and ocean terminals and are returned to customers, inland terminals and ocean terminals.

All containers entering and leaving the scope from and to customers are divided into carrier haulage and merchant haulage. Carrier haulage generates transport, handling and storage costs as flows and merchant haulage generate flows and storage costs until they enter their destination terminal.

Transport from the inland network to any node will be performed by barge and transport between off-dock depots and ocean terminals will be performed by ITT. Unit costs per container size (20' & 40') are applicable to all handling, transportation and storage operations.

2.3.2 Scope 1B: Inland terminals in the hinterland of port of Rotterdam

Scope 1B is also built up out of nodes and arcs, where the nodes represent inland terminals and the arcs represent the possible transport between the nodes considered (see Figure 2-8). All inland terminals in scope 1B combined account for on average 95% of the total empty containers of the NL-CH cluster. Each node provides and receives empty containers from a macronode representing all customers serviced by that particular node. The Swiss inland terminals have been combined into one node as all the Swiss location are constantly highly surplus and therefore no inter Swiss inland terminal moves occur. Rotterdam port takes the role of 'black box'.

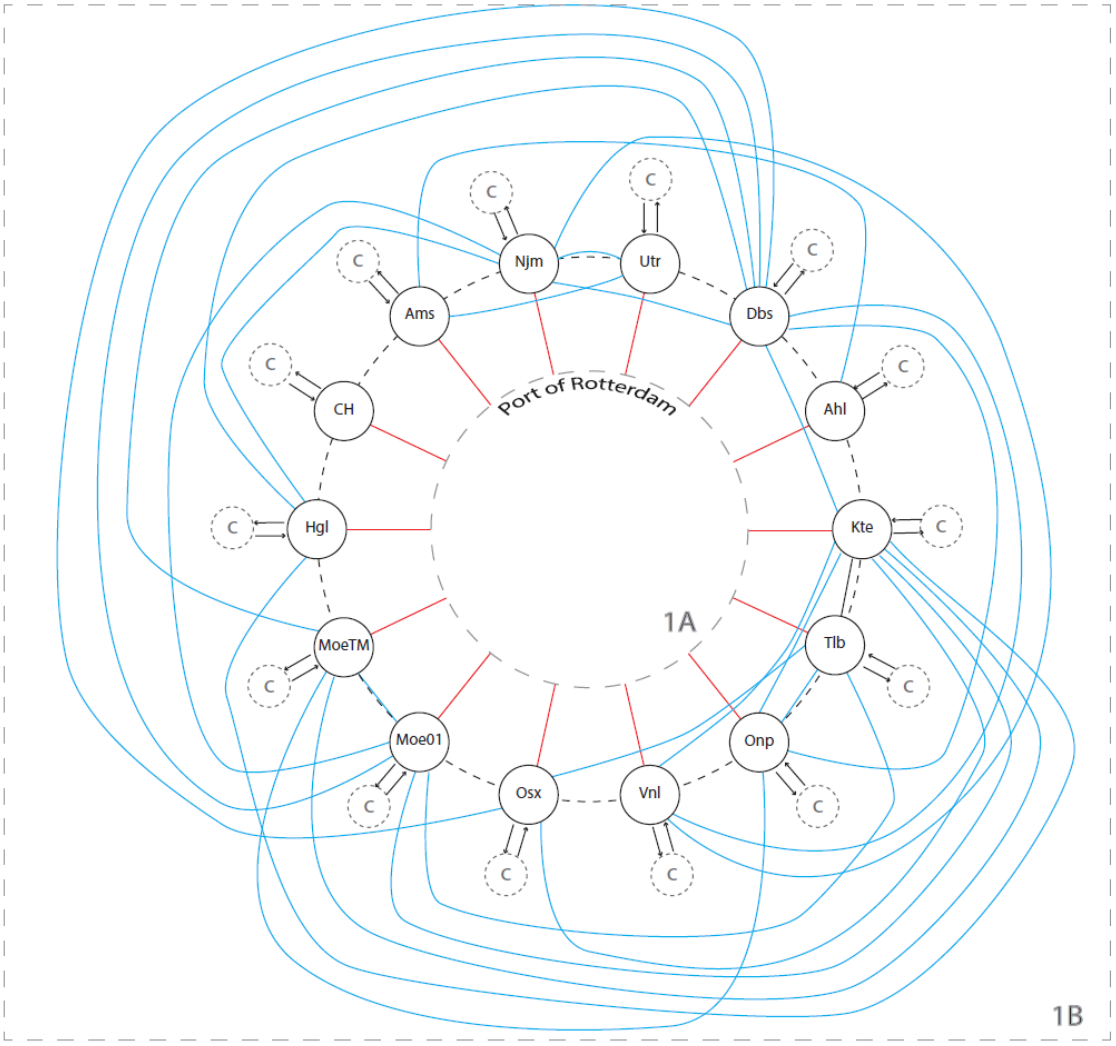


Figure 2-8 Scope 1B showing all inland terminals with the possible interactions. Scope 1A is shown in centre of the figure. (Source: own work)

All inland transport will be taken care of by barge. Even though the modality is slower than truck, it is the preferred modality for empty container flows as reducing costs on these flows has a high priority. Flow between any two locations is subject to a transport operation, handling operation at the origin side and a handling operation at the destination location. The weight of handling cost in comparison to transport cost shifts as the distance increases.

A large variety of containers are used by customers in the network. The scope will be limited for containers of the type 40' Highcube Reefer (40HR), 20' Dry (20DC), 40' Dry (40DC), and 40' Highcube Dry (40HC) containers as these account for more than 95% of all containers in the network. A differentiation between container types is made, because each container is subject to its own seasonality and different EMR operations. The content of containers is left out of scope because the model focusses on empty container movements with respect to the depots.

All inland terminals and off-dock empty depots are subject to a Target Stock Level (TSL), which is based on demand forecasting of the particular pool within the cluster. The TSL will be used to determine the amounts of empty containers allowed to remain at a terminal at the end of a time step.

2.3.3 Combined regional project scope

Scope 1A and 1B are interconnected through the boundaries of the two scopes. Inland operations (scope 1B) affect the handling of empty containers at the empty depots and ocean terminals (1A) and vice versa. The main focus of the thesis lies in varying the topology setup of scope 1A and sequentially investigating its effect on total operation costs of the entire network. The scope of 1B takes the role of a constant as the setup of flows and costs will not vary with the various scenarios to be tested. Furthermore all inland locations are connected with all empty depots and ocean terminals. All moves on arcs are subject to transport costs specific to an OD (Origin-Destination) pair, handling costs of respectively the origin and destination location. See Appendix B for the combined regional project scope.

3 State of art of regional empty container steering

To answer the main research question, a model needs to be developed, that steers containers in a network through a set of off-dock empty depots and ocean terminals, while taking into account damaged and non-damaged states of containers, with the purpose of investigating various network scenarios. Empty container management is an interesting and complex problem to solve and as such has been the focus of much research over the last twenty years. (Braekers et al., 2011) and (Steenken, Voss, & Stahlbock, 2004) both show the vast amount of literature on hinterland and terminal operations. The goal of this literature review is to map existing models, to be able to see how these models can be used to solve the research question in this thesis, and identify the gap in research, which the proposed model from this thesis will fill. To reach this goal it is important to know what type of model is required for this problem and what decision level it supports.

3.1 Scoping of research topics for regional empty container steering

3.1.1 General considerations for modelling container steering problems

Several quantitative models exist, namely mathematical and statistical models. Mathematical models are equation based, and describe system transitions between states through equations and how the variables relates. Mathematical models can be segmented into numerical models and analytical models. Numerical models use time step procedures to derive model behaviour over time. The end result of a numerical model is in the form of a table and/or a graph. Analytical models produce a closed form solution, with a solution that describes how the model behaves under any circumstance. Complex models are often described numerically. Statistical models estimate future behaviour of a system based on historical, extrapolated or interpolated data.

Optimal empty container steering is a quantitative problem which is best modelled numerically due to its complex nature. From literature several types of models are applied to solve problems, namely discrete event simulation and mathematical optimization models. Discrete event simulation is an object focused modelling technique, which simulates state transitions from time to time. Processes which are too complex to describe with a mathematical function are best simulated with a Discrete Event simulation tool. Mathematical optimization models describe a system through a mathematical formulation. Several considerations need to be made prior to making a mathematical formulation. These considerations are described below

1. **Nonlinear or Linear.** Do all variables in the system interact linearly with each other? All costs affecting the total costs of moving empty containers are unit costs, multiplied by the amount of containers requiring a particular operation. The steering of empty containers is a linear model.
2. **Explicit or Implicit.** Are all input parameters known and can the input data be transformed through linear programming into the desired output data? When the answer to this question is yes then the model is denounced as explicit and otherwise implicit and as such simulation would be a better option. All data regarding input flows and unit costs are known, making it

possible to formulate an objective function which can be optimized through numerical modelling. An explicit model is therefore required and a mathematical optimization model is sufficient to calculate the total cost of container steering.

3. **Discrete or Continuous.** Is it important to understand the transition changes between two states or are the outcome of the states only important? If only the outcome is important a model is discrete. For the total costs of empty containers through the depots it is more relevant to look the transition steps rather than the transition and as such the model becomes discrete.
4. **Deterministic or Stochastic**. Are the input data random or unique? The data provided is unique with respect to network flow, unit costs & import and export requirements. The failure rate of containers is dependent on many different aspects, which are uncertain and is therefore best described as a range.
5. **Static or Dynamic**. Are operations connected to empty containers time dependent for the state of the system or is the system in equilibrium? Operations required for empty containers are time dependent as they are performed sequentially. The repair of damaged containers is an example of such a dynamic dependency between time steps. Also available inventory and future TSLis dynamically dependent between time steps.

Following from the above considerations it can be derived that a linear optimization model, where calculations take place in a discrete manner, while taking deterministic input data into account with time dependency between time steps, is required to answer the research question. For container planning models another consideration exists, which categorizes papers, namely;

6. **Single or Multi-commodity.** Is it possible to send multiple commodities between nodes in the model? A model that views multiple commodities can look at multiple container types in single model, multiple modalities in a single model or multiple states of containers within a model. A multi-commodity model, which investigates multiple states of containers (viz. damaged and non-damaged state) is required.

According to (Braekers et al., 2011), the ideal linear optimization model for container planning models is a stochastic, dynamic, multi-commodity model as this takes all aspects of a real world situation with its uncertainty into account, however this is unsolvable due to computational limitation. Therefore a simplification of reality is required in order for the model to be solvable in polynomial time.

3.1.2 Optimization model types supporting planning decision level

A planning model is a form of model that is often used by management to support their decision-making process. The decision making process can be divided into various decision levels. (Braekers et al., 2011), (Crainic et al., 1993) and (Lam, Lee, & Tang, 2007) categorize models by the decision level they influences. These decision levels have a hierarchical order, namely strategic, tactical and operational decisions. Strategic models study and compare the physical network with respect to its efficiency and costs. Tactical models focus on mid-term planning activities for the integration of

new systems into existing operational systems. Operational planning models focus on day-to-day short-term planning activities, subject to dynamic interaction. This follows the same line of reasoning as for empty container repositioning where strategic decisions determined general policies, tactical decisions provide the framework in which operational decisions optimize operations. Each decision level model makes a different decision with respect to empty container repositioning. Figure 3-1 gives an overview of the various models that are connected to the various forms of decision levels. Strategic planning decisions focus on the network design. A tactical decision are made with models that review a service. Container allocation models and routing models handle the operational decision making on how to send containers to achieve the lowest possible cost.

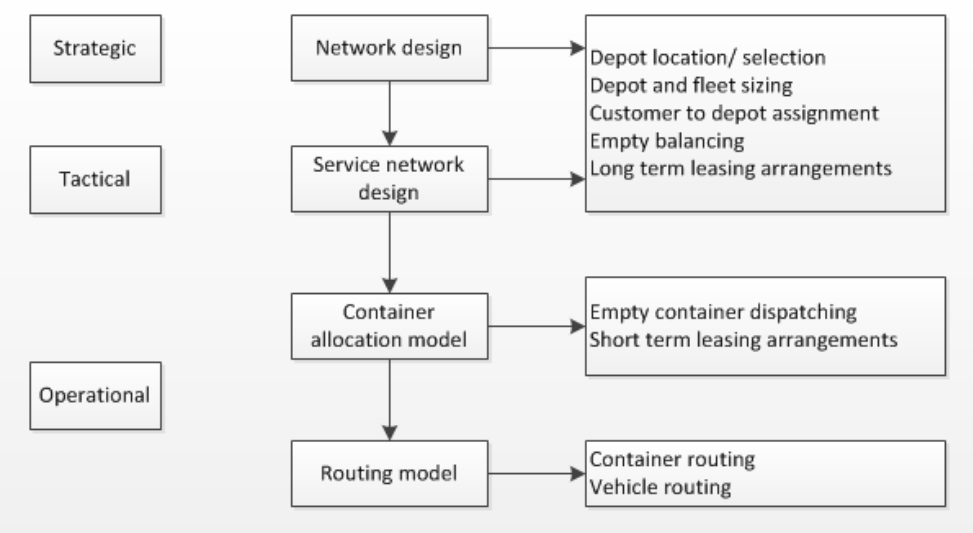


Figure 3-1 Overview of models within different planning decision levels. Source: (Braekers et al., 2011)

The proposed model should aid strategic decision making of the problem owner. The problem owner for this study is the deep-sea carrier, which make use of an already existing network and as such the new model is a review of service, required for the optimal steering of empty containers. Resulting in no start-up cost for opening a facility will apply as the facilities already exist or are built by other parties and only operational costs apply. This study focusses on providing strategic decision support with a tool that reviews tactical and operations planning decisions. Depot selection is a tactical decision-making problem, while empty repositioning is an operational decision-making problem. These two decision levels follow in a hierarchical fashion, where the allocation of empty containers is subject to the architecture of the network (Gao, 1997).

3.1.3 Solutions proposed in tactical/operational planning optimization models

A number of solutions exist, which seek a cost optimization with respect to empty container management. These solutions are primarily focusing on the repositioning of containers for demand requirements. This results in a different point of view when it comes to modelling. The model will need to be built based on the different solutions which have been applied and different solutions which could have been applied. The main aim of applying different scenarios is to determine the

best way to steer containers through the empty off-dock depots. Multiple empty container repositioning solutions have been developed over the years to achieve a cost minimization. These solutions are listed below. Advantages and disadvantages per solution can be found in Table 3-1.

1. *Depot direct*, which decrease the empty container distance travelled before a container is reused (Jula, Chassiakos, & Ioannou, 2006; The Tioga Group, 2002)
2. *Street turns* (also known as triangulation, which decrease the empty container distance by moving containers directly between importers and exporters (Furió, Andrés, Adenso-Díaz, & Lozano, 2013; Jula et al., 2006; The Tioga Group, 2002).
3. *Container substitution*, which allows container types to be interchanged for other similar types. (Crainic et al., 1993; Olivo, Di Francesco, & Zuddas, 2013).
4. *Container leasing*, which reduces the amount of containers owned by carriers and which allow for meeting unexpected demand. (Choong, Cole, & Kutanoglu, 2002; Crainic et al., 1993; Olivo et al., 2013; Olivo, Zuddas, Di Francesco, & Manca, 2005).
5. *Foldable containers*, which increase empty containers capacity of transport modes and off-dock depots thus decreasing costs per container. (Moon, Do Ngoc, & Konings, 2013).
6. *Container sharing*, which reduces empty container moves through cooperation between inland transporters.(Kopfer & Sterzik, 2011)

Table 3-1 Advantages and disadvantages of the various solutions proposed in papers

	Advantage	**Disadvantage**
Depot-direct	+ Low storage costs + Elimination of a transport leg	- Reliable container planning required
Street-turn	+ Elimination of a transport leg	- Labour intensive planning task
Container substitution	+ Versatile use of various container sizes.	- Applicability limited due to fixed max allowed weight of a container.
Container leasing	+ Meet unexpected demand + Less storage cost	- Expensive lease costs - High penalty when returned too late
Foldable containers	+ Reduced storage space when empty + Reduced positioning costs	- Extra cost for folding/unfolding operation - Reliability
Container sharing	+ Higher load rate of containers	- only works in balance network

From the presented solutions, the depots-direct solutions is a solution which can have a considerable influence on cost reductions without extra unexpected costs arising. Inland terminals serve as a cheap location to store containers and are all well connected with the ocean ports with regular barge connections, allowing for bundled transportation. Furthermore, when viewing the cost

structure of Maersk Line, handling costs are considerably lower at Inland terminals as opposed to off-dock empty depots in the Port of Rotterdam. Street turn is a solution, which is focused on local balancing activities, yet it can be translated to the regional scale and as such becomes a good way for regional inland terminals to help each other in meeting demand before moving empty containers from or to ocean ports. The depot-direct and street-turn solutions will be tested in the model through the application of scenarios where certain moves are allowed or disallowed to see the influence on total cost.

3.1.4 Time horizon and time step considerations.

(Crainic, et al., 1993) declare a planning horizon to be at least 10-20 time periods and (Choong, et al., 2002) declare that a horizon should be at least as long as the longest transit times of the modalities. Furthermore end-of-horizon effects should be taken into account, short transit times result in smaller end-of-horizon effects as the model becomes more flexible. For a model to take into account seasonal effects, the model should model at least a year of operations, because it is important to see the effect of seasonality on the overall performance of the system.

Dynamic planning models provide a time related model. Most aspects of a time related model are subject to changes in time, for example transport requires multiple time periods to occur. A transportation leg might take 1 day and as such a container departures at period t and arrives at t+1. This transportation causes for delay to occur, affecting the costs of storage and the way containers are to be steered through the network. To be able to better model transport dynamics it is vital to have a time step which is not too large as it reduces the detail of the model.

A predicament can be noticed; on one hand it is important to model a full year of operation and on the other hand it is important to model day to day state changes. A full year model with time steps of 1 day where demand data is updated every day would result in a complex model and becomes a model with a 365 time step planning horizon. This is too large as the paper declare it should be roughly 10-20 periods for a planning model to reduce unfeasibility of the results.

The model proposed reviews historical data to determine the relative improvement of implemented future scenarios and the historical data available is provided on a weekly basis from Maersk Line. To take into account the effect of seasonality a time horizon of 52 weeks is investigated.

3.2 Contribution from literature for the development of an optimization model

3.2.1 Relevant empty container steering models

In order to correctly model the positioning of empty containers it is important to take damaged and non-damaged containers into account and to incorporate the evacuation of empty containers above TSL. When containers become damaged in any form they become unavailable for export purposes and thus the repair of containers is directly linked to optimally steering empty containers through any transport network. Furthermore, as the repair of empty containers occurs at empty depots and

these play a vital role in the steering of containers. Below each relevant paper is discussed and a more detailed review of the papers is given in Appendix A.

(Crainic et al., 1993) is one of the most referenced papers on the topic of regional allocation models. The paper contributes three elements to empty container allocation models; a single commodity deterministic model, followed by a multi-commodity model taking into account substitution of container types and finally a stochastic single commodity model, which models the uncertain nature of demand and supply. The paper does not present any case study proof of the models presented and as such are difficult to validate, because many other authors have used the models presented to build their own models for their own hypothesis. They have been proven to be accurate nonetheless. The model presented lacks the implementation of damaged containers on empty positioning. The paper provides a good mathematical basis with very clearly described variables and restrictions. This basis will be used to build the mathematical formulation for this thesis in particularly the single-commodity model will be used and expanded to take into account the multiple states of containers and thus becomes a multi-commodity model. The division of the customer nodes into surplus and deficit sets is a very useful way to describe the different aspects of a customer in the model.

(Choong et al., 2002) looked at how a longer planning horizon relates to the empty container management with respect to intermodal container transport networks, where the leasing of containers is allowed. The model is based on the single-commodity model developed by (Crainic et al., 1993) and modified to include multiple modes, storage capacity and transportation modal capacity. The authors assume containers are always ready to use, which means no repair is necessary for containers. A large portion of the discoveries made in this paper are useful for modelling the model proposed in this thesis even though the scope differs. The mathematical model is a basic model for sending containers through a fixed network. Scenarios that investigate different network topologies will be implemented to adjust the objective function for a particular scenario.

(Olivo et al., 2005) present a single commodity model which takes the leasing of empty containers into account, which was based on the work of (Crainic et al., 1993). The model works with a detailed time step of an hour, which requires a similarly detailed dataset which is strongly affected by uncertainty. Container failure has been identified as a factor, which adds to the uncertain nature of available empty containers, yet they do not go into further depth of this aspect. Containers are assumed non-damaged at all times. Another disadvantage to a model which operates at such a detailed level time step is that it will be limited in the length of the horizon and can thus not take seasonality into account. This paper contributes the application of macronodes and dummy arcs to the proposed model and illustrates added influence of damaged containers on the steering of empty containers. Macronodes and dummy arcs will be incorporated into the design of the objective function.

(Jula et al., 2006) provide a single commodity deterministic and dynamic model which optimizes the cost for reuse of empty containers to test two solutions for achieving less movements, namely direct-depot and street-turn. The authors conclude that a large decrease in costs are noticed with the

introduction of the inland depots and street-turn solutions. The model was tested through a case study on actual datasets representing operations in the Los Angeles region. The model does not take into account broken containers, but does provide proof that the direct-depot and street-turn solutions results in cost savings with respect to empty container positioning. These solutions have been implemented through the addition of extra transport arcs between nodes, where they do not exist in the base model. Both solutions will be investigated through scenarios that influence the allowed move between location types (i.e. inland terminal, off-dock empty depot or ocean terminal)

(Wang & Wang, 2007) propose an integer programming which optimizes costs for land. The authors minimize distribution costs for a number of moves, namely port-port, importer-port and port-exporter. Inventory is limited by both a minimum as a maximum to ensure future demands are met and capacity is not exceeded. Inventory will for the proposed model not be limited in a similar fashion. Inventory will be implemented through a TSL, which is predetermined based on future requirements. The model will optimize with TSL as an equality constraint. The influence of a TSL is interesting and will as such through scenarios be further detailed. The model does not take failure of containers into account.

(Furió et al., 2013) propose a multi-commodity regional allocation model for empty container repositioning which analyses the street-turn solution with a case study Valencia port. The main focus of the paper is on the application of a DSS which takes street-turn into account to aid decision making. The authors declare that a reduction in container transfers between empty depots and ocean terminals is found, when direct transport between customers is allowed. This is also expected through the application of the direct depot solution, which operates similar to street-turn. A DSS (Decision Support System) has been shown to allow for an easier decision making process for carriers with respect to inland operations. This paper will serve as the basis for the objective function, parameters, variables and restrictions required for the integer program. Furthermore the street-turn solution proposed will be applied to the model, which takes both damaged as non-damaged containers into account, through a scenario, which allows or disallows certain transport moves between location types.

(Moon et al., 2013) present a model, which investigates the cost advantages of using foldable containers. The solution of foldable containers will not be further investigated for this thesis, because it does not lead to answering the question of empty container repositioning subject to network scenarios. Some of the basic concepts of developing a mathematical formulation was better understood through this paper. As such it contributes to the design of a mathematical formulation for a model, which investigates multi state containers.

(Olivo et al., 2013) present a deterministic, multi-commodity model taking into account substitution and leasing. They have presented their model in a time-extended fashion in order to be able to model activities which occur over multiple time steps. Finally the authors conclude that standard solvers may not be strong enough to solve the problem when uncertainty is taken into account in combination with a large network. As the model proposed in this thesis will not take uncertainty

into account, making existing solvers sufficient to solve the problem. The paper provides a very clear explanation of the variables and restrictions applied to the model. The model takes future requirements into account instead of sending containers back and forth. Future requirements will be investigated through the implementation of an alternating TSL.

3.2.2 Literature study results versus thesis research question

This study aims at understanding how empty container steering through a hinterland network results in optimal total cost. In other words it is a model that investigates various scenario modified networks, which takes into account both damaged as non-damaged containers. A model will be developed, which takes transportation, handling, storage and repair move costs into account, based on a 'from a shipping company acquired' historical dataset. The model will calculate the total costs of steering empty containers subject to various scenarios based on solutions found and problems identified from the state of practice.

The previous chapters have shown that substantial research exists on the topic of empty container management. Firstly, to be able to handle the imbalance in trade around the world it is relevant to provide empty containers from surplus to deficit markets and as container production costs have increased and the competition in shipping is fierce, optimizing cost for empty container management becomes more and more important. Furthermore, most research performed produce models, which predict the future with the purpose of telling shippers how to exactly steer their containers between all locations. The main problem with all those models is that they are prone to uncertainty and errors in prediction value and as such often are only used as an indication on how operations could be steered. The new model proposed in this thesis will first calculate total cost of the current operations based on a network topology similar to that of Maersk Line to establish a reference baseline, which is used to compare results of various future scenarios.

Rather than providing a model that predicts the future subject to uncertainty, this thesis proposes a model which reviews past operations to provide the shipper with a plan on how to steer empty containers for the future. Past operations will be tested according to scenarios which review the impact of off-dock terminals on the total cost of empty container management. Scenarios are based on some of the movement solutions proposed by all the different authors. No other paper was found which, instead of a predicting the future, focusses on past operations to determine future steering. Moreover, this thesis takes repair moves into account as such influences the steering of certain container types and the availability of empty containers.

Because the model will not be used to provide a planning schedule but rather will present a goal for the carrier to pursue, it is less important for the model to provide an exact integer result. Furthermore the model reviews the relative cost change between scenario and the reference baseline to support decision making on a tactical and strategic level, which means that any error between scenarios will be the same. This thesis therefore proposes an Linear Program, which takes direct positioning (street-turn between inland terminals and inland depots) and direct evacuation into account, with the purpose of reviewing past operations to provide future considerations.

3.3 Concluding remarks from state of art assessment

Based on the findings from the literature assessment and its comparison to the research question of this thesis, the type of model required to answer the research question of this thesis can be identified. Table 3-2 gives an overview of the relevant papers, their model characteristics, implemented solution and their contribution to this thesis. Lessons learned from (Choong et al., 2002; Crainic et al., 1993; Furió et al., 2013; Jula et al., 2006; Olivo et al., 2013, 2005)will be used for the development of the model.

Table 3-2 Overview of relevant papers, which discuss regional allocation models based on classification proposed in above paragraph

	Considerations						Solutions					
Authors	Linear	Explicit	Continuous	Deterministic	Dynamic	Multi-commodity	Substitution	Street turn	Leasing	Depot direct	Foldable containers	Contribution to thesis
(Crainic et al., 1993)	X	X	X	X	X	X	X		X			Cost function design
(Choong et al., 2002)	X	X	X	X	X				X			Cost function design
(Olivo et al., 2005)	X	X	X	X	X				X			Aggregated macro-nodes
(Jula et al., 2006)	X	X	X	X	X	X		X		X		Depot direct solution
(Moon et al., 2013)	X	X	X	X	X						X	Cost function design
(Wang & Wang, 2007)	X	X	X	X	X	X						Inventory equality constraint
(Furió et al., 2013)	X	X	X	X	X	X		X				Cost function design and street-turn solution
(Olivo et al., 2013)	X	X	X	X	X		X		X			Influence of future requirements (TSL)

The goal of the model in this thesis will be to review various scenarios influencing the historical data provided by Maersk Line, while taking multiple states of containers into account. The scenarios include network topologies, container moves, container steering, move types and TSL heuristics. Repositioning of containers is subject to time-dependent interactions and container type have a different influence on the way containers flow through a network due to differences in demand per location.

No research was found which proposed a solution for empty containers which are not needed in the import dominant area. Those containers require direct transport from inland locations to the port from where they can be moved to overseas deficit locations. Inland terminals already collect all containers from their local customers and if they are not required elsewhere they should be stored at the cheapest location or repositioned to the overseas deficit markets as quickly as possible (evacuation). The model proposed in this study will incorporate the satisfaction of infinite empty container demand at overseas destinations.

Furthermore no research was found which seeks an optimal cost solution with the focus of identifying the best network topology in a port area. A carrier has access to multiple off-dock empty

depots and operates them due to the existence of agreements between the carrier and the off-dock depot, but knowledge of the impact of those agreements on the cost of steering containers is unknown. The model proposed in this thesis will investigate the influence on cost of network topology scenarios.

Finally no research was found which takes into account the impact of damaged containers on the size of the containers available. In most models containers are assumed non-damaged and thus are always available for use. The proposed model in this thesis will incorporate the damaged and non-damaged state of an empty container to determine total cost.

A Linear Deterministic Discrete Dynamic Mathematical Optimization model will be developed and implemented to solve the research question for finding an optimal cost solution for the steering of empty containers through the off-dock depots of Rotterdam port, while taking both damaged as non-damaged container into account. The model will operate at a timestep of 1 week with a time horizon of 52 weeks.

This study contributes to research by developing a multi-commodity model which takes into account both damaged and non-damaged containers. The proposed model is then used to investigate the impact on different network topologies and the results of applying the street-turn (Furió et al., 2013) or depot-direct proposed by (Jula et al., 2006) solution to the network. The purpose of the model is to support decision making on empty container steering through a network of inland terminals, depots and ocean terminals.

4 Theoretical regional empty container steering model

This chapter discusses the theoretical model developed for empty container steering through off-dock empty depots, while taking into account damaged and non-damaged containers.

4.1 Assumptions specific for theoretical empty container steering model

For the development of the theoretical model the following set of assumptions have been made.

General

Customers are assumed to deliver and pickup containers from the same node.

As soon as containers are delivered back to the same node the remaining costs for positioning and evacuation and EMR are for Maersk Line. CH and MH datasets can therefore be added together. A node takes the role of a macronode with customers aggregated around it.

Only when a container type is deficit, empty containers are assumed to arrive at a surplus ocean terminal from the global scale network.

Even though, the network is mostly surplus an occasional import of empty containers is required. Because Maersk Line owns such a large fleet, they aim to minimize the lease of empty containers. Containers are therefore assumed to be adequately imported from other surplus locations to meet demand in a particular time step.

The ocean terminals are connected with a sink node with an infinite need for empty containers when the network is surplus and with a source node with an infinite production when the network is deficit.

Terminals are connected to the global network, which operates a much larger scale network. At Maersk Line all excess containers available outside the regional requirements and TSL are evacuated.

Move costs are a combination of transport costs plus handling costs at the origin node and handling costs at the destination node.

Between each node an arc is represented by its decision variable. Transportation of empty containers on an arc requires therefore all transport unitized costs to be bundled between two specific locations.

Time

No delivery window is included and no backlogging is permitted

Containers are delivered within a single timestep t equal to 1 week to the location with a demand and a time horizon of 52 weeks is investigated in the model.

The repair activity of a container takes one week and afterwards it cannot become damaged again.

When a 'damaged' container arrives at a depot requiring repair it is brought to a repair shop, repaired and returned to depot within a single time step. The following time step a repaired container is available for export once again. Repaired containers are assumed not to be damaged straight afterwards.

Container type

4 container types are considered separately, 20' dry (20DC), 40' dry (40DC), 40' dry highcube (40HC), 40' reefer highcube (40HR).

The model takes 4 container types separately into account because these account for more than 95% of the complete container fleet handled in the Rotterdam port. The container types are modelled separately because capacity at all locations has been noticed to be sufficiently large that it does not directly affect container transport and allowing for container specific recommendations

EMR

A container quality check is performed on empty containers prior to gate out for export at all inland terminals, depots and ocean terminals.

'Damaged' containers reduce the supply of a node, which occurs at every node in the network. 'Damaged' containers thus increase the demand for containers at any source and sink node. To ensure the container leaves for a customer with the highest quality a check is performed prior to departure of empty containers for export. Repair capacity has been set to 230 containers for every workshop, thus assuming they are equally large. The exact failure rate is unknown, but after investigation of the results from Maersk Line it is found that around 20-25% of the containers passing through Rotterdam requires repair.

Transport

All repair, repositioning and evacuation flows are performed by barge with infinite capacity.

Capacity is assumed infinite, because little congestion occurs on inland waterways except at locks, the barge market is highly competitive making capacity no limiting factor and Maersk Line argues that when there is a transport requirement a solution can always be found.

All barge and ITT transport costs are unit costs independent of distance and time.

The unit costs for transport are an amount agreed upon between carrier and transporter. The amount is paid per container.

Handling

All handling costs are unit costs independent of time.

Handling is performed at the gate in and gate out of a container at any location. Any internal operations of any location are out of scope, because this is operated by a third party. The costs are paid for the service provided independent of the efficiency of internal process.

Storage

Off-dock empty depots, Inland terminals and ocean terminals are subject to a maximum storage capacity and a minimum TSL.

All containers exceeding the TSL level will be evacuated after regional balancing has been performed. Total TSL per country is known. Ocean terminals have a TSL of 0 as it is not preferable to store empty containers at these costly locations. The TSL of each country is calculated by headquarters and the algorithm is unknown to Maersk Line employees in the Netherlands.

All storage costs are unit costs dependant of time.

Storage is in reality calculated per day a container is located in a location exceeding the day of departure and the day of delivery. To compensate for the model assuming time steps of 1 week, unit storage costs have been multiplied by 5 workdays.

4.2 General description of mathematical model

The model solves a minimum cost network flow problem of containers through a set of topology scenarios. A container is considered 'damaged' or 'non-damaged', depending on the state it represents. Below function gives a general description of the min cost flow network problem, which is to be adapted to fit the problem of this thesis.

$$\min Z = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}x_{ij}$$

With

c_{ij}: arc costs

x_{ij}: decision variable

Subject to:

Flow balance (equality constraint): $\sum_{i=1}^{n} x_{ij} - \sum_{i=1}^{n} x_{ji} = b_i \quad \forall i$

Arc capacity constraint: $0 \leq x_{ij} \leq u_{ij} \quad \forall (i,j)$

Nodes can have 3 functions in a min cost network flow problem, namely sink, source and transshipment. A sink node have a demand for empty containers $b_i < 0$, a source node provide a supply of empty containers $b_i > 0$ and a transhipment node, which is neither a supply nor a demand node, thus $b_i = 0$.

The proposed model is represented as a simplification of reality, which is based on the scope of this thesis. It contains elements similar to those described in chapter 3. This model is a network of locations and transport possibilities described by a directed graph $G(N, A)$ with nodes $n \in N$ and A arcs. The nodes in the network represent ocean terminals (m), off-dock empty depots (k), source Inland terminals (i) and sink Inland Terminal (j). Arcs serve as transport legs between nodes for the purpose of carrying container through the network, such that demand is met. The graph $G(N, A)$ (see Figure 4-1) have for clarity purpose been separated into two subgraphs, 'damaged empty container' graph $G^{EMR}(N^{EMR}, A^{EMR})$ (see Figure 4-2) and 'non-damaged empty container' positioning and evacuation (PE) graph $G^{PE}(N^{PE}, A^{PE})$ (see Figure 4-3) which are connected over time between the source and sink nodes $\{i, j, k, m\}$.

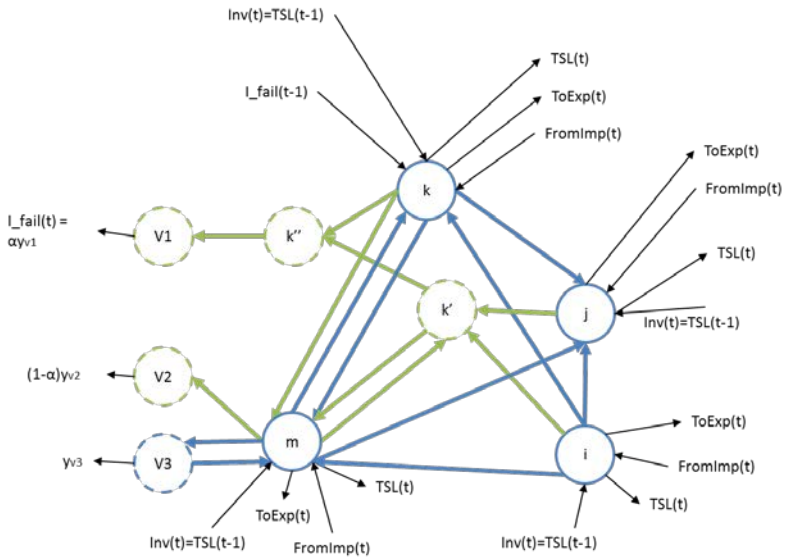


Figure 4-1 simplified network made up out of ocean terminal (m), off-dock empty depots (k) and source inland terminal (i) and sink Inland terminal (j). green arrows represent repair moves, blue lines represent positioning and evacuation moves.

G^{EMR} is a network, which ships damaged containers to a repair location, where EMR operations are performed. EMR operations have been clustered into a single repair operation. Available containers at all locations can fail, according to a failure rate, resulting in the requirement for repair, which are performed at the off-dock empty depots, resulting in a repair move. At the beginning of each time period t, empty containers that have returned from customers are split into 'damaged' containers and 'non-damaged' containers through a failure rate η. Every time step the failure rate is selected randomly between a lower-bound and upper-bound failure rate, because the failure of a container is

due to a large set of external influences, such as human factors, fatigue, weather conditions, previous repair qualities and other factors. Upon arrival at an off-dock empty depot, a container is either repaired or

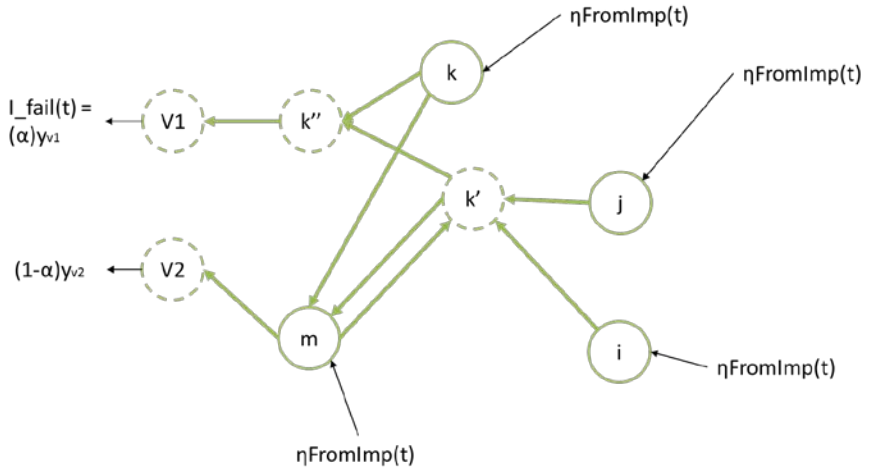


Figure 4-2 EMR graph with all arcs allowing EMR flows of damaged containers

evacuated to be repaired at an overseas repair facility. repair can be performed at the depots or overseas, represented by a 'local repair' rate α. The flow balances and constraints are described in the Paragraph 4.3.

In the network G^{EMR} a depot has 3 tasks, namely it serves as a transhipment node $\{k'\}$, which receives damaged containers from the source nodes and sends them to the repair shop, a repair shop $\{k''\}$, which performs the repair of damaged containes to make them available in the next time step for positioning or evacuation purposes, and a source node $\{k\}$ where damaged containers originate. Virtual1 node $\{v1\}$ represents a sink node equal to sum of locally repaired damaged containers. Virtual2 node $\{v2\}$ represents a sink node equal to the sum of evacuated damaged containers. Inland terminal nodes $\{i,j\}$ both serve as a source nodes for repair flow. Ocean terminal nodes $\{m\}$ have 2 functions, i.e. transhipment and source node. The arcs between $\{k\}$ and $\{k'\}$ and between $\{k'\}$ and $\{k''\}$ represents the repair activity of damaged containers. $I_{fail}(t)$ represents the containers that have failed in a timestep and will re-enter at timestep $(t+1)$ as repaired containers at an off-dock empty depot $\{k\}$.

The G^{PE} graph is similarly built up as the G^{EMR} graph with some differences, but only operates 'non-damaged' empty containers for positioning and evacuation purposes. The off-dock empty depots $\{k\}$ are either sink and transhipment or source and transhipment nodes. Inland terminal nodes are either sink $\{i\}$ or source $\{j\}$. An ocean terminal $\{m\}$ serves as a sink and transhipment or source and transhipment node. A virtual node $\{v3\}$ has been added to serve as the location representing overseas location from where containers enter or leave the network depending on the overall state of the network at time step t.

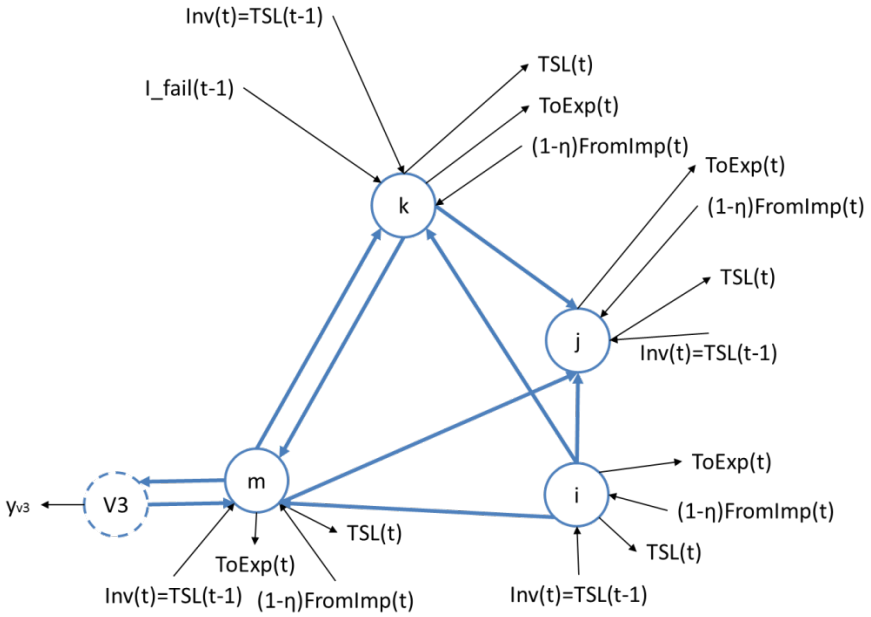


Figure 4-3 PE graph with all arcs allowing positioning and evacuation of containers.

4.3 Mathematical model formulation

The min cost flow network problem is a linear programming problem which seeks the optimum cost of a function restricted by constraints. The theoretical model is of the shape of a mixed integer linear program (MILP), which implies that only some decision variables need to be integers.

4.3.1 Nomenclature

Indices

i	Surplus Inland Terminals, $i \in \{1 \dots ITS\}$ where ITS is the number of Inland Terminals, which are surplus, for time step t
j	Deficit Inland Terminals, $j \in \{1 \dots ITD\}$ where ITD is the number of Inland Terminals, which are deficit, for time step t
k	Off-dock empty depots, $k \in \{1 \dots OD\}$ where OD is the number of Off-dock empty depots
m	Ocean Terminal, $m \in \{1 \dots OT\}$ where OT is the number of Ocean Terminals
t	Periods, $t \in \{1 \cdots T\}$ where T is the number of periods in the planning horizon

Parameters

α	EMR evacuation rate, which describes containers that are too expansive to repair within the reviewed scope
η	Failure rate of containers to separate 'non-damaged' containers from 'damaged' containers
C^A	Arc costs for positioning and evacuation of containers specific for all arcs
C^{Import}	Import arc costs of containers when a time step is deficit
C^{EMR}	Repair costs specific for a depot and container type

C^{EE}	Repair evacuation costs, representing the cost of performing EMR on containers outside scope
C^{Evac}	Evacuation costs
$ncap\ \forall i,j,k,m$	Physical capacity of an inland terminal and off-dock empty depot
$EMRcap_k$	Repair capacity of off-dock empty depot
$FromImp(t)\ \forall i,j,k,m$	Empty containers entering a node from import customers at t
$ToExp(t)\ \forall i,j,k,m$	Empty containers leaving a node to export customers at t
$I_{fail}(t)$	Damaged containers acquiring repair at the depot at t
$TSL\ \forall i,j,k,m$	Target stock level at time step t
$I(t)\ \forall i,j,k,m$	Target stock level from time step (t-1) equal to inventory at t
$y_{v1}(t)$	Amount containers repaired at t
$y_{v2}(t)$	Amount EMR containers evacuated at t
$y_{v3}(t)$	Amount containers evacuated/imported at t
Y_m	Binary value used to 'open' or 'close' arcs connected to ocean terminals
Y_k	Binary value used to 'open' or 'close' arcs connected to off-dock empty depot

4.3.2 Decision variables

As described earlier the network consists of two subgraphs EMR and PE respectively taking care of flow of 'damaged' and 'non-damaged' containers. The decision variables of this network are noted as a variable *X*. Each decision variable is described by the subgraph they occupy and which nodes they connect.

Decision variables

$X_{ik'}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving inland terminal *i* and entering transhipment depot *k'*
$X_{jk'}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving inland terminal *j* and entering transhipment depot *k'*
$X_{kk''}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving depot *k* and entering workshop depot *k''*
$X_{k'm}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving transhipment depot *k'* and entering ocean terminal *m*
$X_{k'k''}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving transhipment depot *k'* and entering workshop depot *k''*
$X_{k''v1}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving workshop depot *k''* and entering transhipment depot *v1*
$X_{km}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving depot *k* and entering ocean terminal *m*
$X_{mk'}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving ocean terminal *m* and entering transhipment depot *k'*
$X_{mv2}^{EMR}(t)$	Amount of 'damaged' containers in EMR subgraph in time period *t* leaving ocean terminal *m* and entering transhipment depot *v2*
$X_{im}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving inland terminal *i* and entering ocean terminal *m*
$X_{mj}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t*

	leaving ocean terminal *m* and entering inland terminal *j*
$X_{km}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving depot *k* and entering transhipment ocean terminal *m*
$X_{mk}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving ocean terminal *m* and entering depot *k*
$X_{mv3}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving ocean terminal *m* and entering virtual node 'China' *v3*
$X_{v3m}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving virtual node 'China' *v3* and entering ocean terminal *m*
$X_{ik}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving inland terminal *i* and entering depot *k*
$\mathrm{X}_{\mathrm{kj}}^{\mathrm{PE}}(\mathrm{t})$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving depot *k* and entering inland terminal *j*
$X_{km}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving depot *k* and entering ocean terminal *m*
$X_{mk}^{PE}(t)$	Amount of 'non-damaged' containers in PE subgraph in time period *t* leaving ocean terminal *m* and entering depot *k*

4.3.3 Objective function

The objective function is a minimization of the cost function under the condition of meeting customer demand, which exists of all arcs taken into account multiplied by their corresponding cost. The goal of the model is to obtain optimal costs for moving containers through the combined network. The minimization of the cost function is subject to several constraint, specifically capacity constraints, flow constraints, repair capacity constraints and non-negativity constraints. Function (1) describes the cost function, which sums all costs for moving containers through the network between all nodes {i,j,k,m} for each time step.

$$\begin{aligned}\min \sum_{i}\sum_{k'} C_{ik'}^{A} X_{ik'}^{EMR}(t) + \sum_{j}\sum_{k'} C_{jk'}^{A} X_{jk'}^{EMR}(t) + \sum_{k}\sum_{k''} C_{kk''}^{EMR} X_{kk''}^{EMR}(t) + \sum_{k}\sum_{m} C_{km}^{A} X_{km}^{EMR}(t) \\ + \sum_{k'}\sum_{m} C_{k'm}^{A} X_{k'm}^{EMR}(t) + \sum_{m}\sum_{k'} C_{mk'}^{A} X_{mk'}^{EMR}(t) + \sum_{k'}\sum_{k''} C_{k'k''}^{EMR} X_{k'k''}^{EMR}(t) \\ + \sum_{m}\sum_{v2} C_{mv2}^{EE} X_{mv2}^{EMR}(t) + \sum_{i}\sum_{k} C_{ik}^{A} X_{ik}^{PE}(t) + \sum_{i}\sum_{m} C_{im}^{A} X_{im}^{PE}(t) \\ + \sum_{k}\sum_{j} C_{kj}^{A} X_{kj}^{PE}(t) + \sum_{i}\sum_{j} C_{ij}^{A} X_{ij}^{PE}(t) + \sum_{m}\sum_{j} C_{mj}^{A} X_{mj}^{PE}(t) \\ + \sum_{k}\sum_{m} C_{km}^{A} X_{km}^{PE}(t) + \sum_{m}\sum_{k} C_{mk}^{A} X_{mk}^{PE}(t) + \sum_{m}\sum_{v3} C_{mv3}^{Evac} X_{mv3}^{PE}(t) \\ + \sum_{v3}\sum_{m} C_{v3m}^{Import} X_{v3m}^{PE}(t)\end{aligned} \quad (1)$$

EMR equality constraint

EMR nodal flow constraints are equality constraints which ensure that all flow into each respective node is equal to all flows out of the node. Equations (2) until (11) provide the equality constraints for the EMR subgraph, ensuring no more 'damaged' containers are moved than existing within the model. Containers arriving at nodes from customers are split into damaged and non-damaged containers by the failure rate η. Failed containers can either be repaired in the network or outside the network, which is determined through the local repair rate α. The equality constraints are a summation of all flow into a node equal to all flow out of a node. A sink node j in the PE subgraph simultaneously has a source function for the EMR subgraph, because all containers can . The equality constraints have all be modelled according to the graph found in Figure 4-1.

$\{i\}$ $$X_{ik'}^{EMR}(t) = \eta FromImp_i(t) \quad (2)$$

$\{j\}$ $$X_{jk'}^{EMR}(t) = \eta FromImp_j(t) \quad (3)$$

$\{k\}$ $$X_{kk''}^{EMR}(t) + X_{km}^{EMR}(t) = \eta FromImp_k(t) \quad (4)$$

$\{k'\}$ $$X_{k'k''}^{EMR}(t) + X_{k'm}^{EMR}(t) - X_{mk'}^{EMR}(t) - X_{ik'}^{EMR} - X_{jk'}^{EMR} = 0 \quad (5)$$

$\{k''\}$ $$-X_{k'k''}^{EMR}(t) - X_{kk''}^{EMR}(t) + X_{k''v1}^{EMR}(t) = 0 \quad (6)$$

$\{m\}$ $$X_{mk'}^{EMR}(t) - X_{k'm}^{EMR}(t) - X_{km}^{EMR}(t) + X_{mv2}^{EMR}(t) = \eta FromImp_m(t) \quad (7)$$

$\{v1\}$ $$X_{k''v1}^{EMR}(t) = I_{fail}(t) \quad (8)$$

$\{v2\}$ $$X_{mv2}^{EMR}(t) = y_{v2}(t) \quad (9)$$

$$I_{fail}(t) = \alpha\left(\eta FromImp_m(t) + \eta FromImp_k(t) + \eta FromImp_i(t) + \eta FromImp_j(t)\right) \quad (10)$$

$$y_{v2}(t) = (1-\alpha)\left(\eta FromImp_m(t) + \eta FromImp_k(t) + \eta FromImp_j(t) + \eta FromImp_i(t)\right) \quad (11)$$

PE (positioning and evacuation) equality constraint

Positioning and evacuation nodal flow constraints are equality constraints which ensure that all flow into each respective node is equal to all flows out of the node. Equations (12) until (17) provide the equality constraints for the PE subgraph, ensuring no more 'non-damaged' containers are moved than existing within the model. The equality constraints are a summation of all flow into a node equal to all flow out of a node. The equality constraints have all be modelled according to the graph found in Figure 4-1. Containers that had failed in the previous time-step become available for positioning and evacuation purposes at the off-dock empty depots $\{k\}$.

$\{i\}$ $$X_{ik}^{PE}(t) + X_{im}^{PE}(t) + X_{ij}^{PE}(t) = I_i(t-1) - I_i(t) + (1-\eta)FromImp_i(t) - ToExp_i(t) \quad (12)$$

$\{j\}$ $$-X_{kj}^{PE}(t) - X_{mj}^{PE}(t) - X_{ij}^{PE}(t) = I_j(t-1) - I_j(t) + (1-\eta)FromImp_j(t) - ToExp_j(t) \quad (13)$$

$$\{k\} \quad -X_{ik}^{PE}(t) + X_{kj}^{PE}(t) + X_{km}^{PE}(t) - X_{mk}^{PE}(t) = I_k(t-1) - I_k(t) + I_{fail}(t-1) + (1-\eta)FromImp_k(t) - ToExp_k(t) \tag{14}$$

$$\{m\} \quad X_{mj}^{PE}(t) + X_{mk}^{PE}(t) + X_{mv3}^{PE}(t) - X_{v3m}^{PE}(t) - X_{im}^{PE}(t) - X_{km}^{PE}(t) = I_j(t-1) - I_j(t) + (1-\eta)FromImp_j(t) - ToExp_j(t) \tag{15}$$

$$\{v3\} \quad X_{mv3}^{PE}(t) - X_{v3m}^{PE}(t) = y_{v3}(t) \tag{16}$$

$$y_{v3}(t) = (1-\eta)\left(FromImp_m(t) + FromImp_k(t) + FromImp_j(t) + FromImp_i(t)\right) - \left(ToExp_m(t) + ToExp_k(t) + ToExp_j(t) + ToExp_i(t)\right) \tag{17}$$

Dynamic interactions between time step t

TSL at timestep t is equal to the inventory at time step $t+1$ and likewise current inventory is equal to TSL of the previous timestep. Also containers repaired in time step t become available for positioning or evacuation in time step $t+1$.

$$I_m(t) = TSL_m(t-1), \quad I_k(t) = TSL_k(t-1), \quad I_j(t) = TSL_j(t-1), \quad I_i(t) = TSL_i(t-1)$$

Capacity constraint

Each node in the PE subgraph is limited by a capacity constraint as found in equations (18) until (21). This capacity constraint represent the amount of containers allowed at a location per time step t

$$0 \leq \sum X_{ik'}(t) + \sum X_{im}(t) + \sum X_{ik}(t) + \sum X_{im}(t) \leq ncap_i \tag{18}$$

$$0 \leq \sum X_{ik'}(t) + \sum X_{k'j}(t) + \sum X_{kjv}(t) + \sum X_{mj}(t) \leq ncap_j \tag{19}$$

$$0 \leq \sum X_{k}(t) + \sum X_{ik}(t) + \sum X_{kj}(t) + \sum X_{km}(t) \leq ncap_k \tag{20}$$

$$0 \leq \sum X_{km}(t) + \sum X_{k'm}(t) + \sum X_{mj}(t) + \sum X_{im}(t) \leq ncap_m \tag{21}$$

Repair capacity constraint

In the subgraph EMR a repair shop is limited by a capacity constraint, representing the amount of containers that can be repaired at a repair shop per time step.

$$0 \leq \sum X_{k'k''}(t) + \sum X_{k''k'}(t) \leq EMRcap_{k''} \tag{22}$$

Topology selection

Topology selection includes different combinations of off-dock empty depots and ocean terminals to be opened or closed. This is done by multiplying open arcs by a binary variable which represents their state. When a node {k} or {m} is closed all arcs leading to and from that node need to be closed as well. In other words closing a 'closed' node results in a reduction of the size of the problem. Variable Y_k in Equation (23) and Y_m in Equation (24) ensures that those decision variables cannot be selected by model when closed. M represents the sum of all flow over those arcs.

$$X_{ik'}^{EMR}(t) + X_{jk'}^{EMR}(t) + X_{kk''}^{EMR}(t) + X_{k'm}^{EMR}(t) + X_{k'k''}^{EMR}(t) + X_{k''v1}^{EMR}(t) + X_{ik}^{PE}(t) + X_{kj}^{PE}(t) + X_{km}^{PE}(t) + X_{mk}^{PE}(t) \leq Y_k M \tag{23}$$

$$X_{km}^{EMR}(t) + X_{k'm}^{EMR}(t) + X_{mk'}^{EMR}(t) + X_{mv2}^{EMR}(t) + X_{im}^{PE}(t) + X_{mj}^{PE}(t) + X_{km}^{PE}(t) + X_{mk}^{PE}(t) + X_{mv3}^{PE}(t) + X_{v3m}^{PE}(t) \leq Y_m M \tag{24}$$

Non – negativity constraint

To ensure all decision variables are only allowed to be non- negative integer values equation (25) is required.

$$X_{ik'}^{EMR}(t), X_{jk'}^{EMR}(t), X_{kk''}^{EMR}(t), X_{k'm}^{EMR}(t), X_{k'k''}^{EMR}(t), X_{k''v1}^{EMR}(t), X_{ik}^{PE}(t), X_{kj}^{PE}(t), X_{km}^{PE}(t), X_{mk}^{PE(t),}(t), X_{km}^{EMR}(t), X_{mk'}^{EMR}(t), X_{mv2}^{EMR}(t), X_{im}^{PE}(t), X_{mj}^{PE}(t), X_{mk}^{PE}(t), X_{mv3}^{PE}(t), X_{v3m}^{PE}(t) \geq 0 \ \forall i, j, k, m, v1, v2, v3 \ \ integers \tag{25}$$

5 Development of DSS tool based on theoretical model

In this chapter the scope presented in chapter 2, findings from the literature assessment in chapter 3 and the theoretical model in chapter 4 will be combined for the development of a DSS tool for empty container steering.

5.1 A tool for decision making

Decision making can be a challenging assignment, when the choices are influenced by a large set of variables. Empty container steering is an example of such a challenge. The process of sending containers to locations where demand exists over a network with an endless possibilities is difficult if not assisted by a tool to support the decision making process. This type of tool is categorized as a Decision Support System (DSS). Chapter 3.1.2 presents a state of art description of the various existing decision planning models and there it was established that the proposed model assists in tactical/operational decision making.

This model can be used to;

- Calculate from a user-specified network, expandable up to 75 nodes, transport, handling, storage and repair costs,
- Investigate different scenarios to support decision making at a tactical and operational decision level. The results serve as proof of performance towards higher management.
- Investigate and compare a set of solutions for the given input variables and visualizes them

In Appendix D the Graphical User Interface (GUI), which serves as the interface towards the decision maker, is described.

5.2 Software considerations for DSS tool

As the input parameters are known and the system can be described through a linear objective function, the model is best analysed with the use of linear programming. Multiple types of Linear Programming, depending on the input data, environment and required results, e.g. Linear Inter Programming, Mixed Linear Integer Programming, Stochastic Integer Programming. They are listed in an increasingly complex order. Linear Integer Programming is capable of finding a solution P within polynomial time. Several tools exist to solve linear optimization problems, viz. CPLEX, Excel, Matlab and AIMMS.

Excel is an example of spreadsheet software which allows cell based calculations. Results can be simple organized through the use of pivot tables and graph tools in the program. Through the addition of macros and the visual basic programming language Excel's capabilities can be extended outside the limitations of cell calculations.

Table 5-1 Advantages and Disadvantages of Excel

Excel	
(+) Excel is available for use at Maersk Line	(−) The spreadsheet is limited in maximum size of the sheet.
(+) Easy application for Maersk employees	(−) Instability of the tool due to long run times of excel programs and complex calculations
(+) Simple visualization of results in graphs and tables.	(−) Functions need to be programmed from scratch.
(+) Experienced in working with Excel.	(−) Little experience in working with macro's

Matlab is a numerical computation, visualization and programming tool, which allows models to analyse data through algorithms. The programming language is math focused and is very strong at performing optimizations with multiple restrictions and decision variables. The result found can be visualized through graphical plots. Matlab even provides the ability of building applications, which can be used by non-Matlab users. This allows for a tool which is usable by Maersk Line upon completion of the thesis even without owning a license.

Matlab (built-in solver)	
(+) Stable for large and complex mathematical problems	(−) Compiler does not work in accordance with external solvers.
(+) Matlab script can be compiled to standalone shape.	(−) Certain functions in toolboxes need to be reprogrammed to fit the case.
(+) Toolboxes with predefined functions exist, i.e. Matlog	(−) non-editable after compilation
(+) Export knowledge available through fora	(−) Limited experience in programming language

Table 5-2 Advantages and Disadvantages of Matlab in combination with a built-in solver

CPLEX is a commercial solver of IBM, which is very frequently applied in literature. It has a proven track record for providing quick solvability. The solver is specialized in LP, ILP and MILP problems and as such fits great to the problem at hand. IBM's CPLEX can be used in combination with Matlab. The major drawback with the solver is its high price and that Matlab's compiler does not work in combination with CPLEX.

Matlab (CPLEX solver)	
(+) A strong solver, often applied to similar optimization	(−) Expensive product
(+) Available toolboxes online	(−) Not usable in compiled Matlab tool.
(+) Export knowledge available through fora	(−) Functions need to be programmed from nothing
	(−) No experience with working with CPLEX

Table 5-3 Advantages and Disadvantages of Matlab in combination with a CPLEX solver

AIMMS is an established modelling system applied to logistics problems such as the minimum cost network flow. The tool works with predetermined and editable functions that perform a certain task existing in transport models. It applies built-in functions to a model developed within the program.

AIMMS	
(+) Established optimization tool	(−) Expensive commercial product
(+) Predetermined functions	(−) Little knowledge online through fora
(+) Some expert knowledge at TU Delft	(−) No experience with working with AIMMS

Table 5-4 Advantages and Disadvantages of AIMMS

A number of pros and cons exist for the various tools available and investigated. One tool stands out from the rest, due to its possibility to compile a program to a standalone version. Matlab 2014a with the built-in linear programming solver will be used to build the model proposed as it outweighs the other tools in calculation power and usability for the end-user. The toolbox Matlog (Kay, 2014) will be used for writing the minimum cost network flow into the correct format required by the solver.

5.3 Established reference datasets as input for DSS tool

Historical data is used from Maersk Line to test the theoretical model. This data was retrieved from Maersk Lines empty container management system based on the assumptions made for the model and the combined scope presented in chapter 2.3. The establishment of a dataset for the model was a complicated process as it was difficult to modify the open network to a closed network required for the proposed model. Through the intermodal history tool used by Maersk Line, which shows per container type the amount of gate-in and gate-out that occur on a weekly basis, an empty container demand and supply dataset could be established. A gate-in represents an empty container which returns from an import customer after discharge and a gate-out represents an empty containers, which is sent to an export customer for loading. The respective datasheets are henceforth known as the FromImp dataset and ToExp dataset.

Each node in the model has a predetermined target stock level (TSL), which is based on the future demand versus the available supply at a node. The TSL reference input data has been established with the help of the expert knowledge from Maersk Line employees.

	20' empty	Inland terminals														depots				ocean term		
		CH	ALPHERIUM	CONTAINER TERMINAL VREDE AMSTER	BCTN DEN BOSCH BV.	COMBI TERMINAL TWENTE B.V.	BCTN WANSSUM / VENRAY	MOERDIJK CONTAINER TERMINAL	DELTA MARINE TERMINAL BV	BCTN NIJMEGEN BV.	BARGE TERMINAL BORN	OSSE OVERSLAG CENTRALE (OOC)	BTT BARGE TERMINAL TILBURG	CONTAINER TERMINAL UTRECHT	ECT VENLO TERMINAL	Depot A	Depot C	Depot B	Depot D	Terminal 1	Terminal 2	Terminal 3
aggregated inland terminals	Switzerland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Inland terminal	ALPHERIUM	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1	1	1
Inland terminal	CONTAINER TERMINAL VREDE AMSTERDAM	0	1	0	0	0	0	0	0	0	0	0	0	1	0	1	1	1	1	1	1	1
Inland terminal	BCTN DEN BOSCH BV.	0	0	0	0	1	1	1	1	1	1	1	0	0	1	1	1	1	1	1	1	1
Inland terminal	COMBI TERMINAL TWENTE B.V.	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1
Inland terminal	BCTN WANSSUM / VENRAY	0	0	0	1	1	0	1	1	1	1	1	1	0	1	1	1	1	1	1	1	1
Inland terminal	MOERDIJK CONTAINER TERMINAL	0	0	0	1	0	1	0	1	1	0	0	1	0	0	1	1	1	1	1	1	1
Inland terminal	DELTA MARINE TERMINAL BV	0	0	0	1	0	1	1	0	1	0	0	1	0	0	1	1	1	1	1	1	1
Inland terminal	BCTN NIJMEGEN BV.	0	0	0	1	1	1	1	1	0	1	0	0	1	1	1	1	1	1	1	1	1
Inland terminal	BARGE TERMINAL BORN	0	0	0	1	0	1	0	0	1	0	0	1	0	0	1	1	1	1	1	1	1
Inland terminal	OSSE OVERSLAG CENTRALE (OOC)	0	0	0	1	0	1	0	0	0	0	0	1	0	0	1	1	1	1	1	1	1
Inland terminal	BTT BARGE TERMINAL TILBURG	0	0	0	0	0	1	1	1	0	1	1	0	0	0	1	1	1	1	1	1	1
Inland terminal	CONTAINER TERMINAL UTRECHT	0	0	1	0	0	0	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1
Inland terminal	ECT VENLO TERMINAL	0	0	0	1	0	1	0	0	1	0	0	0	0	0	1	1	1	1	1	1	1
Depot	Depot A	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1
Depot	Depot C	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1
Depot	Depot B	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1
Depot	Depot D	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0	1	1	1
Ocean terminal	Terminal 1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Ocean terminal	Terminal 2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0
Ocean terminal	Terminal 3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	0	0	0

Figure 5-1 Physical network OD (origin-destination) matrix, with an 'open' arc equal to 1 and a 'closed' arc equal to 0.

For the implementation of the model a physical network was required, which represents the arcs that exist in the model between each node. First the current network has been established, which exists out of all inland terminal nodes being connected to all off-dock empty depots and respectively all off-dock empty depots connected to all ocean terminals. Through cooperation with Maersk Line experts all inland terminal to inland terminal connections were established as deemed possible. The network is similar to the combined scope in chapter 2.3.

Finally for the model a set of unitized operational costs were required. These unitized costs are the costs of moving a single container along arcs in a network $G(N, A)$. The unitized move costs have been derived from existing rate agreements between Maersk Line and the transporter providing transport between a specific OD-pair. Rate agreements exist for handling, transport, storage and repair costs. All arcs costs represent an origin and destination specific barge cost and a handling cost at the origin of the arc and a handling cost at the destination of the concerning arc. Only off-dock depots and ocean terminals charge a storage costs for inventory at the end of a time step, however ocean terminals have a TSL of 0 and will therefore not store containers in this model. Furthermore only 'opened' off-dock empty depots offer repair operations and is limited by an EMR capacity constraint.

5.4 Relaxation of Integer Linear Programming

Matlab 2014a is the first edition of Matlab that also offers a Mixed Integer Linear Programming (MILP) solver in the program's optimization toolbox, allowing for the investigation of min cost network flow problems as an integer problem. This offers a more accurate model as it in comparison to a Linear Programming (LP) searches for a solution where the variables are restricted to integers. The biggest problem of an Integer Linear Programming problem is that it makes a problem NP-hard. NP-hard does not necessarily mean that the problem becomes infeasible but that exponentially expanding the problem could result in the solving time required also to expand exponentially.

The current model has been solved with a LP solver, allowing the model to send partial containers through the network, which is incorrect in comparison to reality. The main reason for simplifying the model with a linear programming solver was due to the main purpose of the model, which focusses on providing a DSS tool for understanding the effect of steering empty containers through the off-dock empty depots in the Rotterdam Port. The most important aspect of the model is to compare results between various topology and network scenarios. Furthermore the tool does not serve the purpose of a planning tool, where it is important that the model assigns integers to the decision variables, but of a tactical decision support tool, where the impact of various network compositions are investigated.

To enforce the choice of simplifying the model by applying a LP tool, a test has been performed where the current model has been modified to an ILP tool. A base year scenario was tested both in the ILP model as the LP model and the results have been compared to see what the added value of an ILP model would be. For the test the following settings were used for both models;

Depot topology:	Open: Depot A, Depot B, Depot C; Closed: Depot D
Ocean topology:	Open: Terminal1, Terminal3; Closed: Terminal2
Steering:	None
Move type:	Only indirect positioning and indirect evacuation allowed
TSL heuristic:	Pre-set TSL
Local repair rate:	75%
Failure rate:	25% (fixed)

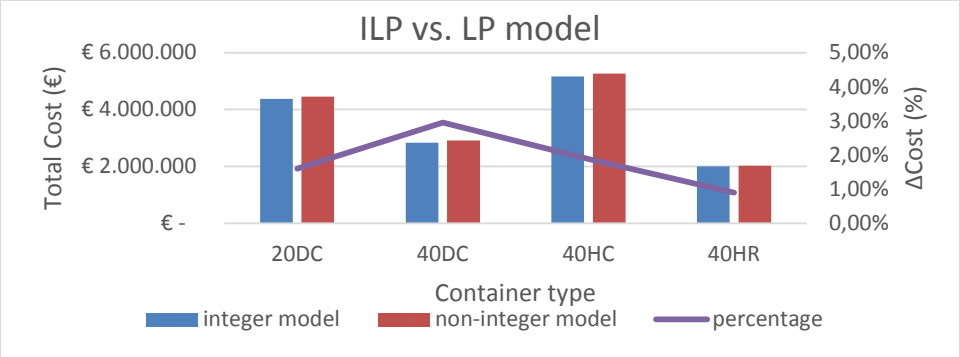


Figure 5-2 shows the comparison of results from an integer linear program and a linear program

When comparing the results from the two models for the different container types, a difference of in average 2% can be noticed. The difference depends on how the containers are located within the datasets provided. Two aspects seem to influence the difference in cost between the two models, namely where containers are required and originate and the total amount of containers moved within the model. As stated earlier the main focus of the model is to investigate the impact of various network topologies and physical limitations on total cost. The error from applying a LP model will be similar for each set of scenarios run on the various container types as the location of demand does not change and the amount of containers moved by the model does not change. Following this line of reasoning a linear programming model will be sufficient for the comparison of various network topologies.

5.5 Verification of newly developed DSS tool

To ensure the model is correct, prior to the implementation process a plan was developed to stepwise build the model. The simplified network graph $G(N, A)$ is typical for the problem of repair, positioning and evacuation flow through a network with empty depots. The model needs to be implemented on a network consisting of 14 inland terminals, 4 off-dock empty depots and 3 ocean terminals. A general rule that applies to the model is that all requirements on a regional scale must first be met with empty containers available on a regional scale before it is allowed to look a global opportunities. This is done to avoid containers being shipped globally to solve local requirements in a surplus regional scale network. Balancing activities occur on the containers available and with a 'non-damaged' state. Containers with a 'damaged' state reduce the ability of a location to supply deficit locations. This leads to an order to follow with respect the implementation of the theoretical model;

1. Determine available containers per node at t
2. Determine amount of containers requiring EMR at t
3. Determine amount of containers requiring EMR but too expensive to repair at t
4. Determine amount of containers to be positioned regionally at t
5. Determine amount of containers to be positioned globally at t

In Appendix E some of the issues that have been encountered in the verification process are discussed in greater detail with a description on how this was solved.

6 Implementation of tool to Maersk Line specific case

This chapter describes the implementation of scenario on the developed Matlab tool. Results from the scenario runs are analysed and investigated to establish a basis for the case conclusions. A sensitivity analysis is performed on the model to identify the cost drivers of the model.

6.1 Establishment of an empirical setup for the investigation of case scenarios

The goal of the research is to determine the total costs of different topologies of the network within project scope (see chapter 2.3). Multiple scenarios will be investigated by the model. The scenarios have been generated from the state of art solutions (see chapter 3.1.3), contributions from other researcher's models (see chapter 3.1.4) and Maersk Line expertise. The complete set of scenarios will be applied to the datasets of different container size types. These scenarios are further detailed in Appendix D. Each of these scenarios need to be run for 4 different container types to establish a complete picture of the problem. The implementation of the scenarios is detailed in Appendix D.

- *Ocean terminal topology*; different points in time with respect to operational ocean terminals (4 scenarios)
- *Depot topology*; different combinations of open off-dock depots (12 scenarios)
- *Container steering*; forcefully steering empty containers through open off-dock depots in steps of 20% (amount of scenarios depend on open off-dock depots)
- *TSL heuristics*; various ways of calculating TSL and a pre-set TSL (4 heuristics)
- *Move type*; extra opening of network arcs (4 scenarios)

A total of 9216 combinations of scenarios exist per container type to run in the model. The evaluation 36864 scenarios would be an impossible job, which is why the empirical setup needs to be reduced to a solvable size. The scenario investigation are divided into the primary, which focuses on various combinations of ocean terminals scenarios (see Table 6-2) and off-dock empty depot scenarios (see Table 6-3) and the impact of forced steering through off-dock empty depots (See Table 6-4), and secondary scenarios, which investigate the impact from a different TSL and a different move type (See Table 6-5).

The primary scenarios will first be run for the 'base' year case, where the model is set through a network topology and steering scenario similar to current operations per container type. The 'base' year serves as the reference to which all scenarios are compared. Afterwards the various depot and steering scenarios are run for the various ocean terminal topologies (transition 1, transition 2 and future scenario) to identify, which off-dock empty depots result in the most optimal cost difference. The second part is divided into two steps, namely first the unsteered scenarios are investigated and afterwards the best scenarios are further investigated when steering is applied. This stepwise analysis is justified because the unsteered situation of a mostly uncapacitated linear optimization model will provide the lowest cost composition. Steering will force the model in another direction resulting in higher costs.

The 'base year' scenario represents the current operation at Maersk Line per container type is used to relate the optimal costs of the different scenarios to current costs and to validate the model results with actual operation costs made by the carrier. Each container type has its own base year with respect to container flow. Table 6-1 shows the 'base' year scenario settings.

Table 6-1 'Base year' topology scenario setup

Container type	DepotA	DepotB	DepotC	DepotD	Terminal1	Terminal2	Terminal3
20DC	Open	Closed	Open	Closed	Open	Closed	Closed
40DC	Open	Closed	Open	Closed	Open	Closed	Closed
40HC	Open	Closed	Open	Closed	Open	Closed	Closed
40HR	Open	Open	Open	Closed	Closed	Closed	Open

Table 6-2 Set of ocean terminal topology scenarios

Ocean Terminal topologies:	Terminal1	Terminal2	Terminal3
'Base'	Open	Closed	Open
'Transition 1'	Open	Open	Open
'Transition 2'	Closed	Open	Open
'Future'	Closed	Open	Closed

Table 6-3 Set of depot topology scenarios

Empty Depot topologies	Depot A	Depot B	Depot C	Depot D
4 open	Open	Open	Open	Open
3 open	Open	Open	Open	Closed
	Closed	Open	Open	Open
	Open	Closed	Open	Open
	Open	Open	Closed	Open
2 open	Open	Open	Closed	Closed
	Open	Closed	Open	Closed
	Open	Closed	Closed	Open
	Closed	Open	Closed	Open
	Closed	Open	Open	Closed
	Closed	Closed	Open	Open
0 open	Closed	Closed	Closed	Closed

Table 6-4 Set of container steering scenarios through off-dock empty depots

	Combinations of depots open/closed		
Depot container steering:	2 depots open 50/50 40/60 20/80 Unsteered	3 depots open 33.3/33.3/33.3 20/20/60 20/40/40 Unsteered	4 depots open 25/25/25/25 20/20/20/40 Unsteered

Running the different primary scenarios and comparing the results to the base year scenario results in the identification of the best off-dock empty depots. The last depot scenario, where all depots are

closed will be judged separately, because this solution is expected not to be comparable to the scenarios, where depots are opened. The set of depot topology scenarios can be found in Table 6-3.

Afterwards, per category, the scenario with the most optimal result will be further evaluated. This further evaluation is done by steering containers through different depots. There are two secondary scenario sets, specifically TSL heuristics and move types. The TSL scenarios investigate the impact of setting TSL to a different value than the pre-set TSL. Three heuristics have been designed for this purpose. The TSL heuristic 'Future average demand' divides total TSL based on the average demand over 4 time-steps. The TSL heuristic 'Future nodal potential' divides total TSL based on the average demand compared to the average supply over 4 time-steps. The TSL heuristic 'Factorized future demand' assigns a TSL factor equal to demand multiplied by a factor of 1,3. See Appendix D for further details. For container steering, a step size of 20% has been selected for the different possible weighted steering scenarios, as this provides a clear insight into the influence of different steering of containers without making the solution size too large.

Table 6-5 Secondary scenario sets, consisting of TSL heuristics and various move-types

Name	Different settings
TSL heuristic:	'Maersk Line pre-set' TSL 'Future average demand' TSL 'Future node potential' TSL 'Factorized future demand' TSL
Move type:	Direct positioning disallowed and direct evacuation disallowed Direct positioning allowed and direct evacuation allowed Direct positioning disallowed and direct evacuation allowed Direct positioning allowed and direct evacuation disallowed

All scenarios will be run 5 times and an average cost will be computed per scenario because the failure rate of a container is between 20-25%. The implemented model follows the model architecture with a detailed description of the elements, which can be found in Appendix D.

6.2 Results from applying the empirical setup on the implemented DSS tool

The method of splitting scenarios into primary and secondary scenarios leads to a set of 223 scenarios to be investigated per container type for the primary scenarios set. Prior to describing the results found by the model, the different cost categories of the model will be described. The model calculates an optimal cost of moving empty containers in a network as proposed in chapter 2.3. The model assigns flow to arcs based on the cost structure and constraints applied to the model, which leads to total costs for such a flow pattern. Costs have been divided into transport cost, handling cost, storage costs and repair costs.

Supply and demand locations

Before results of scenarios are described it is important to know where containers come from and go to. In Figure 6-1 and Figure 6-2 graphs are shown that provide this information. They respectively shows per node the supply and demand of empty containers.

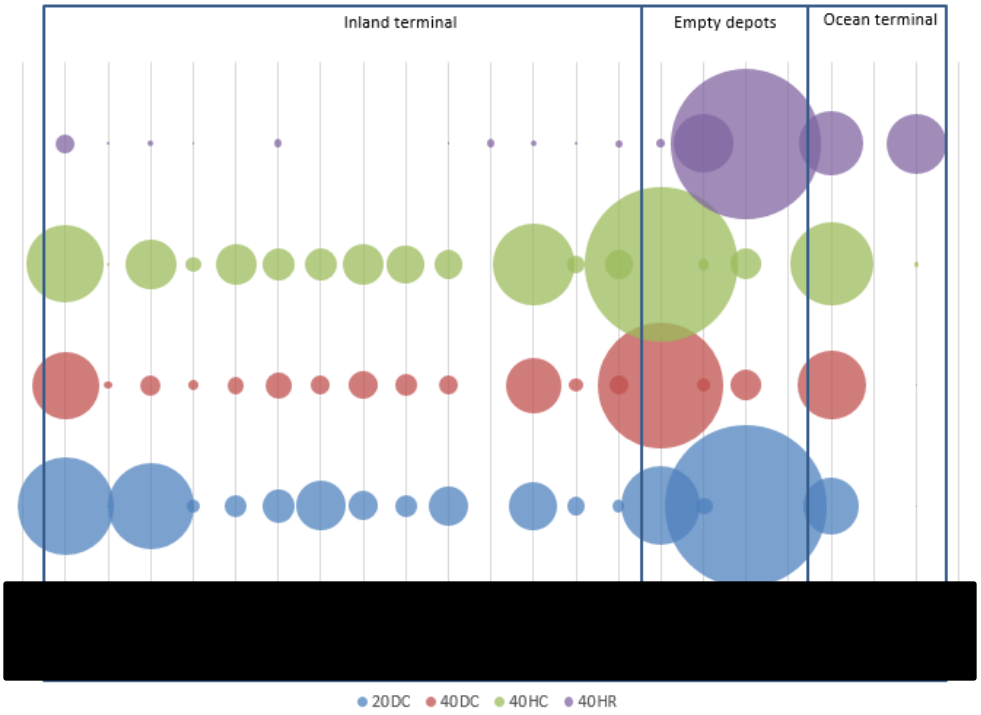


Figure 6-1 shows where demand is located in the network. The bubble size represents the magnitude of containers in a location

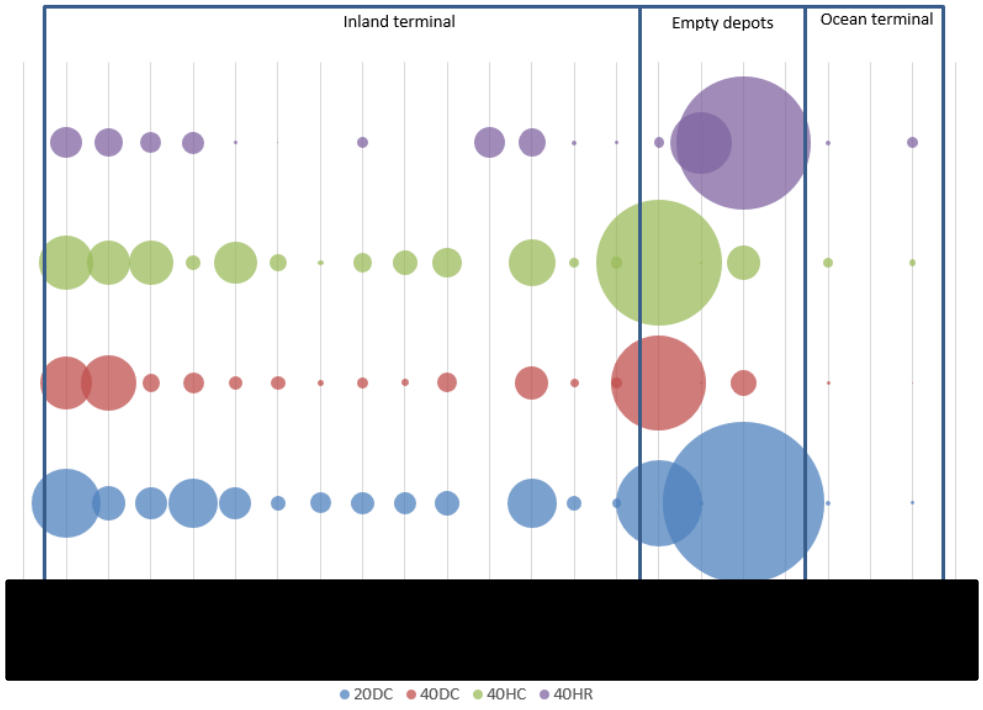


Figure 6-2 shows where supply is located in the network. The bubble size represents the magnitude of containers in a location

This information is needed to better understand the cost aspects generated by the various scenarios. Table 6-6 gives the results from the unsteered scenario run on the primary set of scenarios. Dry containers are generated and required more inland in comparison to reefer containers, which are generated and required near the port. Most reefer customers are located near the Terminal3 terminal resulting in a relatively lower transport cost for those container.

Unsteered primary scenario set

Table 6-6 shows results from the first part of the primary scenario investigation.

container type	ocean terminal typology	depot typology	Transport cost	Handling cost	Storage cost	repair cost	Total cost
20DC	base						
	transition 1						
	transition 2						
	future						
40DC	base						
	transition 1						
	transition 2						
	future						
40HC	base						
	transition 1						
	transition 2						
	future						
40HR	base						
	transition 1						
	transition 2						
	future						

A number of conclusions can be drawn from investigating Table 6-6. The table shows per row which depot topology scenario provides the best result in different ocean topology scenarios.

- The relative weight between transport and handling costs seems to fluctuate depending on container type. The reason for this fluctuation is caused by two aspects. Firstly, where are the containers available and where are they required influences the size of transport costs. Secondly, the distance travelled by empty containers to go from origin to destination greatly influences the size of transport costs. Combined the aspects result in roughly 75% of the total cost.
- Storage costs are constant per container type, because no TSL heuristic has been applied and the pre-set TSL is constant over time for the different locations. In the current setup storage costs has minimal influence on total cost, because the costs are only charged at off-dock empty depots.
- Repair costs are depending on the amount of containers in the model and the unit cost of repair, which deviates per container size and type. With a failure rate of 20-25% the repair costs depending on the unit costs for repair, account for around 20% of the total costs.

- Handling costs and transport costs of the 20DC and 40HR container scenarios are almost equal, which indicates that more containers are transported within an area, where transport costs are a lot lower than handling costs. This area is in fact within the port of Rotterdam.
- The 40HR container cost composition is different compared to the other commodities resulting in transport and handling cost aspect accounting to 50% and repair cost accounting to 45%. Repair of reefers has a larger impact on total cost.

For the 20DC containers, all ocean terminal topology scenarios in combination with the depot topology scenario, Depot A and Depot D 'open', result in the lowest total costs. For the 40DC and 40HC for the transition ocean terminal typologies, the model chooses a combination of Depot B and Depot D and for the future, where only Terminal2 is open the preference goes out to the combination of Depot A and Depot D. Finally, the 40HR container is similar to the 20DC containers transported cheapest over a combination of Depot A and Depot D, which is interesting as today the 40HR container is mostly steered through Depot B, because a lot of the reefer customers for Maersk Line can be found near the Depot B depot. The model does not know where the customers are located around the terminal and therefore will not select its solutions based on this input. Transport to the customers is left out of scope, which means that the model could present wrong information, however keeping those aspects in mind still makes the solutions valuable to investigate. The results found by the model will be used for further investigation, because it is interesting to see what the model determines to be the best solution.

It is noticeable that Depot C is never selected by the model for any of the future scenarios, which is logical with the given costs of using this depot. Also due to the poor connection of this depot to the barge modality and the expensive ITT transport, this depot has little advantage over the other depot locations. Depot D scores very well in the different scenarios due to the very low costs of handling and transport costs in the port area between the depot and Terminal2.

Costs for container moves between depots and ocean terminals is much greater affected by handling costs than transport costs. Inland transport this balance lies in the other direction due to some of the larger distance transport connections. EMR costs also seem much more at 40HR, which is due to a higher average repair cost per reefer.

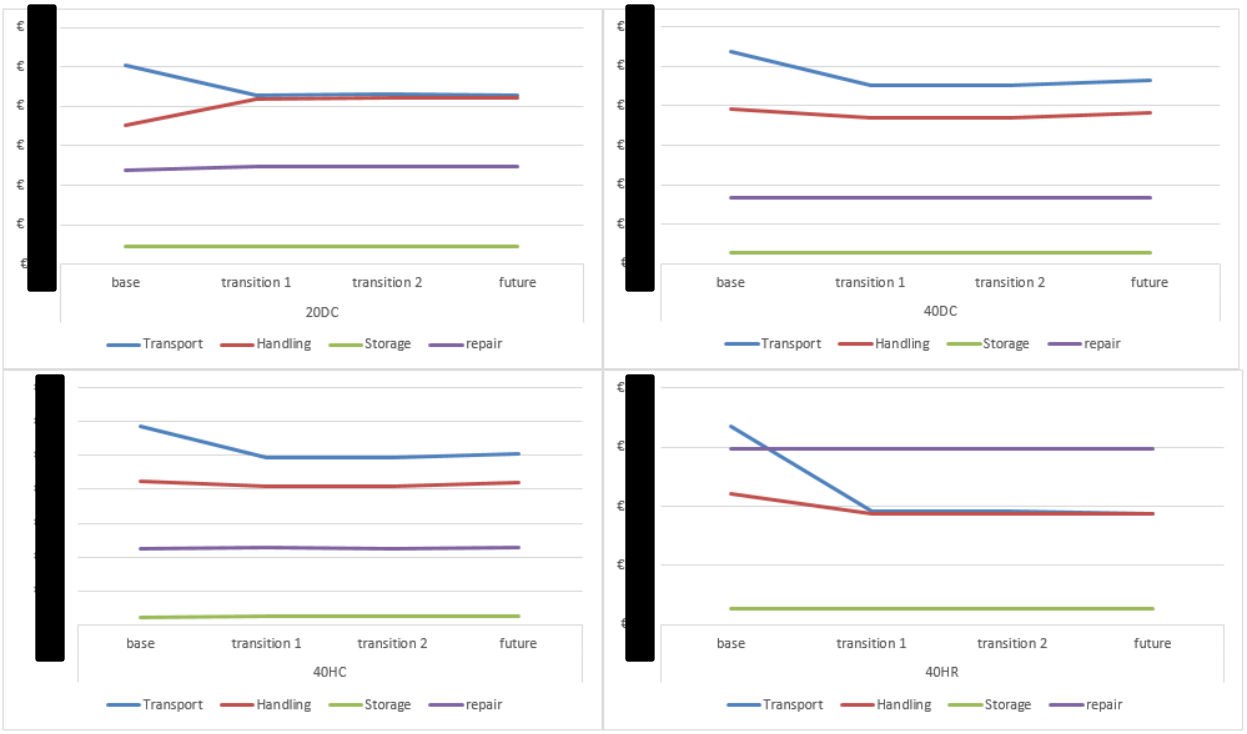


Figure 6-3 Normalized cost graphs for the first step of the scenario analysis per commodity and per cost category.

If we look at the 4 graphs in Figure 6-3, which contains the normalized costs per container type for the different scenarios, we see that the normalized transport costs for 40HR container is lower, indicating less inland transport and more transport within the port area. The graphs also show a sudden change in transport costs when the transition and future scenarios are run. At these moments the new Depot D has been opened, which operates at costs a lot lower than the competing depots.

Steered primary scenario set

The second part of the primary scenarios investigation is to determine the influence of steering containers in the best topology compositions. An unsteered network will send all flow over the arc, which has the lowest cost, until a capacity is reached. The current model is hardly restricted by capacity constraints, as capacity is in operational aspect not been seen as a limiting factor in how containers are treated within the network. The model therefore in the optimal case will send all over a single cheapest depot. In real-life a carrier, such as Maersk Line, would never only consider the cheapest depot due to monopoly reasons and due to the importance of spreading the risk of operations. For instance if by chance a depot would become unreachable, this would render a carrier incapable of performing its operations, had it been the only depot used.

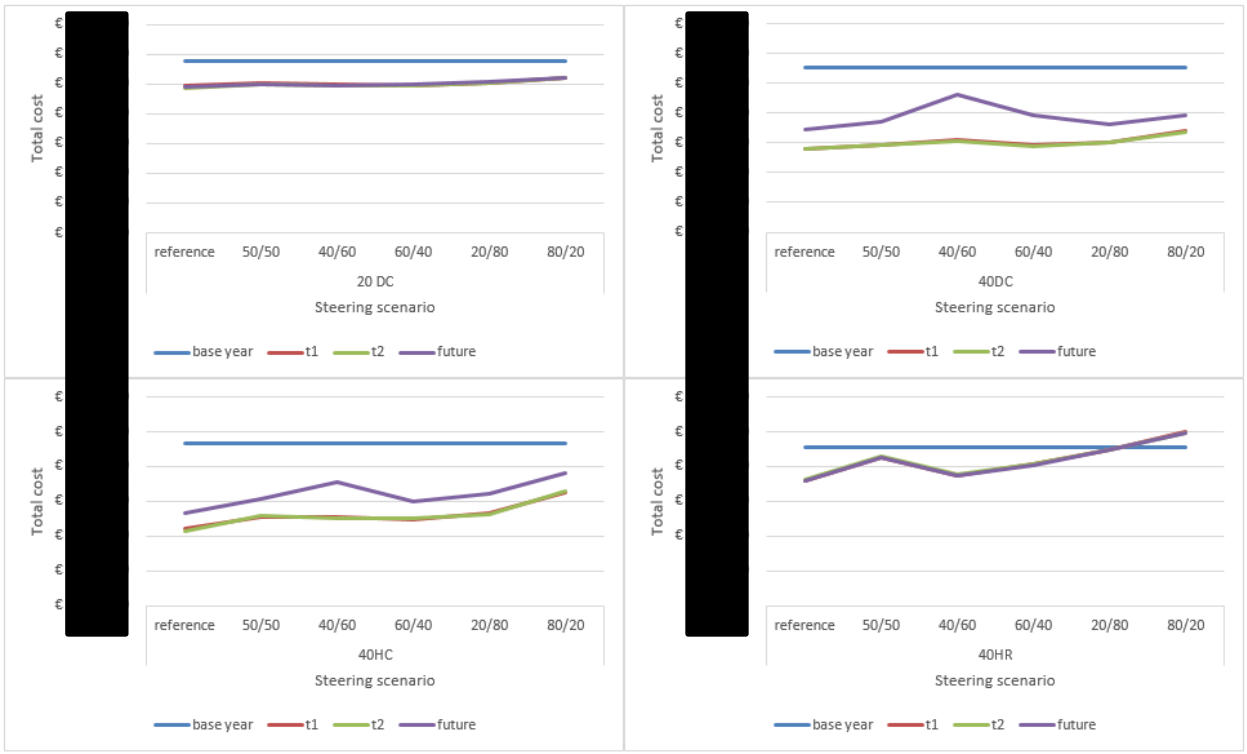


Figure 6-4 The total costs of the different steering scenarios on the depot scenarios found in part 1 of investigating to be the best solution for container types 20DC, 40DC, 40HC and 40HR

In Figure 6-4 the total cost as a results from steering flow through the depots combinations found earlier have been graphically represented. In all graphs the unsteered container flow scores the lowest costs for every ocean terminal topology. Furthermore in all cases the base year scores higher, due to the later introduction of the Depot D depot in the two transition scenarios and the future scenario, which is due to the very low transport costs between Depot D and Terminal2. Table 6-7 gives an overview of the depot scenarios that resulted in the lowest costs in the steered scenarios.

Table 6-7 Overview of best results from step 2 of the primary scenario investigation

		transition 1	transition 2	future
20 DC	depots	Depot A/ Depot D	Depot A/ Depot D	Depot A/ Depot D
	steering	60/40	60/40	40/60
	cost change	-3.91%	-3.97%	-3.92%
40DC	depots	Depot B/ Depot D	Depot B/ Depot D	Depot A/ Depot D
	steering	60/40	60/40	20/80
	cost change	-8.81%	-8.90%	-6.53%
40HC	depots	Depot B/ Depot D	Depot B/ Depot D	Depot A/ Depot D
	steering	60/40	40/60	60/40
	cost change	-8.23%	-8.12%	-6.27%
40HR	depots	Depot A/ Depot D	Depot A/ Depot D	Depot A/ Depot D
	steering	40/60	40/60	40/60
	cost change	-17.64%	-17.37%	-17.82%

Secondary scenario set

Step 2 of running the scenarios is to see what the influence of the different move types and TSL heuristics would be on the costs of transporting containers through the scoped network. As described in chapter 6.1 and elaborated in Appendix D, there are four TSL methods and four combinations of moves allowed in the network. Table 6-8 contains the results from the second part of scenario results. Columns 3 through 6 give the results when only indirect moves are allowed with different TSL heuristics and Columns 7 through 10 give the results when pre-set TSL heuristics is selected and the various move type scenarios are run. Column 3 and column 7 are equal and the same as the results found from the first step of the primary scenario analysis. Columns 4 through 6 and respectively 8 through 10 show the relative total cost result compared to the reference total cost.

A number of things can be noticed from investigating Table 6-8. In the scenarios where no change is made to the move type and only the TSL heuristics, it seems that nearly all heuristics lack the capability of reducing the costs significantly. Only the TSL heuristic named arithmetic TSL, which bases its results on the averaging of demand over the next ρ weeks, provides a reduction in costs. For these results ρ=4 has been chosen. Even though the different TSL heuristics mostly provide an increase in costs in comparison to a pre-set heuristic which is experience-based, it does show a decrease in cost when combined with direct positioning for 40HR containers. This poses that investigation on how to best divide the national TSL over the different locations has a large influence on the total costs of empty repositioning and evacuation.

With respect to move types the results show an immediate advantage of using direct positioning for serving regional balancing purposes. Even by allowing direct evacuation a cost reduction can be obtained. These result might give the impression, that by allowing direct connections between export and import customers, an easy and obvious cost reduction can be made, however it is important to realize what the model results does not show. The implementation of direct positioning

or direct evacuation makes the planning of transport a more complex operation and therefore a more costly operation due to the extra hours work in implementing such a solution. Another aspect that should be considered is the congestion that can occur at the ocean terminal when the off-dock depots are removed from the network. Better communication between all parties is required with a more streamlined planning to allow for direct transport to be implemented. The streamlined planning is imported to know at what point off-peak conditions exist such that containers can be directly transported to the ocean terminal.

Table 6-8 Relative results of the second scenario set investigations compared to the reference results

		fixed scenario:							
		only indirect move type				pre set TSL heuristic			
		Varied scenario:				Varied scenario:			
container type	ocean topology	pre set TSL	mean demand TSL heuristic	Nodal Potential TSL heuristic	Factorized TSL heuristic	only indirect move type	direct evacuation and direct positioning	only direct positioning	only direct evacuation
20DC	base	0%	-4%	4%	11%	0%	-13%	-12%	-5%
	transition 1	0%	-3%	5%	12%	0%	-11%	-10%	-4%
	transition 2	0%	-3%	5%	12%	0%	-11%	-10%	-4%
	future	0%	-2%	4%	15%	0%	-11%	-9%	-4%
40DC	base	0%	-1%	0%	7%	0%	-14%	-13%	-5%
	transition 1	0%	-1%	3%	9%	0%	-10%	-9%	-3%
	transition 2	0%	-1%	2%	8%	0%	-10%	-9%	-3%
	future	0%	0%	2%	9%	0%	-7%	-5%	-3%
40HC	base	0%	-1%	-1%	7%	0%	-16%	-15%	-5%
	transition 1	0%	-1%	1%	9%	0%	-13%	-10%	-4%
	transition 2	0%	-1%	0%	8%	0%	-12%	-10%	-4%
	future	0%	0%	0%	9%	0%	-8%	-6%	-3%
40HR	base	0%	-17%	-2%	-7%	0%	-29%	-29%	-15%
	transition 1	0%	-3%	16%	8%	0%	-16%	-17%	-1%
	transition 2	0%	-3%	16%	8%	0%	-17%	-16%	0%
	future	0%	-3%	17%	9%	0%	-17%	-16%	0%

No depots open

Finally a scenario where no depots are open is investigated. In Table 6-9 the results from this scenario can be found. A large cost reduction can be noticed when no depots are open, due to the elimination of a transport leg in moving containers around.

Table 6-9 provides the cost difference compared to the 'base' year for no depots open and only direct evacuation allowed.

container type	ocean topology	cost reduction compared to base	container type	ocean topology	cost reduction compared to base
20DC	base	0%	40HC	base	0%
	t1	-46%		t1	-54%
	t2	-46%		t2	-54%
	future	-46%		future	-54%
40DC	base	0%	40HR	base	0%
	t1	-61%		t1	-62%
	t2	-61%		t2	-62%
	future	-61%		future	-63%

The costs show a large opportunity to save costs, yet it is important not to forget the purpose of empty depots, which is to provide cheap container storage, EMR facilitation and congestion reduction at the ocean terminal. Completely erasing the function of empty depots is thus unwise, but as an ocean terminal is not constantly congested it does allow for opportunities to reduce costs on container moves from inland terminals for evacuation purposes.

6.3 Validation of DSS tool results to Maersk Line results

Validation is the process of investigation the correctness of the results from the model. To validate the results of the model towards reality of Maersk Line a comparison first needs to be made between the model dynamics, and input and reality. To allow for modelling of the real system a set of assumptions have been made, see chapter 6.1

Maersk Line	Implemented Model	Explanation
Large network with interregional and global interactions	Closed network with a limited set of nodes.	Empty containers available at each location can in reality also be used to meet demand outside of scope in other clusters of Maersk Line. The model assumes all flow will move within the closed network.
Only cost of transport between inland terminal and off-dock depots is taken into account	Both hinterland transport as depot to ocean terminal transport	The empty positioning datasheets of Maersk Line only show the cost of hinterland transport between inland terminal and depot. The model also calculates costs between empty depot and ocean terminal.
Multiple modalities	Single modality	In Maersk Lines network multiple modalities are taken into account. The effect is an increased total transport cost in Maersk Lines systems
Whole containers	Fractional containers	An error occurs when partial containers are shipped within the network as a container cannot be shipped fractionally.
All container types	4 container types	95% of the total container flow is transported in the model, resulting in a slight deviation from reality with respect to move costs.
Other factors influencing transport	Only supply and demand interaction	The model will send containers because there is an expected demand, however other reasons for shipping are not possible, such as special case decisions.

Comparing results from the model with results from Maersk Line proved a challenging task. Operational cost for empty containers is managed in the NOPS POS datasheet, which serves as a cost datasheet for cost control purposes. A number of shortcomings are identified when investigating the content of the datasheet. The datasheet shows for the different cost aspects of empty positioning activities how much was paid for an operation for both the Netherlands and Switzerland per two years of operation.

- Costs presented in the NOPS POS sheet are based on an open network with a large set of interdependencies which cannot be taken into account as a model operates based on a closed network. Furthermore as the data available is based on the information from a costs dataset and not operational flow data it is difficult to make the information fit the scope of this study.
- Handling costs in the NOPS POS sheet at first glance appear much greater than the other costs, which is strange as the model shows transport costs to be larger than handling costs. The NOPS POS sheet shows for handling costs very large values especially at the off-dock empty depots, because the value shown represent multiple product handling, i.e. both Maersk Line positioned containers as commercially positioned empty containers. A depot such as Depot A does not make a difference in product as they consider each container similar and charge for a service. This presents a skewed handling cost, which is incoherent with transport cost.

To compare model results with Maersk Line results, the cost of the model have been reduced by subtracting the cost of the model for Switzerland operations. Furthermore due to the incoherence of the handling costs compared to transport costs only transport costs are representative compared to the operation in the implemented model. Finally due to the difference in network size, the fact that the implemented model looks at fractional container transport the process of validation is very tough.

The validation of the model results was performed by presenting the results to the management team of the operations department. When comparing the calculated positioning transport costs minus the Switzerland transport costs and minus the costs between depot and ocean terminal it was shown that they are in the same order of magnitude. As the model investigates the influence on cost improvement of various scenarios, making an error acceptable as the same error exists in both the base year as scenario.

6.4 Sensitivity analysis of model's parameters on cost aspects

The main purpose of the sensitivity analysis is to identify the cost drivers in empty container steering that affect normalized transport costs and which have little effect. The sensitivity analysis has been performed on the 'base' year network for the 20DC container type, where Depot A, Depot C and Depot B depot have been opened.

Sensitivity of failure rate η

The container failure rate is limited by a lower-bound and upper-bound value, which for the scenario evaluation in chapter 6.2 were set between 20% (lower bound) and 25% (upper bound). For the sensitivity analysis the failure rate lower-bound is varied in steps of 1% up to the upper-bound limit. Three upper-bound limits i.e. 25%, 50% and 75% are investigated. Figure 6-5 and Figure 6-6 show the results from these sensitivity tests. The model showed infeasibility when the upper-bound failure rate was set to 75%, which occurs due to the amount of damaged containers exceeding the repair capacity of the workshops. In the figures it can be seen that transport and handling costs reduce as the failure rate increases. This means that the average failure rate increases resulting in more damaged containers in the model and as such less containers are evacuated or positioned to meet demand. It is important to realize that this depends on where containers become damaged in the network. Damaged containers are drawn from the supply and thus only affect the FromImp dataset. An increase in damaged containers could in short term mean less evacuation moves from inland locations, but in long term results in more positioning moves from other locations to meet the demand. The current network is very surplus, meaning this should not occur. Improving on container quality is thus important to keep costs at a minimum.

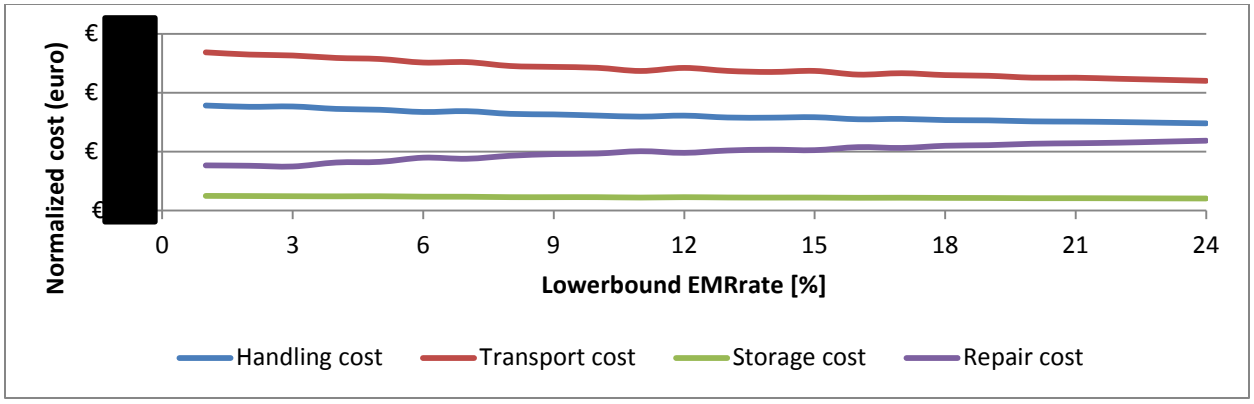


Figure 6-5 Results from a sensitivity analysis on the failure rate ρ with a lower-bound from 1 to 24% and an upper-bound of 25%

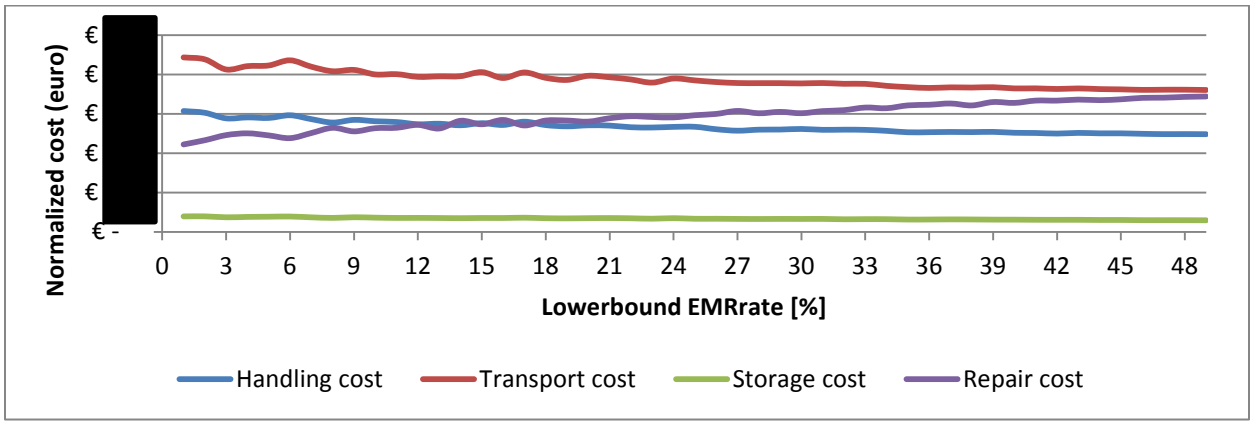


Figure 6-6 Results from a sensitivity analysis on the failure rate ρ with a lower-bound from 1 to 49% and an upper-bound of 50%

Sensitivity of local repair rate α

The local repair rate is a factor that describes the amount of containers which are repaired in Rotterdam compared to elsewhere. In the model the local repair rate has been set to 75%. To identify the sensitivity of this factor on the model results a local repair rate is varied between 0 and 99%. 0% means that no containers are repaired in the model and the only cost for repair spent is to transport the containers to the ocean terminal. 99% results in almost all containers receiving repair in the Rotterdam port, allowing for a maximum amount of containers, which can be used for future demand in the next time step. Notice that at a local repair rate equal to 57% a critical point is found from where transport and handling costs start increasing again. The lower this rate is the more containers are repaired elsewhere, which does not necessarily benefit the company at a global scale. This rate can only be optimized by collaboration on a global scale within the company.

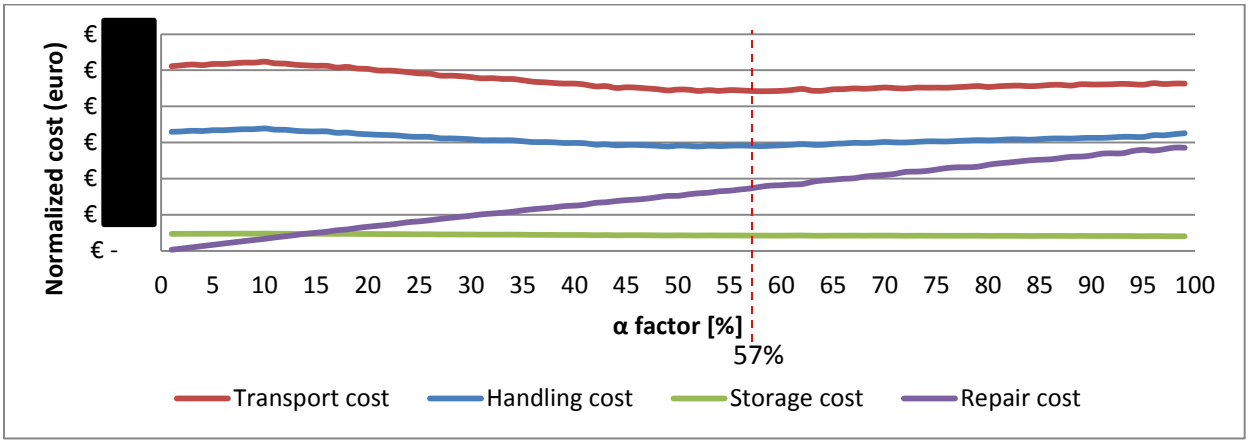


Figure 6-7 Results from a sensitivity analysis on the local repair rate α between 1% and 99%.

Sensitivity analysis of ρ parameter in Mean demand TSL and Nodal potential TSL heuristics

The factor ρ determines the dampening of the TSL heuristic. The sensitivity of this factor for mean demand TSL and nodal potential TSL heuristics is investigated to see the effect of a less responsive total TSL division. The factor is varied between 1 and 52 weeks. $\rho = 1$ results in a TSL division greatly influenced by fluctuations in demand and $\rho = 52$ results in a constant TSL division. In Figure 6-8 the results from both tests can be found. A too low ρ means an unstable division and a too high ρ means a too constant division. Currently the parameter is set to 4 and this is sufficiently stable and thus not affected by sudden demand peaks.

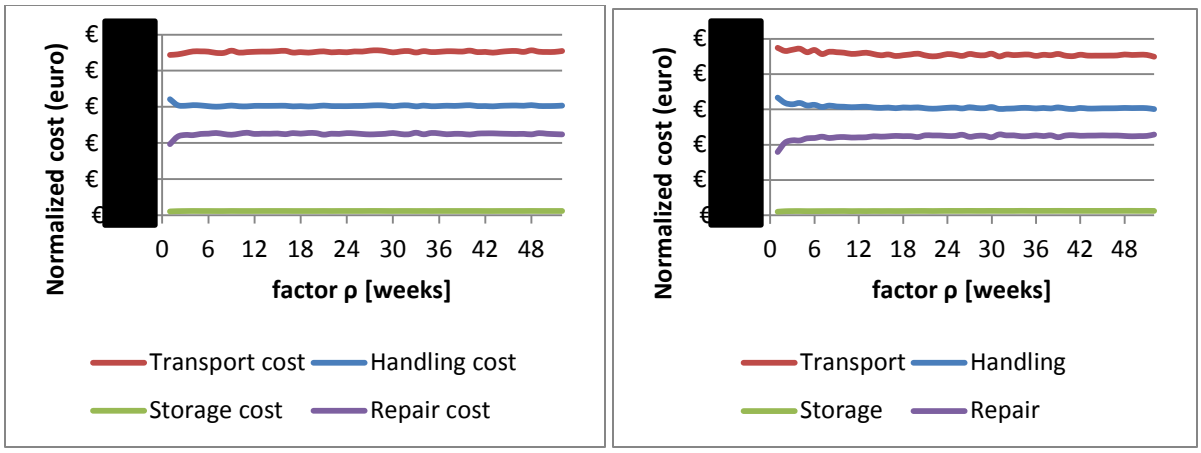


Figure 6-8 Left graph: Results from a sensitivity analysis on the factor ϱ for the mean demand TSL. Right graph: Results from a sensitivity analysis on the factor ϱ for the nodal potential demand TSL heuristic

Total TSL used by mean demand TSL and nodal potential TSL

This sensitivity analysis investigates the influence of a factorized total TSL where the factor ranges from 0% to 300%. This means more containers stay within the network at surplus time-steps and more containers are imported at deficit time-steps. Figure 6-9 shows the normalized cost when the factorized total TSL is divided with the mean demand TSL heuristic. A slight decrease in normalized repair costs can be explained by the fact that only empty supply can be declared 'damaged' and once checked a container serves a purpose of storage or demand. The model does not show which containers remain and how long they remain at a node. In Figure 6-10, the effect of increasing the factorized total TSL can be seen more directly. Normalized transport and handling costs increases as repair costs decrease, which is similarly explained by TSL adding containers to the network, while keeping the damaged containers constant to the network, because TSL is met with non-damaged containers. Inventory is divided much more inland in this heuristic, which results in much higher transport costs opposed to the mean demand TSL. In Appendix D this is discussed in greater detail, specifically see Figure D-11.

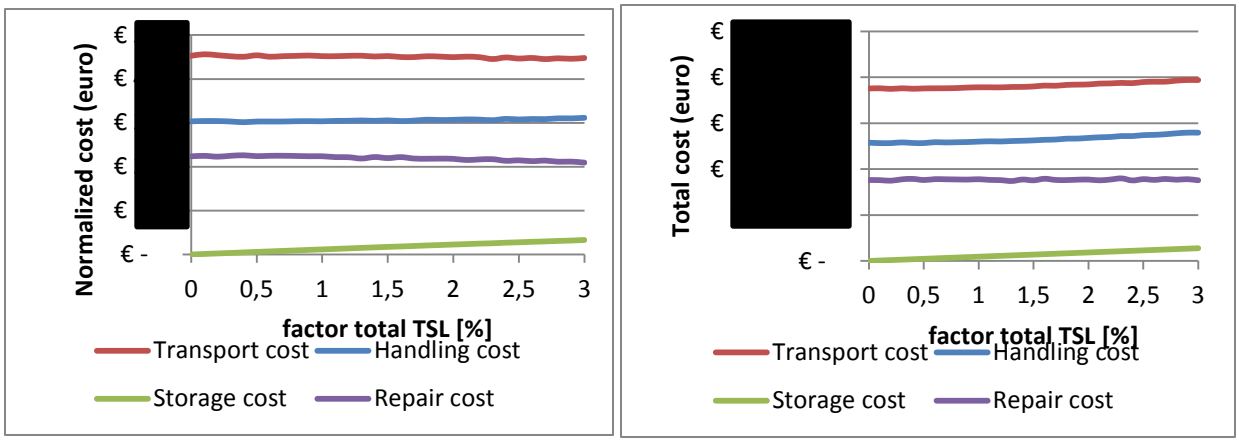


Figure 6-9 shows on the left, the sensitivity analysis of varying the total TSL when the mean demand TSL heuristic is applied and on the right the total cost variation due to a factored TSL

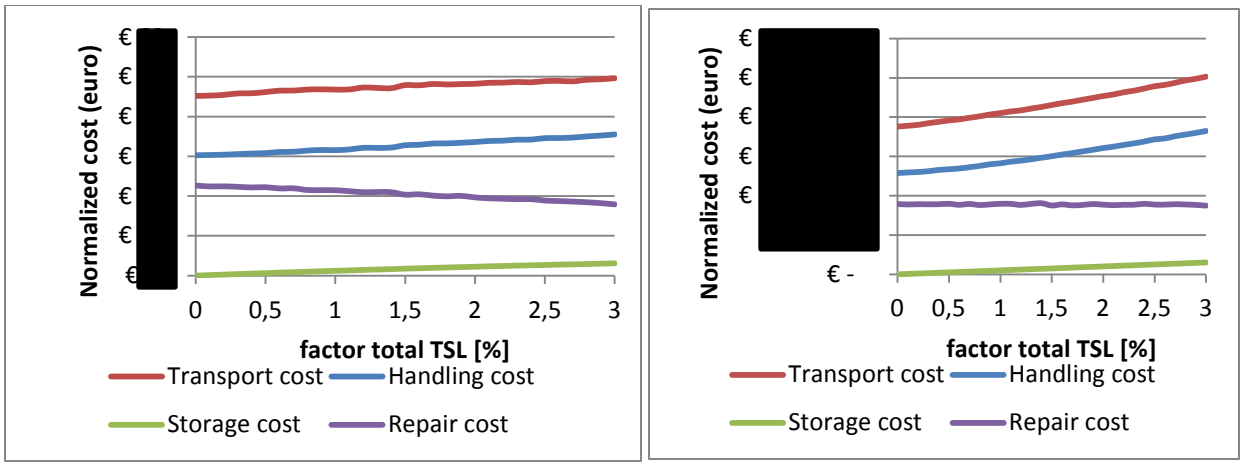


Figure 6-10 shows the sensitivity analysis of varying the total TSL when the nodal potential TSL heuristic is applied and on the right the total cost variation due to a factored TSL.

7 Conclusion, Recommendation & Future research

This final chapter shall conclude the thesis and provide an answer to the research question described in chapter 1.4. Recommendations will follow and finally the thesis will be evaluated to determine further research.

7.1 Conclusions

To recap the research question,

> *How can Maersk optimize total costs on the steering of empty container through the empty depots, while keeping operations in the hinterland and terminals in mind?*

To answer this question a mathematical model has been developed to optimize the total cost for steering empty containers through off-dock empty depots in a network of inland terminals and ocean terminals. The mathematical model, which is developed based on a state of art review and a state of practice investigation, takes into account multiple states of containers, both damaged as non-damaged containers, as damaged containers reduce the availability of supply to meet demand. The mathematical model has been implemented into a DSS (Decision Support System) tool in Matlab and validated against existing Maersk Line datasets. The DSS tool was used to explore multiple future strategies to reduce the total costs of steering empty containers. The investigated strategies involved forced container steering through a modifiable network topology, the influence of allowing different move types in the network and the influence of inventory control. Finally through a sensitivity analysis the cost drivers were identified.

Conclusions from primary scenario runs

- The Depot C depot is, given the models assumptions and network's costs profile, not an interesting depot to use for any of the ocean terminal typologies, due to the limited access to the barge modality. The depot only has access to barge via Depot A, which charges an extra handling and ITT for this modality.
- The Depot A depot is often selected by the model when the Terminal1 or Terminal2 terminal is included into the ocean terminal topology. The advantage of the Depot A depot is that it is the largest most modern depot, which makes it possible to perform any task involved in empty container steering. The disadvantage of Depot A is that it is a large depot and therefore can force expensive costs onto the system.
- The Depot B depot is only used when the Terminal3 terminal is opened. Only when the Terminal3 terminal is in operation it is relevant to make use of the Depot B depot. Terminal3 is a terminal which is limited by the size of ocean carriers that can enter the terminal and therefore cannot easily compete with the port advantages of the new Terminal2.
- Depot D scores very strong in all future scenarios, due to its low operational costs. The main advantage of this depot is that it is going to be located on the Terminal2 site allowing for low

transportation costs. The depot is operated by Star container, which is a part of the Maersk group and therefore also serves the purpose of aligning other depot operators to Maersk Line's wishes.

Table 7-1 gives the best way to steer containers through the depots for the various ocean terminal topologies.

Table 7-1 The best combination of empty depot topology with the proposed steering and the cost reduction relative to the base year for different ocean terminal topologies only allowing indirect move types, a pre-set TSL for all container size types.

		transition 1	transition 2	future
20 DC	depots	Depot A/ Depot D	Depot A/ Depot D	Depot A/ Depot D
	steering	60/40	60/40	40/60
	cost change	-3.91%	-3.97%	-3.92%
40DC	depots	Depot B/ Depot D	Depot B/ Depot D	Depot A/ Depot D
	steering	60/40	60/40	20/80
	cost change	-8.81%	-8.90%	-6.53%
40HC	depots	Depot B/ Depot D	Depot B/ Depot D	Depot A/ Depot D
	steering	60/40	40/60	60/40
	cost change	-8.23%	-8.12%	-6.27%
40HR	depots	Depot A/ Depot D	Depot A/ Depot D	Depot A/ Depot D
	steering	40/60	40/60	40/60
	cost change	-17.64%	-17.37%	-17.82%

- The results for 40DC, 40HC and 40HR during Transition1 and Transition2 show a different way of handling containers than done in the 'base' year. Depot B currently does not handle 40DC and Depot A does not handle 40HR containers, yet these are presented as the cheapest solutions in comparison to the base year with the opening of Terminal2.
- The closing of all depots provides huge cost savings but can only be implemented at daily off-peak moments as then the ocean terminal is less occupied by deep-sea vessels and congestion can be avoided.
- 75% of total cost for dry containers (20DC, 40DC and 40HC) is due to transport and handling operations, 5% due to storage and 20% due to repair operations. For reefer containers (40HR) 50% of the total cost is due to transport and handling, 5% due to storage and 45% due to repair operations. Improving transport and handling cost for dry containers has a larger impact and improving repair cost for reefers has a larger impact on total cost.
- Finally from investigating the results of the tool it is found that when containers are transported short distances, handling costs has a much larger share in total cost as compared to when containers are transported large distances. Depending on the distance travelled a different focal point exists with respect to reduction of operations costs.

Conclusions from secondary scenario runs

- The implementation of the various TSL heuristics have shown that the heuristics applied do not improve the total costs, however they do show the importance of placing the TSL per location. The current pre-set TSL results in the most optimal cost in comparison to any of the TSL heuristics applied.
- The direct positioning and direct evacuation of containers to the port results in large cost savings for empty container moves in the network. Especially direct positioning is beneficiary providing cost reductions of around 13%. The direct moves do not only provide benefits as it also results in extra planning tasks and it requires a better control over a container's transport schedule.

Conclusions from sensitivity analysis

The sensitivity analysis has shown that, besides the unit operation costs (e.g. transport cost, handling cost, storage cost and repair costs), costs are influenced by total TSL, failure rate and local repair rate;

- Reducing total TSL can result in cost savings, however it may also cause demand being missed.
- Reducing the failure rate will lead to a smaller chance for containers to not be available for demand and will result in a higher quality assurance towards customers.
- The local repair rate can resort to cost savings when there is a global plan to reduce the shipping of damaged containers to other clusters. A global repair plan is required.

7.2 Recommendations

Following from the state of practice, state of art and scenario investigations a number of recommendations can be established with respect to Maersk Line.

1. The validation process of the model proved a much more difficult task than expected, due to the way costs are managed in the NOPS POS cost sheet. A number of aspects should be modified to allow for better investigation of the costs for positioning of empty containers;
    a. Establish a dataset that allows for the selection of flow within a closed network, because such a dataset provides the good basis for any future improvements on container steering.
    b. Include the costs from different clusters into the cost overview, because it provides a complete picture of empty container steering.
    c. Have depot operators separate commercial costs from positioning costs in the monthly cost statements with respect to handling, such that handling costs for only positioning can be reviewed.
    d. Include transport and handling cost between depot and ocean terminal into the cost overview as it allows for a better understanding of the complete costs of handling empty containers.

2. For strategic reasons two depots should be operated simultaneously as this allows for better quality and cost assurance for Maersk Line. The off-dock empty depots Depot A and Depot D result in the most favourable cost when Terminal2 is taken into operation. Depot D is a depot that offers a competitive pricing in comparison to the other depots and Depot A depot offers a large array of services. Combining those two depots with the current cost structure and assumptions results in a cost reduction between 3% and 17%, which could be reduced even greater when rates are decreased, depending on container size and type.
3. A regional collaboration is required between all inland terminals and ocean terminals to allow for direct evacuation and the reduction of use of empty depots, thus resulting in large cost savings for the positioning of empty containers.
4. To improve on costs induced by damaged containers, two cost drivers should be further investigated, viz. local repair rate and container failure rate.
    a. A study on the failure of a containers
    b. A study should be made to identify when a damaged container should be shipped and repaired elsewhere and furthermore a global agreement should exist, which states when container repair is taken care of and thus avoiding damaged containers being shipped globally.
5. Currently TSL is managed by the equipment team of the operations department within the NL-CH cluster. To guarantee the expertise on dividing the TSL is not lost it is important that the mechanism of a correct TSL is investigated. Correctly dividing TSL is a complex operation and directly relates to the quality of the service provided.

7.3 Future Research

The model developed can be expanded in several ways to provide a more accurate optimal cost profile for various empty depots;

1. In the current model, a fixed TSL or heuristic is used to divide the total TSL over all nodes. The model calculates TSL outside the algorithm which optimizes flow through the network. Effectively dividing TSL over the different nodes can cause the model to generate lower total costs than currently possible in the model. By implementing the inventory or TSL as a decision variable into the model, the model would choose a TSL which fits the future demand pattern. Appendix F contains some extra work to describe how this theoretically should be implemented into the model proposed in chapter 3.
2. Repair is a part of the EMR operations, which all influence the way containers are steered through a network with the purpose of meeting demand. Each of the activities has a different influence on how the containers will be moved through the network. Adding more operations of EMR (in other words more states of containers) into the model allowing a more accurate model, and thus resulting in better investigation of scenario influence on total costs of steering empty containers.

3. The current model takes a single modality between nodes into account. The depots within the scope are often connected to multiple modalities and therefore a different result might be found when multiple modalities are taken into account. The model could be further expanded to include multiple modalities. Depending on distance in the network a different modality becomes the more favourable. Also when the interaction with customers is expanded upon a truck modality needs to be added.

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Appendix A General description of Maersk Line

Maersk Line is one of many carriers providing the shipping of containerized cargo between ports on a global scale. The containerized cargo volumes are expected to reach 684 million TEU for 2014 (Ship-Technology.com, 2014). Due to the imbalance in trade an accumulation of empty containers at import dominant locations is noticed and with the growth of the market, this amount is expected to increase (UNCTAD, 2013). A container will on average during its lifespan (15-20 years) spend 56% of its lifespan being repositioned or in an idle state. (Inter Asset Systems, 2000; Rodrigue et al., 2013). The European market is an example of such an import dominated market. The repositioning of empty containers is required for carriers to meet export demand on a global, regional and local scale.

For Maersk Line the European market is divided into several clusters each taking care of shipment to a particular hinterland area. The Rotterdam port is part of the Netherlands & Switzerland cluster (NL-CH cluster), which serves all Maersk Line customers in the Netherlands, Belgium, Luxembourg, North of France, Germany and Switzerland. The Rotterdam port area currently is made up of 9 container terminals and 16 depots of which Maersk Line uses an Terminal1, located at Maasvlakte and Terminal3 Terminal, located in the city, and 3 empty depots (Depot C (Maasvlakte I) , Depot A (Maasvlakte I) and Depot B (city)).

In the near future (Q4 2014) the new Terminal1 2 located on Maasvlakte will be opened and possibly a depot will be opened on the site of Terminal1 2. The current setup of terminals and depots needs to be re-evaluated to determine if future operations can be optimized. Empty depots result both in cost savings and in added costs. Many operations performed between the empty depots and Terminal1s and its hinterland are identified today to be *ad-hoc* resulting in unnecessary costs being made for unnecessary movements as the information available is hardly used. Understanding the costs of handling empty containers through the Rotterdam port could result in a better organization of the empty containers in the Rotterdam port and thus the achievement of cost reductions.

The image shows the complete scope of the project with all connections allowed between the different inland terminals, ocean terminals and off-dock depots. The red lines represent the connection to any location within the Port of Rotterdam. Unit transport costs are paid per container shipped from inland terminal to the port, allowing for the port to be connected to inland terminal as an aggregated node. Within that aggregated node a division of flows occur. This aggregation of the port of Rotterdam has the benefit of showing a less chaotic image of the network as all inland locations are connected to all nodes within the Port of Rotterdam.

Note CH represents Switzerland. All inland terminals of Switzerland are highly surplus for all container types resulting in no interactions between the inland locations required. Empty containers from Switzerland are only shipped to the port of Rotterdam for evacuation purposes.

Appendix B Full project scope

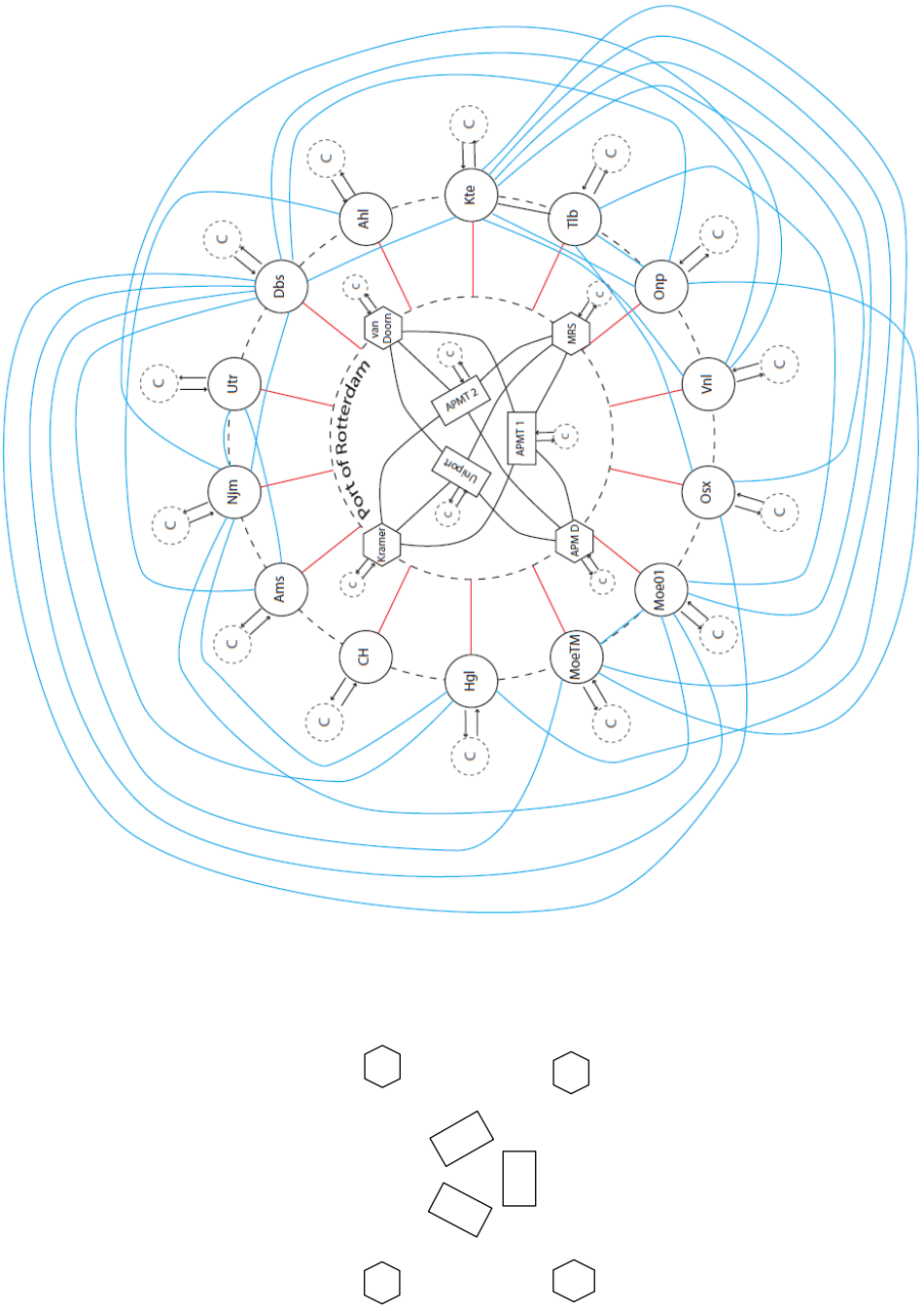


Figure B-1 Graphical representation of all nodes and arcs considered in the network.

Appendix C Literature review

a) Literature framework

This paragraph contain the papers which have provided the basis for developing a framework, which is used to sort papers and to realize that the model proposed should focus on operational regional allocation planning problems.

Challenges in managing empty container movements at multiple planning levels

Paper content

(Braekers et al., 2011) gives a clear overview of the empty container repositioning models existing for different planning levels, developed by other authors and categorize them accordingly. Three decisions levels are presented, namely strategic, tactical and operational planning. For each decision level a certain amount of model types exist, namely network design, service network design, container allocation model and routing model. Below flowchart gives the relation of all the models existing.

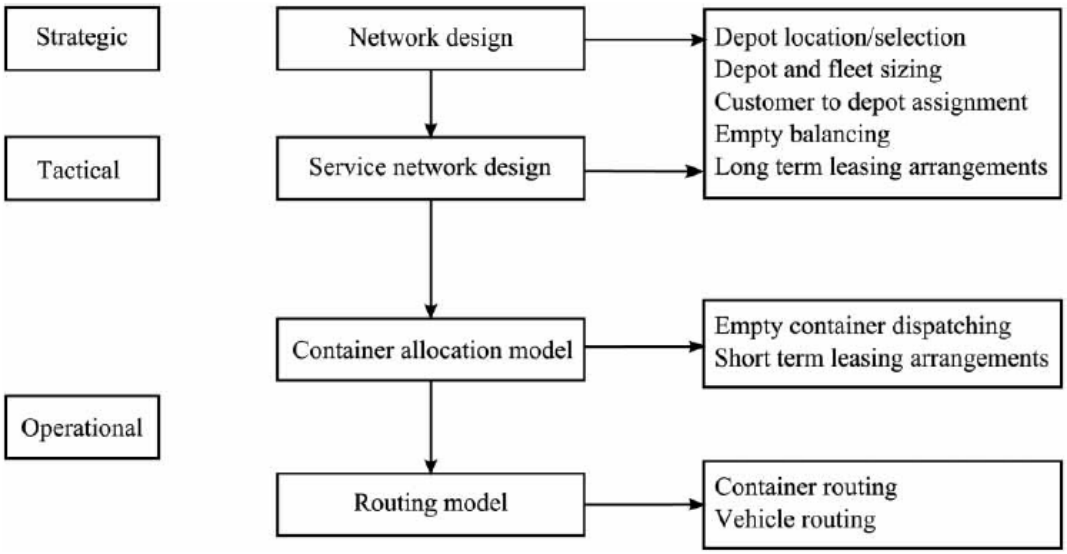


Figure C-2 Different model types per decision level. (Braekers et al., 2011)

The operational decision level is assumed time dependent, making it a dynamic environment. The optimal operational solution is described as using the most effective routes to meet demand and minimize costs. Ideally a single model should be created which simultaneously performs allocation and routing, however due to complexity this is unobtainable. The allocation model seeks the best way to distribute containers to meet required export demand and the routing model aims to minimize transport costs of loaded and empty containers. Two scales are studied with respect to allocation models, namely regional and global. Regional allocation models are subject to a number of considerations;

1. Deterministic or stochastic
2. Static or dynamic
3. Single or multi-commodity

4. Substitution, leasing or street-turn allowed?

Ideally allocation models are stochastic, dynamic, multi-commodity and allow substitution, leasing and street-turn, however this would make the assignment too complex to solve. As such certain simplifications are required to make the model feasible. (Braekers et al., 2011) present per paper what level of complexity their respective models implement. Below figure gives this categorisation of regional container allocation model papers.

Table 2. Overview of regional container allocation models

Author(s)	Stochastic	Multi-commodity	Substitution	Dynamic	Street turns	Leasing	Solution
Crainic et al. (1993b)		x	x	x		x	None
Crainic et al. (1993b)	x						None
Wang and Wang (2007)		x		x			Exact
Chu (1995)	x			x		x	Approximately
Olivo et al. (2005)		x				x	Exact
Di Francesco et al. (2006)		x	x	x			Approximately
Di Francesco (2007)		x	x	x		x	Exact
Jula et al. (2003)		x		x			Exact
Chang et al. (2008)		x		x	x		Approximately
Chang et al. (2006)	x						Approximately
Le-Griffin and Griffin (2010)							Exact
Jansen et al. (2004)					x		Exact

Figure C-3 overview of regional container allocation models (Braekers et al., 2011)

Furthermore global container allocation models are further explained and tactical and strategic level models are discussed, which will be left out of the literature review. These topics are not interesting for this thesis, so they will be left out.

The authors also discuss different solutions proposed by all the literature available up until 2011. Those solutions are as followed;

- Inland depots; temporary storage of empty containers at inland depots instead of moving the containers back to the port. Little extra storage costs would be induced by third party inland terminals.
- Street-turn; direct movement of containers between importer and exporter. The solution is limited due to delivery window, location, ownership and type of containers. The solution results in large complex planning issues.

- Container substitution; the use of different container types for a certain export requirement. Substitution options are limited by factors such as weight, type and destination of cargo.
- Internet based systems; detailed information system for carriers, transporters and terminals and depots. The goal of such a system is to facilitate better communication and improve on planning capabilities. The solution is limited due to lack of willingness to share business information.
- Container leasing; lease of containers to meet unexpected demand increase. The solution is limited as the lessee is subject to the same imbalance in trade resulting in surplus and deficit ports with respect to leased containers. A pickup and drop-off fee is charged to counter this effect.
- Foldable containers; the reduction of unavoidable empty moves by reduction of space required by an empty container. The solution is limited due to the extra costs required to fold or unfold and purchase a foldable container. Also the solution is perceived to be limited due to scepticism with respect to the durability and technical performance of the foldable container.

Certain modelling issues are discussed. Preferably an infinite horizon is assumed as this is how long a company is expected to operate, however most dynamic models cover limited planning horizon. A limited horizon results in errors for the model's results with respect to ending inventories. These effects are often excluded or minimized by applying a rolling horizon. Furthermore the different articles analysed discuss the length of a planning horizon. A too long horizon will result in a decrease in reliability of results. A minimal planning horizon of a complete transport leg should be chosen and a maximum of 10 to 20 periods.

With respect to container models an integer value is sought after as it is important exactly how many containers should be moved. However, depending on the research question the integer restriction could be relaxed to reduce complexity of the problem.

Relevance of paper to thesis

This paper provides the basis for the literature review as it immediately provides an overview of all that has been studied up until the paper was submitted for publication. The categorization of papers after 2010 will be further studied and categorized according in a similar fashion. This thesis will be focussing on solving an operational decision problem of the allocation of empty containers with the main focus of determining how empty off-dock depots perform in the network. The allocation of empty containers determines the input of containers for the off-dock empty containers in Rotterdam. Changing the setup of the off-dock depots has a direct impact on the way containers need to be allocated or are allowed to be allocated. Much of the research performed is looking at ways to reduce costs by changing the network or by applying new allocation methods.

Empty maritime container logistics: facts, issues and management strategies

(Theofanis & Boile, 2009) have researched empty container logistics at a global, interregional, regional and local level in general. The paper presents a number of theoretical descriptions of how operations are performed within the different levels and how the levels interact.

Trade imbalance is described as the main cause for empty container handling problems. Furthermore cost involved with inland transportation, repositioning, inspection and maintenance are mentioned as having an influence.

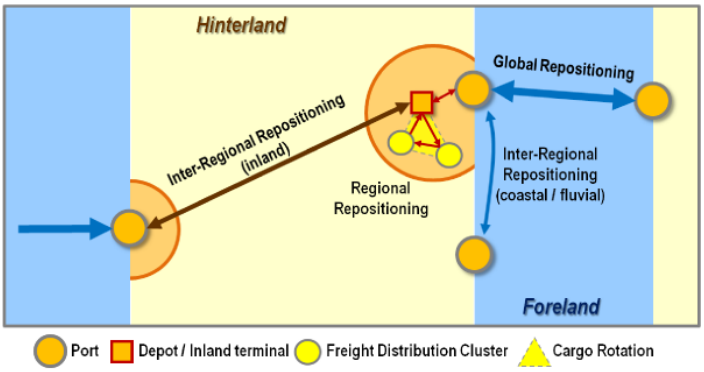


Figure C-4 graphical description of the reposition scale levels presented by (Theofanis & Boile, 2009) adapted by to differentiate between inland and coastal interregional repositioning. (Rodrigue et al., 2013)

Global level is involved in the overseas repositioning of empty containers to serve globe trade imbalance. Interregional level is involved in repositioning between regions to serve a wide area imbalance, however not yet global. Regional level is involved in serving trade imbalance in the hinterland of a port. Figure C-4 shows the different levels of repositioning existing.

With respect to scale level, trade imbalance and container manufacturing costs a feasibility graph has been provided by the authors to determine when repositioning is interesting and when it is too costly. Figure C-5 shows this graph and as such illustrates the relation between all topics involved with empty repositioning.

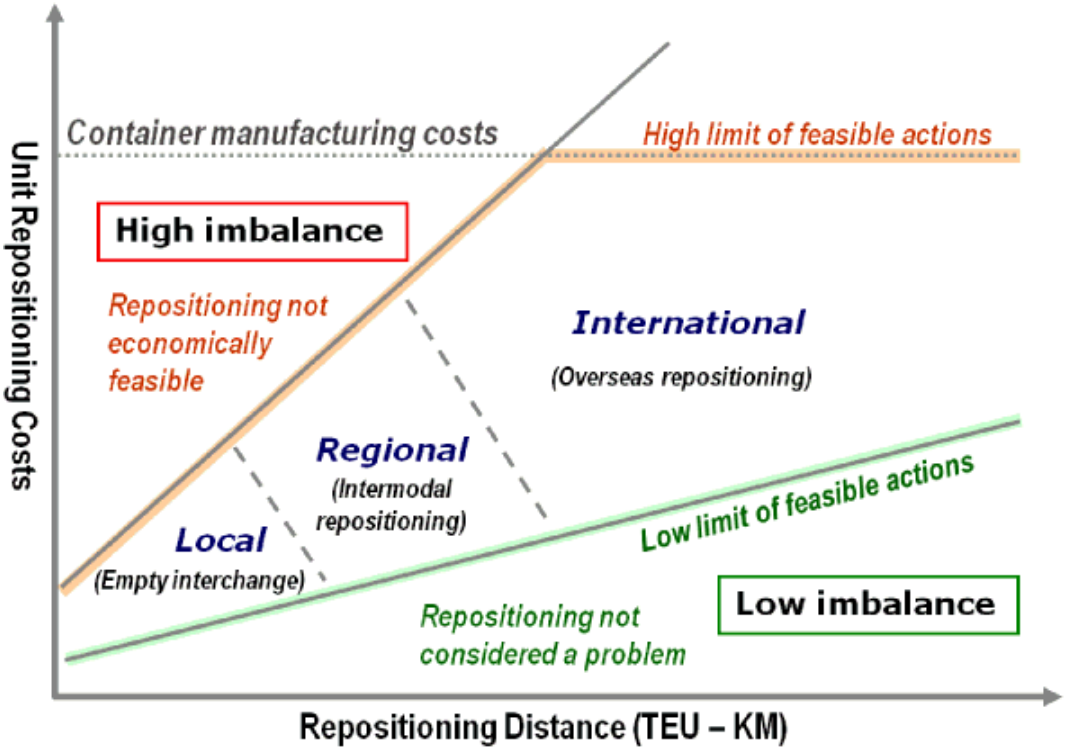


Figure C-5 feasibility of repositioning with respect to scale level, manufacturing costs and trade imbalance. (Theofanis & Boile, 2009)

The authors describe two contractual arrangements for the shipping of containers in Europe, namely merchant haulage and carrier haulage. Merchant haulage puts responsibility for inland transport at the customer and carrier haulage puts it with the ocean carrier. Carrier haulage gives the carrier the freedom of determining how containers are moved around. Merchant haulage leaves empty return costs with the customer, who is only allowed to return a container to the inland terminal where it was picked up.

Figure C-6 gives an overview of all flows possible according to the authors, which was used for Figure 2-4

Relevance of paper to thesis

The paper gives a very condensed description on empty container repositioning. The paper forms the basis for describing the architecture of empty container repositioning. All figures provided by the authors will be adapted with the purpose of explaining the scope of this thesis. The authors also provide a review and categorization method for the papers which is later used by (Braekers et al., 2011). The categorization of (Theofanis & Boile, 2009) and (Braekers et al., 2011) is adapted to fit this thesis and provides a framework in where this thesis adds to research.

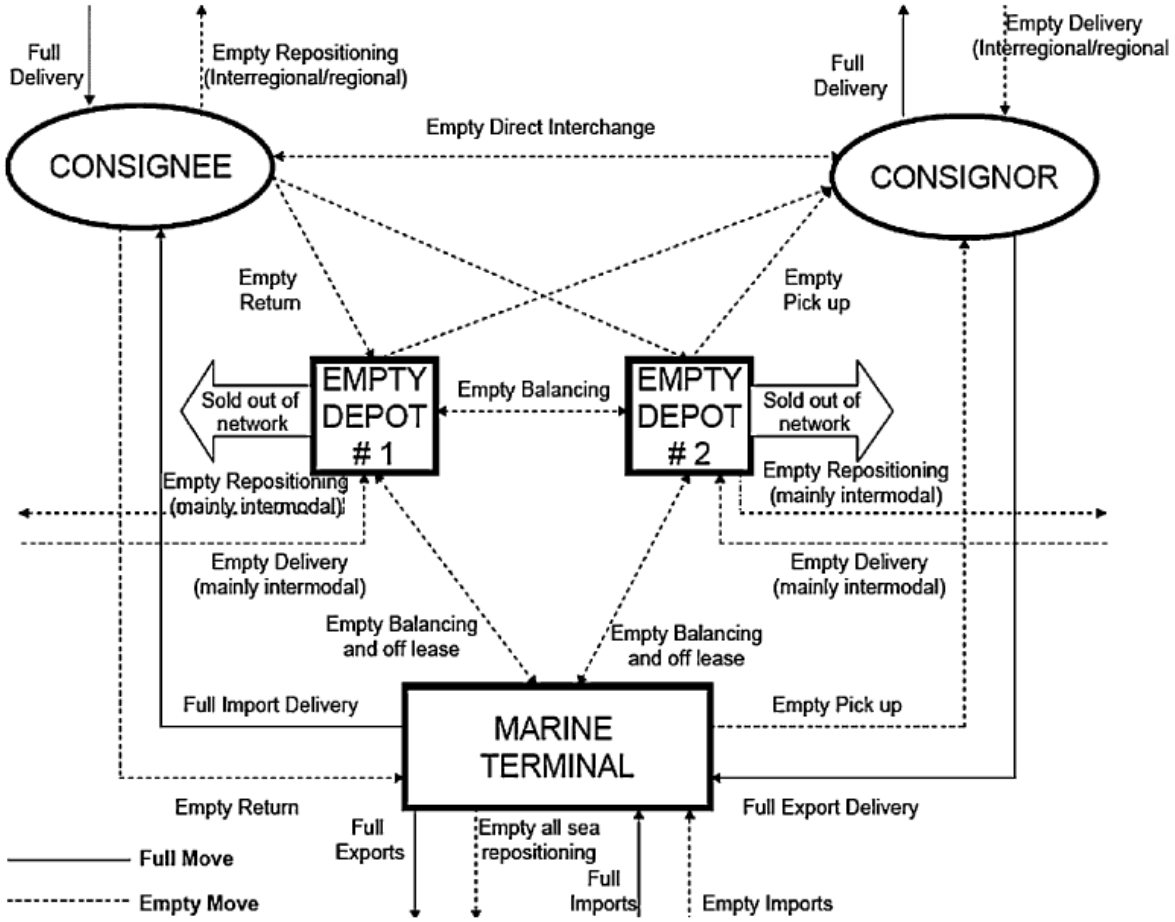


Figure C-6 Regional container flows (Theofanis & Boile, 2009).

Asian container cargo transportation model including multi-layer transportation network and economy of scale

Paper content

(Ishiguro & Mirchandani, 2013) present a Multi-layer transportation model, which looks at the international layer, regional layer and local layer, which corresponds to the multi layered hyper network presented by (Rodrigue et al., 2013) in his book the geography of transport. Both authors describe a three layered model with gateways that connect the different layers. The paper provides the addition of economies of scale at transhipment combined with a hierarchical configuration.

Container cargo is assumed to be generated at ports. No inland transport is taken into account. The model contains three types of maritime networks, viz. Trunk routes (only connecting international hubs), regional routes (connecting regional and international hubs) and feeder network (connecting ports within the same region). Interregional connection is performed through trunk or regional networks. A differentiation is made in costs between the different networks.

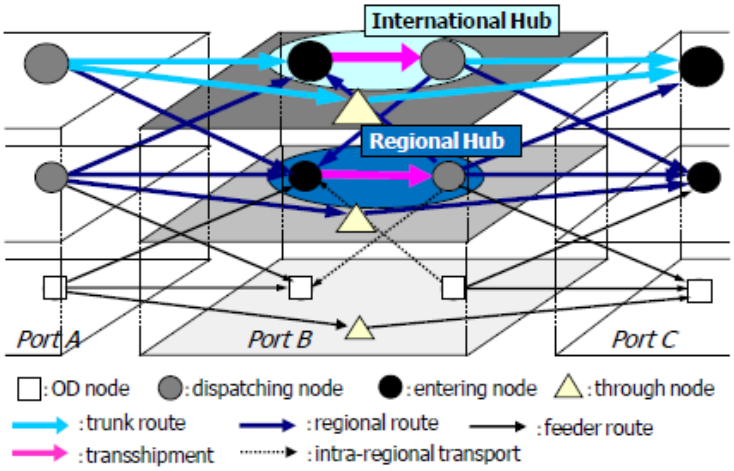


Figure C-7 Transportation scales and interregional transportation (Ishiguro & Mirchandani, 2013).

Economies of scale are investigated through firstly, a reduction in shipping costs due to the increase of cargo and thus reducing the unit costs for containers with respect to container handling, secondly, a large amount of terminals have a redundancy of capacity. A terminal cooperation consolidation and aggregation is provided to provide these benefits.

Transhipment costs and transportation costs are mathematically described. The transhipment costs are divided into fixed costs and variable costs, which are affected by the economies of scale. These costs take port type into account. Scale is described by multiplying the costs by the objective value obtained for a particular port. Transportation costs are described as the unit costs multiplied by the distance travelled.

A simple search algorithm is applied to the model to find the effects of the economies of scale on the multi-layer network.

Relevance of paper to thesis

This paper remains vague on how the model looks like and what the exact results are. Only a graphical estimation is given on the results. The author claims that the results are reasonable and serve as a good basis to take into account for port policy. The model scale might not be relevant for this thesis, but it does give a good overview of the influence of economies of scale on the shipping network and some assumptions made for the model they produced are relevant to take into account

b) Regional allocation models

This paragraph contains the papers which focus on regional allocation models. These papers form the basis for the model proposed.

Optimization of empty container movements using street-turn: Application to Valencia hinterland

Content of paper

(Furió et al., 2013) present two mathematical models for the optimization of empty container movements among shippers, consignees, terminals and depots along with a minimization of storage costs. They propose optimal movements can be performed through street turn operations, which implies a container can be directly moved between a consignee and a shipper to meet transport requirements. The mathematical models have been applied to the Valencia hinterland through a Decision Support System (DSS).

For the allocation of storage facilities to empty container (import or export) operations a minimum cost network flow problem has been modelled, which seeks an optimal solution for the everyday problems of local maritime agents. The authors argue that existing models on the relocation of empty containers is modelled mostly on a global scale and that the inland allocation of empty containers is less studied and that no other studies consider both repositioning of containers in comparison to shipping company policies.

The model looks at a single modality, multi-commodity, multiple terminals, consignees and shippers in a network flow problem and determines the most cost-effective allocation of empty container in the system. The model assumes no repair of containers, resulting in them being taken out of service. At each storage point a maximum capacity is determined. The first model is a basic model not taking street-turn operations into account, which minimizes transport and storage costs of each container type. The model is in other words a container fleet management tool.

The paper describes some experiences to keep in mind; a DSS model should contain three main components, namely the database component, program and output file. Seven tables are identified to be important for the model;

- Port terminals and empty depots
- Shippers and consignees
- Container types
- Historic data of transport operations associated with different line services
- Ships arrival forecasts
- Road transport costs information
- Storage costs information

The DSS was coded into a Visual Basic application. The DSS provides a printout with the proposed line of business for the planning horizon. The exact OD pair in combination with container type is provided. The authors declare that the model is too complex to use for a longer horizon, thus a random sample of 2 weeks has been tested and they determine that for the

sample of a cost saving of 0,85% is calculated. They also state that it is still necessary to investigate further policies for the implementation of street-turn. The mathematical model has been tested through experimentation on a case of Valencia port. A set of 40 instances have been solved, which is five replications of a combination of 2 different time horizons, 2 different network sizes, 2 different demand levels. Through the Wilcoxon signed rank test they declare that a significant effect on costs is confirmed. Furthermore the response ratio between the basic model and the model including street-turn operations (triangulation) determines that not using triangulation results in a 4% increase of logistics cost. The results between the two models were plotted into one graph showing a linear relation and through linear regression an accurate savings calculation determines that the saving accumulates to 1,84% when triangulation is applied. Moreover the authors noted that the optimal solution does not include movements between terminals and depots and that it is logical because a cost minimization is sought after.

Relevance of paper to thesis

The paper is very clear on the benefits of inland repositioning of containers between shipper and consignee, as it assumes a tenfold of consignees in comparison to shippers. The two mathematical models can be used in the hinterland network model to simulate network operations and to calculate the impact on depot operations. Street-turn operation is a solution requiring extra planning activities for the shipper, which is only possible when shippers and transporters have clear agreements on where containers are returned, which is only the case for Carrier Haulage containers at the moment. The final remark of the authors that the optimal solution results in no terminal-depot movement does not have to result in cost minimization as for a surplus markets empty containers are frequently evacuated towards overseas deficit markets. A natural push from the inland terminals or pull of ocean terminals on empty containers will occur due to this imbalance. When empty depots exist in the network a transportation arc between depot and ocean terminal will occur.

The mathematical model is very similar to the problem to be solved by this thesis and will be used for the development of the objective function and With respect to the databases; a few things are different for this thesis. This thesis looks at barge transport in the network; no ship arrival will be taken into account as terminal operations are left out of scope. The main focus of this thesis lies on the empty depots in the Rotterdam port area and the network determines the amount of containers entering the Rotterdam port area. Furthermore the paper only looks at costs and lacks the relation of the costs towards the consequences.

An optimization model for the inland repositioning of empty containers

Paper content

(Olivo et al., 2013) propose a model for optimizing the inland repositioning of empty containers. They propose a multi-commodity time-extended network optimization model to solve the flow problem, which looks at the allocation of containers to the correct location to meet demand.

The model takes into account the leasing of containers and substitution possibilities between container types. The network it models takes into account a node where a lessor makes lease containers available to the lessee. Customers are only served by one inland terminal depot.

Furthermore, Empty depots are considered the spine of the system offering storage for empty equipment. These empty depots are situated at the location of an inland terminal. Finally ports are modelled which are denoted as intermodal transit facilities, which is where empty containers are moved from when the region is deficit and towards when the region is surplus. For the different inland location a target stock is determined per location for the purpose of serving future demand.

Ports are described as "intermodal transit facilities between inland and maritime distribution systems", from where deficit replenishment and surplus evacuation occurs. A shipper is presumed to know the exact amount of containers in a port making it impossible to move more containers than available. The authors argue that empty container supply is uncertain as a container can remain for a prolonged time at the customer and empty demand isn't accurate as unexpected assignments can occur. As demand and supply is unclear an adjustment of forecast input is required, in other words a rolling horizon will be looked at.

The network is built up out nodes and arcs, with 3 nodes per inland terminal each with a single purpose, node with owned empty container requirement, node with owned empty container availability and node with leasable empty containers availability. The model looks at past, present and future decisions in a rolling horizon fashion. The objective function minimizes shortage, transportation, storage, substitution, on-hiring and off-hiring costs. All variables are considered integers and as such a mixed integer linear program problem exists. Ports are considered not to have demand requirements for empty containers as they presume transportation opportunities would be lost. Capacity of ports is limited by the amount of containers they can receive without causing congestion at the ports. The linear model subject to flow conservation and capacity restraints is solved with the use of optimization algorithms (solver) from CPLEX. The model has been tested for several amount of container types considered and has been proven to be quickly solvable. A 50 period planning horizon is tested of which the first and last 10 periods are truncated to reduce begin and end effects.

The authors conclude that a new optimization model has been presented which provides shippers with the freedom of choosing which containers are available for substitution. The model is quite complex but quickly solvable due to the CPLEX solver. The model has the potential of being expanded to combine both inland and maritime networks.

Relevance of paper to thesis

The paper provides a very complex model which compares the empty container management in an inland network, yet it lacks to present the cost savings. It seems like it is a model to show that it is possible to model the problem. It provides a forecast on how containers should be moved with respect to the requirement of the network. Leasing and substitution are solutions which are more frequently applied to locations which are deficit as not enough containers exist in the area to meet export requirements. This thesis focuses on an import dominant region and therefore it is possible for all locations to meet export requirements. The addition of those solutions to the model would result in a very complex model for little added value and therefore considered negligible. The authors split surplus and deficit terminals into separate sets, which will be applied to the mathematical model of this thesis as well.

An operational model for empty container management

Paper content

(Olivo et al., 2005) present a model which minimizes cost of empty repositioning management, which was based on the work of (Crainic et al., 1993). The paper assumes an hourly time step and argue this to be feasible due to increased computing power and because presently real-time information is available on the state of a container. Due to detailed time unit, the model requires knowledge of customer requirements and exact transit time. The authors state that a carrier cannot know exactly when containers become available yet based on experience can make a strong prediction. Uncertainty is taken into account through the application of a rolling horizon. The model takes three inland modalities into account (truck, rail and barge) and two container types (20' and 40' dry). The model is made up of macronodes, which aggregate empty supply and demand for the local customers, and regular nodes. Supply and demand nodes are combined into separate sets. The model takes no substitution of containers into account. Containers are assumed non-damaged at all times. The authors state that the model becomes infeasible when transport takes too long and demand is not met. They introduce dummy arcs which provide extra available containers to fulfil demand backlogs. These dummy arcs are subject to a cost representing either a penalty for not meeting demand, leasing, borrowing or purchasing of containers, which are set to a high value to ensure such options are only considered when no other option is available.

Relevance of paper to thesis

The aggregation of customers into macronodes is a smart way to reduce the size of the modelled network while still taking each customer into account. Seasons have a different impact on the solution of the model and this cannot be shown within a one week time horizon. The authors do not take end-of-horizon effects into account, which results in unreasonable high inventories at the beginning and end of the time horizon. The mathematical model will be used to develop an objective function and restrictions for this thesis. The introduction of dummy arcs is a very smart solution to counteract infeasibility when supply cannot meet demand over multiple time steps. This thesis aims to take seasonality over the entire year into account where a time step is one week. As such transport will depart and arrive in the same time step. Dummy arcs are therefore not required. Furthermore the authors recommend that through scenarios a detailed result can be shown of a model. The use of scenarios coincides with the different solutions proposed in this model.

Foldable and standard containers in empty container repositioning

Paper content

This paper, by (Moon et al., 2013), compares the costs of foldable containers to that of standard containers to find out whether a foldable container could provide a cost savings with respect to empty container handlings.

First a mathematical model for normal containers was developed, followed by a model for only foldable containers and finally a model for both normal as foldable containers in a network

containing multiple ports, which has a certain supply and/ or demand for empty containers. Each port considers supply, purchase, repositioning and inventory as inbound flows and demand and repositioning as outbound flows.

The model considers weekly periods with a planning horizon of 13, 26, 39 and 52 weeks. Also, the paper distinguishes two problem sizes, namely small problems looking at 4-10 ports and large problems looking at more than 100 ports. By applying Lingo (optimization software) and an own developed heuristic algorithm the problems were solved. Purchasing costs, storage costs, un-/folding costs and transportation costs are considered. The authors argue that the Lingo tool is incapable of running large problems, due to a memory allocation issue, through application of heuristic algorithms the problems are reduced. The heuristic algorithms functions are based on the following sequence.

1. Determine current inventory level
2. Generate number of deficit and surplus terminals (Deficit and surplus terminals are added to their own set.)
3. Determine network flow
4. Loop until time horizon is met
5. Improve solution with local search algorithm

The model is tested according to four experiments to determine the sensitivity of the model, specifically demand increases, purchase price decreases (decreased purchasing price), oil price increases (increased transport costs) and folding/unfolding costs decreases. For each experiment a number of scenarios were tested.

The paper concludes that at the moment foldable containers are a lot more expensive than standard containers.

Relevance of paper to thesis

This paper lacks to describe which container size is compared as it is assumed that the construction costs between a 1 TEU and 2 TEU containers is not linear. It is questionable if foldable containers can be applied as it would not work for all container types e.g. reefers. Moreover, the paper assumes an ideal world in which there are both surplus terminals as deficit terminals, creating a closed system, in which a container always has a purpose. It lacks to look at an area where there isn't a balanced demand and supply. The objective function presented for standard containers is usable as a basis for this thesis to calculate the minimal costs of empty repositioning. Furthermore the heuristics algorithm for determining the amount of containers fit for repositioning will be used in solving the problem of this thesis. Especially the separation of deficit terminals and surplus terminals into separate sets is a smart way of calculating the transportation possibilities.

The build-up of the research can be used as a guideline for this thesis, in which first a mathematical model is developed, which will be modelled to determine the minimal costs of that objective function, validated through a sensitivity analysis and verified by comparing the calculated objective value with actual costs of Maersk Line of historical data.

The implementation of foldable containers will not happen in the current situation; only through greatly decreasing manufacturing costs a foldable container becomes feasible.

Empty container management for intermodal transportation networks

Paper content

(Choong et al., 2002) looked at how a longer planning horizon relates to the empty container management with respect to intermodal container transport networks. Planning horizon studies have been performed in many businesses except for empty container management, except for some papers provided by the same other in the years prior to publication.

The model proposed is an integer linear program for moving containers in intermodal transportation networks at a minimal total costs subject to meeting full container demand with the goal of investigating the planning horizon effect on the costs. The model is based on the model developed by (Crainic et al., 1993) and modified to include multiple modes, storage capacity and transportation mode's capacity, yet it leaves out the delivery window for containers as they assume containers to be delivered at the required moment. A number of assumptions made in the paper coincide with this thesis, namely

1. No difference is made between owned and leased containers
2. Number of arriving containers for all nodes is known
3. Number of departing containers for all nodes is known
4. Demand in the current time step will be delivered within the same time step.
5. Inventory and required stock is known.
6. Routes between nodes which do not exist will be set to a very large value to ensure they are not picked in the minimization with respect to travel cost.

The integer program is applied to a case study on the Mississippi area, which was modelled using the AMPL modelling language combined with IBM's CPLEX solver. The CPLEX solver can be used in combination with matlab to make the results readable and extractable. Three scenarios have been investigated (3, 5, and 7 container pools in combination with 12 customers and 3 modalities)

The conclusion presented by the authors is that depending on the size of the network modelled a longer planning horizon could give better distribution plans for the first time periods. A too short planning horizon depends on:

1. Concentration of the activities in the network; when the periods after the short period are very busy, a longer period might improve the results.
2. Transit time of the container movements; In order for the model to take slower modes into account a model would require enough modelling time.
3. End of horizon effect;

The authors propose a model that combines full and empty container flow in a single location-allocation model.

Relevance of paper to thesis

The paper proposes an objective function which could be used for this thesis apart from the multi-modality aspect as it is assumed that for inland repositioning in the Dutch hinterland no cheaper modality exists than barge (when it comes to carrier haulage) and Merchant Haulage is

mostly performed by truck as customers rarely can supply enough containers for this to be profitable. Finally the authors assume containers are always ready to use, which means no repair is necessary for containers. In fact when containers are damaged they are taken out of the available container pool and transported directly to maintenance facilities. The addition of maintenance into the steering of empty containers results in a reduction of containers available for empty repositioning. A large portion of the discoveries made in this paper are useful for modelling the model proposed in this thesis.

A heuristic solution for the empty container substitution problem

Paper content

(Chang, Jula, Chassiakos, & Ioannou, 2008) propose two models for reducing costs by substitution between container types, the first model is a two commodity deterministic substitution model and the latter is a multi-commodity substitution model. The model focuses on a multi-commodity empty container problem, which takes no specific modality into account. Furthermore, only transportation costs are looked at.

The paper first provides a single commodity substitution deterministic model and then expands it to a two commodity and finally a multi-commodity substitution deterministic model. The single commodity model covers three sets of variables, namely demand, customers and consignee. Depots are assumed a dummy location without a requirement for empty containers. The multi-commodity model is expanded with a substitution dummy set. Now two types of demand are implemented, namely exact demand and substitution demand, which allows for substitution between container types to take place.

To test the quality of the results a Branch and Bound algorithm is used to find an integer solution. The results are compared to a relaxed Linear Program solution, according to the simplex method, and the decomposed IP method, which yields a suboptimal integer solution. The BB algorithm often is unable to obtain a result due to the long run time and complexity of the model.

The model was afterwards tested on a case of the LA port scenario, which looks at 12 consignees, 8 shippers, 2 depots and 1 terminal. The model is run on projected data for 2010. They assume a growth of 1.8-2.0 times in demand and conclude a 50% reduction in empty trip activity can be noticed from the case. Costs are denoted as distance rather than currency. The authors argue that if street-turn operations are introduced a further cost reduction can be obtained.

Relevance of paper to thesis

This paper has provided an idea on the added value of allowing substitution of containers between types and owners. The paper presents a good description of the way empty container flow occurs. The authors state that containers are mostly shipped to terminals before being shipped back to export customers, which strongly relates to how containers are moved in the scope of this thesis. As substitution is not taken into account the dynamics proposed will not be used for the development of the objective function but does provide a basis from which

Dynamic and stochastic models for the allocation of empty containers

Paper content

(Crainic et al., 1993)present a framework for sorting research done on empty container management. This framework was later used by (Braekers et al., 2011) to sort literature up until 2011. That same fundament will be used for this thesis to sort the relevant papers on the topic of allocation models, which focus according to the authors on determining the best distribution of empty containers to meet known and expected demand.

The paper is much quoted by all authors, which have researched allocation models. Many newer papers use the mathematical models as a basis for their own research. According to the authors an allocation model should be of the stochastic dynamic form with a 2 week horizon. (Choong et al., 2002) later elaborate on the horizon length for prediction models. The allocation models are an operation decision level problem and are one of two models existing for operation problems. The other is a routing problem, which minimizes transport costs of full and empty containers.

According to the authors a large amount of information is required from the carriers in order to build a well-rounded model, specifically;

1. Demand data
2. Pricing data
3. Transport policy rules of the carrier
4. Container owning costs

The physical models are built up of nodes e.g. ports, inland depots and customers. Ports serve as the entry and exit point for containers either full or empty, because ship schedules are assumed known. Depots are located either near a port or in the hinterland and serve as a storage point, operating under constant configuration during a predetermined time horizon. They are the location from where empty containers are controlled in the hinterland location. Customers are divided into import or export customers per commodity. As such the models have a push and a pull location for empty containers. Note a customer can be both in the import or export set of customers for these models.

For each container it is thus known where and when they are required and how long it takes to ship the containers (delivery window). The model is required to assume containers are provided to their locations when required. In an allocation model no backlogging is possible and/or allowed due to the definition of delivery window considered. Empty container supply is defined as the containers which are available to allocate in any time step. Empty container demand is defined as the containers which are required for export at any time step.

The first model presented by the authors is a deterministic single commodity regional model. This model is provided to first understand the basic problem upon which a more elaborated version is presented, namely a multi-commodity deterministic regional model. Decision variables are defined as container movements through space and time, however arriving time is depending on the transit time plus starting time. The model is constrained is such a way that multiple topics and assumptions are covered, namely customer demand, customer supply, stock at non-port

depots, port supply, port demand and port stock, balancing flows and the physical network (nodes and arcs). These topics need to be covered for a model of such architecture.

A multi-commodity model results in a 3 dimensional structure of time, space and products. The authors have added substitution to the multi-commodity model in order for a carrier to better meet the empty container requirement. For this model substitution is added to determine serve as a solution for meeting demand of a multi-commodity allocation problem. The single commodity model is also expanded differently for stochastic demand as it is assumed that demand is uncertain.

Relevance of paper to thesis

The authors have compared the models to other literature provided earlier and some implementation issues which they encountered for this model. The model is built to be applied in a model context of a centralized organisation which oversees the entire network and movements. Data requirements for such a model are of a huge nature as multiple time-periods, demand requirements, commodity types and locations are addressed. A planning horizon should be between 10 and 20 time periods and to minimize end-of-horizon effects, a rolling horizon can be applied and of end-or-horizon conditions which opposes a lower and upper limit to stocks need to be determined, if the horizon is feasible. The length should be sufficient to cover a certain amount of demand before termination. However, ultimately no pure guidelines can be offered about the length of the horizon as it depends on the problem to be modelled.

The paper does not present any case study proof of the models presented and as such are difficult to verify. However, many other authors have used the models presented to build their own models for their own hypothesis and through that have proven the original mathematical model presented to be accurate for solving an allocation problem. Of the models presented the multi-commodity model excluding substitution comes closest to the subject of this thesis. When substitution is excluded from the model, the complexity of the model decreases and it actually becomes more of a simultaneous multiple single-commodity model due to the lacking interaction between the multiple commodities taken into account.

The paper provides a good mathematical basis with very clearly described variables and restrictions. This basis will be used to build the mathematical formulation for this thesis in particularly the single-commodity model will be used and expanded to take into account depot-direct (Direct repositioning) into account. The division of the customers into surplus and deficit sets is a very useful way to describe the different aspects of a customer in the model. Furthermore, the allocation model proposed in this thesis looks at inland terminals to have either a deficit or surplus aspect, as inland terminals are assumed to be both a storage point as a aggregation of the closest surrounding customers. The assumptions presented by the authors of the single-commodity model are translatable into the proposed model.

Port dynamic empty container reuse

Paper content

(Jula et al., 2006) propose a dynamic single commodity single modality deterministic allocation planning model which takes into account the reuse solutions street-turn and depot-direct. The mathematical model assumes that all moves are feasible in time, which makes the model non-linear. Only through relaxation techniques the model becomes solvable with Integer Linear program solver. A two-phased optimization method is proposed which first modifies the model into a bipartite network (a network divided into two disjoint sets such that every edge connects a vertex without containing odd length arcs) and afterwards determines the best match for supply and demand.

The model was tested through a case study of the Los Angeles/Long Beach geographical area. 12 importers, 8 exporters, 2 empty depots and one terminal were taken into account. The network was developed using a GIS system and shortest paths were generated with an analyser. Only trucking is taken into account making all connections between locations possible. First a base year is simulated and afterwards a reuse operation. The reuse scenario is subject to a design parameter, which makes sure empty containers are not stored in one location and a container is moved as quickly as possible.

Matlab has been used to program the optimization model. The model calculates that half costs were achieved, when reuse solutions were applied. A sensitivity analysis was performed on transportation speed, total costs, planning horizon and design parameter. A high design parameter results in container being transported through depot direct and a low design parameters enforces street-turn solutions.

Relevance of paper to thesis

The authors claim little research on empty container reuse has been done until then. Only four papers have been reviewed of which one is focusing on a global stochastic model. The authors do provide a good description of the two reuse solutions proposed. The depot direct movement is in my view a solution which is the most feasible to implement by carriers as this requires little extra planning work in comparison to the costs saved assuming that the results presented by (Jula, et al., 2006) are accurate. Only a part of the consignees considered are based on real time information, the rest is randomly generated. Furthermore, the importer/exporter ratio considered is in my view unrealistic for an import dominated area. When less shippers would be considered the added value of the reuse policies would greatly decrease, which is more likely to occur

Street-turn reuse solutions are a much more detailed solution requiring more work in comparison to the added value. The amount of containers reused through street-turn is expected to be low as it only covers the last part of a transport leg, between customers. Street turn only affects single container moves whereas depot-direct affects larger quantities of containers at once.

c) Papers covering global allocation planning problems

This paragraphs contains the reviews and lesson's learned of the articles that focus on a global allocation planning problem. These papers have mostly contributed in understanding the problems of modelling global allocation and some of the mathematical restrictions and decision variables are strongly related to that of regional allocation problems.

Positioning empty containers under dependent demand process

Paper content

(Dang, Yun, & Kopfer, 2012) propose a single commodity single gateway port model to determine the replenishment of empty containers for depots within an export dominant area, while assuming a dependent demand process and applying different ordering policies. Three possibilities were considered, ordering from overseas ports, positioning between depots and leasing of empty containers. The model seeks the optimal cost of ordering empty container for export through a discrete genetic algorithm. An optimal ordering policy is eventually determined with the model.

The model focuses on the replenishment of empty containers for export purposes and assumes a single commodity, which is the opposite of what this thesis aims to accomplish as it focusses on a multi commodity model with the purpose of effective positioning (evacuation) of empty containers. Furthermore the authors make no distinction between off-dock depots and inland depots, which can have a strong influence on move preferences.

Relevance of paper to thesis

The authors provide a flowchart for the model which can be learned from and adapted to fit a model not taking into account the overseas activities, as this does not affect the costs of inland intermodal container steering. This thesis assumes empty containers are generated at the empty depots as it is an import dominant market. The empty depots generate sufficient containers reducing the necessity for overseas ordering of containers. Where this paper focusses on ordering policy in an export driven area, this thesis looks at optimal empty container steering in an import driven area.

Optimal inventory control of empty containers in inland transportation system

Paper content

(Yun, Lee, & Choi, 2011) propose an efficient inventory policy to control empty containers. Empty containers are repositioned from hubs based on an (s,S) inventory policy. The model considers a deficit port requiring empty containers. The model offers two solutions to provide empty containers to a deficit port, empty repositioning from a surplus port or leasing containers at a deficit port under probabilistic demand and supply with seasonality. Furthermore, holding, leasing and repositioning costs are taken into account. The results are an optimal inventory possible which minimizes costs. The simulation was performed using OptQuest© (optimization tool) in Arena©

The model focus lies on a single commodity subject to seasonality effects. Lease containers are expected to have a zero lead time and empty repositioning has a constant lead time. An (s,S)

ordering policy is used, which means that a certain amount of containers S is ordered when stocks reach below the safety stock level s.

Relevance of paper to thesis

This paper assumes a network that can deliver enough containers to meet requirements at the deficit terminal (Busan, Korea). In the Rotterdam port an opposite situation is in effect. The ports and most surrounding inland terminals are surplus. The entire Rotterdam hinterland is required to ship containers to Deficit areas, in order to get rid of the overcapacity of empty containers. The deficiency of the Asian market is expected to be large enough to allow all containers to be evacuated through the European gateways to the other ports. The simulation runs a very large time horizon between 500 and 6000 weeks, with a warm-up period of 10%. This time step is 1 week.

The authors do not provide any conclusions other than a model which determines the optimal ordering and stock for different scenarios where costs are varied. If the gap between demand and supply increases per season, a increase in stock and order value can be noticed. For the thesis, this paper is not directly important. It does provide a further understanding of the issues involved in handling empty containers, but the model does not coincide with the model proposed.

A DSS for integrated distribution of empty and full containers

Paper content

(Bandeira, Becker, & Borenstein, 2009)propose a decision support system (build in Microsoft Windows© with a Lingo© integer programming solver) which models both full as empty containers as they declare that the empty containers follow from full container demand. A single-commodity (1 TEU), semi multi-modality, global scale is assumed for this model, which combines a routing and allocation problem into one; furthermore, the model takes storage and handling into account.

The authors argue that a number of papers proposing empty and full container distribution planning models, yet they all look at the problems separately. Their contribution is a combination of existing models, where the allocation model is based on the work of (Crainic et al., 1993).

The model is build up out of nodes and arcs, where the nodes represent ports, warehouses, customers and container leasers and the arcs represent the physical connection that exists between the nodes. The network does not allow containers to be directly moved between origin and destination, which they argue is because containers must circulate through intermediate locations, such as the warehouse and depots are locations where storage takes place until delivery. The shippers and customer are divided into sub groups of whether they require or provide empty or full containers, representing a customer's type of role in a transportation network.

The authors want to minimize deadheading (costs for empty repositioning) costs and full container loads. For this minimization an objective function has been presented.

The model is divided into two parts, namely a static model and a dynamic model. The static model is used to calculate the movement and allocation of both full as empty containers, which is fed by the dynamic model which updates the full containers demand forecasting. The dynamic model takes transport time and cost into account. Capacity of terminals and vessels was considered infinite for simplicity sake.

The authors noticed a problem with the model as container transportation problems are unbalanced resulting in an unfeasible static model. To counter this unfeasibility they propose to modify demand and supply for both full as empty containers per time step, which is only achievable by delaying certain demand from the current time to the next time step. Making the choice which containers to delay is performed by 3 criteria in consecutive order, namely the Original date of order to enable a service level guarantee, the estimated transportation cost as the lowest cost is sought after to be able to minimize costs and the estimated transportation time as lowest transportation time is required for flow minimization.

The conclusion is a model, which ensures cost and service level is optimal, is complex. It is therefore advised to make use of heuristics to solve the large number of variables and constraints. The model allows for judging allocation policies with the goal of assuring a sound service level.

Relevance of paper to thesis

The paper offers some good assumptions which can be used for this thesis. The paper is of a very complex nature depicting the complexity of a container transportation network. The most important lesson learned from the paper is that it is important to keep in mind that full containers influence the movement and allocation of empty containers; however the combination of both systems into one makes modelling time very long and thus forcing the researcher to make more assumptions. In comparison to this thesis the model only looks at a single commodity and single modality, which when added to the DSS proposed would make the model to program too complex.

Maritime repositioning of empty containers under uncertain port disruptions.

Paper content

(Di Francesco, Crainic, & Zuddas, 2013) propose a integer stochastic programming model which minimizes cost of repositioning and shortages of empty containers with respect to unexpected disruptions. The focus of the model is on the port operations which are affected by unexpected alterations in the container shipping process. An example of such a disruption is a Hurricane. The paper focusses on two types of disruptions: partial and complete disruptions.

The model looks only into empty container repositioning as empty containers have no fixed origin-destination pair. Two models were presented, the first deterministic and the latter based on scenarios to take data uncertainty into account.

The model is modelled by a time-space network of nodes and arcs. Two shipping lines and 5 ports are looked at each servicing different ports at different time steps. At the end of the time horizon a super sink node is linked to all nodes and a cost is added to the arcs leading to the node to account for end-of-horizon effects. Those arcs are set to $10.000.

The model takes storage, transportation and handling capacities and costs into account. Decisions are modelled through several decision variables and multiplied with unit costs to determine costs. The decision variables (here-and-now decisions) are as follows

- Available empty containers to be loaded at port i.
- Number of empty containers to be moved from port i to port j.
- Number of empty containers to be discharged at port j.
- Number of empty containers to be stored at port j instead of loaded.
- Number of empty containers in shortage at port j.

Disruptions result in demand and supply being set to 0 for the port affected and operations are resumed at the period after the disruption has finished. These disruptions are uncertain and are modelled as a set of parameters representing different futures or scenarios on different ports affected.

The multi scenario stochastic integer model can be converted to a two-stage stochastic model, the here-and-now decisions are made in the first stage and the disruption decisions in the latter.

The proposed model is tested through the application of numerical tests with the use of ILOG OPL Studio combined with CPLEX 12.2, a commercial solver. Several scenarios were developed;

- G1: "normal" operations
- G2: Partial or complete disruption is forecasted.

These scenarios are handled by three policies;

- P1: use deterministic model and use G1 as a point forecast;
- P2: use deterministic model and use G2 as a point forecast
- P3: use multi-scenario model and G1 and G2 are included in the multi-scenario formulation and connected through non-anticipativity constraints.

For a number of days tests are carried out with the following sequence;

- The models are solved per policy and here-and-now decisions are applied
- Costs are generated and demand fulfilment percentage (value that represents disruptions) calculated for t=1
- New period is added to the planning horizon end, rolled forward once and forecasts are updated.

End-of-horizon effects are taken out by truncating the first and last 15 periods of a 50 period planning horizon.

The authors conclude that the model produces effective results when the forecasts meet the disruptions, however that shippers are subject to uncertain events and thus cannot with full certainty declare the reliability of the results. The model presents high demand fulfilment percentages with respect to diverse future changes.

Relevance of paper to thesis

The paper covers a very interesting subject which declares the uncertain nature of making future prognoses. It allows for better understanding of the implications which could occur in a larger network. It is very complex to make reliable and sound forecasting. The deterministic model shows much coincidence with the model proposed in this thesis. The topic itself focuses more on a overseas network of ports and how ports are affected by uncertainty. The paper has provided a better understanding of how the general topic of uncertainty, however this particular topic will be left out of scope. The main lesson learned is that port operations are never certain and even with good forecast a port cannot prepare itself from all external influences.

The effect of multi-scenario policies on empty container repositioning

Paper content

(Di Francesco, Crainic, & Zuddas, 2009) is the predecessor of the empty reposition under port disruptions. It originates from a particular case in the Mediterranean where some ports offer long-term storage and small ports limit storage through a maximum allowed dwell time. For all locations empty container supply and demand is described as the availability of and requirement for empty containers. The paper follows an approach in which shippers give distributions of uncertain parameters, which are used to generate scenarios. These are connected in a multi-scenario multi-commodity time-extended optimization model and connected by non-anticipativity constraints. The paper provides an allocation multi-scenario policy and deterministic policy for empty repositioning subject to uncertainty and data shortage. As it handles uncertainty a rolling-horizon is implemented, which adjusts itself according to the scenario at hand. Only effects limiting container flow have been investigated.

The authors conclude that the multi-scenario policies provide a better result than the deterministic policies even though the model calculates higher costs, because they argue that with a deterministic policy the company suffers a larger loss of profit. The deterministic model fails to serve 31 containers and the multi-scenario model fails to serve 4 containers. The assignment was solved using a simple solver. The exact solver used is not described.

Relevance of paper to thesis

The paper focuses on a network with ports each subject to different costs and limitations. For this thesis there is also a difference between different nodes. Ports, depots, inland terminals make up the backbone of the network which are limited in their own way. The different types of nodes will be combined into different sets. This thesis does not focus on uncertainty of future demands as the main focus lies on steering empty containers through off-dock depots with the purpose of repositioning or evacuation. The paper provides a clear description of the advantages at looking at a multi-scenario and as such stress the importance of understanding that future operations are subject to multiple influences. This thesis looks at a case which has no data shortage issues

A DSS for empty container distribution planning

Paper content

(Shen & Khoong, 1995) provide a DSS model for the global allocation of empty containers. The authors take a deterministic, single commodity problem which allows leasing of containers into account. The paper focus lies on the business aspect of planning models.

Ports are considered either demand or supply driven. At a port four decisions influence the imbalance of containers (leasing of containers, returning of leased containers, arrival of positioned containers and the departure of to position containers). A DSS deployment framework is presented, where regional ports are surplus and deficit. First imbalance is solved regionally and afterwards it is solved inter-regionally. Each arc is described by a capacity and a cost. Dummy nodes are added to facilitate leasing of containers. Extra arcs between nodes are added to allow prepositioning. A rolling horizon is applied to limit uncertainties. The authors

conclude that the model can be expanded to land transportation systems, but that requires expansions with respect to business processes.

Relevance of paper to thesis

The paper speaks of minimizing an objective function and ways to relax some of the commitments presented to make the model feasible, yet no objective function was presented and results of the model were presented to determine the actual quality of the model. The authors describe a DSS for solving large problems with multiperiod distribution, yet it is unclear how large these problems can actually be. The paper does present a nice framework which can be used to connect models of different scales to produce a model that combines both regional as global repositioning. This is however unfeasible as long as it is not possible to model the ideal model as described by (Braekers, Caris, & Janssens, 2012).

Appendix D Model architecture

The model proposed follows the below model architecture. Based on the mathematical model and constraints, a Matlab script is developed, which calculates the optimal cost of empty container steering through a network subject to different scenario's and physical network limitations. Through a Graphical User Interface (GUI) the results are shown and the physical network limitations and scenarios are selected. The scenario vary between used off-dock empty depots and whether direct-depot movements are allowed. Paragraph a) discusses the input data for the model. Paragraph b) focuses on the matlab script and paragraph

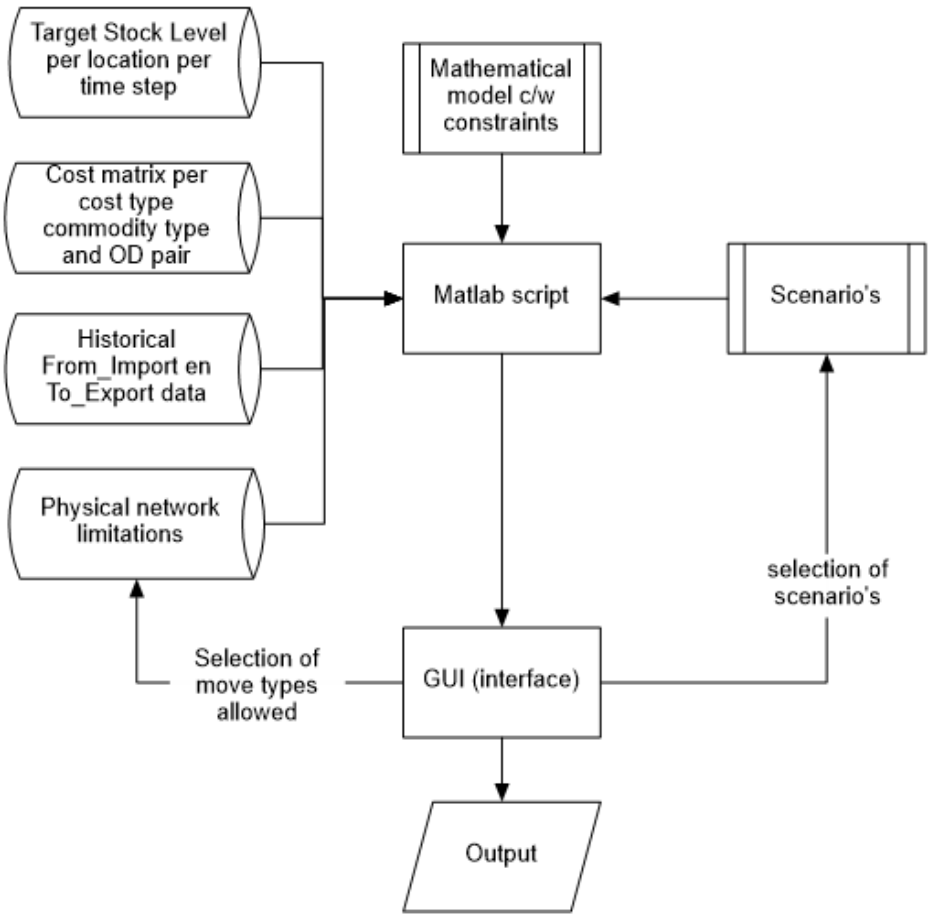


Figure D-8 Model architecture proposed for model

a) Input data

The model starts by reading all input datasets from excel, which are required for the calculation. Depending on the size chosen by the user the model reads the required dataset into the model. The model will only work if the datasets provided are of a similar size and organized in a similar fashion. For instance the data needs to be sorted similarly starting with all inland terminals, then depots and

finally the ocean terminals. The model will create a linear programming optimization program which is subject to scenarios selected and the Origin Destination (OD) cost-matrix provided in the cost input. This OD cost-matrix has the general shape found in Figure D-9. A cost matrix for 20' containers and 40' containers is provided as they are transported at different rates. Depending on the container type of interest the model uses the correct OD cost-matrix. A disallowed transport arc is represented by 0 costs. Reefer containers are subject to an extra cost in comparison to the other container types, namely for Pre Trip Investigation. This is performed on every container leaving a depot.

Table D-1 general shape of OD cost-matrix. The order of the nodes is vital for the correct calculation of the network total cost.

		Destination nodes		
		Inland terminals	Depots	Ocean Terminals
Origin nodes	Inland terminals	All transport costs between Inland terminals	All transport cost between inland terminal and depot	All transport costs between inland terminal and ocean terminal
	Depots	All transport cost between depot and inland terminal	disallowed	All transport from depot to ocean terminal
	Ocean Terminals	All transport from ocean terminal to inland terminal	All transport from ocean terminal to depot	disallowed

All other input files, namely historical data, pre-set or calculated TSL, other transport vectors should be organized in a similar fashion in order for the model to function correctly. Figure D-9 gives a screenshot of the nodal order used in the model.

node		Switzerland	ALPHERIUM	CONTAINER TERMINAL VREDE AMST	BCTN DEN BOSCH BV.	COMBI TERMINAL TWENTE B.V.	BCTN WANSSUM / VENRAY	MOERDIJK CONTAINER TERMINAL	DELTA MARINE TERMINAL BV	BCTN NIJMEGEN BV.	BARGE TERMINAL BORN	OSSE OVERSLAG CENTRALE (OOC)	BTT BARGE TERMINAL TILBURG	CONTAINER TERMINAL UTRECHT	ECT VENLO TERMINAL	KRAMER DELTA / RCT	VAN DOORN	MAINPORT ROTTERDAM SERVICE	APM D	APM TERMINALS ROTTERDAM	APM TERMINAL MAASVLAKTE II	UNIPORT TERMINAL
1	Switzerland	0	0	0	0	0	0	0	0	0	0	0	0	0	0	###	###	###	###	###	###	###
2	ALPHERIUM	0	0	###	0	0	0	0	0	0	0	0	0	0	0	###	###	###	###	###	###	###
3	CONTAINER TERMINAL VREDE AMSTERDAM	0	###	0	0	0	0	0	0	0	0	0	0	###	0	###	###	###	###	###	###	###
4	BCTN DEN BOSCH BV.	0	0	0	0	###	###	###	###	###	###	###	0	0	###	###	###	###	###	###	###	###
5	COMBI TERMINAL TWENTE B.V.	0	0	0	###	0	###	0	0	###	0	0	0	0	0	###	###	###	###	###	###	###
6	BCTN WANSSUM / VENRAY	0	0	0	###	###	0	###	###	###	###	###	###	0	###	###	###	###	###	###	###	###
7	MOERDIJK CONTAINER TERMINAL	0	0	0	###	0	###	0	###	###	0	0	###	0	0	###	###	###	###	###	###	###
8	DELTA MARINE TERMINAL BV	0	0	0	###	0	###	###	0	###	0	0	###	0	0	###	###	###	###	###	###	###
9	BCTN NIJMEGEN BV.	0	0	0	###	###	###	###	###	0	###	0	0	###	###	###	###	###	###	###	###	###
10	BARGE TERMINAL BORN	0	0	0	###	0	###	0	0	###	0	0	###	0	0	###	###	###	###	###	###	###
11	OSSE OVERSLAG CENTRALE (OOC)	0	0	0	###	0	###	0	0	0	0	0	###	0	0	###	###	###	###	###	###	###
12	BTT BARGE TERMINAL TILBURG	0	0	0	0	0	###	###	###	0	###	###	0	0	0	###	###	###	###	###	###	###
13	CONTAINER TERMINAL UTRECHT	0	0	###	0	0	0	0	0	###	0	0	0	0	0	###	###	###	###	###	###	###
14	ECT VENLO TERMINAL	0	0	0	###	0	###	0	0	###	0	0	0	0	0	###	###	###	###	###	###	###
15	KRAMER DELTA / RCT	###	###	###	###	###	###	###	###	###	###	###	###	###	###	0	0	0	0	###	###	###
16	VAN DOORN	###	###	###	###	###	###	###	###	###	###	###	###	###	###	0	0	0	0	###	###	###
17	MAINPORT ROTTERDAM SERVICE	###	###	###	###	###	###	###	###	###	###	###	###	###	###	0	0	0	0	###	###	###
18	APM D	###	###	###	###	###	###	###	###	###	###	###	###	###	###	0	0	0	0	###	###	###
19	APM TERMINALS ROTTERDAM	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	0	0	0
20	APM TERMINAL MAASVLAKTE II	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	0	0	0
21	UNIPORT TERMINAL	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	###	0	0	0

Figure D-9 shows shape of a typical container transport cost-matrix.

b) Matlab script

This appendix chapter describes how the model works and how it calculates the total costs. It is aimed at describing the algorithms implemented in Matlab. Prior to developing the algorithms a search was performed online to find a toolbox aimed at solving minimum cost network flow problems. A number of toolboxes exist and one that was recommended by other Matlab users is called Matlog and is developed by the logistics department of the North Carolina State University. It contains functions which rewrites a network and its boundaries to the form required for a linear optimization problem. The toolbox showed some limitations with respect to scenario selection, nodes with no demand and supply and multi-period models, which meant that functions needed to be developed. After the problem has been rewritten to the form of a linear programming problem, the problem is solved by using the 'linprog' function available on the Matlab 2014a 64-bit version. The linprog function has been set to use the simplex solver. In the program code every step has been supplemented with comments explaining what happens at each point.

The model aims to solve a linear optimization problem of steering containers through a network $G(N, A)$. The linear optimization function requires a number of input vectors and matrices.

$$LP = [f, A_{ineq}, B_{ineq}, A_{eq}, B_{eq}, UB, LB]$$

With:

f : Decision variable cost vector
A_{ineq} : Left Hand Side of the inequality constraints
B_{ineq} : Right Hand side of the inequality constraints
A_{eq} : Left hand side of the equality constraints
B_{eq} : Right hand side of the equality constraints
UB : Upper bound limit of a decision variable
LB : Lower bound limit of a decision variable

Based on the input data and the mathematical formulation, the model generates per time step, a discrete minimum cost network flow linear optimization problem, which needs to be solved. The mathematical model has been formulated in chapter 4. Depending on the shape of the physical network due to scenario selection and fundamental OD cost-matrix used the mathematical model can be modified to fit each network topology. Every scenario tested in the model reduces or increases the problem in number of decision variables that effect the end result depending on the locations opened or closed. In the case that a node has no supply and demand for a particular time step, the corresponding equality constraint is left out of the equation for that particular time step calculation. The network choice and historical input data determines the size of the inputs f, A_{ineq}, b_{ineq},A_{eq}, b_{eq}, U and L used for the linear optimization. For every time step the RHS (right hand side) of the inequality and equality constraints need to be re-determined based on results from the previous time step. With the input from the previous time step the next time step is calculated by linear optimization, which is repeated until t equals to the modelling time horizon. To ensure that the model is not affected by end of horizon effects the initial model input for t=0 has been based on the results from the input at t=52. In other words the problem has been made cyclic. Figure D-10 gives the flowchart, which gives an overview of the Matlab script's logic.

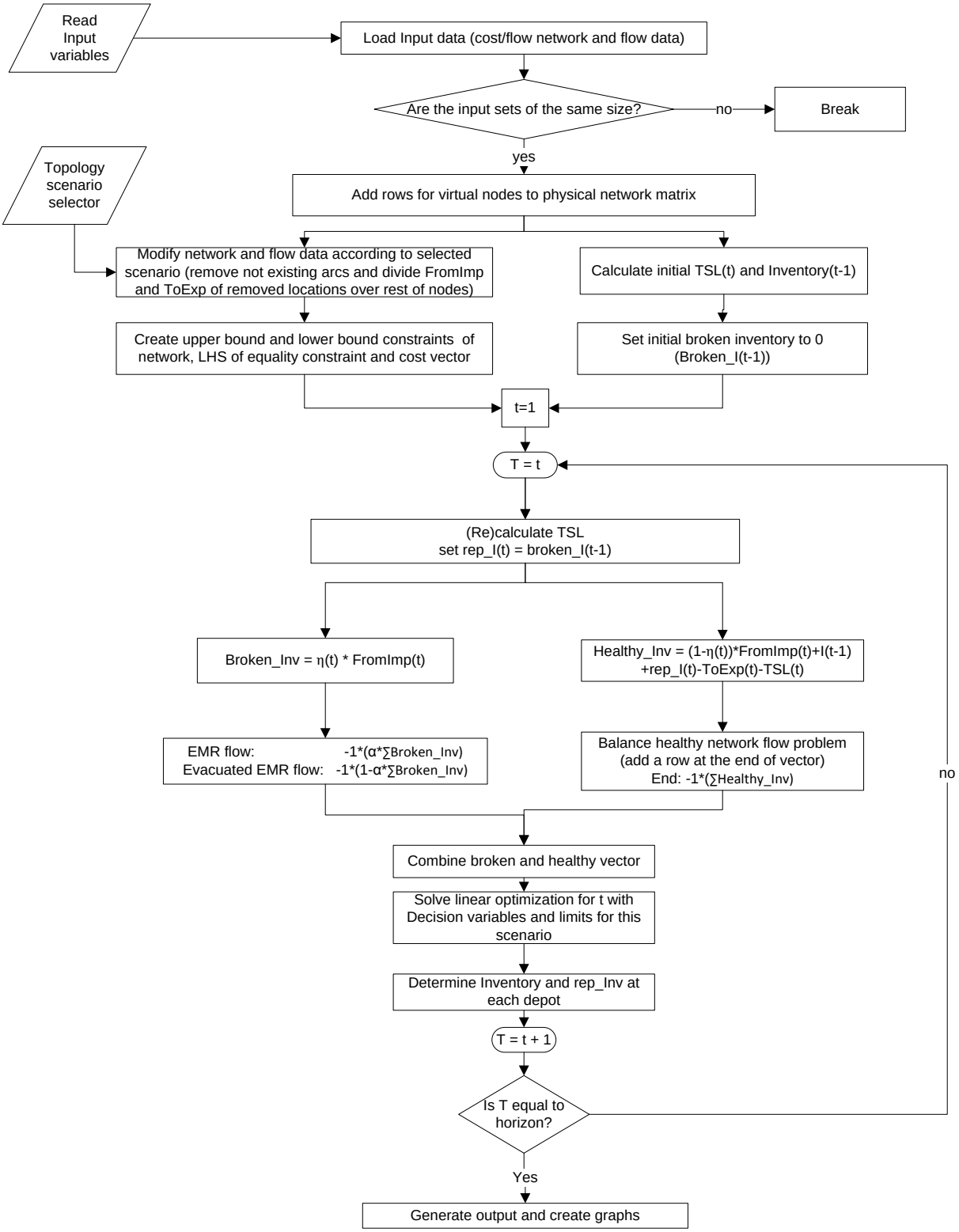


Figure D-10 Flowchart describing the process followed by the Matlab script

c) Scenario selection

Topology scenario

Investigation of scenarios results in some fundamental changes to the network investigated. Depot and ocean terminal nodes are closed or opened to investigate the impact of topology on the costs of container handling. Opening or closing a node means that a number of elements of the program need to be altered to ensure that the network input data remains unchanged. When in real life a node is not taken into account containers are sent to other locations as the amount of shipped containers is not affected by whether the node is open or not. A number of input matrices need to be altered to make sure the model does not cause infeasibility to occur, which are;

- Network adjacency and Cost matrix (LHS (Left hand side) equality constraint (A_{eq})
- RHS (Right Hand Side) equality constraint (b_{eq})
- Capacity constraint values

By changing the layout of the network adjacency matrix, the model automatically reduces the cost matrix and its decision variables in a similar fashion. Modification of the network adjacency matrix is easily performed by multiplying the matrix by a matrix, which contains a 1 for every 'open' arc and a 0 for every 'closed' arc.

Changing the values of the equality constraints was more complicated. The RHS equality constraint bound is calculated by below function.

$$s = FromImp(t) + I(t-1) + I_{rep}(t) - ToExp(t) - TSL(t)$$

With

$FromImp\ (t)$: Flow returning from the customer after a full container has been discharged

$I\ (t)$: Inventory at the previous time step equal to TSL from the previous time step

$I_{\text{rep}}\ (t)$: repaired 'damaged' inventory from the previous time step available for repositioning

$ToExp(t)$: Flow to be sent to the customer prior to a loading activity

$TSL(t)$: Calculated or pre-set Target stock level

When depots are closed all variables need to be modified to incorporate a 'closed' node and when ocean terminals are closed all variables except $I_{rep}(t)$ are affected.

```
    %divide closed fromimp and toexp over open depot locations
    idxdep=find(depot_scen==0); %index the rows with a 0 in the input
    ToExp_scen_dep =
((repmat(depot_scen',1,t).*ToExp(IT+1:IT+d,1:t))+norm_dep(:,IT+1:IT+d)'*
sum(ToExp(IT+idxdep,1:t),1));
    FromImp_scen_dep =
((repmat(depot_scen',1,t).*FromImp(IT+1:IT+d,1:t))+norm_dep(:,IT+1:IT+d)'*
sum(FromImp(IT+idxdep,1:t),1));
    %divide closed fromimp and toexp over open OT locations
```

```
    idxOT=find(OT_scen==0); %select the rows with a 0 in the input
    ToExp_scen_OT =
(repmat(OT_scen',1,t).*ToExp(IT+d+1:IT+d+OT,1:t))+norm_OT(:,IT+d+1:IT+d+OT)'*
sum(ToExp(IT+d+idxOT,1:t),1);
    FromImp_scen_OT =
(repmat(OT_scen',1,t).*FromImp(IT+d+1:IT+d+OT,1:t))+norm_OT(:,IT+d+1:IT+d+OT)
'*sum(FromImp(IT+d+idxOT,1:t),1);
    %concatenate scenario specific fromimp and toexp
    ToExp_scen_combined = [zeros(IT,t); ToExp_scen_dep; ToExp_scen_OT];
    FromImp_scen_combined = [zeros(IT,t); FromImp_scen_dep; FromImp_scen_OT];
    %replace Exp and Imp value by 0 to make place for new amounts
    ToExpscen(IT+1:k,1:t)=0;
    FromImpscen(IT+1:k,1:t)=0;
    %calculate new ToExp and FromImp
    ToExpscen  = ToExpscen(:,1:t)  +ToExp_scen_combined;
    FromImpscen= FromImpscen(:,1:t)+FromImp_scen_combined;
```

The code separately looks at the depot and ocean terminal and in a similar fashion. The locations are fractionally weighed according to their nodal capacity, which implicitly describes the size of the node and thus the probability of receiving a larger proportion of the flow when other locations are 'closed'. The division of original input data is performed in a similar way for both the depots as the ocean terminals.

With the 'open depot' vector Y_k equal to: $\begin{bmatrix}1\\1\\0\\0\end{bmatrix}$ and the 'closed depot' vector equal to: $\begin{bmatrix}0\\0\\1\\1\end{bmatrix}$

$$FI_{k1} = \left(FI_{k1} + \left(\left(\begin{bmatrix}0\\0\\1\\1\end{bmatrix} [FI_{k1} \quad FI_{k2} \quad FI_{k3} \quad FI_{k4}] \right) \left(\frac{Y_{k1} * cap_{k1}}{\begin{bmatrix}1\\1\\0\\0\end{bmatrix} [cap_{k1} \quad cap_{k2} \quad cap_{k3} \quad cap_{k4}]} \right) \right) \right) * Y_{k1}$$

With

FI_1 : From Import data for node 1

cap_1 : capacity constraint

Y_{k1} : open or closed variable for node k1

Y_k : 'open' vector for node all nodes k

When running all different scenarios, the model sorts the input data correctly over de open locations. Only the IEEE binary floating point standard posed a problem at a later stage causing the model to deem a feasible scenario infeasible.

TSL heuristics

The accuracy of TSL influences costs made on repositioning and evacuation of empty containers, because TSL determines the inventory at a node and because a better estimation of future demand results in less unnecessary transportation of empty containers and as such lower unnecessary inventory. Calculation of TSL depends on a large amount of unknown variables and uncertainties. To investigate the accuracy of TSL four different heuristics have been developed to see the influence of TSL on total costs. A TSL value is only applicable to inland terminals and empty depots, because it is not preferred to keep containers on ocean terminals. These heuristics will be discussed below;

'Maersk Line pre-set' TSL

The first is in fact not a heuristic but more the implementation of values used by Maersk Line today. These values are determined by Maersk Line headquarters on a monthly basis based on Import and Export of that month from previous year, projections made for that month for the entire Northern Europe cluster and then divided over each country based on their contribution to the total flow of Maersk Line. TSL on node level is based on expert knowledge of the operations department in the Netherlands cluster.

Future average demand

The second heuristic looks at future demand for the next 4 weeks and then divides the total TSL fractionally over all locations depending on their contribution to total demand for that week. Preparing the model to send containers to a location with a future expected peak in demand, works as a dampening of extremes in the model input data.

$$TSL_n = \frac{\sum_{t=1}^{\rho} ToExp_n}{\sum_{n=1}^{IT+d} \sum_{t=1}^{\rho} ToExp_n} \times TSL_{total} \quad (26)$$

With

ρ : Forecast

t : Time step with t=1 is equal to the current time step

n : Nodes $n \in IT + d$

IT : Total number of inland terminals

d : Total number of empty depots

Future node potential

The third heuristic investigates a nodes potential by looking at the rank a location has in respect to competing locations. The potential value of a node n is based on the demand required and the supply available at a location over the next 4 weeks. Then the TSL is divided fractionally over all locations based on the value a location has in relation to the total. The idea of this heuristic is to take the relative demand of a node.

$$nPot_n(t) = \sum_{t=1}^{\rho} FromImp_n(t) - \sum_{t=1}^{\rho} ToExp_n(t) \tag{27}$$

$$TSL_n = \frac{nPot_n(t)}{\sum_{n=1}^{IT+d} nPot_n(t)} \times TSL_{total}(t) \tag{28}$$

With

ρ : TSL gradient

t : Time step with t=1 is equal to the current time step

n : Nodes $n \in IT + d$

Factorized future demand

The fourth heuristic lets TSL be equal to a factorized demand of a node. This heuristic works on the premises that it is cheaper to have a very large inventory instead of positioning empty containers to where they are required. This heuristic only holds as long as storage costs of containers is free at nodes.

$$TSL_n(t) = ToExp_n(t) \times f_{TSL} \tag{29}$$

With

f_{TSL} : TSL factor set to 1.7 (based on Maersk equipment expert knowledge)

t : Time step with t=1 is equal to the current time step

n : Nodes $n \in IT + d$

Below graphs show the calculated TSL for a 20DC container type. Each graph serves as an illustration of where inventory is kept in the model. The pre-set TSL, mean demand TSL heuristic and factorized demand TSL al show a similar form with most inventory kept at the depots as this is where most demand exists in the model. The nodal potential TSL more evenly divides the TSL over the all inland terminals and depots.

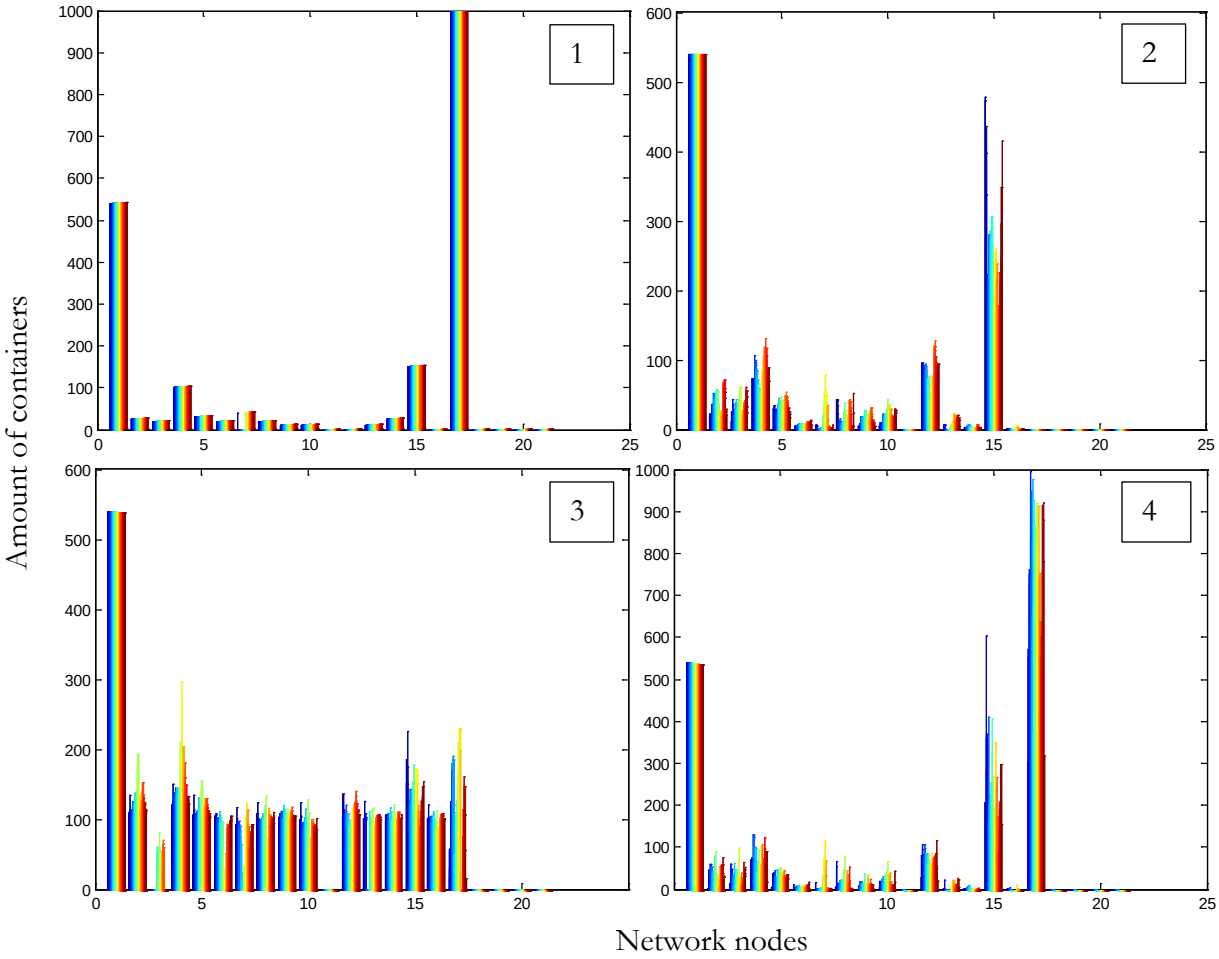


Figure D-11 From upperleft to lower right: (1) Total TSL set as divided by Maersk line, (2) Total TSL as divided by the mean demand TSL heuristic, (3)Total TSL divided by the nodal potential TSL heuristic and (4) Total TSL as divided by the factorized demand TSL heuristic. Each color gradient shows TSL at a different timestep per node in the network. Nodes 1 is the aggregated node Switzerland, 2-14 are inland terminals, 15-18 are depots and 19-21 are ocean temrinals.

Move type scenario

To investigate the influence of allowing transport directly between import and export customers (direct positioning) and between import customers and ocean terminals (direct evacuation), four scenarios have been derived which vary the size of the linear optimization problem. This variation is best illustrated by the OD cost-matrix used in Paragraph a) in Appendix D. The move scenario matrix is a general matrix containing square blocks of '1' and '0', describing whether flow is allow between nodes $\{i, j, k, m\}$. A '1' represents an allowed move type and a '0' represents a disallowed move type. Each OD combination describes what type of flow is found at that position in the matrix. The different scenarios for move type are as listed below;

1. Direct positioning disallowed (0) and direct evacuation disallowed (0)
2. Direct positioning allowed (1) and direct evacuation allowed (1)
3. Direct positioning disallowed (0) and direct evacuation allowed (1)

4. Direct positioning allowed (1) and direct evacuation disallowed (0)

These scenarios influence the OD cost matrix as followed and therefore the size of the linear optimization problem.

Table D-2 Areas of the OD cost matrix affected by the different move type scenarios

		Destination nodes		
		Inland terminals	Depots	Ocean Terminals
Origin nodes	Inland terminals	Direct positioning	Always allowed flow	Direct evacuation flow
	Depots	Always allowed flow	disallowed	Always allowed flow
	Ocean Terminals	Always allowed flow	Always allowed flow	disallowed

Container steering scenario

To make the model forcefully steer containers through a certain depot the nodal lowerbound limit of the model at the depot k can be set to a value equal to the percentage of all flow at time step t. Depending on the depot topology scenarios 2, 3 or 4 depots are 'open'. When 'no steering' is selected no nodal boundary is added to the depot location, however if 'steering' is selected the amount of flow forced through a depot can be determined. To force containers over a certain depot, a nodal lowerbound capacity has been applied to the network. This lowerbound capacity is equal to the total flow for a time-step through the depot divided over the open depots in the dispersion as found in Table D-3

Table D-3 Container steering scenarios available to select in the model.

	Combinations of depots open/closed		
Container steering:	2 depots open	3 depots open	4 depots open
	50/50	33.3/33.3/33.3	25/25/25/25
	40/60	20/20/60	20/20/20/40
	20/80	20/40/40	

d) Graphical User Interface

The graphical user interface (GUI) serves as the interface, which provides the user a front to the model where the model can be modified to solve a future scenario. A DSS tool requires a certain generality such that the impact from different networks other than those investigated for this thesis

can be investigated. This generality allows for it to serve its function of providing decision support. Currently the model runs a network of 14 inland terminals (total 21 nodes), however this can be increased to a size of 68 inland terminals (75 nodes). In the GUI the decision maker can choose the settings for investigating the optimization problem of the specified network. The following tasks are done in the GUI window;

- Scenario selection
- Problem Size definition
- Load input from Excel files
- Run single steered scenario
- Run multiple steered scenarios
- Show results
- Show graph flow plot

Each scenario investigated in this thesis can be reproduced by selecting the scenario setup investigated.

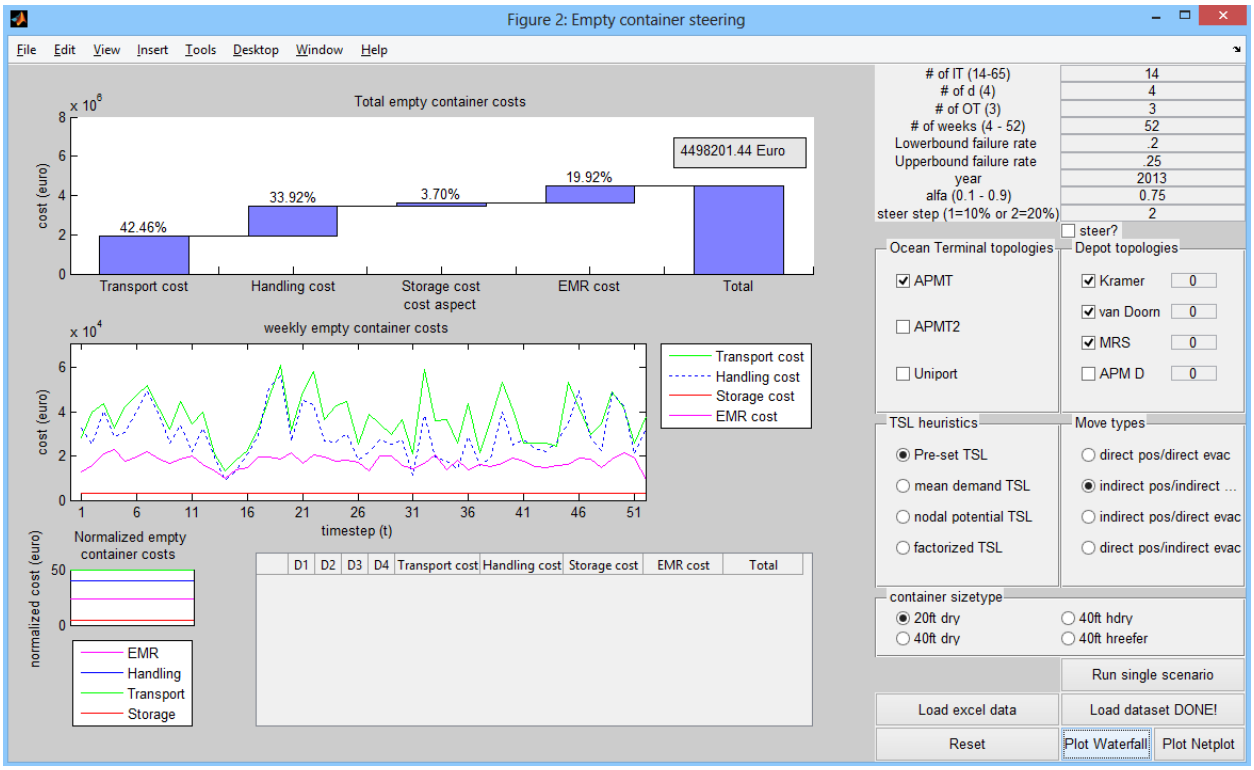


Figure D-12 Preview of the developed Graphical User Interface.

Appendix E Verification and Validation

In order to be able to trust the outcome of the model, the model needs to be verified and validated, which can be formulated in the form of questions. Verification answers the question of whether the model has been correctly built and validation answers the question if the models results are correct.

a) Verification

Verification is the process of checking whether the mathematical model has been correctly implemented, in other words if the various algorithms and heuristics in the model have been calculated correctly. The development of the proposed model is a time consuming and complex process, which is prone to contain errors. In order to eliminate those errors the model has been developed according to a predetermined sequence. This sequence starts with a simplified small test model and eventually leads to the final product. The benefits of such a sequential build up are that it allows for a stepwise verification of the model. The sequence followed is listed below;

1. Single commodity, single time step, small network with 3 inland terminals, 2 depots and 2 ocean terminals. The model is subject to input data similar to the final model.
2. Single commodity, multiple time step, small network with 3 inland terminals, 2 depots and 2 ocean terminals. The model is subject to input data similar to the final model.
3. Multi commodity, simplified network with 3 inland terminals, 2 depots and 2 ocean terminals. Depot-direct and direct evacuation moves allowed
4. Multi commodity, actual network with 14 inland terminals, 4 depots and 3 ocean terminals. Depot-direct and direct evacuation moves allowed
5. Final model with a Graphical User Interface allowing for quick testing of single scenario's

Multi commodity refers to the separation of damaged and non-damaged containers. Many of the smaller problems have been solved to make the model work for every step in the sequence. A number of the "larger" problems encountered will be discussed in this section of the report.

Occasional deficit market

The first three modelling sequence step was to build a model for a test dataset, which was randomly generated. The original test network contained 3 inland terminals, of which 1 was deficit and 2 were surplus, 2 off-dock empty depots, which were both surplus and an ocean terminal, which was surplus. I assumed that the model would only need to act on an exclusively surplus market resulting in the model only needed to send its containers from the hinterland towards the ocean terminals. When the model was tested on actual data in step 4 infeasibilities occurred and I realized by comparing the input data with one another that it resulting in an occasional deficit market for the 20' DC, 40' DC and 40' HC container types. The 40' HR container is far more often deficit, which made it important to allow the model to import containers from the overseas location. An arc has been added from the overseas node {v3} to the ocean terminal {m}.

In the original network no connection was taken into account from the virtual node, where all containers are evacuated to, to the inland network. This resulted in an infeasible problem, where even though the network is mainly a surplus dominated region, an occasional deficit time step occurs. To allow the model to function under these conditions it is vital that containers can enter the network from the evacuation node. Therefore an arc has been added to the network originating from the virtual node and depending on the move scenario selected certain arcs have been opened.

Model number precision (IEEE floating point standard)

After the model was finalized for a single commodity, the model was tested for the implementation of different input datasets. The model returns a fitting result for the container types 20DC, 40DC and 40HC, but not for the 40HR. After investigating the input data it is noticed that the source and sink values for the input varied greatly. My first investigations showed, that it only occurred when direct evacuation was disallowed, however when I allowed direct evacuation, no containers were transported over the opened arcs. Eventually I realized that each time I re-ran a particular setup a different time step caused the infeasibility to occur. This resulted in the realisation that either the repaired 'damaged' inventory or the TSL heuristics were wrongfully implemented as this is the value that fluctuates between time steps as the other elements required to calculate the RHS equality constraint. The problem was solved by realizing that the numerical tool works with a floating point precision

Matlab is a tool, which is limited by the floating point precision it can handle. This means there is a limit to the size of the numbers which the program can handle. In certain cases where the program calculates a value towards 0 such as when applying fractional multiplication the result will be a value very close to 0 but unequal to 0. When calculating the change in FromImp and ToExp data for a particular node under a certain topology scenario case, this problem occurred The result is a model which is overly stringent in its constraint, making it infeasible. For instance when a location with a supply and demand of 0 for a particular week, would have a fractional result equal to 1e-68 and therefore a little bit supply or demand at that particular location. This problem could be solved by rounding the results from one time step to be implemented in the next time step or by programming certain conditions into the program which sets low values under a certain value equal to 0. Rounding results in the middle of a time step causes inaccurate model results when expanded over a total time horizon of 52 weeks.

The problem was solved by controlling the TSL heuristics developed for the problem and by adding a constraint which prevented the model to send negative containers through an arc.

b) Validation

To validate the model the results have been compared to cost results provided by Maersk Line and by presenting the results to Maersk Line experts. It may seem like the model generates much higher costs than those provided. There are a number of reasons why at first glance the results from the

model vary from those costs. To be able to compare them correctly it is vital to first understand how costs are reported within the business prior to comparing the results.

In the company results the operational costs for empty container positioning at first glance seem a lot higher than those calculated by the model. The handling costs show a substantial larger share compared to any of the other cost aspects, which is due to cost filing system. These costs appear a lot larger than they are in reality. The NOPS POS sheet shows the cost paid by Maersk Line for services involved with empty containers.

The FromImp and ToExp dataset used by the model as container input is taken from the database Intermodal history of Maersk Line. It shows all gate in and gate out moves of empty containers between a node and a customer. To be able to model the problem it is evident that the network becomes a closed system, yet the scope chosen is a lot smaller than the actual network which Maersk Line operates. The smaller area and no interaction with out of scope nodes causes that relatively more containers are transported over the Rotterdam inland terminal. Furthermore container flow of Maersk Line is subject to a large variety of variables, which cannot all be incorporated in the model. This is acceptable, as the purpose of the model is to support decision about the topology of the Rotterdam port area given a certain amount of flow. The exact composition of the input data is less important as long as the model sends the empty containers in the 'base year' scenario in a similar fashion to the location where required as Maersk Line does. Maersk Line today performs hardly any transport between inland terminals with respect to empty positioning.

The network cost input data has been checked by Maersk Line experts and has been considered correct. Furthermore the transport arcs which exist in the model have been modelled according to existing, possible and allowed transport legs.

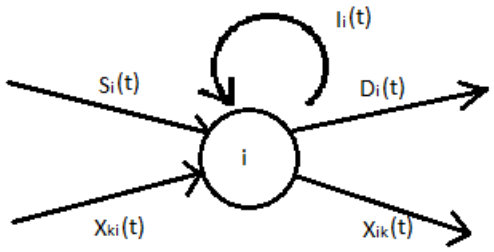
Also the model takes different costs into account than those presented by the Netherlands – Swiss cluster (NL-CH cluster), because certain costs are paid by different clusters and are therefore not corresponding. For instance when a container is sent from Amsterdam inland terminal to Duisburg inland terminal, positioning costs fall under the German cluster. Another example is ITT transport, which falls under the LOC cluster which takes care of global positioning of empty containers.

The reduced scope size, relative reduced flow through Rotterdam and the fact that the model calculates an optimal flow for a simplified model, results in an expected lower monthly and yearly cost for the positioning of empty containers. The costs are in the same order of magnitude as costs made by Maersk Line.

Appendix F Further research

a) TSL as a decision variable

In the current model TSL has been calculated through the application of heuristics, however as a reflection on the work presented it is also possible to include TSL as a decision variable into the model. If we consider a node i with flow arriving from node k, flow leaving to a node k, supply and demand input data, available inventory and current required inventory. Current required inventory



represents the TSL of the model.

The inventory of the current time step is based on the flow balance of the previous time step. If a location is not allowed to store containers at their facility the inventory is always equal to 0 and thus this added equation does not exist.

$$TSL_i(t) = I_i(t)$$

For locations which allow containers to be stored such as the above node I, the equality constraint takes a similar shape as presented in chapter Objective function4.3.3:

$$I_i(t) = I_i(t-1) + S_i(t-1) - D_i(t-1) + \sum_k X_{ik}(t-1) - \sum_k X_{ki}(t-1)$$

Locations that disallow container storage therefore receive a TSL and thus an inventory equal to 0.

$$I_i(t) = 0 \; \forall t$$

By adding the following constraints to the model, the model can calculate a value for TSL best fitting the future and try to minimize the size of the inventory when searching for a problem optimum. Equation (30) is an equality constraint that states that inventory at node i should be larger than or equal to sum of all flow from node i to k for time step t and the demand at node i at time step t. Equation (31) ensures that the sum of all Inventory is equal to the total TSL for a region.

$$I_i(t) \geq \sum_i X_{ik}(t) + D_i(t) \tag{30}$$

$$\sum_i I_i(t) = TSL^{total}(t) \tag{31}$$

Appendix G Evaluation

The idea of performing a research study sounded scary at first as a common tale from fellow students involves the horrors of setbacks experienced in the process of performing such a study. Furthermore I had set the goal that I wanted to build an optimization tool, as I had in the course of my study never really had to do so. This added to the feeling of standing in the dark and sometimes having the idea that I made a rash decision.

From listening to other students that had recently graduated I had created a person goal, which involved clear communication between all parties. I constantly strived at informing everybody involved in the process. I took the problem by the hand and decided this was my research project and that only I could bring it to its final stage resulting in the graduation from the TU Delft.

As I had never had to perform an optimization I had no experience in coding this into Matlab. The process of going from a theoretical model to implementing the model into Matlab is a very time intense job and sometimes not as easily done as primarily expected. Through the implementation process I learned that available functions sometimes result in a limitation with respect to achieving the final goal.

Prior to building the Matlab model I heard that writing code can be such a labour intensive operation that one should take into account that each line in a script takes roughly one hour to code. This includes thinking about the content, writing the line and debugging the line. I experienced this first hand, but in doing so have developed a proficiency in programming that I never expected to exist. The entire process of my master thesis has been a great lesson for me and I can state that I have really learned from it.

The largest part of this study I have performed at the office of Maersk Line in Rotterdam. I started there with investigating the process of empty container steering. I realized quickly that the process of steering containers is such a complex job, subject to a large set of variables that cannot be modelled. As I developed this knowledge I grew more and more frustrated about this aspect as I was trying to create a model that reviewed a closed network with limited influences, yet all I heard and read about were the special situations. This aspect really confused me making it difficult for me to find a red line in my process. This distraction of uncertainty in container transportation resulted in me getting lost in datasets and information and thus experiencing some delay. After communicating my frustration with my company supervisor and colleagues at Maersk Line they helped me to redefine my problem and change my view on how to solve the problem. I learned there that it was very important for me to accept that assumptions were needed if I were to reach my end goal.

Even though one hears it from many students and colleagues that went through a similar process, producing the report required for graduating from a masters is a bumpy road. A healthy part of this process is experiencing setbacks and instead of giving up, learning to deal with them. Research is a time consuming activity, which feels very rewarding as soon as the end goal has been reached. This master thesis has changed me substantially.